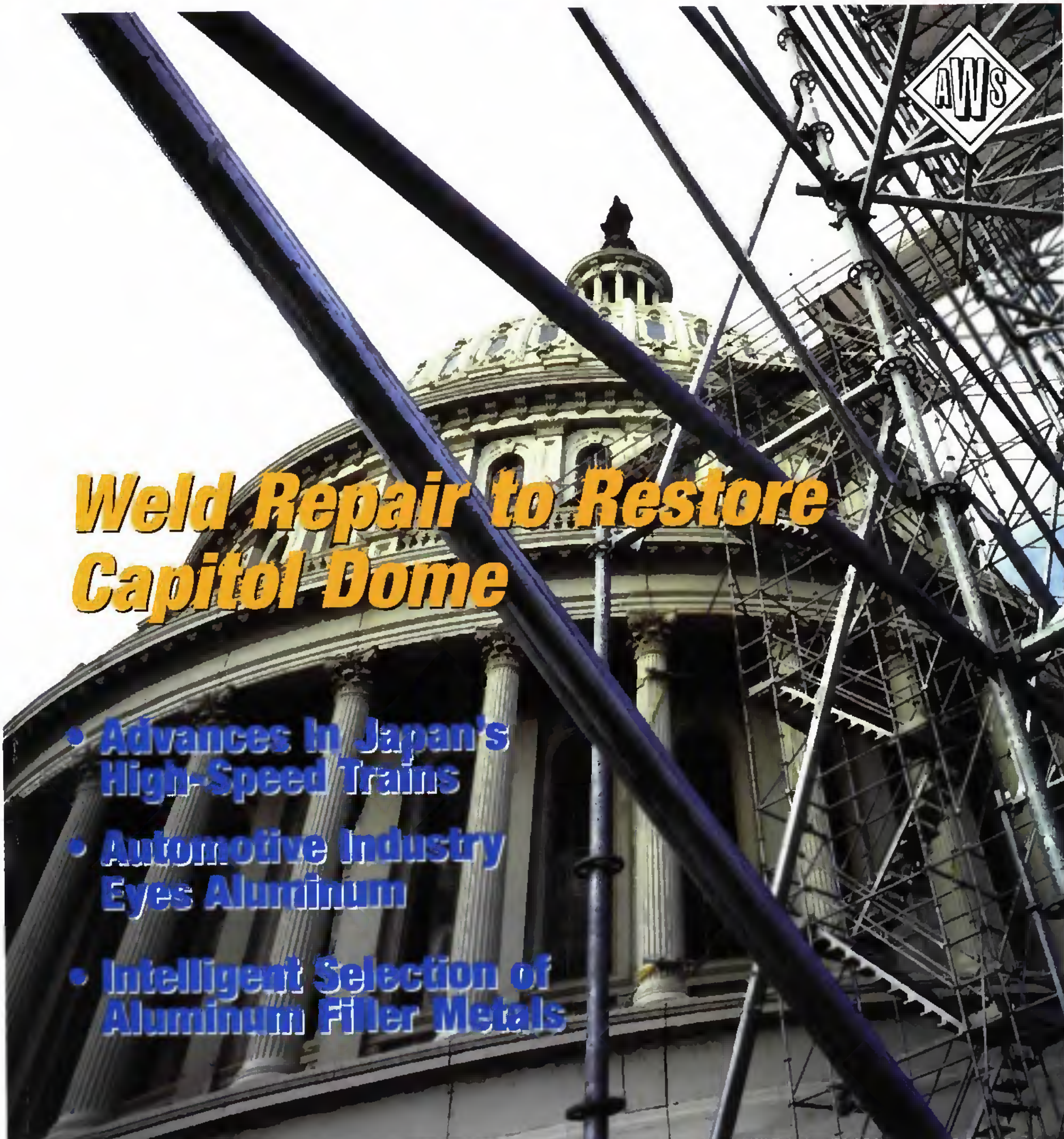
WELDING Journal

NOVEMBER 2000



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AWS Web site: http://www.aws.org

Feature Articles

Welding Research Supplement

Monthly Columns

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Lincoln Electric Ends Offer to Buy Charter, Parent Company of ESAB

Lincoln Electric Holdings, Inc., Cleveland, Ohio, recently announced its offer to acquire Charter plc, the parent company of ESAB, has lapsed and will not be extended. The acquisition will not be completed and Lincoln will take additional after-tax charges of approximately $17 million in the fourth quarter to account for the remaining costs of the lapsed bid.

"We believe the acquisition of Charter's welding and cutting business would have greatly enhanced the company's leadership position in the global arc welding market," said Lincoln Chairman and Chief Executive Officer Anthony A. Massaro. "It is unfortunate the acquisition did not succeed as structured. We remain convinced, however, that our global growth plan is the correct strategy for Lincoln, and we will continue the pursuit of other opportunities meeting our standards and our long-term stated objectives."

While the company did not state the reason for ending its offer to buy Charter, in late September Lincoln announced it had reduced its initial offer from 500 to 410 pence per share. At that time, the need for new terms arose from regulatory demands imposed by the U.S. Federal Trade Commission. The prior bid had received approval from countries outside the United States in which regulatory approval was required or desirable. However, clearance in the United States hinged on FTC-mandated divestitures, most likely ESAB's welding consumables business.

London-based Charter's core businesses are ESAB, a manufacturer of welding and cutting products and equipment, and Howden, a manufacturer of air and gas handling equipment.

New Jet to be Built with Friction Stir Welding

Eclipse Aviation Corp., Albuquerque, N.Mex., recently announced it will use friction stir welding (FSW) as the primary fabrication process for the fusilage and wings of a new jet, the Eclipse 500.

"The benefits of friction stir welding are numerous," said Oliver Masefield, vice president of engineering for Eclipse. "It eliminates the need for thousands of rivets, resulting in reduced assembly costs. It also produces stronger, lighter, more efficient joints than traditional processes."

Eclipse Aviation announced its existence in March. Production of its first jets is expected to begin in summer 2002, with delivery in August 2003. The Eclipse 500 is a five- to six-seat twin engine jet that will be built from aluminum. Its maximum cruise speed will be 355 knots at 41,000 ft. It will have a range of 1300 nautical miles.

The company is working closely with MTS Systems Corp., Eden Prairie, Minn., and the Alcoa Technical Center, Pittsburgh, Pa., to develop, validate and certify FSW for the lightweight aluminum to be used in the plane.

Mike Skinner, applications manager at MTS, said the company has been working with Eclipse for about six months developing procedures for 2024, 7075 and 6000 series aluminum alloys, mostly about 1 mm (0.040 in.) thick. While FSW will be the primary fabrication process for the fuselage and wings, a small amount of rivets will still be used, he said.

Besides producing strong, lighter weight joints, FSW offers benefits in reduced labor costs and the need for a smaller factory floor, according to Cory Canada, public relations manager at Eclipse.

ITW Acquires Jetline Engineering

Illinois Tool Works (ITW) Welding Products recently announced it acquired Jetline Engineering, Inc., Irvine, Calif.

Jetline, founded in 1972, specializes in the automation of arc welding processes. It manufactures fixturing products, controls and accessories, and system integration products.

Over the past six years, ITW, headquartered in Glenview, Ill., has acquired seven welding-related equipment and consumable companies, including Miller Electric Mfg. Co., Hobart Brothers and Arcsmith.

"We believe our relationship with ITW's Welding Products Group will have a positive impact with our customers," Jetline President Mervyn Roberts said. "We will have added support from our sister companies, Miller and Hobart, providing a more comprehensive product offering to our customers."

Superior Wins Dodge Ram Aluminum Wheel Contract

Superior Industries International, Inc., Van Nuys, Calif., recently announced it has been awarded a new aluminum wheel supply contract for the 2002 Dodge Ram pickup truck by DaimlerChrysler. Over a period of a few weeks, the company has won new and replacement aluminum wheel contracts valued at approximately $120 million annually.

Superior supplies aluminum wheels and other aluminum automotive components to Ford, General Motors, DaimlerChrysler, BMW, Volkswagen, Audi, Rover, Toyota, Mazda, Mitsubishi, Nissan and Isuzu.

"Last year we committed to significantly expanding our manufacturing capacity in anticipation of Superior's continued growth in the aluminum wheel market," a company spokesman said. "As part of this expansion program, we have now completed construction of a new building near our existing facility in Chihuahua, Mexico."


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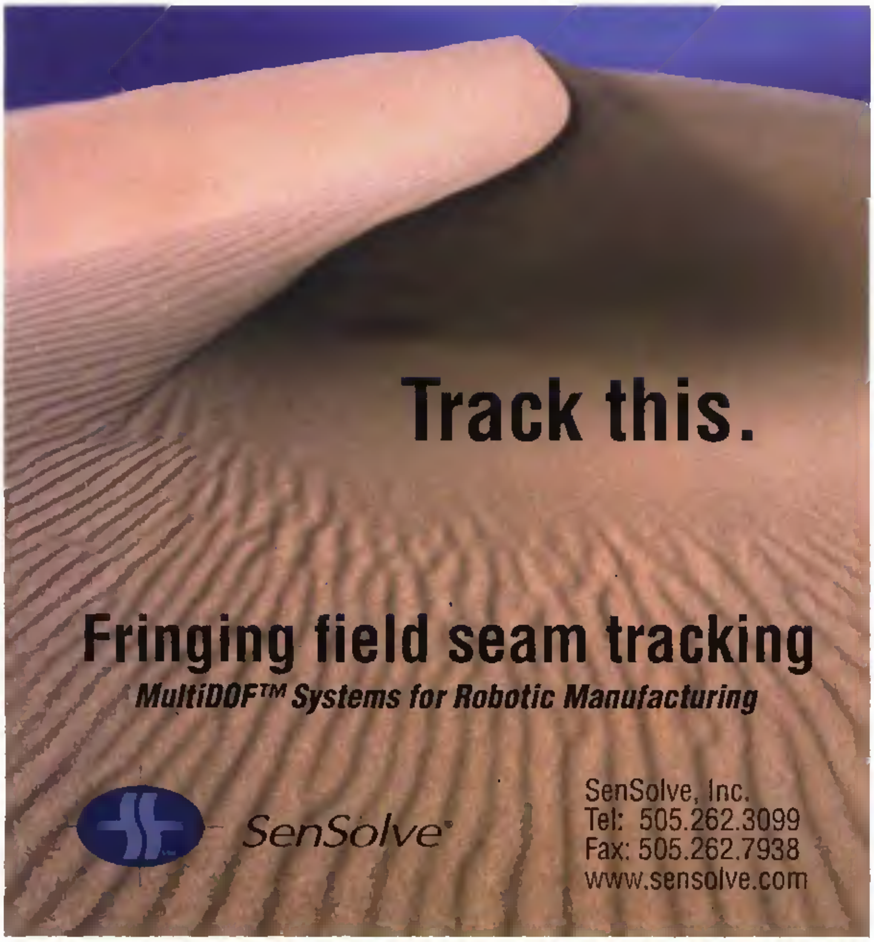
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Commentary

A Look behind the Scenes

Who are the people behind (800) 443-9353, (888) WELDING (935-3564) and *www.aws.org*?

The American Welding Society is more than telephone numbers and a Web site. There are many talented individuals working behind the scenes to make sure when you call our phone numbers or access our Web page you get the help needed and the information you seek. I would like to introduce you to a few of those staff members at AWS headquarters, who are hard at work for our members.

Doris Moore, Receptionist. The first voice you hear when you contact AWS belongs to Doris. Her always-courteous demeanor and ever-present smile are two of AWS's best assets. Doris is always very helpful to the phone customer, to the people who visit AWS headquarters and to the AWS staff. One of her "more important" duties is keeping the AWS popcorn machine full, a very popular staff benefit. Doris has been with AWS since January 1981.

Keith Thompson, Webmaster. Keith, who joined AWS in November 1996, is the person behind the very successful *www.aws.org*. Keith's efforts have made the AWS Web site a popular place to visit on the Internet, receiving an average of 40,000 visits a month. Keith strives to inform and assist our members with useful tips and up-to-date information. He is always ready to answer your questions and listen to your concerns and advice.

Jim Lankford, Corporate Director, Administrative Services. A veteran AWS staff member, Jim has held various staff positions since joining AWS more than 20 years ago. One of Jim's early responsibilities in the 1980s was computerization of the Society's departmental functions. He currently oversees several departments including Purchasing, Publication Sales, Shipping & Receiving and the Receptionist function, as well as serving as the data base administrator for our computer system.

William (Bud) Kinnehrew, Director, Customer Service/Order Entry. Bud heads up the important Publication Sales team, the dedicated individuals who are hard at work taking phone orders for all AWS publications and registering folks for conferences and seminars. It's the job of Bud and his staff to provide the most informative and expedient service to all AWS members and other customers.

Linda Williams, Director of Quality Management Systems. Working closely with staff members in the 17 business units at headquarters, Linda assists employees in the development and maintenance of quality system documentation, and promotes continuous quality improvement throughout headquarters. She is also responsible for employee recognition programs, designed to motivate and recognize outstanding accomplishments of staff. Linda joined AWS in September 1988.

Dennis Bileca, Director, Purchasing. Dennis has been with the Society for 16 years, and has served in numerous positions of responsibility. Over the years, he has managed the departments of Education, Membership, Certification and the AWS traveling booth. For the past two years, Dennis has managed the Purchasing Department. His innovations for efficiencies in past areas of his work continue to be operational to this day.

Jose Lopez, Graphic Designer. Jose has been on staff since July 1995. He brings to AWS more than 20 years of experience in the field of advertising and graphic design. Jose's work has won several awards from the Florida Magazine Association, including its highest honor, the "Charlie," for best in category.

At headquarters, many more dedicated AWS staff members work every day to ensure you, our members, are served in an efficient and courteous manner. Space constraints limit me to introducing only a few of them, but I encourage you get to know more of the people behind the scenes the next time you contact AWS.

John J. McLaughlin
AWS Deputy Executive Director

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CyberNotes

A collection of industry news from the Internet

BY MARY RUTH JOHNSEN, Features Editor

Flexible Cables and Carriers Highlighted

igus®, inc. The company, which is based in East Providence, R.I., specializes in Energy Chain® cable carrier systems, Chainflex® continuous-flex cables and iglide® polymer hearing products—28,000 products in all, according to the site. The Web site features a scroll down menu to link browsers to similar sites for Germany, Brazil, Denmark, Italy and Japan; a listing of trade shows the company will attend; QuickSpec RFQ, through which visitors can get a price quotation within 24 hours; on-line design guides; and CAD drawings of the products, which can be downloaded.

Additional pages allow visitors to request catalogs, CD-ROMs and samples; view detailed product information, and examine job opportunities. There are also conversion tables for temperature, pressure, torque, dimensions, area, speed, acceleration and volume.

http://www.igus.com

Airco Distributors Develop Web Site

Airco® Distributor Association (ADA). The 120-member organization, which is comprised of authorized U.S. distributors of BOC Gases, recently developed a Web site for the benefit of its members. Parts of the site are password protected for ADA members and vendors, but nonmember visitors can browse other areas of the site. General information available includes a brief history of the organization, membership information, news about member companies and vendors and a list of upcoming trade shows. There is also a list of ADA committees, with contact information for the members.

"One important benefit of the Web site will be the enhanced interactivity among ADA members," according to Bill Higley, senior vice president and chief operating officer of Interstate Welding Sales, Marinette, Wis., and ADA cochairman. "The level of communications has increased steadily in recent years as members consult each other about common issues."

http://www.adabuy.com

Site Familiarizes Users with Automated Gas Detection Tool

Industrial Scientific Corp. The company recently launched a microsite to familiarize users with its DS1000 Docking Station™, an instrument and data management system that can simultaneously control up to five gas detection systems. The tool fully automates calibration, maintenance and recordkeeping duties with portable gas detection instruments.

The site provides information about the company, a manufacturer of gas monitoring instruments and systems, headquartered in Oakdale, Pa., and a link to its complete Web site at *www.indsci.com*.

It also includes a product overview, specifications, ordering information, step-by-step assembly instructions and the answers to frequently asked questions.

http://www.ds1000.com

Robot Systems Information Available

FANUC Robotics North America, Inc. Based in Rochester Hills, Mich., FANUC develops, produces and installs robots and robotic systems for manufacturing. Its Web site provides information on the company's history, its locations in North America and that of its affiliated companies around the world, job opportunities, news regarding the company and a list of the trade shows it will attend.

Besides offering plenty of product information, the site details applications and industries for which its products can be used. The site also includes case histories. The arc welding section details a manufacturer of lightweight steel and aluminum wheelchairs that installed three robotic arc welding cells to weld all of the frame components. Workers who previously performed manual brazing were retrained to operate the robots. Another case study profiles a supplier to the automotive industry that needed to weld brackets to car bumpers. Because the job would require multiple weld orientations, a solution was needed that offered more flexibility than a "hard" automation option would permit, as well as weld consistency and high production speeds. A system was designed that incorporated two welding stations, each equipped with two six-axis robots, application-specific software, control units and peripheral equipment.

http://www.fanucrobotics.com

On-Line Welding Supply Store Open

Welding-Direct.com. Visitors to this site can purchase a wide variety of welding and cutting equipment. The site sells gas metal arc welding guns and parts; gas tungsten arc welding torches and parts; plasma arc cutting systems, torches and parts; welding power sources; safety equipment; oxyacetylene welding and cutting equipment; and welding consumables. While most of the items it sells are made by or for Welding-Direct.com, it also sells products from original equipment manufacturers. The site also includes a selection of discounted items.

http://www.welding-direct.com

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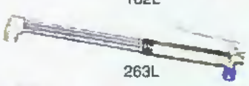
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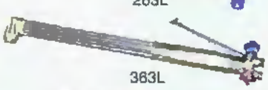
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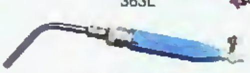
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Code week continues with corresponding subjects geared toward engineers, supervisors, planners, welding inspectors and welding technicians. Since your work is based on a reputation for reliability and safety, you want the latest industry consensus on prequalification. If you want to improve your competitive position by referencing the latest workmanship standards, inspection procedures and acceptance criteria, you won't want to miss this seminar! Each day will be in-depth and intense.

(Day 1, Monday) **D1.1 Road Map**

Houston, Tex. — January 29, 2001 San Francisco, Calif. — March 5, 2001
St. Louis, Mo. — April 9, 2001 Chicago, Ill. — July 16, 2001
Las Vegas, Nev. — September 17, 2001 Atlanta, Ga. — November 5, 2001

(Day 2, Tuesday) **Design of Welded Connections**

Houston, Tex. — January 30, 2001 San Francisco, Calif. — March 6, 2001
St. Louis, Mo. — April 10, 2001 Chicago, Ill. — July 17, 2001
Las Vegas, Nev. — September 18, 2001 Atlanta, Ga. — November 6, 2001

(Day 3, Wednesday) **Qualifications**

Houston, Tex. — January 31, 2001 San Francisco, Calif. — March 7, 2001
St. Louis, Mo. — April 11, 2001 Chicago, Ill. — July 18, 2001
Las Vegas, Nev. — September 19, 2001 Atlanta, Ga. — November 7, 2001

(Day 4, Thursday) **Fabrication**

Houston, Tex. — February 1, 2001 San Francisco, Calif. — March 8, 2001
St. Louis, Mo. — April 12, 2001 Chicago, Ill. — July 19, 2001
Las Vegas, Nev. — September 20, 2001 Atlanta, Ga. — November 8, 2001

(Day 5, Friday) **Inspection**

Houston, Tex. — February 2, 2001 San Francisco, Calif. — March 9, 2001
St. Louis, Mo. — April 13, 2001 Chicago, Ill. — July 20, 2001
Las Vegas, Nev. — September 21, 2001 Atlanta, Ga. — November 9, 2001

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UPCOMING CONFERENCES

HOW TO COMPETITIVELY WELD THE 21st CENTURY SHIP
November 8–9 — Norfolk, Va.

This three-day event will feature presentations on one-sided, single-pass, multiwire SAW; two-wire GMAW; plate cutting technologies, plasma vs. laser vs. water jet; robotic welding; panel line fitting; welding automation; laser butt-joint welding; weldable primers; line heating technology; laser mapping for accuracy control; low-carbon bainitic electrodes; carbon equivalent; double-sided arc welding and more.

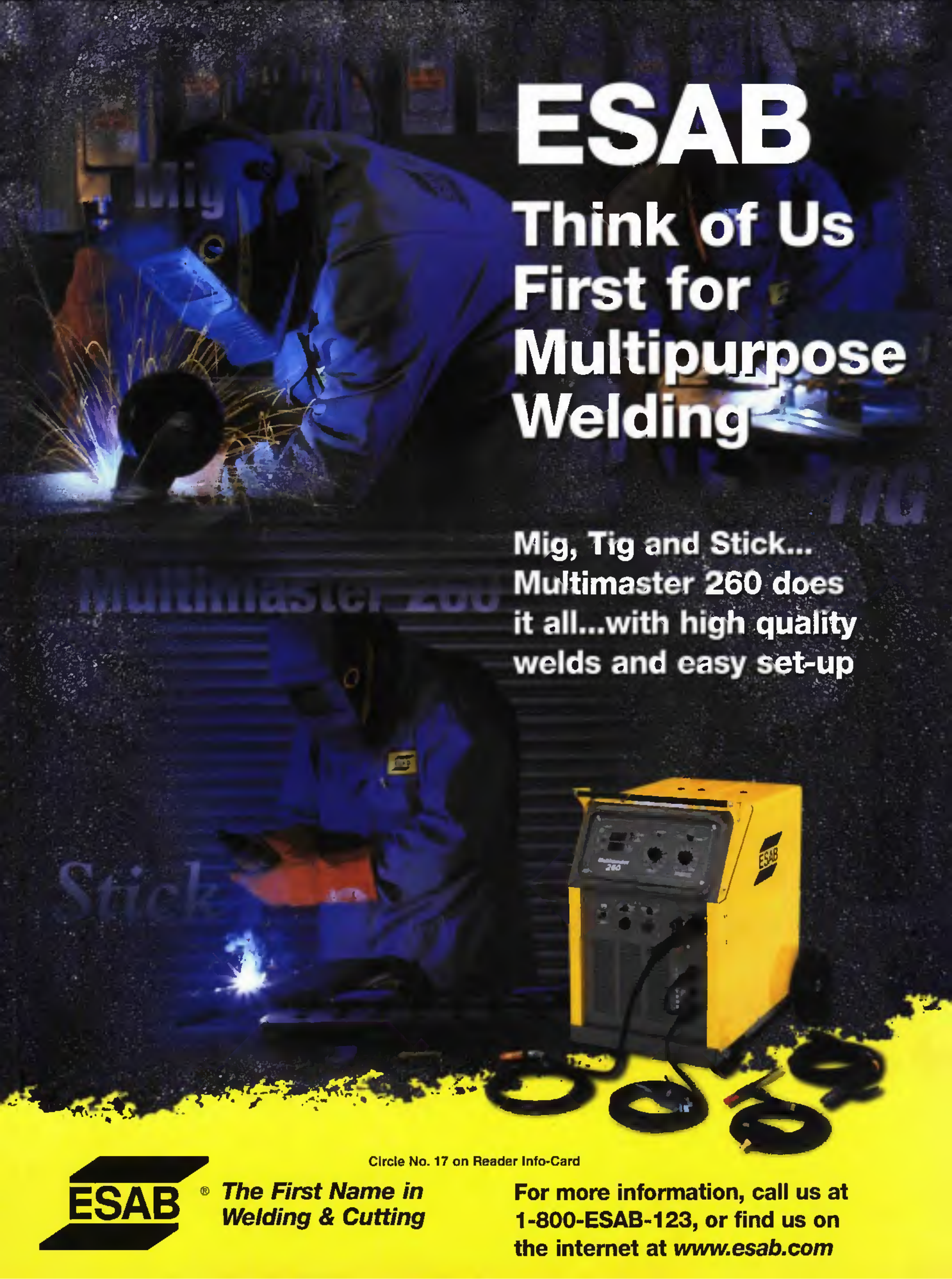
ICAWT 2000 (GAS METAL ARC WELDING FOR THE 21st CENTURY)
December 6–8 — Orlando, Fla.

This is a landmark conference on the gas metal arc welding (GMAW) process and the related flux cored arc welding (FCAW) process, celebrating 50 years of GMAW and evaluating ways in which the application of the latest developments in GMAW technology can assist users in increasing productivity and quality. International experts will give keynote papers, and the latest process developments will be discussed in five sessions over three days.

AWS 5th ROBOTIC ARC WELDING CONFERENCE AND EXHIBITION
February 5–6, 2001 — Orlando, Fla.

This conference is aimed at welding engineers and technicians, manufacturing specialists, managers, and all others concerned with the latest developments in the fast-changing field of arc welding robotics and associated topics. Particular emphasis is given to case studies of actual applications in motorcycle, ship and heavy equipment manufacturing, and on criteria used in robot selection. Other areas covered include the impact of the Internet, fixturing, off-line programming, remote monitoring, computer interfaces with welding cells and metal arc welding. A special activity is a luncheon featuring a keynote speech on the present status of robotic welidng.

For further information, contact: Conferences, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126, Telephone: (800) 443-9353 ext. 223 or (305) 443-9353 ext. 223, FAX: (305) 443-1552. Visit the Conference Department homepage *http://www.aws.org* for upcoming conferences and registration information.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News of the Industry

SkillsUSA Champions Receive Miller GMAW Machines

Miller Electric Mfg. Co., Appleton, Wis., recently awarded Millermatic® 185 gas metal arc welding machines to Tom Foster and Jason Hill, the winners of the welding contests held during the 36th annual SkillsUSA Championships in Kansas City, Mo., in June.

Foster and Hill won in the secondary and postsecondary categories, respectively. This year marked the first anniversary of SkillsUSA, which was previously known as the Vocational Clubs of America (VICA). The national organization represents students receiving education in trade, industrial, technical and health-related occupations.

During the contest, each competitor received a set of welding procedures, with all drawings, symbols and terms conforming to American Welding Society standards. They then moved through four workstations that tested various aspects of welding.

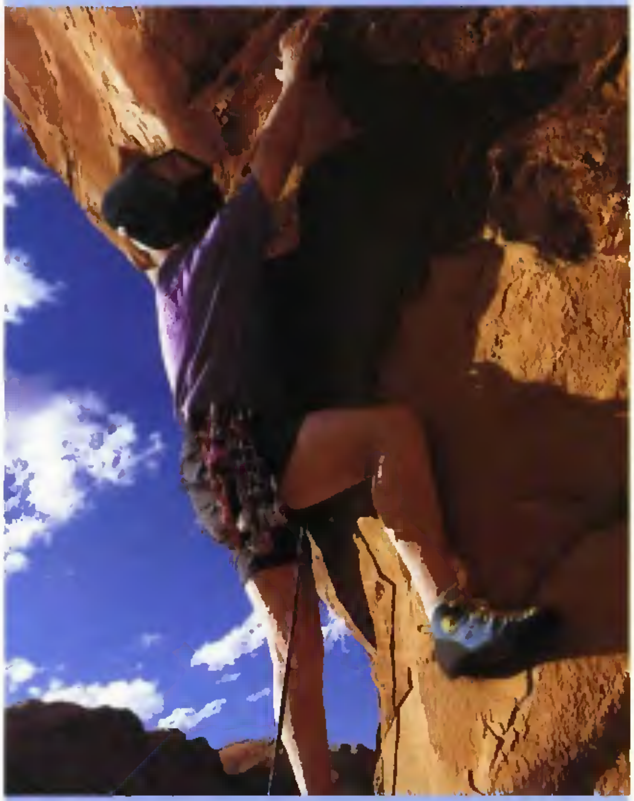
In addition to the Millermatic units, Miller Electric donated a Thunderbolt® XL shielded metal arc welding machine to each of the regional SkillsUSA welding contest winners, $5000 to SkillsUSA and the time of five of its employees who served on the welding competition's technical committee during the conference.

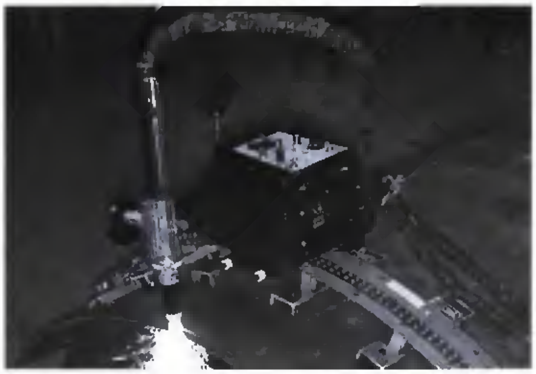
A competitor works on a steel project in the gas metal arc welding area at the SkillsUSA championships.

Winners of the SkillsUSA welding contest stand with Miller Electric employees who served on the technical committee. Pictured are (front row) Duane DiPietro, Miller Electric, and secondary division winners Nicolas Burke (second place), Tom Foster (first place) and Christopher Lowe (third place); (second row) postsecondary division winners Jose Gomez (second place), Jason Hill (first place), Joseph Kight (third place) and Bob Campbell, Miller Electric; (third row) Ralph Kahler and Carl Tengesdal, Miller Electric.

Air Products and WeldersMall.com Form New Internet-Based Company

Air Products and Chemicals, Inc., Lehigh Valley, Pa., and WeldersMall.com, Independence, Ohio, recently announced their intention to create an Internet-based company to serve the $20 billion global welding and cutting market. The new company has acquired all existing assets and staffing of WeldersMall.com., and is building a network of manufacturers, wholesalers and local distributors.





"The aim of the new company is to become the reference point for welding supplies around the world," according to Robert E. Gadomski, Air Products' executive vice president, Gases and Equipment Group.

The new company will receive additional financial and operational support from a venture capitalist group that specializes in helping new Internet-based companies with infrastructure, technology, recruiting, marketing and other operations.

Air Products currently operates more than 100 cylinder filling and distribution outlets throughout the United States that supply gas products and equipment to the welding and cutting market. In May 2000, WeldersMall launched an Internet trading site to serve the needs of welding and cutting customers. Until the new company is operational, WeldersMall will continue to serve customers on its site, *www.weldersmall.com*.

PTR Receives Order for Electron Beam Welding Units for Automotive Industry

PTR-Precision Technologies, Inc., Enfield, Conn., recently received an order for four electron beam welding systems that will be delivered to an automotive parts supplier in Ohio. The systems are similar to five units the company recently delivered to DaimlerChrysler's Kokomo, Ind., transmission plant. The new systems will include a rotating part process, instead of a rotating beam, one as shown in the figure, and employ a slightly different technique for workholding and material handling tasks. Delivery is expected in the third quarter of 2001.

— continued on page 132

New Products

For more information, circle number on Reader Information Card.

Unit Has Built-in GMAW-P Capabilities for Aluminum

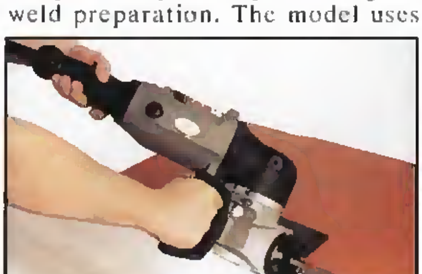
The Millermatic® Pulser has been introduced to help solve aluminum welding problems related to melt-through, warping, spatter, bead appearance, pool control

and welding out of position. The system allows welding aluminum as thin as 0.039 in., and meets I-CAR standards for welding 1- and 3-mm aluminum automobile components.The system features a 35 to 210 amp output, making it suitable for fabricating and repairing car bodies, boats, trailers, signs and irrigation pipes made of aluminum up to ⅜ in. thick. The Pulser comes equipped with two GMAW guns: the Spoolmate 185 spool gun for GMAW and GMAW-P, and the M-015 GMAW gun for running 0.023–0.045 in. solid and cored wires.

Miller Electric Mfg. Co. 100
1635 W. Spencer St., P.O. Box 1079, Appleton, WI 54912

Lightweight Machine Added to Beveling Line

The Model 4000 Bevel-Mill is designed for plate edge beveling for weld preparation. The model uses

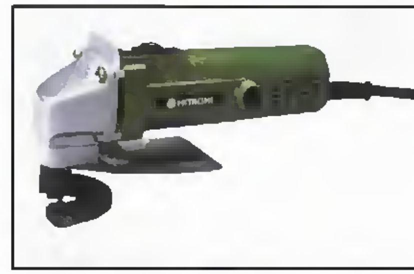


indexable carbide inserts in a milling-type cutting machine to produce clean and accurate bevels. The 4000 Bevel-Mill uses a 2-hp motor for beveling up to 6–8 ft/min on aluminum and stainless steel, and yet weighs only 22 lb. Additional features include variable angle of 15–45 deg, adjustable depth of cut, convenient trigger operation and variable speed controller. Corner rounding or radiuses can be performed with interchangeable inserts.

Heck Industries, Inc. 101
P.O. Box 425, 1480 Old U.S. 23 South
Hartland, MI 48353

Shear and Nibbler Return to Metalworking Line

After seven years, the company returned two tools to its welding line: the Shear and the Nibbler. The CE16 Shear protects the operator's hand from sharp cut-off strips by sliding excess material smoothly off its lower stainless



steel surface to ensure a cleared cutting line. The unit minimizes the scattering of chips and leaves the upper surface clean so the pre-marked cutting line can be seen at all times. This downward cutting feature enables the CN16 Nibbler to cut both corrugated metal plate and trapezoidal metal plate. The CN16 also has a three-positive-stop die holder that permits forward, right and left cutting. This die has a service life of approximately 1000 ft when cutting mild steel plate ⅛ in. thick.

Hitachi Power Tools 102
3950 Steve Reynolds Blvd., Norcross, GA 30093

Power Supply and Controller Designed for Orbital Welding

The Model 227 is a 100/200 A power supply and controller designed for, but not limited to, automatic orbital welding applications that require the addition of filler material. Welds produced with this machine, together

with the company's brand of weld heads, meet or exceed the specifications required by most industries. This product is compatible with the company's fusion weld heads without welding wire, pipe weld heads with welding wire and open-frame weld heads with or without welding wire.

Arc Machines, Inc. 103
10500 Orbital Way, Pacoima, CA 91331

Laser Position Sensor Line Has Class 1 Rating

The 18K series of laser position sensors meets the Class 1 rating per EN 60825-1, guaranteeing safety in all applications and eliminating the need for beam termination. Accidental eye contact with the beam is not a problem. The 18-mm tubular sensors use a 650-nm red laser and are available in all popular sensing modes, including diffuse, retroreflective and through-beam. Diffuse versions have a range up to 300 mm and resolution to 0.5 mm for applications requiring high accuracy at short sensing distances.

Balluff Inc. 104
8125 Holton Dr., Florence, NY 41042

Respirator Features Valve to Quickly Release Hot Air

The 2700N95 respirator comes equipped with the Handy Strap®,

which allows the respirator to hang comfortably around the neck when not in use. The Ventex™ valve releases hot air faster to allow users to breath easier and stay cool longer. The soft, foam nose flange also provides extra comfort around the nose bridge. This respirator is NIOSH-approved to have a filter efficiency of 95% or greater against particulates free of oil. The item is available in two sizes.

Moldex-Metric, Inc. 105
10111 W. Jefferson Blvd., Culver City, CA 90232

Cooling Power of Chillers Increased, Size Decreased

The improved 6000 Chiller series offers extended cooling in a more compact size. The 6000 series features the energy-saving Cool Command™ refrigeration technology that is standard in each of the company's units. The pressure regulator, reusable fluid filter and reusable air filter are easily

accessed to reduce downtime. A reservoir drain has been added for easy fluid removal.

PolyScience 106
P.O. Box 48312, 6600 W. Touhy Ave.
Niles, IL 60714

Electrodes Designed for Railroad Frogs and Diamonds

FrogMang® shielded metal arc and flux cored wire electrodes are designed specifically for building up frogs and crossing diamonds in the railroad industry. These high-strength electrodes can handle the weight of railroad cars, reducing the need for repeated repairs. Features include low smoke and spatter levels, easy slag removal and reduced grinding time after work hardening. The electrodes are used to eliminate low spots on the surface and wheel pounding that destroys track surface and creates metal fatigue.

The Lincoln Electric Company 107
22801 St. Clair Ave., Cleveland, OH 44117

Medium-Frequency RSW Machine Handles Wide Range of Metals

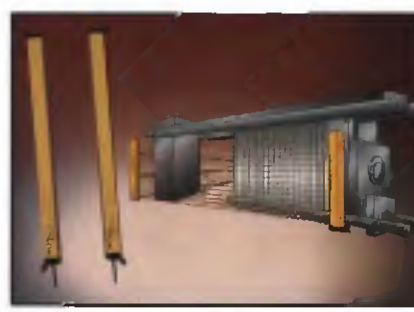
An inverter-controlled, medium-frequency version of the Stronghold resistance spot welding machine has been released. Advantages of using medium frequency include an even distribution of load over three phases, less mains current and a power factor in excess of 0.9. Other advantages include

the ability to weld a wide range of metals, such as softer metals with high electrical and thermal conductivity. An absence of high peak current and minimal splashing extend the life of the electrode.

British Federal Ltd. 108
Castle Mill Works, DUDLEY
West Midlands DY1 4DA, England

Safety Light Curtains Ideal for Perimeter Guarding

The OptoFence OF4600-50 safety light curtain system comes standard with individual beam indicators for simplified alignment and a Start/Restart interlock operating mode for perimeter guarding applications. The compact two-box design requires no cable

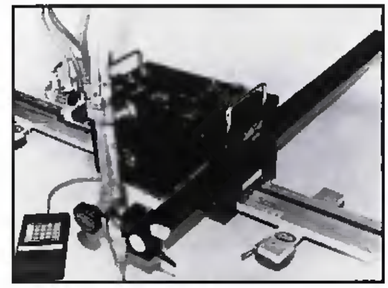


between the transmitter and receiver. Exact channel select allows for permanently blocked beams in the detection zone; floating banking up to two beams to be blocked anywhere in the zone; and two solid-state safety outputs that provide 500 mA of current at 24-V- DC. This safety light curtain system provides 2-in. resolution, 80-ft. range and is available in heights from 27 to 69 in.

Scientific Technologies Inc. 109
6550 Dumbarton Circle, Fremont, CA 94555

Programmable Shape Machine Easy to Use

The programmable shape machine is a two-axis machine that can be programmed to run any contour or pattern for both welding and cutting applications. A hand-held terminal

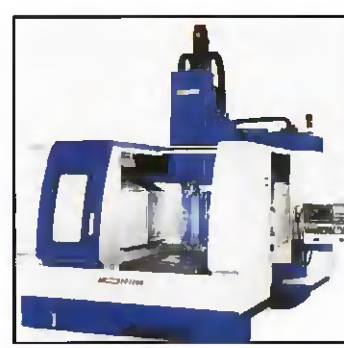


supplied with the unit is used to program the required shape and operation sequence. Other functions can be programmed, such as repeats, starts, stops, deletes and rapid traverse. Ten programs can be stored in the machine memory at any one time. An optional IBM-compatible computer software program is available.

BUG-O Systems 110
3001 W. Carson St., Pittsburgh, PA 15204

Machining Center Designed for Mold and Die Applications

The FP120A bridge-style machining center is designed for the mold and die market. The unit's high speed and high horsepower spindle design make it ideal for rough cutting and fine finish cutting. A specially designed bridge-structure ensures load distribution and accuracy. A 30-hp Cytec® AC digital motor powers the spindle to speeds



ranging from 60 to 20,000 rpm. The unit's large tool capacity allows permanent-set tooling to be stored in the magazine, minimizing setup time.

YCI Supermax Inc. 111
10629 Forest St., Santa Fe Springs, CA 90670

aluminations

Burnback. Wire stubbing. Porosity. Erratic feeding. These common problems plague fabricators that MIG weld aluminum. Often, they result from an inadequate or improperly adjusted wire feeder system. If you want to gain more control over MIG aluminum productivity, this aluminations provides troubleshooting tips and introduces new push-pull feeder technology.

Shedding light on aluminum welding issues

questions ANSWERS

Q. I have gas flow from the gun, but not a clean weld. How can I solve this?

A. *Porosity and black welds indicate poor gas coverage or contamination. To ensure good coverage, check for: proper gas flow (CFH), leaks in the system (loose fittings, cuts in the gas hose, worn O-rings) and excessive spatter in the nozzle. Make sure the contact tip is recessed about 1/8" in the nozzle. To ensure 100% coverage and prevent contamination, Miller designed a unique gas delivery system for its XR-Edge™ gooseneck gun. It even sends gas through the contact tip with the wire. This enhances the cleaning action and reduces porosity and post-weld clean-up.*

Q. What causes aluminum wire to burn back to the contact tip?

A. *90% of "burnbacks" result from poor arc starts caused by incorrect run-in speed, not tuning the wire feeder to the power source and poor electrical continuity between the wire and contact tip. [Note that the patent pending XR-Edge gun design helps eliminate poor electrical pick-up.]*

Q. How can I prevent birdnesting?

A. *Soft aluminum wire is prone to buckling, so using a larger diameter may help. Better yet, invest in a push-pull feeder. In such systems, a torque motor at the wire spool steadily feeds the wire while a drive motor located in the gun precisely controls wire speed at the arc. This maintains constant tension, so the wire feeds consistently, even when the cable is looped, and at distances up to 50 ft. The XR-Edge torque motor features a high and a low torque setting, letting you adjust performance, respectively, for larger or smaller diameter wires.*

David Almy
Welding Engineer
Miller Electric Mfg. Co.

The inherent properties of aluminum make it prone to poor MIG arc starts. For example, aluminum wire requires a lot of current to initiate the arc, yet the wire melts very quickly once the arc starts. It requires a fast wire feed speed, but any oxide on the weldment delays arc initiation because it melts at a much higher temperature. Thus, the solution to arc starting problems often involves fine-tuning the speed at which the wire approaches the weldment.

Assuming you have a "push-pull" style wire feeder, start by finding the run-in speed control. This sets the wire feed speed from the time you pull the gun trigger until arc initiation (after sensing an arc, the machine switches to welding speed). Because run-in speed is generally slower than welding speed, the arc has more time to establish itself. If you experience wire stubbing, use a slower run-in speed.

Always adjust run-in speed first. For additional fine-tuning, Miller incorporated a unique feature in its XR-Edge™ push-pull feeder that adjusts how long the wire drive motors take to ramp up to full speed. This "motor ramp control" can help tune the wire feeder to better match a welding power source's arc starting characteristics. To prevent long, flaring arc starts or wire burning back to the contact tip, increase ramp control. For example, ramp control is factory-set at maximum speed to match Miller's fast-responding Invision™ 354MP inverter. Slower ramp speeds have benefited users who pair the XR-Edge with magnetic amplifier-type CV welders or CC machines for running larger wires.

Smooth Groove, Smoother Performance

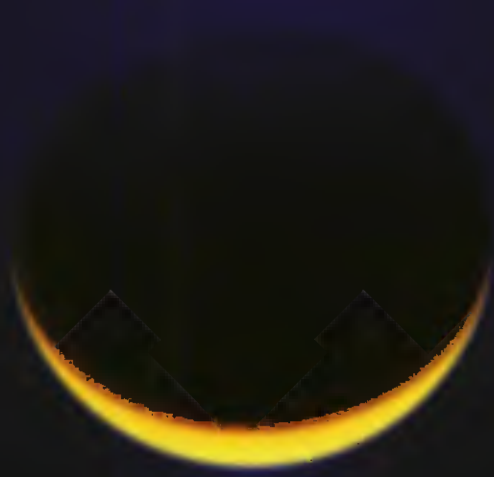
The soft nature of aluminum wire leads to feeding problems. For example, when the wire slips through the drive rolls, burnbacks and arc stumbling often result. Don't over-tension the drive rolls or use knurled drive rolls as a "solution." This inevitably deforms and defaces the wire, producing shavings. These wire particles then build up in the drive roll grooves, cable liner and contact tip. Ironically, this also causes burnbacks and arc stubbing.

Instead, look for a wire feeder system with 1) the new-style smooth groove drive rolls and 2) all gear driven drive rolls (no idler roll). Both the gun and the feeder rolls on Miller's new XR-Edge have these features, and this particular system offers excellent feeding performance without deforming and defacing the welding wire.

XR-Edge gun with all gear driven drive rolls.

For more information on wire feeder systems and welding power sources that give you the flexibility and control to optimize MIG welding aluminum, call 1-800-4-A-MILLER (1-800-426-4553, ext. 603) or visit our website at www.MillerWelds.com.

Circle No. 32 on Reader Info-Card



New Visions for Materials Joining in the 21st Century

American Welding Society and AWS Foundation Annual Report 2000

American Welding Society

AWS Foundation, Inc.

A Foundation of the American Welding Society

Board of Directors' Message

Just over a decade ago, the American Welding Society set a new course of leadership to guide the welding industry into the 21st century.

Education, government and industry leaders joined with us in developing a Strategic Plan designed to keep pace with modern technology and the industry's inevitable growth.

History reflects that the action was timely and prudent. Our revenues during the past ten years have more than doubled. The AWS Foundation was established in 1990 and is now a multimillion-dollar charitable entity. Today, our education programs stretch from middle schools to university research work, and our certification programs range from entry level welder to welding engineer.

Solid management and close adherence to the Strategic Plan also produced significant gains in other areas. Membership has grown to more than 50,000. The Exposition's attendance has grown by 30%, while exhibitor participation has grown by 29%. Certification programs have grown substantially, as is described elsewhere in this report. Influential participation in sister societies, counterpart groups and international welding organizations has earned us an enviable reputation for industry leadership.

2000 AWS Fellows Inducted at Annual Meeting

Donald Clement Bertossa
General Electric

John W. Elmer
Lawrence Livermore National Laboratory

James L. Jellison
Sandia National Laboratory

Thomas M. Mustaleski
Lockheed Martin Energy Systems, Inc.

Thomas W. Shearer, Jr.
Retired
General Motors

Chon-Liang Tsai
The Ohio State University

Our entrepreneurial spirit allows us to continuously improve the programs and benefits we offer the welding industry. Support for research links us with the next generation, our rejuvenating source of energy. As a result, we effectively serve our diversified membership with industry-specific projects, career development and creative efforts that will impact the future course of materials joining and its role in the overall industrial complex.

Major initiatives are underway to ensure continued progress well into the new millennium. They include a restructuring of our Strategic Plan, a cooperative effort with the Department of Energy (DOE) in defining the industry's vision of the issues and opportunities it will face up to the year 2020, and a joint research project led by AWS and the Edison Welding Institute (EWI) to quantify the economic impact of welding in the U.S. economy.

Working under the auspices of the *DOE Industries of the Future* program, experts from all sectors of the welding industry including equipment manufacturers, end users, educators and industry leaders are developing vision and roadmapping documents that will present a long-term technology plan. This Plan will identify how welding will meet the needs of manufacturers, the marketplace and society by 2020. We are pleased to report that the documents have been well-received.

Welding—Its Economic Impact on the United States Economy is a comprehensive study that will, for the first time, answer several key questions about the welding industry, including its contribution to the U.S. Gross Domestic Product. Over eighty percent of the funding necessary for the project has been raised. In addition to AWS and EWI funding, financial support has been obtained from the U.S. Navy, the U.S. Department of Commerce, the State of Ohio, several welding equipment manufacturers, and several large corporate users of welding technology. Among the study's primary benefits will be a clear understanding, based on empirical quantitative data, of the true scope and impact of the welding industry on the nation's economic well being. As a result, it will furnish a business/financial foundation for the industry vision and technology roadmap being developed by the AWS/DOE *Industries of the Future* program.

In summary, great progress has been made in the past decade. We attribute our ongoing success to our volunteers, staff and industry leaders. It has been said that where there is no vision, greatness passes by. With our vision solidly intact, we are moving confidently into the new century and believe it will lead us and the industry to new heights.

American Welding Society, Inc. and AWS Foundation
Combined Statement of Financial Position

May 31, 2000 with Comparative Totals for 1999

Assets	Operating Fund	Reserve Fund	AWS Foundation	Total 2000	Total 1999
CURRENT:					
Cash and cash equivalents (Note 2)	$ 240,126	$ 1,673,539	$ 1,549,496	$ 3,463,161	$ 1,885,681
Grant and contract receivable	34,323	-	40,000	74,323	68,711
Investments in U.S. Treasury Bills	-	1,143,313	514,024	1,657,337	-
Accounts receivable, less allowance for possible losses of $58,961 and $61,424 in 2000 and 1999, respectively	2,913,672	2,118	-	2,915,790	1,672,152
Pledges receivable (Note 3)	-	-	152,250	152,250	75,231
Inventories	1,507,628	-	-	1,507,628	1,470,949
Prepaids and other	816,737	29,156	107,726	953,619	1,049,343
TOTAL CURRENT ASSETS	5,512,486	2,848,126	2,363,496	10,724,108	6,222,067
INVESTMENTS IN U.S. TREASURY NOTES	-	-	-	-	1,659,600
INVESTMENTS IN EQUITY AND OTHER DEBT SECURITIES	-	1,930,213	596,680	2,526,893	4,463,078
PROPERTY AND EQUIPMENT, less accumulated depreciation (Note 4)	2,564,916	-	-	2,564,916	2,730,283
PLEDGES RECEIVABLE (Note 3)	-	-	264,000	264,000	85,308
DEPOSITS	62,198	-	5,790	67,988	77,291
	$ 8,139,600	$ 4,778,339	$ 3,229,966	$16,147,905	$15,237,627
Liabilities and Net Assets					
CURRENT LIABILITIES:					
Accounts payable, short term portion of capital leases and accrued expenses	$ 3,676,228	$ 8,400	$ 49,347	$ 3,733,975	$ 1,723,406
Deferred membership, subscription and convention income	2,712,834	-	-	2,712,834	2,846,711
TOTAL CURRENT LIABILITIES	6,389,062	8,400	49,347	6,446,809	4,570,117
OTHER LIABILITIES:					
Customer deposits, long term portion of capital leases and other	346,491	-	-	346,491	159,620
TOTAL LIABILITIES	6,735,553	8,400	49,347	6,793,300	4,729,737
COMMITMENTS (Note 9)					
NET ASSETS					
Unrestricted	1,404,047	4,769,939	2,675	6,176,661	8,117,782
Temporarily restricted (Note 5)	-	-	1,237,245	1,237,245	832,996
Permanently restricted (Note 6)	-	-	1,940,699	1,940,699	1,557,112
TOTAL NET ASSETS (Note 7)	1,404,047	4,769,939	3,180,619	9,354,605	10,507,890
	$ 8,139,600	$ 4,778,339	$ 3,229,966	$16,147,905	$15,237,627

The accompanying notes are an integral part of these financial statements.

American Welding Society, Inc. and AWS Foundation
Combined Statement of Activities and Changes in Net Assets

For the Year Ended May 31, 2000 with Comparative Totals for 1999

	Unrestricted Net Assets			Temporarily Restricted	Permanently Restricted	Total	Total
	Revenues	Expenses	Net	Net Assets	Net Assets	2000	1999
OPERATING ACTIVITIES:							
Convention	$ 4,238,752	$ 2,066,210	$ 2,172,542			$ 2,172,542	$ 2,116,269
Education	1,879,634	1,661,616	218,018			218,018	2,607
Conference	330,420	542,495	(212,075)			(212,075)	(210,962)
International, governmental affairs and marketing	71,251	1,705,743	(1,634,492)			(1,634,492)	(1,510,410)
Navy Joining Center	20,706	20,706	-			-	-
Membership	3,020,477	1,688,228	1,332,249			1,332,249	1,267,845
Certification	2,905,151	1,330,463	1,574,688			1,574,688	1,446,644
Technical	3,198,300	2,067,022	1,131,278			1,131,278	736,074
Publications	3,226,512	3,604,155	(377,643)			(377,643)	(260,536)
Administration (Note 9)	309,929	4,822,652	(4,512,723)			(4,512,723)	(3,853,617)
Building operations	116,966	173,054	(56,088)			(56,088)	(32,910)
Interest income	4,240	-	4,240			4,240	14,399
Board approved programs (Note 8)	-	57,114	(57,114)			(57,114)	(45,290)
TOTAL OPERATING FUND	19,322,338	19,739,458	(417,120)			(417,120)	(329,896)
RESERVE							
Gain on investments reported at fair value	158,831	-	158,831			158,831	368,405
Board approved programs (Note 8)	-	100,000	(100,000)			(100,000)	(100,000)
TFPS, Inc.	25,500	24,073	1,427			1,427	-
Interest and dividends	236,112	-	236,112			236,112	153,239
TOTAL RESERVE FUND	420,443	124,073	296,370			296,370	421,644
AWS FOUNDATION							
Donations	222,222	-	222,222	$ 435,589	$ 383,587	1,041,398	525,919
Interest	26,408	-	26,408	46,204		72,612	85,005
Gain on investments reported at fair value	25,143	-	25,143			25,143	45,607
Reclassifications - net assets released from restrictions by satisfaction of purpose restrictions	77,544	-	77,544	(77,544)		-	-
Operating expenses	-	152,337	(152,337)			(152,337)	(115,582)
Scholarships	-	127,287	(127,287)			(127,287)	(112,418)
Fellowships	-	93,333	(93,333)			(93,333)	(66,666)
Fundraising and other	-	105,646	(105,646)			(105,646)	(224,638)
TOTAL AWS FOUNDATION	351,317	478,603	(127,286)	404,240	383,587	660,550	137,227
CHANGE IN NET ASSETS BEFORE LOSS ON IMPAIRMENT OF ASSET			(248,036)	404,249	383,587	539,800	228,975
Loss on Impairment of Asset (Note 2)	-	1,693,085	(1,693,085)			(1,693,085)	-
CHANGE IN NET ASSETS			(1,941,121)	404,249	383,587	(1,153,285)	228,975
BEGINNING NET ASSETS			8,117,782	832,996	1,557,112	10,507,890	10,278,915
ENDING NET ASSETS			$ 6,176,661	$ 1,237,245	$ 1,940,699	$ 9,354,605	$10,507,890

The accompanying notes are an integral part of these financial statements.

American Welding Society, Inc. and AWS Foundation
Combined Statement of Cash Flows

For the Year Ended May 31, 2000 with Comparative Totals for 1999

	Operating Fund	Reserve Fund	AWS Foundation	Total 2000	Total 1999
CASH FLOWS FROM OPERATING ACTIVITIES:					
Change in net assets	$ (2,110,205)	$ 296,370	$ 660,550	$ (1,153,285)	$ 228,975
Adjustments to reconcile change in net assets to net cash provided by operating activities:					
Gains on investments reported at fair value	-	(240,597)	(23,191)	(263,788)	(414,012)
Depreciation	467,304	-	-	467,304	492,216
Provision for losses on accounts receivable	10,000	-	-	10,000	10,000
Loss on impairment of asset	1,693,085	-	-	1,693,085	-
Loss on disposal of property and equipment, net	-	-	-	-	44,917
(Increase) decrease in accounts receivable	(1,257,289)	3,651	-	(1,253,638)	128,978
(Increase) decrease in pledges and endowments receivable	-	-	(255,711)	(255,711)	53,136
(Increase) decrease in grants and contract receivable	(5,612)	-	-	(5,612)	44,966
(Increase) decrease in inventories	(36,679)	-	-	(36,679)	242,295
Decrease (increase) in prepaids and other assets	99,454	6,530	(43,028)	62,956	(333,359)
Decrease (increase) in deposits	15,093	-	(5,790)	9,303	(14,924)
Increase (decrease) in accounts payable and accrued expenses	1,378,826	8,400	(16,882)	1,370,344	(356,332)
(Decrease) increase in deferred membership, subscription and convention income	(133,877)	-	-	(133,877)	704,572
(Decrease) increase in customer deposits and other	(1,881)	-	-	(1,881)	129,116
Contributions restricted for permanent investment	-	-	-	-	(144,323)
Net cash provided by operating activities	118,219	74,354	315,948	508,521	816,220
CASH FLOWS FROM INVESTING ACTIVITIES:					
Purchases of property and equipment, net	(938,501)	-	-	(938,501)	(495,758)
Maturities of U.S. Treasury obligations	-	-	-	-	4,866,103
Maturities of debt and other equity securities		1,583,682	618,554	2,202,236	-
Purchase of U.S. Treasury obligations	-	-	-	-	(2,378,357)
Purchase of debt and other equity securities	-	-	-	-	(2,400,000)
Net cash provided (required) by investing activities	(938,501)	1,583,682	618,554	1,263,735	(408,012)
CASH FLOWS FROM FINANCING ACTIVITIES:					
Interfund transfer	655,184	(655,184)	-	-	-
Payments on capital leases	(194,776)	-	-	(194,776)	-
Contributions restricted for permanent investments	-	-	-	-	144,323
Net cash (required) provided by financing activities	460,408	(655,184)	-	(194,776)	144,323
NET INCREASE (DECREASE) IN CASH AND CASH EQUIVALENTS	(359,874)	1,002,852	934,502	1,577,480	552,531
CASH AND CASH EQUIVALENTS AT THE BEGINNING OF YEAR	600,000	670,687	614,994	1,885,681	1,333,150
CASH AND CASH EQUIVALENTS AT THE END OF YEAR	$ 240,126	$ 1,673,539	$ 1,549,496	$ 3,463,161	$ 1,885,681
SUPPLEMENTAL SCHEDULE OF NON CASH INVESTING AND FINANCING ACTIVITIES:					
Property and Equipment acquired under capital lease	$ 621,915	$ -	$ -	$ 521,915	$ -

The accompanying notes are an integral part of these financial statements.

NOTE 1 - NATURE OF ORGANIZATION

The accompanying combined financial statements include the accounts of American Welding Society, Inc., its wholly-owned subsidiary, TFPS, Inc., and its commonly controlled affiliate, AWS Foundation (collectively, the "Organizations").

All material inter-organization accounts and transactions have been eliminated in combination. American Welding Society, Inc. and AWS Foundation are not-for-profit entities, exempt from income tax under Section 501 (c)(3) of the Internal Revenue Code and are primarily engaged in welding technology, education and research activities. For income tax purposes, publication advertising revenue and rental income are considered unrelated business income and subject to income tax (none in the current year). TFPS, Inc., a taxable organization, engages in profit-oriented activities. American Welding Society, Inc. grants credit to certain of its customers which are located principally within the United States of America.

In 1995, American Welding Society, Inc. became a subrecipient of federal funds from the Edison Welding Institute on a $486,000 contract to develop codes and standards and various educational projects. Funding during fiscal year 2000 totaled approximately $20,000.

NOTE 2 - SUMMARY OF ACCOUNTING POLICIES

A) FUND BALANCES

The accounts of the Organizations are categorized into separate funds. The purpose and net asset classification are as follows:

Operating - This fund is used to account for all unrestricted net assets of American Welding Society, Inc., except for those accounted for in the reserve fund.

Reserve - This fund is used to account for Board designated reserve funds which are to be used to supplement the cash needs of the operating fund and to account for the activities of TFPS, Inc.

AWS Foundation - AWS Foundation's temporarily restricted net assets consist of donor restricted contributions to be use for awards and scholarships. Permanently restricted net assets consist solely of an endowment fund.

B) ESTIMATES

The preparation of the financial statements in conformity with generally accepted accounting principles requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities at the date of the financial statements and the reported amounts of revenues and expenses during the reporting period. Actual result could differ from those estimates.

NOTE 2 - SUMMARY OF ACCOUNTING POLICIES (CONTINUED)

C) INVENTORIES

Inventories of publications are valued at the lower of cost or market. Cost is determined by the weighted average method.

D) INVESTMENTS

The Organizations' investments in debt and equity securities are accounted for at fair value (quoted market price). Debt investments are comprised of U.S. Treasury obligations and mutual funds. Equity investments are comprised of mutual funds.

E) PROPERTY, EQUIPMENT AND DEPRECIATION

Property and equipment are stated at cost. Expenditures for additions, renewals and betterments are capitalized; expenditures for maintenance and repairs are charged to expenses as incurred. Upon retirement or disposal of assets, the cost and accumulated depreciation are eliminated from the accounts and the resulting gain or loss is included in revenues or expenses. Depreciation is computed using the straight-line method over the following estimated useful lives:

	Years
Building and improvements	14 - 20
Furniture and equipment	6 - 7
Transportation equipment	3

F) REVENUE RECOGNITION

The Organizations conduct an annual convention near the Organizations' fiscal year-end. The Organizations recognize convention revenue in the fiscal year the convention is held, or normally held, thereby recognizing one event during any fiscal year.

Membership and subscription revenues are deferred when received and recognized as revenue when earned, substantially in the subsequent year.

Gifts of cash or other assets are reported as restricted revenue if they are received with donor stipulations that limit the use of the donated assets. When a donor restriction expires, that is, when a stipulated time restriction ends or purpose restriction is accomplished, temporarily restricted net assets are reclassified to unrestricted net assets and reported in the statement of activities as net assets released from restrictions. However, if the restriction is received and met in the same period, the amount is recorded as unrestricted revenue. Unrestricted gifts of property and equipment are recorded as revenues at the date of donation and are valued at fair value.

NOTE 2 - SUMMARY OF ACCOUNTING POLICIES (CONTINUED)

F) REVENUE RECOGNITION (CONTINUED)

Endowments received are subject to restrictions that the principal be invested and only the income be used for scholarships and fellowships. Such investment income is recognized as temporarily restricted revenues when earned. However, if the restriction is received and met in the same period, the amount is recorded as unrestricted revenue.

G) ALLOCATION OF EXPENSES

The costs of performing the Organizations' various activities have been summarized on a functional basis in the accompanying statement of activities. Certain occupancy costs have been allocated among the activities benefited.

H) STATEMENTS OF CASH FLOWS

For the purpose of reporting cash flows, the Organizations consider all unrestricted investments in highly liquid debt instruments purchased with a maturity of three months or less to be cash equivalents. Cash and cash equivalents on the balance sheet includes repurchase agreements of $137,690 and $1,069,525, short-term certificates of deposit of $697,000 and $497,000, and money market funds totaling $2,315,152 and $83,958 in 2000 and 1999, respectively.

I) RECLASSIFICATIONS

Certain 1999 amounts have been reclassified to conform to the 2000 presentation.

J) LONG-LIVED ASSETS

The Organizations had capitalized various costs incurred in connection with the acquisition and installation of a new computer system throughout the year ended May 31, 2000. Management decided that the new system is not capable of handling the business requirements of the Organizations and has established a plan to dispose of the system. As a result of Statement of Financial Accounting Standards No. 121 "Accounting for the Impairment of Long-Lived Assets and Long-Lived Assets to be Disposed Of" ("SFAS 121"), the Organizations are required to review any long-lived assets for impairment whenever events or changes in circumstances indicate that the carrying amount of the asset in question may not be recoverable. As a result of the plan to dispose of the system, the Organizations have written off certain assets with a net book value of $982,967. Additional costs of the computer system totaling $202,372 and prepaid expenses totaling $32,768 have also been included as a part of the loss on impairment. In addition, an accrual has been established for costs in connection with the plan to dispose of the asset totaling $474,978. The total loss on impairment of the asset is disclosed on the Statement of Activities as a separate line item.

NOTE 3 - PLEDGES AND ENDOWMENTS RECEIVABLE

Unconditional promises are expected to be realized as follows:

In one year or less	$ 152,250
Between one and five years	254,000
More than five years	10,000
	$ 416,250

Endowments receivable in the amount of $209,000 as of May 31, 2000 are restricted for awards and scholarships.

NOTE 4 - PROPERTY AND EQUIPMENT

Major classes of property and equipment consist of the following as of May 31, 2000:

Land	$ 816,726
Building and improvements	3,793,810
Furniture and equipment	3,250,135
Transportation equipment	21,564
	7,882,235
Less accumulated depreciation	5,317,319
	$ 2,564,916

NOTE 5 - TEMPORARILY RESTRICTED NET ASSETS

Net assets in the amount of $1,237,245 as of May 31, 2000, are restricted for awards and scholarships. Net assets of $77,544 were released from donor restrictions by granting awards and scholarships.

NOTE 6 - PERMANENTLY RESTRICTED NET ASSETS

Net assets in the amount of $1,940,699 as of May 31, 2000, are permanently restricted endowments which are to provide a source of funds predominantly for educational, research and other charitable purposes.

NOTE 7 - TOTAL NET ASSETS

Changes in net assets during the year ended May 31, 2000 are as follows:

	Operating	Reserve	AWS Foundation	Total
NET ASSETS, beginning of year	$ 2,859,068	$ 5,128,753	$ 2,520,069	$ 10,507,890
(Deficiency) excess of revenues over expenses	(417,120)	296,370	660,550	539,800
Loss on Impairment of Asset	(1,693,085)	-	-	(1,693,085)
Interfund transfers	655,184	(655,184)	-	-
NET ASSETS, end of year	$ 1,404,047	$ 4,769,939	$ 3,180,619	$ 9,354,605

NOTE 8 - BOARD APPROVED PROGRAMS

American Welding Society, Inc.'s Board of Directors periodically approves expenditures for special programs designed, among other things, to further the development and public awareness of welding technology, education and standards. For the year ended May 31, 2000, such special program expenses amounted to $157,114.

NOTE 9 - COMMITMENTS

American Welding Society, Inc. is self insured for employees' health benefits to the extent of $30,000 per employee per annum. Claims in excess of $30,000 are reinsured. The accrued expenses include approximately $110,000 in connection with un-reimbursed claims as of May 31, 2000. The Organization incurred health insurance expenses totaling approximately $840,000 during the year ended May 31, 2000.

American Welding Society, Inc.'s Executive Director is employed under the terms of an employment contract. The contract renews unless cancelled timely by either party. The contract provides for base compensation and bonuses at the discretion of the Board of Directors. Additionally, the Executive Director is eligible to retire and receive lifetime fixed retirement payments and lifetime health insurance coverage. The actuarial present value of the future benefit obligation is being accrued over the period from 1999 to 2005. For the year ended May 31, 2000, this expense amounted to $126,000 which is included in administration expenses in the accompanying combined statement of activities and which has been designated within the reserve fund net assets for payment of the future benefit obligation. The agreement also provides for certain severance benefits.

NOTE 10 - RELATED PARTY TRANSACTIONS

AWS Foundation administers investments on behalf of certain affiliated sections. The investments aggregated $965,882 at May 31, 2000 and are not included in the combined financial statements.

NOTE 11 - CAPITAL LEASE

The Organizations lease certain computer and other office equipment under capital leases expiring on various dates through the year 2004. Assets are depreciated over the lower of their related lease terms or their estimated productive lives. Depreciation of assets under capital leases totaled $70,890 for the year ended May 31, 2000.

The following is a schedule of future minimum lease payments under the capital leases:

2001	$ 227,940
2002	223,211
2003	68,810
2004	42,531
Total minimum lease payments	562,492
Less current maturities	227,940
	$ 334,552

Independent Auditor's Report

To the Board of Directors
American Welding Society, Inc. and AWS Foundation

We have audited the accompanying combined statement of financial position of American Welding Society, Inc. and AWS Foundation ("AWS") as of May 31, 2000 and the related combined statements of activities and changes in net assets and cash flows for the year then ended. These financial statements are the responsibility of AWS's management. Our responsibility is to express an opinion on these financial statements based on our audit. Information for the year ended May 31, 1999 is presented for comparative purposes only and was extracted from the financial statements presented for that year, which were audited by another independent certified public accountant, and whose report dated July 30, 1999, expressed an unqualified opinion.

We conducted our audit in accordance with generally accepted auditing standards. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion.

In our opinion, the combined financial statements referred to above present fairly, in all material respects, the financial position of American Welding Society, Inc. and AWS Foundation as of May 31, 2000, and the changes in its net assets and its cash flows for the year then ended in conformity with generally accepted accounting principles.

Morrison, Brown, Argiz & Company
Certified Public Accountants
Miami, Florida
August 31, 2000

WEMCO and Sustaining Members

A.E.S. Destructive & Non-Destructive, Inc.
ABB Alstom Power Heat Exchange
ABB Combustion Engineering, Inc.
ABB Flexible Automation WS Div
Accudata, Inc.
Acute Technological Services
ADB Industries
Advanced Steel Systems, Inc.
AGA Gas, Inc.
AGA General Gases
AGA, SA
AGA, SA - Quito
Air Liquide America Corp.
Air Products & Chemicals, Inc.
Air Products And Chemicals, Inc.
Airgas Northeast
Aker Gulf Marine
Alabama Shipyard, Inc.
Aladdin Welding Products, Inc.
ALCOA
ALCOA Cressona Operation
ALCOA, Inc.
Alcotec Wire Company
Abicor Binzel Corp.
All Star Bleachers Manufacturing, Inc.
Alpine Steel LLC
Aluminum Company Of America (Alcoa)
Aluminum Company Of America (WA)
American Bureau Of Shipping
American Filler Metals Company
American Mechanical Contractors
American Torch Tip Co.
Amet, Inc.
Arc Machines, Inc.
Arc One
Arcos Alloys
Arcsmith, Inc.
Arctec Alloys Limited
Artisan Industries, Inc.
Askaynak
Atlantic Marine, Inc.
Atlas Welding Accessories, Inc.
Auburn Mfg, Inc.
Avondale Shipyards, Inc.
Azco, Inc.
Base Line Data, Inc.
Bath Iron Works
Bechtel Corp.
Belmont Technical College
Bender Shipbuilding & Repair
Benteler Automotive
Bethlehem Steel Corp.
Bishop State Community College
Bms, Inc.
Boc Gases
Bohler Thyssen Welding USA, Inc.
Bombardier Concarril SA De Cv
Bortech Corporation
Boss Manufacturing Co.
BP Amoco Plc
Brown & Root, Inc.
Browne Dreyfus International
Bug-O System
Carolina Steel Corp.
Caterpillar, Inc.
Cee Kay Supply
Cement Industries
Centerline Limited
Centrucut, LLC
Cerbaco Ltd
Certanium Alloys & Research Company
Chart, Inc.
Chicago Bridge & Iron
Cigweld
CK Worldwide
Cloos Robotic Welding, Inc.
College Of Eastern Utah
College Of The Canyons
Comm Coll Of Southern Nevada
Concurrent Technologies Corp.
Controls Corp Of America
Cooperheat, Inc.
COR-MET, Inc.
CRC-Evans Automatic Welding
D/F Machine Specialties, Inc.
Daihen, Inc.
Daimler Chrysler
DBI, Inc.
Deere-Hitachi Specialty Products
Dept. Of Corrections Folsom State Prison
Devasco International, Inc
Direct Wire & Cable
Dixie Metal Products, Inc.
Donaldson Co., Inc.
Dovatech Ltd
E. G. Heller'S Son, Inc.
E. H. Wachs Company
Eagle Bending Machines, Inc.
Eastman Chemical Company
Eastman Kodak Company
Edison Welding Institute
Elco Enterprises, Inc.
Electrodos Oerlikon Colombia
Electromanufacturas Sa
Electron Beam Technologies, Inc.
Electronics Research, Inc.
Emirates Bldg Sys (LLC) Dubai
Empresas Hopsa, SA
Engineering & Mats Grp - Ewi
Erlikon Metal Manufacturing
Esab Welding & Cutting Products
Essex Grp Div Superior Essex
Estructuras De Acero D-G, SA
Eutectic Corporation
Exsa, SA
Fanuc Robotics North America
Federal Aviation Administration
Fibre-Metal Products Company
Filler Metals, Inc.
Fisher Tank Company
Florida Power & Light Co.
Fraunhofer Inst For Lasertech
Friede Goldman Offshore
FTV Proclad (UAE) LLC
Florida Pneumatic Manufacturing Co.
G. A. L. Gage Company
GM Powertrain/Mats Engr Dept
Gateway Safety, Inc.
Gauld Equipment Co.
Ge Aircraft Engines
Genesis Systems Group
Gibson Tube Company
Global Engineering Documents
Goss, Inc.
Greystone Adult School - Voc Wldg P.I.A.
Grupo Zeta
GSE Construction Co., Inc.
GSI Lumonics
Gulf States Airgas
Gullco International Inc.
H & H Sales Co Inc.
H & M Pipe Beveling Machine Co.
H20 2000 Corp.
Harbert'S Prods/Allied Flux
Harris Calorific, Inc.
Harris/Welco
Henderson Mfg., Inc.
Hobart Bros Co.
Hornell Speedgas, Inc.
Hougen Maufacturing, Inc.
Houma Industries, Inc.
Hyd-Mech Saws Ltd
Hypertherm, Inc.
Icesa / Modicon
ICM, Inc.
Idaho Testing Inspection, Inc.
Illinois Tools Works
Indura SA Industria Y Comercio
Industrial Quality Concepts
Ingalls Shipbuilding
International Training Inst.
Interstate Welding Sales Corp.
Inversiones Arcometal
Inweld Corp.
Ipsco Steel (Alabama), Inc.
ITT Engineered Valves
J P Nissen Co.
J Ray Mcdermott, Inc.
J W Harris
J Walter, Inc.
J&S Machine, Inc.
J. A. Cunningham Equipment Co.
Jackson Products, Inc.
James Morton, Inc.
Janey Engineering Co.
Jetboat Division Acms
Jetline Engineering, Inc.
Joe Fuller & Company, Inc.
John Deere Co.
Katsi-Valco
Kawasaki Robotics Usa, Inc.
Kedman Company
Kellogg Brown & Root ,Inc.
Kemper USA, Inc.
Kennametal, Inc.
Keystone Fastening Tech, Inc.
Klingspor Abrasives, Inc.
Kobelco Welding Of America, Inc.
Koike Aronson, Inc.
La-Co Industries Inc/Markal
Lake Washington Tech College
Le Tourneau, Inc.
Liburdi Pulsweld Corporation
Lincoln Electric Co.
Lincoln Steel Co.
Link-Belt Construction Equip
Lockheed Martin Astronautics
Lockheed Martin Missiles Fire
Lucas-Milhaupt, Inc.
M K Products ,Inc
Machinery & Welder Corp.
Mack Products
Madison Area Technical College
Magnatech - The DSD Company
Major Tool & Machine, Inc.
Manitowoc Crane Co.
Marion Testing & Inspection
Martinez Refining Co Equilon
Mathey Dearman, Inc.
Matsuo Bridge Co, Ltd
Mauritzon Inc.
McNeilus Truck & Manufacturing
Mechanical Contractors, SA
Messer - Welding Products
Met-Fab City
Metal Industries Dvlp Center
Metal Processing Systems, Inc.
Miller Electric Mfg Co.
Mitsubishi Materials Corp.
Mndot Bridges & Structures
Mohave Generating Station
Moltech
Motoman, Inc.
Municipal Testing
Mcmahon Steel, Inc.
Nacco Materials Handling Group
Nassau Research Corp.
Nassco
National Certified Pipe Wldg
National Energy Skills Center
National Standard Co.
Naval Surface Warfare Center
Naylor Pipe Co.
Nederman, Inc.
New Orleans Pipe Trades
Newcor Bay City
Newport News Shipbldg & Dry Ck
Newtex Industries Inc.
Nordan Smith Welding Supplies
Norfolk Southern Corporation
Norris Cylinder Co.
Norton Company
Nelson Stud Welding Co., Inc.
Oci Wyoming Lp
Oshkosh Truck Corporation
Osram Sylvania
Otc America, Inc.
Otis Elevator Co.
Oza Tech Community College
Pacific Technical Services
Panasonic Factory Automation
Pandjiris, Inc.
Pangborn Corporation
Peddinghaus Corp. Tool Div.
Pennsylvania Power & Light Co.
Penton Media Inc/Wldg Design
Perkins Engines
Pferd, Inc.
Phoenix International, Inc.
Pkm Steel Service, Inc.
Plant Maintenance Service Corp.
Plymovent Corp.
Postle Industries, Inc.
Praxair Peru SA
Precision Components Corp
Preston-Eastin, Inc.
PRL Industries, Inc.
Profax/Lenco
Public Transport Corporation
Quality Inspection Services
Ransome Co.
Revco Industries, Inc.
Roman Manufacturing Co., Inc.
Robinson Industries, Inc.
Saf-T-Cart, Inc.
Salinas Valley State Prison
Salvino Steel & Iron Works, Inc.
Sandvik Steel
Sappi Fine Paper North America
Sciaky, Inc.
Scott Manufacturing, Inc.
Select-Arc, Inc.
Selectrode Industries, Inc.
Sellstrom Manufacturing Co.
Serra Soldadura SA
Servo-Robot, Inc.
Sewerage & Water Board New Orl.
Sgl Carbon Group
Shanghai Grand Tower Steel Structure
Sheet Metal & Air Conditioning
Smith Equipment Mfg. Co. LLC
Soldadura Movil SA
Special Metals Corporation
Springs Fabrication, Inc.
Steiner Industries
Stoody Co.
Stupp Bridge Company
Superior Products, Inc.
Syncro Vac, Inc.
Tatras Inc.
Taylor-Wharton
Team Industries, Inc.
Techalloy Co., Inc. / Baltimore Div.
Techniweld Prods Corp/Robinson
Technostyle Ltd
Tenaka SA
Tempil, Inc.
Testwell Laboratories, Inc.
Texas State Technical College
The Detroit Edison Co.
The Esab Grp / Welding & Cutting
The Esab Grp/Equip-Automation
The Herrick Corp.
The Nippert Co.
Thermadyne Industries
Thrall Car Manufacturing Co.
Thrall Car Manufacturing Co.
Thrall Car Manufacturing Co.
Thrall Car Mfg Co.
Thrall Europe
Tien Tai Electrode Co., Ltd
Tomco Equipment Co.
Torit Products-Donaldson Co.
Tower Automotive
Transcoastal Marine Svc
Tregaskiss Ltd
Tri Tool, Inc.
Triangle Engineering, Inc.
Trinity Industries, Inc.
Underwater Engr Services Inc.
Union Tank Car Co.
United Abrasives, Inc.
United Airlines Moc
United States Welding, Inc.
United Steel Products Company
Uniweld Products, Inc.
Us Steel Corp. Tech Center
Utp Brasileira De Soldas Ltda
Valley State Prison For Women
Vermeer Manufacturing Co.
Weld Aid Products
Weld Mold Co.
Weld Wire Co., Inc.
Weldco, Inc.
Weldcoa
Welding Consultants, Inc.
Welding Engineering Research Center
Welding Engineering Supp. Co.
Weldsale Co. Div. J A Cunningham
Western Enterprises
Westinghouse Government Services Grp-Emd
Wilson Industries
X-Ergon
Yarborough Machine & Iron Works

Welding Equipment Manufacturers Committee members printed in bold & blue

WEMCO
WELDING EQUIPMENT MANUFACTURERS COMMITTEE

American Welding Society

550 N.W. LeJeune Road
Miami, Florida 33126

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305-443-9353
305-443-7559 Fax
e-mail: info@aws.org
www.aws.org

AWS Foundation, Inc.

A Foundation of the American Welding Society

550 N.W. LeJeune Road
Miami, Florida 33126

800-443-9353, ext. 293
305-445-6628
305-443-7559 Fax
e-mail: found@aws.org
www.aws.org/foundation/index.html

AWS Fellowships and WRC Grants-in-Aid

To: Professors Engaged in Joining Research

Subject: Request for Proposals for AWS Fellowships and for WRC Grants-in-Aid for the 2001-02 Academic Year

The American Welding Society (AWS) and the Welding Research Council (WRC) seek to foster university research in joining and to recognize outstanding faculty and student talent. Each of these two organizations has its own programs to channel funding into graduate research programs at universities. In recent years, AWS and WRC have coordinated their award programs and have made their respective selections based on responses to a joint Request for Proposals. We are again requesting your proposals for consideration by AWS and WRC.

Please note that AWS and WRC have separate selection committees, criteria and objectives as described below. However, if you wish, you need only provide a single proposal for consideration by the two organizations in their respective evaluation activities. Of course, only one award, a Fellowship to the Student (from AWS) or a Grant (from WRC) will be made for any one program of research at a university.

With both organizations, it is expected that the winning researchers will take advantage of the opportunity to work with industry committees interested in the research topics and report work in progress.

Please note, there are important changes in the schedule which you must follow in order to enable the awards to be made in a timely fashion. Proposals must be received at American Welding Society by **February 5, 2001**. New AWS Fellowships will be announced at the AWS Annual Meeting, May 6-10, 2001. WRC will notify applicants for its Grants by mail by June 1, 2001.

THE AWARDS

The Fellowships or Grants are to be in amounts of up to $25,000 per year, renewable for up to three years of research. However, progress reports and requests for renewal must be submitted for the second and third years. Renewal by AWS or WRC will be contingent on demonstration of reasonable progress in the research or in graduate studies. WRC expects awardees to interact with any of its committees working in related areas of research.

The AWS Fellowship is awarded to the student for graduate research toward a Masters or Ph.D Degree under a sponsoring professor at a North American University. The qualifications of the Graduate Student are the key elements to be considered in the award. The academic credentials, plans and research history (if any) of the student should be provided. **The student must prepare the proposal for the AWS Fellowship**. However, the proposal must be under the auspices of a professor and accompanied by one or more letters of recommendation from the sponsoring professor or others acquainted with the student's technical capabilities. Topics for the AWS Fellowship may span the full range of the joining industry. Should the student selected by AWS be unable to accept the Fellowship or continue with the research at any time during the period of the award, the award will be forfeited and no (further) funding provided by AWS. The bulk of AWS funding should be for student support. AWS reserves the right not to make awards in the event that its Committee finds all candidates unsatisfactory.

The WRC Grant is to the university and professor for support of research in the defined area. The student need not be identified for consideration by WRC. Thus, if WRC makes the award for a proposal in which the student has been identified a change may be made at any time without loss of the Grant from WRC. It is hoped that the WRC funds will seed broader programs and any such plans to obtain follow-on or supplementary support should be mentioned in the Proposal. Proposals may be for innovative research in new areas or for research of interest to current WRC Committees. Subjects of interest to WRC Committees include underwater welding, linepipe welding, evaluating susceptibility to hydrogen cracking, corrosion resisting alloys such as duplex or other high alloy steels, high-strength welding consumables, hardfacing, automation or other timely subjects.

All proposals received will be considered for an award by WRC. Only those proposals containing suitable supporting information about the student and identified as having been prepared by the student will be considered by AWS. Please clearly specify in your cover letter if you intend AWS consideration.

SELECTION

The AWS and WRC selection committees operate separately, AWS may award up to six Fellowships. WRC will award as many Grants as funding permits. The number will depend on the size of the requests and the number of renewals from last year's group. Topics selected by WRC's group in recent years have been:

(a) Underwater Welding Consumables Research
(b) Joining of Particulate Reinforced Metal Matrix Composites
(c) Residual Stresses in Weldments
(d) Fundamental Studies on Metallurgical Causes for Reheat Cracking
(e) Analysis of Transient Liquid Phase (TLP) Diffusion Bonding
(f) Hydrogen Effects on Cracking of Duplex Steel Welds
(g) Brazing Alloys for Ceramic Substrates
(h) On-Line Underwater Welding Control and Inspection by Ultrasonics
(i) Weld Pool Geometry
(j) Microstructure and Property Development of HSLA 100 and 130 Steel
(k) Crack Growth in Weldments
(l) Causes of Hot Cracking
(m) Corrosion Behavior of Welds

DETAILS

The Proposal should include:

1. Annualized Breakdown of Funding Required and Purpose of Funds (Student Salary, Tuition, etc.)
2. Matching Funding or Other Support for Intended Research
3. Duration of Project
4. Statement of Problem and Objectives
5. Current Status of Relevant Research
6. Technical Plan of Action
7. Qualifications of Researchers
8. Pertinent Literature References and Related Publications
9. Special Equipment Required and Availability
10. Statement of Critical Issues Which Will Influence Success or Failure of Research

In addition, for the AWS Fellowship:

1. Student's Academic History, Resume and Transcript
2. Recommendation(s) Indicating Qualifications for Research
3. Brief Section or Commentary on Importance of Research to the Welding Community and to AWS, Including Technical Merit, National Need, Long Term Benefits, etc.
4. Statement Regarding Probability of Success

The technical portion of the Proposal should be about ten typewritten pages. Four copies should be sent by **February 5, 2001,** to:

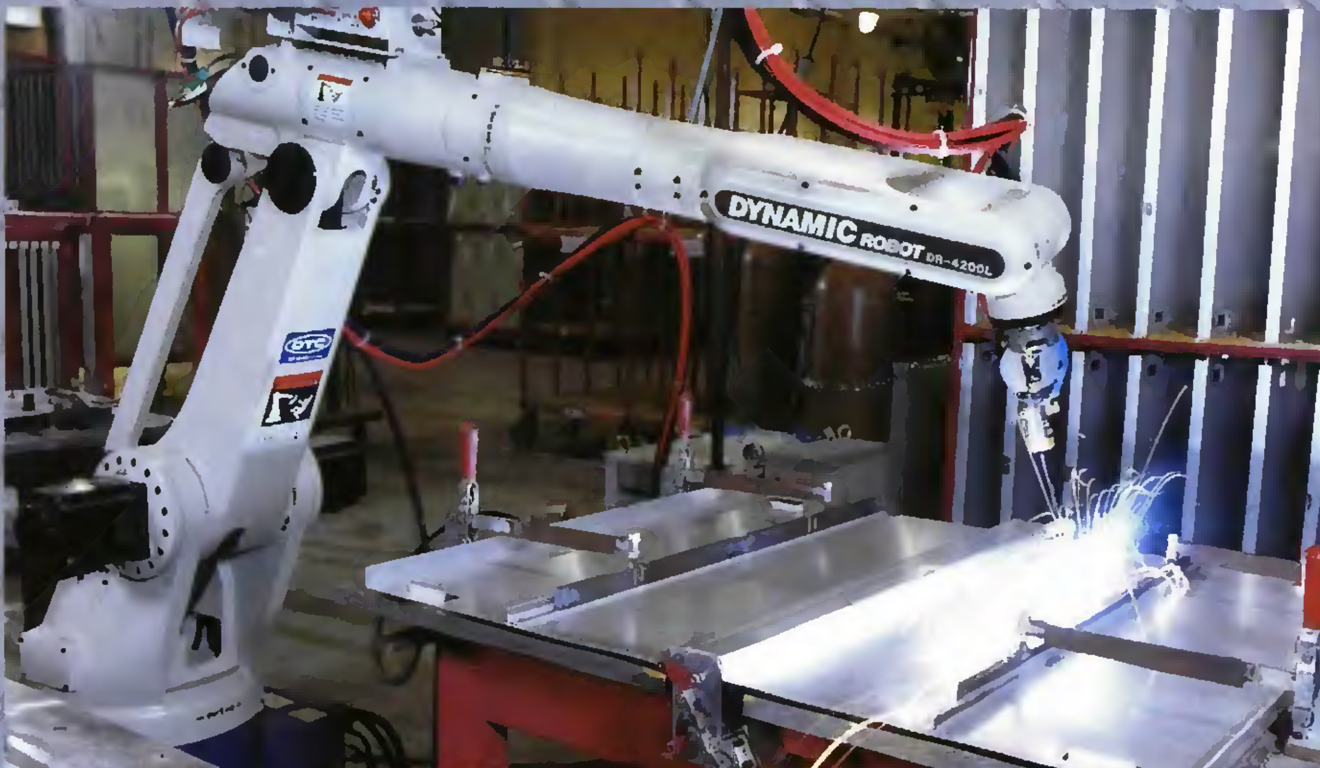
Richard D. French
Deputy Executive Director
American Welding Society
550 N. W. LeJeune Rd.
Miami, FL 33126

Yours sincerely,

Frank G. DeLaurier
Executive Director
American Welding Society

Martin Prager
Executive Director
Welding Research Council

WHO SAYS WELDING ALUMINUM IS TOUGH?



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WELDING ROBOTS

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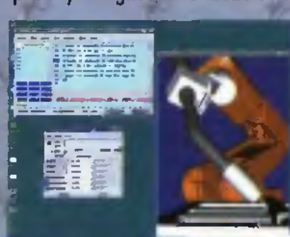

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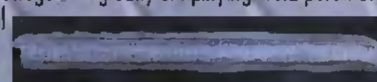

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ADVANCED WELDING TECHNOLOGY

Keeps Japan's High-Speed Trains on Track

The Shinkansen passenger system has become known throughout the world as an economical and environmentally friendly transportation system.

BY SOTARO YAMADA and KOICHI MASUBUCHI

In 1964, high-speed trains called Shinkansen, traveling with a speed of greater than 200 km/h (125 miles/h), were put into service on the 515-km (325-mile) main line between the two cities of Tokyo and Osaka. It was in the same year the Olympics were held in Tokyo. Since then, Japan has dramatically progressed in economic development and the high-speed train has contributed to this growth by providing the most efficient passenger transportation system possible.

The system has operated for 36 years without any serious accidents and has carried more

DR. SOTARO YAMADA is Executive Adviser, Kawasaki Heavy Industries, Co., Kobe, Japan, and former Chairman of Kawasaki Rail Car Inc., Yonkers, N.Y., and Professor KOICHI MASUBUCHI is with Massachusetts Institute of Technology, Boston, Mass.

than 5 billion passengers since its inception. This record has shown high-speed trains to be an efficient and safe form of transportation. As a result, Shinkansen has had an innovative influence on the passenger railway business worldwide, especially in European countries such as France, Germany and Italy. The French high-speed train fleet TGV began service in 1981, followed by Pendalino in Italy, X2000 in Sweden and ICE in Germany. In the United States, the trains in the northeast have been designed to run faster, with Metro lines already operating at a maximum speed of 125 miles/h. World-class, high-speed trains are expected to start service within a year on a route between Washington, D.C., and Boston, Mass.

Japan has played a leading role in the design, manufacture and operation of high-speed trains.

Features of the Japanese High-Speed Trains

The Shinkansen system presently has the longest service route in the world, totalling almost 2000 km (1260 mi). This has been done by continually extending lines following the inaugural line

Fig. 1 — Shinkansen Type 700 standard high-speed train.

from Tokyo to Osaka. The trains are electric multiple units (EMU). The EMU system has maintained its performance in speed acceleration, braking length and flexibility of forming a train. EMU makes it possible to install most of the equipment under the floor of the cars, allowing floor space for more seats and passenger service facilities. The trains operate with the most up-to-date and advanced technology. Newly built trains are employing inverter controls in a traction system with advanced power electronics.

Types of High-Speed Trains

High-speed trains are designed to meet the demands of riders, to comply with geographical and climatic conditions and to be competitive with other transportation systems.

As shown in Table 1, many types of Shinkansen trains have been put into use in response to local needs. These trains can be categorized into three groups based on the purpose of their use: 1) main lines of a relatively long range; 2) through-lines from main to branch lines; and 3) main lines for commuters and tourists.

Trains for main lines occupy the major portion of the entire fleet, and are designed to attain speeds ranging from 270 to 300 km/h (170 to 190 mi/h). The standard trains for this purpose are designated as types 500 and 700 — Fig. 1. Type 500 trains run at the maximum speed of 300 km/h, which is the fastest among the fleet.

Figure 2 shows a Type E3 train, which is used for lines running from main to branch. The trains operate at speeds up to 275 km/h (173 mi/h) on a main line, then, after entering a branch line, run at a reduced speed of less than 130 km/h (82 mi/h). These trains are designed to have a shorter length and a narrower width compared to the standard types because they must comply with the dimensional limits of conventional lines.

The trains for commuter use consist of double-deck cars that can travel at a maximum speed of 240 km (151 mi/h). The double-deck cars can accommodate 40% more seats than ordinary single-deck cars, making it possible for more passengers to sit while commuting.

High-Speed Mass Transportation

The trains are dispatched from the terminals early in the morning through late night in intervals of 5 min. Shinkansen is a mass transportation system, and the number of passengers using it is approximately 700,000/day. While the cars might seem crowded, they are designed to have reasonable room. For instance, the seat-to-seat spacing in the cars ranges from 980 to 1040 mm (38.5 to 41 in.), which is higher than those of European high-speed rail cars.

Car Body Structures and Materials Used

The operation of high-speed trains often brings about environmental issues of excessive noise and ground vibrations. The trains tend to get larger in proportion to an increase in speed or weight. In addition, an increase in speed or weight raises the burden on the track foundations. To avoid adverse effects, high-speed trains need to be carefully designed to limit weight, and reduce it when possible. The original cars had steel bodies. The modern cars, operating at much higher speeds, are designed to be lighter. Aluminum alloys are used for the body structure, and some new design ideas were introduced for the car body

Table 2 shows elements of typical trains such as Types 500, 700 and E4. Although the highest speed is presently 300 km/h due to the restrictions of infrastructure, the trains have the capability of running at 320 km/h, and are expected to perform to full capacity in the near future. All cars of the train mount a traction motor on each axle. To compensate for the weight gain caused by the increased number of motors and to reduce the effects of the increase of speed, the cars employ special panels of honeycombed aluminum, providing an excellent strength-to-weight ratio — Fig. 3. The panels contribute to a substantial reduction in the total weight of the train.

Type 700 trains are the flagship fleet now in service on the Tokaido-Sanyo line, which travels through the most heavily populated areas of Japan. Already, more than 1500 cars, including the Type 700 and its sister Type 300, have been built and placed

Fig. 2 — Type E3 trains attain speeds as high as 170 mi/h.

in service. The Type 700 can travel at a maximum speed of 285 km/h (180 mi/h). The maximum speed permitted on the Sanyo line is 285 km/h, and the maximum speed on the Tokaido line is 275 km/h because of restrictions related to infrastructure and environmental issues.

The trains were designed to balance performance with manufacturing cost. Based on that concept, the cars employ double-skin extrusions extensively for their body structure.

The Type E4 trains are used for commuters as well as tourists, so the trains consist of all double-deck cars. Double-deck cars typically weigh more than single-deck cars. When designing double-deck cars, it is important to keep the cars' weight at a tolerable level, and to minimize cost. For those reasons, single-skin extrusions of aluminum alloys are used to build Type E4 cars — Fig. 4.

Car Body Assembly

The car body is basically a hexagonal shape with a rectangle that consists of six panels including the underframe panel, two side panels, roof panel and two end panels. Each of the panels is prefabricated and subassembled. Then the six panels are assembled to make a car body. Finally, a large number of supporting pieces used for installing pipes, interior panels and equipment are fitted to it.

Development of Large-Sized Extrusions of Aluminum Alloys

When aluminum alloys were first introduced to car body structures, the structures were made of aluminum plates reinforced with small aluminum extrusions through welding. The structures required a fairly large amount of welding, which generated distortion and caused some appearance issues, as well as cost increases. To resolve those issues, intensive research was done to find aluminum alloys that would have satisfactory properties for extrusions and have good weldability. The successful materials were designated as A6N01 or A7N01 in JIS. Since then, large aluminum alloy extrusions with complicated shapes have been available.

The car body structures of newly built trains use large extrusions shaped for single-skin or double-skin cars — Fig. 5. The large-sized extrusions have made it possible to reduce the number of pieces to be assembled and welded, and to build Shinkansen car bodies in a more economical way.

Employment of a Honeycomb Panel

Honeycomb-patterned panels were developed to reduce the weight of the cars' bodies as much as possible. Both the skin and core material are made of a high-strength aluminum alloy A6951P-T6. The skin and core material are brazed in a vacuum condition with a filler metal of A4045. Honeycomb panels are very effective for reducing the weight of the structure; however, at present, production cost doesn't allow their extensive use. Therefore, honeycomb panels are applied only to the side structure and the floor panel in Type 500 cars.

Fabrication of Aluminum Alloy Extrusions

Aluminum alloys used as structural materials for car bodies have superior fabricability when compared to structural steels. A saw-type cutting machine is typically used to cut the large extrusions and a NC machining center is employed for making the extrusions with complicated shapes. Laser beam cutting machines are used on small components such as supporting pieces, stiffeners and ribs. Laser beam cutting offers better appearance than plasma arc cutting.

Welding of Aluminum Alloys

The gas metal arc welding (GMAW) process is used extensively to weld the aluminum alloys on car bodies. Resistance

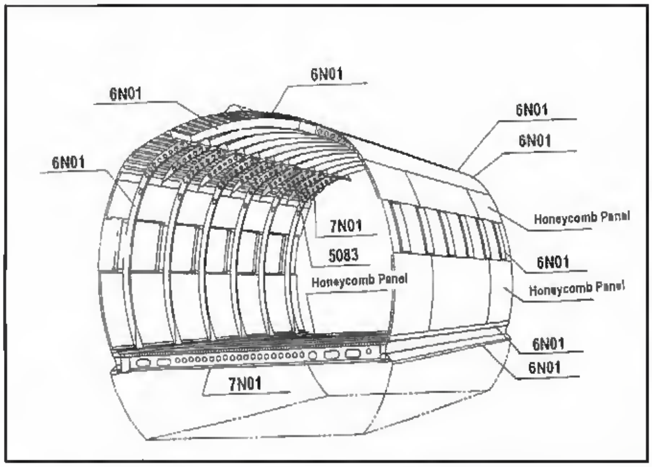


Fig. 3 — Car body structure of Type 500 train.

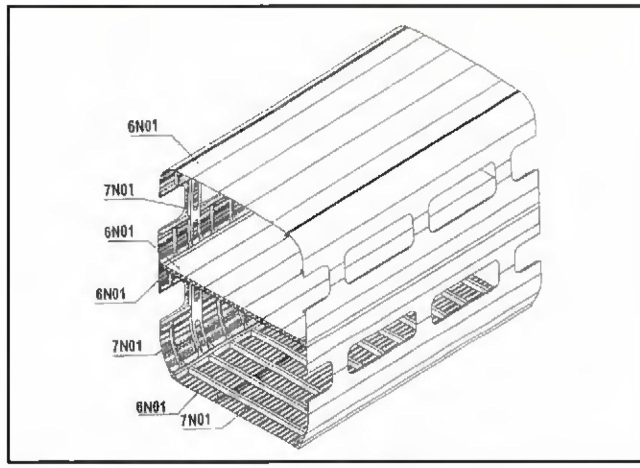


Fig. 4 — Car body structure of Type E4.

spot welding (RSW) and gas tungsten arc welding (GTAW) are employed in a limited scope; RSW is used for subassembly of end panels and GTAW is used for repair welding.

GMAW is carried out using 1.2-or 1.6-mm -diameter wire and 100% argon shielding gas. Inverter-type welding machines with pulse controls are used.

Mechanization of Welding and Application of Robots

In the making of the car body, welding occupies a major portion of the total work hours and plays a key role in the quality of the structure. Improvement in productivity and quality of welding are the most important goals for production engineers. Concentrated efforts are now made to mechanize the welding and to apply robots to it. The large extrusions are restricted to less than 600 mm (23.6 in.) in width, although they can be produced at 25 m in length to cover the full length of the car body. This means a panel with a required width in floor, side and roof structure needs to be made by joining extrusions to form a wide panel. This joining uses a mechanized multihead welding machine. To minimize weld distortion, two or three joints are simultaneously welded from one side.

To sense the relative location of the torch to the weld groove, automatic laser sensor scanning equipment is installed for each of the heads. This system is able to get two-dimensional (2D) image data by oscillating the laser beam toward the vicinity of the weld joint laterally in the welding direction. Based on this data, the computer calculates an accurate position of the weld torch to the weld joint and programs the machine to adjust the welding head position. Therefore, the head is always controlled to maintain a correct position and to obtain the required weld penetration and configuration.

As can be seen in Fig. 6, robots weld stiffeners to an extrusion panel made by a mechanized welding machine. These robots are programmed with an off-line teaching system that can deal with data from 2000 to 3000 joints for one car. This system accommodates the basic data supplied from a computer- assisted design (CAD) system. The system responds to each of the joints to be welded and examines the necessary modifications of the data according to the production engineering data, such as longitudinal camber, marginal extension for weld shrinkage and welding sequences. In addition, the laser beam sensing device informs the computer of the deviation of the weld head from the weld joint. Moreover, the computer constantly monitors the weld current and voltage, and stores the data of weld parameters used for each joint. When it senses a weld is being done with inappropriate parameters, a welding interruption is ordered and, at the same time, a warning is given to the operator. Together, these systems ensure the robot works correctly to produce high-quality welds.

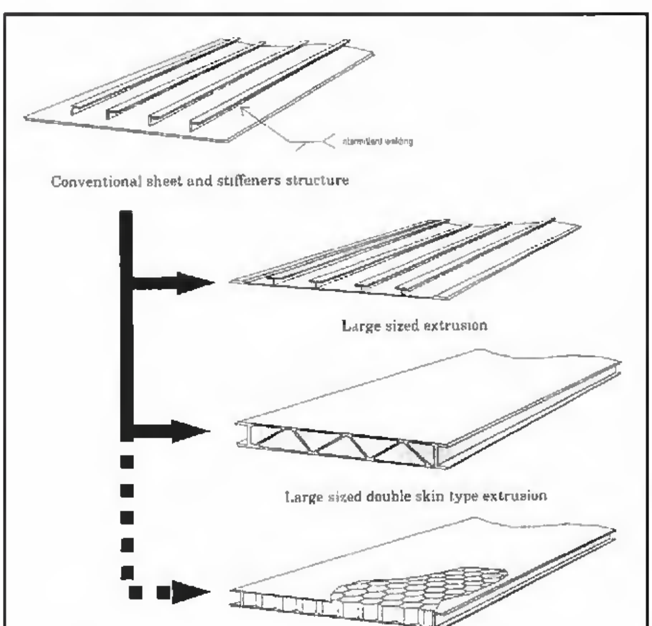
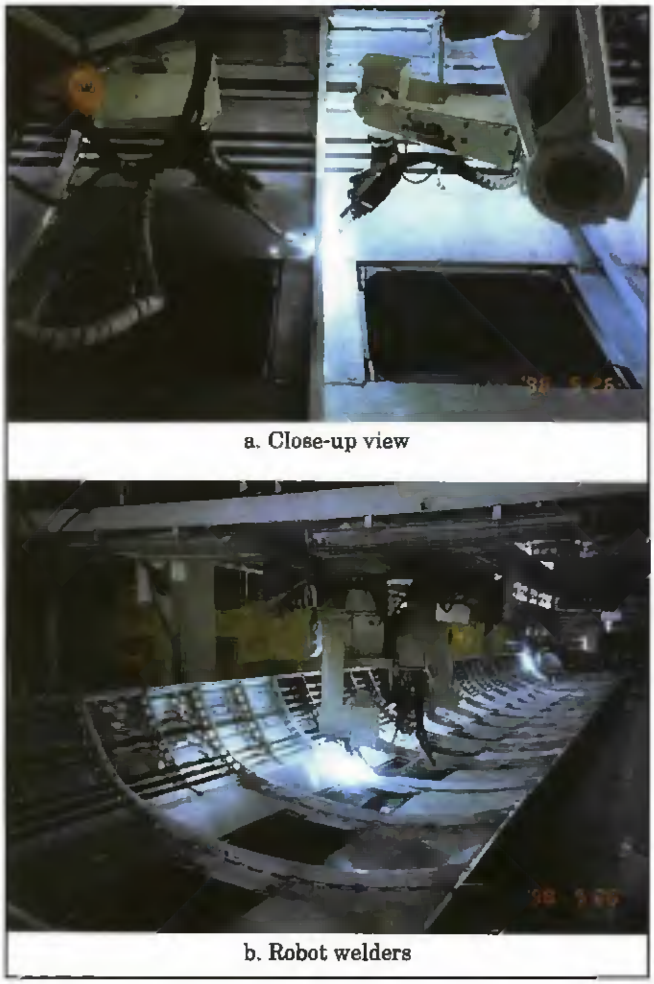


Fig. 5 — Large extrusions of aluminum alloys used on car bodies.

Advanced Welding Process

Fusion welding inevitably brings about some weld distortion due to heat input, so a welding process that does not typically add heat was requested. Friction stir welding (FSW), developed by The Welding Institute (TWI), was chosen. The basic mechanism of FSW (Fig. 7) utilizes a plastic flow phenomenon of metals induced by friction. Therefore, this process creates the least distortion and the narrowest heat-affected zone (HAZ) because of its very low heat input. Friction stir welding is being used to



a. Close-up view

b. Robot welders

Fig. 6 — Robots employed for welding stiffeners to panels.

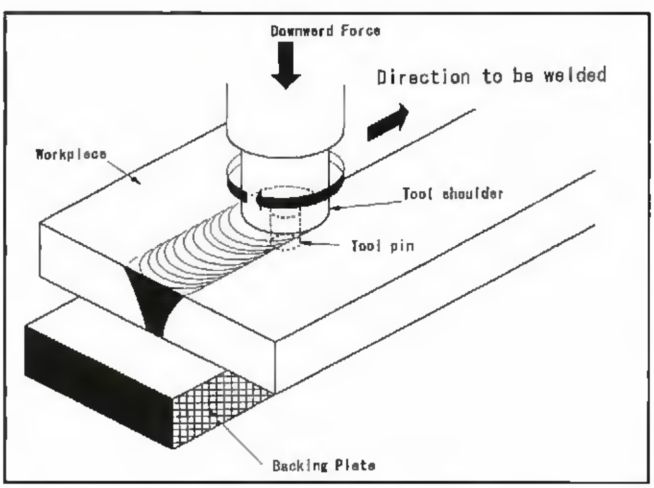


Fig. 7 — Principle of friction stir welding (FSW).

weld aluminum extrusions for cars on a trial basis, and its application is expected to expand.

Conclusion

Shinkansen has led the development in high-speed trains throughout the world, and welding technology plays a vital role in manufacturing of car bodies. The development of welding technology for high-speed trains is expected to be an important challenge for welding engineers.

In many countries, railway transportation is viewed as an environmentally friendly mode of transportation. High-speed train lines are expected to be introduced or extended to additional places throughout the world. A mutual exchange of knowledge among the engineers will enhance the further development of welding technologies for this venture.◆

Acknowledgments

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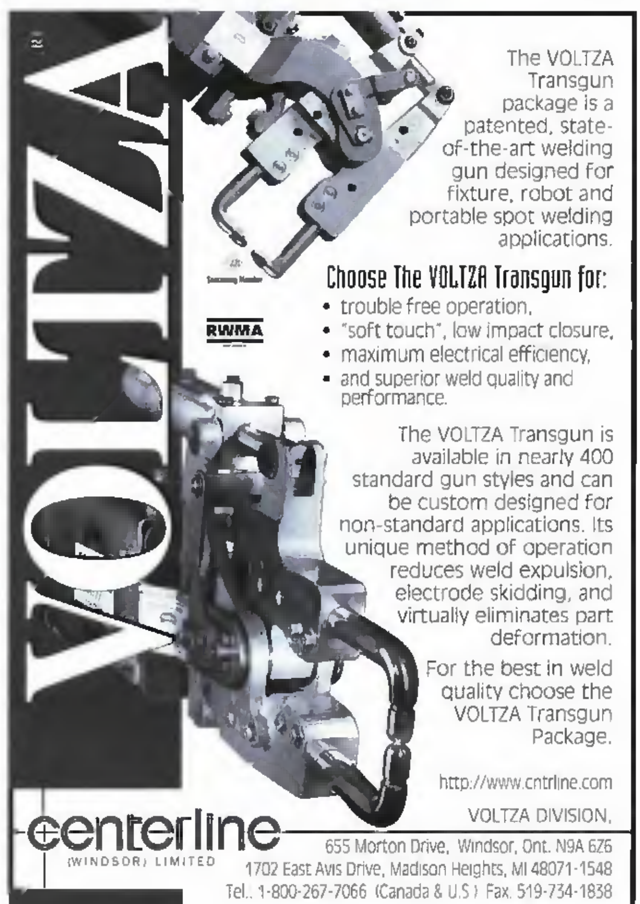
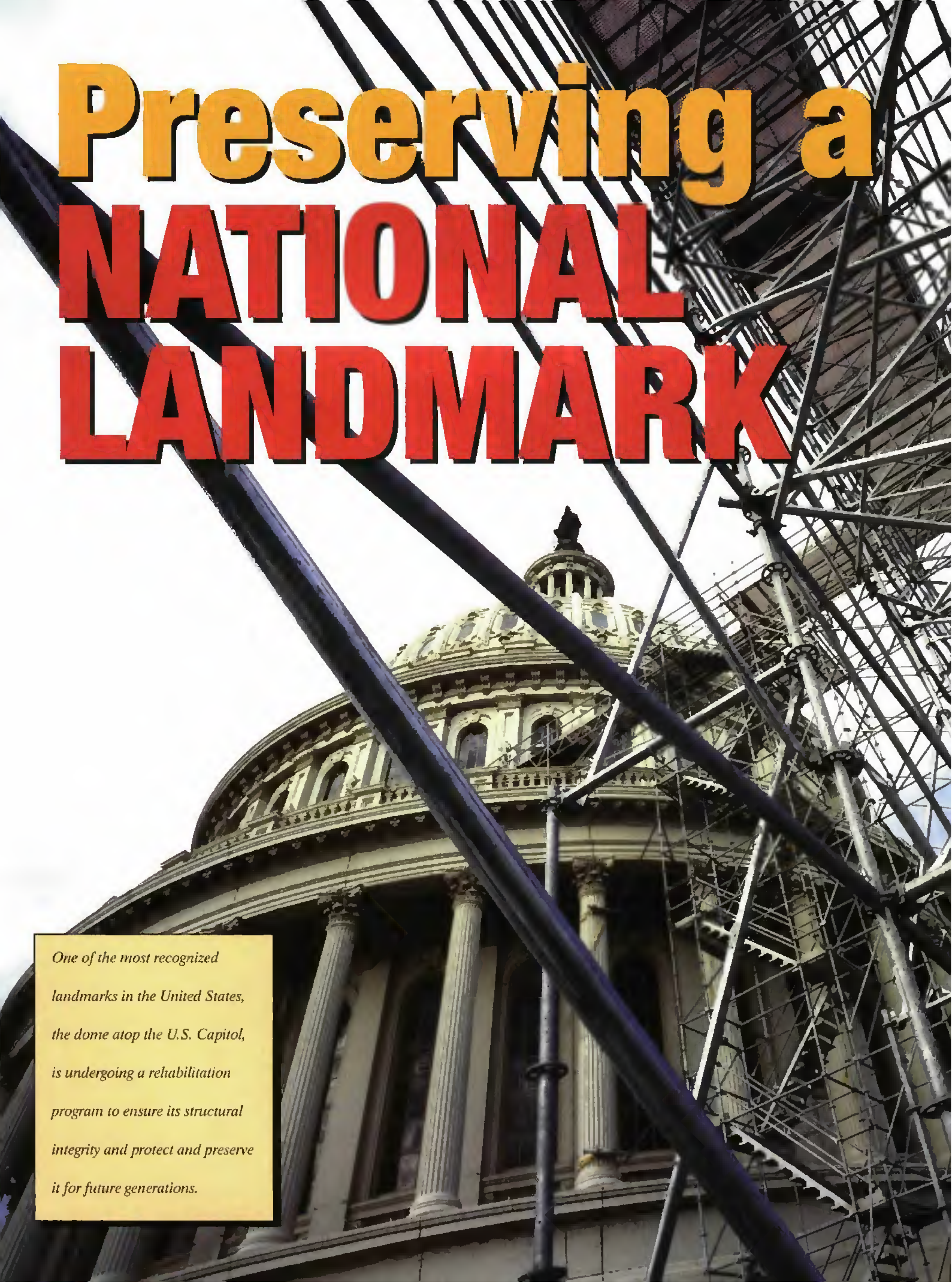


Preserving a NATIONAL LANDMARK



One of the most recognized landmarks in the United States, the dome atop the U.S. Capitol, is undergoing a rehabilitation program to ensure its structural integrity and protect and preserve it for future generations.

A team of welding experts studied the best way to make weld repairs to the cast-iron outer shell of the U.S. Capitol dome

BY TOM SIEWERT, CHRIS MCCOWAN, ROGER BUSHEY, BILL ROBINSON, TOM CHRIST AND KEVIN HILDEBRAND

The dome of the U.S. Capitol has been a focal point of the nation's capital city ever since the 1860s when workers used a steam-powered boom and derrick to hoist the ironwork into place. One of the most recognized landmarks in the United States, the nearly 140-year-old dome is undergoing the first phase of a rehabilitation program. Over the years, corrosion has built up at joints, leading to cracking of some of the castings that form the shell. Since the dome is a national landmark, the goal is to restore the castings to their original condition, replacing as few components as absolutely necessary. The major challenge is the castings were produced with 1850s' technology, so the composition is far different from current castings designed for weld repair.

Thomas U. Walter designed the present Capitol dome in the 1850s. It was the second cast-iron dome in the world and is the world's largest iron dome. Primarily constructed between 1855 and 1863, it replaced an earlier wooden dome that was no longer in scale with expansions to House and Senate wings — expansions needed to accommodate legislators from states then recently added to the Union. A larger, masonry dome was ruled out because the existing Rotunda walls could not support the weight. However, calculations showed the Rotunda could support a cast-iron dome, which could be cast with cutouts in areas where material wasn't needed. In addition, cast iron was fire resistant and could be formed in complex shapes and erected in conveniently sized pieces. Recognizing heating and cooling cycles would subject the dome to movement, the designer included features to accept this movement.

Although the majority of the dome, complete with its inner and outer shells and lower skirt, is composed of cast iron, wrought iron was used in a few places. The dome's main framing consists of 36 arched ribs that bear on 36 paired pillars. These, in turn, bear on 36 pairs of cast-iron brackets embedded in the Rotunda's masonry walls. Bands or hoops consisting of either cast-iron sections or wrought-iron riveted plates tie the ribs together at multiple levels. From the main rib framing, an elaborate arrangement of cast-iron brackets support the dome's outer shell, giving it its distinctive shape. Wrought-iron hangers or cast-iron brackets suspend the inner shell from the main ribs. Also suspended from the main ribs near the top of the dome is a shell of cast-iron grating to which the plaster base of the fresco titled *The Apotheosis of Washington* is applied. At the top of the dome, the 36 ribs converge into 12 that continue upward to support the Tholos and Lantern levels and the *Statue of Freedom*. More information, including Walter's elevation and cross-section drawings from 1859, is available at the Web site of the Architect of the Capitol at *www.aoc.gov*.

TOM SIEWERT (siewert@nist.gov) *and CHRIS McCOWAN are with the Materials Reliability Div., National Institute for Standards and Technology, Boulder, Colo. ROGER BUSHEY, BILL ROBINSON and TOM CHRIST are with ESAB Welding and Cutting Products, Florence, S.C. KEVIN HILDEBRAND is with the Office of the Architect of the Capitol, Washington, D.C.*

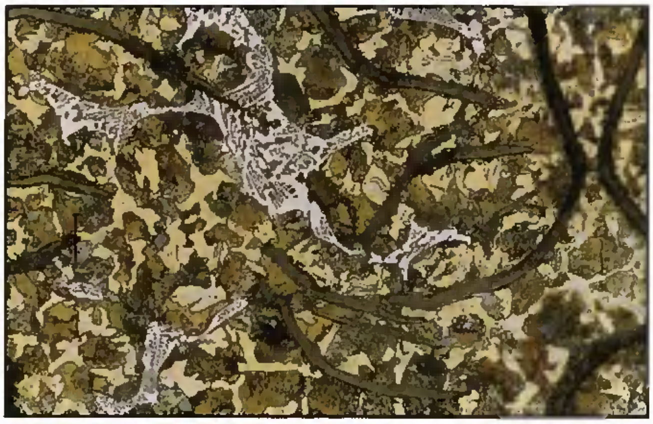


Fig. 1 — Microstructure of the 1860s-era cast iron in the Capitol dome.

Getting Involved in the Restoration

In June 1998, a group of researchers from the National Institute of Standards and Technology (NIST) visited staff from the Office of the Architect of the Capitol to learn if their skills could help with the planned restoration of the Capitol dome. Also present were Richard Kadlubowski of Hoffmann Architects, the consultant for the dome rehabilitation, and A. J. Julicher, an independent structural engineer familiar with the weld repair completed six years ago to the cast-iron ring at the base of *Freedom*, the statue at the very top of the dome. Restoration is a priority because moisture is leaking into some of the interior areas of the building. The goal is to restore the dome to its original condition, with minimum replacement of castings. Therefore, welding is an important option for repair of cracks and corrosion damage.

While touring the dome, we noticed the interior rib structure was in good condition, but the outer shell had some cracks and visible corrosion at a number of joints (where paint did not reach all the surfaces). The current moisture leakage problems are attributed to movement caused by expansion and contraction of the exterior shell and failing joint filler material between abutting plates. Most of the joints in the exterior skin are difficult-to-seal hairline joints. The leakage has led to corrosion at the joints of the outer shell and railings (about 1-cm-thick castings or wrought structural forms). The corrosion accumulates in the joints until they stress the component castings beyond what the mechanical fasteners can accommodate, leading to cracking of the shell panels and railing components. This allows more moisture to penetrate, which leads to further corrosion.

During our tour, we saw a few weld repairs believed to have been made about 40 years ago. Some of these welds had cracks that appeared to originate in the heat-affected zone (HAZ) and then propagated further into the castings, transverse to the weld. There was no documentation on the procedures used for these welds, but the shiny surfaces suggested they were of one of the nickel-rich compositions (commonly nearly pure nickel or a 55Ni/45Fe alloy) typically used on cast irons, while the bead shape suggested the welds were applied as a wide weave bead with a high heat input (leading to a wider and more brittle HAZ). A July 14, 1998, report from Lucius Pitkin Testing Laboratories indicated the castings were quite low in strength (17.8–18.8 ksi tensile strength). Current technology gray iron castings often have strength minimums of 210–280 MPa (30–40 ksi) although there are grades as low as 140 MPa (20 ksi) and as high as 420 MPa (60 ksi). While gray iron castings are not expected to have much ductility, a doubling of casting strength through technology improvements in the last 140 years means current castings can tolerate double the deformation of the castings in the dome simply from the absorption of elastic strain. This means the casting repair technology in use today might not be optimal for the historical castings found in the outer skin of the dome.

The Architect of the Capitol's staff had collected a team with structural analysis and corrosion expertise, and their consultants could oversee most aspects of the repair operation. We were to investigate alternative materials and procedures for the weld repairs of the cracked panels of the outer shell. These alternative materials and procedures would be designed especially for the rehabilitation task (optimized for the properties of the castings used in the dome) and would be stable over time. In particular, we could look for innovative ways to reduce the tendency for cracking, both during the repair and into the indefinite future. Our team included Tom Siewert, leader of the welding activities at NIST; Chris McCowan, a NIST metallographer and metallurgist; and Roger Bushey of ESAB Welding and Cutting Products, a former chairman of the AWS A5J Committee on Electrodes for Cast Irons and member of the AWS D11 Committee on Welding of Iron Castings. The welds were made and tested for strength in the ESAB laboratory, then sent to NIST for macrographic and microstructural examination. Both groups were involved with the experimental design.

Evaluating the Problem

At NIST, we examined several sections of a railing from the original casting (Fig. 1), and confirmed the microstructure was a pearlitic gray cast iron. The microstructure contains type A graphite flakes (with some regions of graphite rosettes) in a matrix of pearlite (with some free ferrite), decorated with an interdendritic phase. This phosphorus-rich phase likely caused the low effective strength and low ductility of the dome material. This microstructure, together with the low strength and low ductility of the dome castings, caused us to question whether the materials and electrodes currently recommended and used to repair cast irons were appropriate for use on the special microstructures and properties found in the dome. For example, the nickel electrodes designed for joining cast irons (designated ENi-Cl-A, according to AWS A5.15) are required to meet a specified room temperature yield strength of 262–414 MPa (38–60 ksi) and tensile strength of 276–448 MPa (40–65 ksi). Current technology ENiFe-CI-A (55Ni/45Fe alloy) electrodes have yield strengths between 294 and 434 MPa (43–63 ksi) and tensile strengths between 400 and 579 MPa (58–84 ksi). These strengths are quite appropriate for gray iron castings manufactured in strength grades ranging up to 400 MPa (60 ksi). For current technology castings, this high-strength filler material keeps the strength of the casting above a specified minimum and reduces the likelihood a repaired casting will fail in the weld repair through overload. For the castings found in the dome, the repair criteria are far different, focusing more on restoring the casting integrity (relatively low loads) and serving as a moisture barrier.

After reviewing the previous repairs to the outer shell, we considered how to avoid a repeat of the cracking problems noted in these earlier repairs. The fundamental cause of the cracks in those welds was likely a result of the residual stresses that form as the weld cools. Degradation can appear immediately after welding (during or shortly after cooling) or after time (such as when seasonal thermal stresses and corrosion damage add to the residual stresses and exceed the strain tolerance of the castings). Therefore, the optimal filler composition would seem to be one near to or even below the strength of the castings. A low-strength filler would induce less stress in the casting due to the buildup of shrinkage stresses during cooling, and be able to selectively accept more of the strains developed during the weld repair and through the future service conditions. In fact, some steel structures have been built with filler materials that have lower strengths than the base plates. This strategy is known as undermatching and is applied in situations where more ductility is required. We searched for filler metals and techniques not normally used on cast irons, especially those that would produce welds lower in strength than the traditional nickel and nickel-iron compositions used. Using a lower strength, but higher ductility, filler material for the dome castings is justified in that the repairs are not in structure-critical regions but simply restore the dome surface integrity.

We also reviewed preheating, a common recommendation for the welding of cast irons. Preheat slows the cooling rate of the welds, and so can change the strength and residual stress distribution because the cooling rate determines which phases form in the cooling metal and how the stresses build up. Techniques have been developed to calculate a no crack temperature for castings, a suggested preheat temperature above which the cracking tendency is low. The first step of the procedure is to obtain a carbon equivalent (CE) using an equation such as CE = C + 0.31 Si + 0.33 P + 0.45 S – 0.28 Mn where these elements are in weight percent (Ref. 1). Inserting the composition data (3.39% C, 2.92% Si, 0.61% P, 0.10% S and 1.07% Mn) reported by Lucius Pitkin for one of the dome ribs into this equation gives a CE near 4.24. Next, the CE is matched to a chart that relates it to a preheat temperature range (Ref. 1). The chart recommends a preheat temperature of 260–315°C (500–600°F). This is quite a bit higher than the preheats used for steel construction and is awkward to maintain for a casting as large as the dome's outer shell. Some researchers and welding engineers have found success with the exact opposite approach for welding cast irons; using very low or no preheat to reduce the amount of carbon that goes into solution during welding, the primary cause of the cracking problem. Our study of preheating was designed to learn what preheat would work best with the alternate weld compositions and the actual castings of the dome, and whether the benefits of preheating would outweigh the additional complexities of applying it during the repairs.

Another option for reducing the residual stress of the weld was peening, a mechanical deformation process where the welder uses a small impact tool or ball peen hammer on the weld just after completing a weld bead. The weld is relatively soft while still hot, so the blows deform the crystalline structure, relieving the shrinkage stresses that are forming.

Buttering was also considered. Buttering can reduce the thermal effects of welding on the casting microstructure and redistribute the residual stresses that form as two castings are joined together. A thin surfacing weld or thermal spray (effectively a cladding) is applied to each surface of the casting at the joint area. This thin weld layer cools with very little restraint, so the chance of cracking is minimized, and the low heat input reduces the amount of carbon that can go into solution in the casting. When the two buttered castings are actually joined by producing a weld between the buttered layers, only the buttered layers reach the very highest temperatures of welding and experience the highest residual stresses. This allows the welding engineer to minimize the microstructural changes in the casting and transfer the residual stresses from the welding process to the buttering layers. The material for the buttering layer is selected on the basis of metallurgical stability to the heat of welding and good ductility under the stresses of cooling from the welding temperature. Even the highest strength nickel alloys can serve as suitable buttering material since little stress is introduced.

As we reviewed the criteria for selection of the welding process, the leading candidates seemed to be shielded metal arc welding and oxyacetylene (gas) welding variants such as flame spraying and braze welding. These processes have the widest selection of compositions, can be used in all orientations and are efficient for the short repair welds that would be needed. Other advantages of flame spraying and braze welding include the following:

◆ They are performed at lower temperatures so less carbon enters the welds, and the heating is more gradual so thermal shock and distortion are reduced.

◆ The weld deposits are relatively soft and ductile, so residual stresses are low.

◆ The equipment is simple and easy to use.

◆ Flame heating during welding reduces the need for additional preheat.

The potential disadvantages of flame spraying and braze welding — low joint strength, service temperature limited to 260°C and poor color match — are not problems for this particular application.

Other welding processes, such as gas metal arc and flux cored arc, were ruled out based on criteria such as higher penetration in the base metal castings, limits to the orientations that can be welded or fewer options on compositions. Gas tungsten arc welding has been used effectively for autogenous welds if the heat input is kept low, but was not included in this study.

U.S. Capitol Dome Facts

◆ Thomas U. Walter, the fourth architect of the Capitol, designed the U.S. Capitol dome as well as the extension to the Senate and House wings.

◆ Superintendents of Construction Montgomery C. Meigs and William B. Franklin built the dome between 1856 and 1866.

◆ It is made of 8,909,200 lb of cast iron.

◆ The cast-iron dome replaced a wood dome covered with copper designed by Charles Bulfinch, a Boston architect. By the 1850s, the wood dome was considered too small. It was also a fire hazard, and often in need of repair.

◆ Total cost for the dome: $1,047,291.

◆ While work stopped on the Capitol extensions for a year at the outbreak of the Civil War, work on the dome continued uninterrupted. The reason: In 1859, the New York foundry of Janes, Fowler, Kirtland and Co. proposed to finish all remaining work on the dome for 7 cents per pound "complete and put up." The offer was accepted in February 1860, which placed the work under a single contract.

◆ The dome's crowning feature is the bronze *Statue of Freedom*, a classical female figure of Freedom draped in flowing garments. The statue stands 19 ft 6 in. tall and weighs approximately 19,000 lb. It rises 288 ft above the east front plaza.

◆ The final section of the *Statue of Freedom* — the head and shoulders — was placed atop the dome on December 2, 1863, to a salute of 35 guns answered by guns from the 12 forts then around Washington.

◆ On May 9, 1993, a helicopter removed the statue from its pedestal for restoration. Extensive pitting and corrosion had occurred on the surface of the bronze and there was a crack and rusting on the cast-iron pedestal. Repairs included insertion of more than 700 bronze plugs. A helicopter returned the statue to its pedestal on October 23, 1993, amidst the celebration of the bicentennial of the U.S. Capitol.

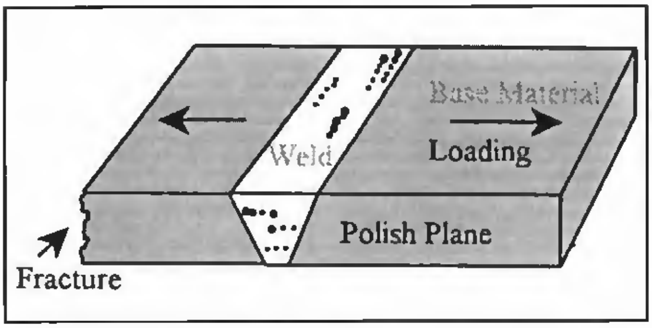


Fig. 2 — Joint K showing the fracture location in the casting outside the heat-affected zone and the small pores found in the weld.

Evaluating Welding Consumables and Procedures

Evaluating filler materials and test procedure variables proceeded in several steps. We began with general weldability evaluations of a wide range of candidate materials, then conducted more detailed evaluations of the best performer. These evaluations are summarized by test series in the following paragraphs.

To save the limited supply of the dome material for some final compatibility testing, we obtained a cast iron of current manufacture for our preliminary screening tests that was as similar as possible to the dome iron. Microstructural examination revealed the current technology cast iron was predominantly a type A gray iron (uniform graphite flakes with random orientations) in a matrix of pearlite and some ferrite. Some areas had a small amount of type B structure (rosette grouping of flakes). The composition was 3.56% C, 0.55% Mn, 2.41% Si, 0.11% P and 0.14% S. It had a similar preheat recommendation, but differs from the composition Lucius Pitkin reported by having a lower manganese content and a substantially lower phosphorus content. Mechanical tests showed this cast iron has a tensile strength near 175 MPa (25 ksi). This current technology cast-iron was considered suitable for early screening of filler materials; however, a final check of compatibility to the actual dome material was included as the last step in our study.

Screening Test 1: Five Candidate Alloys/Procedures on Current Cast Iron

This first test was designed to screen the suitability of five electrode compositions on the current technology cast iron, as follows: Electrode A, a copper-tin alloy (A/S 24 AC); Electrode B, a typical ENi-CI-A composition (Ni99); Electrode C, a typical ENiFe-CI-A composition (Ni55O); Electrode D, an aluminum-bronze alloy (Al Bronze A2); Electrode E, a nearly pure copper composition (A/S 26).

The electrodes were used to make transverse tensile test specimens with cast iron at each end and a transverse weld in the middle. Each electrode was welded in four conditions:

1) No preheat, interpass temperature of 167–204°C (350–400°F)

2) No preheat, but with peening, interpass temperature of 167–204°C

3) 93–149°C (200–300°F) preheat, interpass temperature of 121°C (250°F)

4) 260–315°C (500–600°F) preheat, interpass temperature of 121°C

After welding, the specimens were inspected, then pulled to failure in tension with the following results.

Electrode A. No obvious cracks during visual inspection, but welds with conditions 1 and 2 were so brittle they broke prior to tensile testing. Welds with conditions 3 and 4 produced transverse tensile strengths between 84 and 112 MPa (12–16 ksi). When preheat was used, the performance was fairly good, and this composition advanced to the next level of screening tests.

Electrode B. Conditions 2, 3 and 4 showed slight cracking along the sides of the welds. Condition 1 produced a strength near 70 MPa (10 ksi), condition 2 broke prior to testing, condition 3 produced a strength near 45 MPa (6 ksi) and condition 4 produced a strength near 175 MPa (25 ksi). The tendency toward cracking was considered undesirable, although the data for condition 4 was promising. A compositional variant (electrode F in the next screening test) could overcome the cracking, and so was included in screening test 2.

Electrode C. All welds showed at least slight cracking during visual inspection, but the condition 4 weld produced a strength of 175 MPa (25 ksi). The tendency toward cracking was considered undesirable, and, with no ideas for modification, this composition was excluded from further testing.

Electrode D. Conditions 1, 3 and 4 showed slight cracking along the sides of the welds. Condition 2 produced a strength near 70 MPa. The tendency toward cracking was considered undesirable, and this composition was excluded from further testing.

Electrode E. Poor weldability; eliminated from further evaluation.

We were looking for a weld composition/procedure combination with no cracks and good ductility. We found that only condition 3 was considered suitable for further evaluation. The welds without preheat all had poor performance, and very high preheat (developed from the predictive diagrams) was considered impractical for the dome shell. Only the copper-tin and nearly pure nickel compositions were recommended for further evaluation.

Screening Test 2: Three Candidate Alloys/Procedures on Current Cast Iron

This second test screened the suitability of three revised electrode compositions/procedures on the current technology cast-iron, as follows:

Electrode F, a special ENi-CI-A composition variation of electrode B (NC). This variant had a coating without the carbon traditionally added to ENi-CI-A electrodes, and so had a lower strength (a better match to the dome castings) and less tendency toward arcing to the joint sidewalls, at the cost of poorer weldability.

Electrode G, a copper-nickel composition (CuNi).

Electrode H, a copper-tin alloy (A/S 24 AC). The same as electrode A, it was given a new letter to distinguish the revised procedure details.

The electrodes were again used to make transverse tensile test specimens with cast iron at each end and a transverse weld in the middle. Each electrode was welded in two conditions: 93–149°C preheat, 93–149°C interpass temperature; and 93–149°C preheat, 93–149°C interpass temperature, followed by peening.

After welding, the specimens were inspected, then pulled to failure in tension, with the following results:

Electrode F. The weld for condition 2 was so brittle it broke prior to tensile testing. The condition 1 weld produced a strength near 120 MPa (17 ksi).

Electrode G. Both conditions broke prior to the tensile test, so this electrode was eliminated from further consideration.

Electrode H. Condition 1 broke prior to testing and condition 2 only produced a strength near 21 MPa (3 ksi).

We found only condition 1 was considered suitable for further evaluation. Peening was not found beneficial. Only the nearly pure nickel compositions (with the special coating without carbon) were recommended for further evaluation.

Screening Test 3: Two Candidate Alloys/Procedures on Dome Cast Iron

At this point, we used what we had learned in the first two screening tests to search for an alternate material or technique that could be compared to the best candidate from Screening Test 2 when welded on pieces of casting from the dome. In particular, we searched for another low-strength material that could meet our goals of good ductility and crack resistance. We selected a nickel composition (PA-7) that could be applied as a flame-spray powder and had the advantage of low strength and low melting point (below that of the cast iron). It was added to this screening to see if it could offer advantages over welding. In addition, the spray coating was used to butter the casting surface before welding, to spread the stresses and minimize cracking at the heat-affected zone in the casting. Therefore, this third test screened the suitability of the best electrode composition and procedure against a spray technique, as follows: Electrode J, the same ENi-CI-A composition variation identified as electrode F in test 2; Spray powder K, a high-nickel-content powder with some Si, Cr and B (PA- 7).

The electrode and spray powder were used to make two transverse tensile test specimens with cast iron from the dome at each end and a transverse weld in the middle. Electrode J was welded with the preheat and interpass temperatures identified in screening test 2, and the powder spray weld K was made by bringing the joint up to temperature (red heat) with the torch and then adding the powder to the flame with the following results:

Electrode J. Both welds fractured in the base material, well away from the weld (like that for weld K, as shown in Fig. 2) indicating the weld was stronger than the casting, and the heat-affected zone was not the critical fracture location. In other words, the HAZ was free from crack starters and unacceptably high residual stresses. The tensile strengths of the two welds were 56 and 63 MPa (8 and 9 ksi), substantially lower than the values Lucius Pitkin reported. Since both fractures were away from the welds and HAZ, these strengths suggest at least some parts of the dome shell might be best characterized as a Grade 10 casting. This data supports the case for treating the casting in a very gentle manner and that this repair procedure is appropriate.

Spray powder K. Both welds fractured in the base material, well away from the weld (Fig. 2), indicating the weld was stronger than the casting and the heat-affected zone was not the critical fracture location. Once again, the HAZ was free from crack starters and unacceptably high residual stresses. The tensile strengths of the two welds were 49 and 91 MPa (7 and 13 ksi), which again suggested the dome might be best characterized as a Grade 10 casting. The regions in the casting adjacent to welds J and K have an HAZ about 2 mm thick. The 0.5 mm nearest the fusion boundary has a high percentage of martensite, a brittle phase formed in iron castings by the heat of the welding process. This phase should be controlled by minimizing the time and temperature of the welding process. As shown in Fig. 3, the graphite flakes retain a type A morphology right up to the weld interface where the filler metal begins. The exception was in the weld root, where there was less of the type A structure and more of a brittle martensite phase in the HAZ. The weld has numerous pores that tend to be arranged in linear or planar configurations (Fig. 2) and are an artifact of the powder spray technique. The level of porosity appears to be within an acceptable (and expected) range.

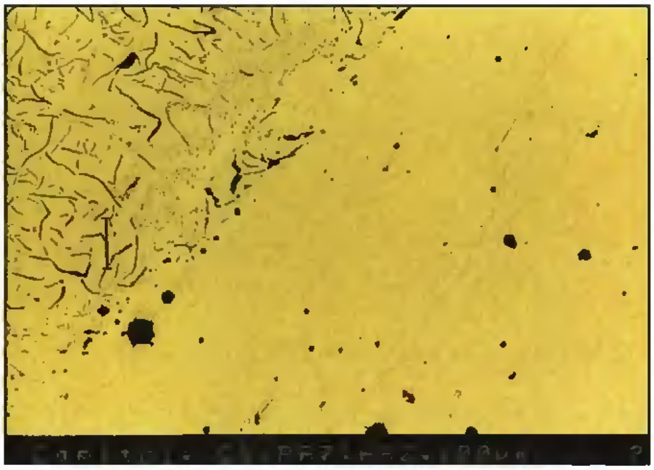


Fig. 3 — Micrograph of joint K (PA-7) showing the good fusion at the interface with the dome cast iron. The powder spray deposit is at right and the cast iron at left.

The fusion zone at the interface is similar for both welds J and K, as expected, since PA-7 was used at the interface of both. The interface is nearly a straight line, the same boundary produced during the joint beveling operation just prior to welding. This means the PA-7 never reached a temperature where it melted the cast iron at the surface; however, the bond is very good. That most of the transverse tensile tests failed far away from the weld or HAZ, and that the PA-7 penetrated into cracks on the beveled surface substantiates the quality of this bond. This penetration into the cast iron produced mechanical, as well as metallurgical, bonding across the interface. In one case, J1, the failure traveled through a portion of the HAZ, but seems to have originated at an imperfection on the surface, not as a result of the microstructure.

We measured a hardness profile across the HAZ in weld K. Figure 4 shows the results of this hardness survey, with negative position numbers signifying measurements in the casting and positive numbers signifying measurements in the weld (PA-7). The far left is data outside the HAZ, and shows a range of hardness between 150 and 300 Vickers (HV). The Vickers indenter is a microindentor, and so measures local regions much smaller than those detected by the 10-mm ball Lucius Pitkin used for its Brinell hardness tests, yet the scale is quite similar. Therefore, these data values are close to the 142 and 171 BHN values Lucius Pitkin reported. The reason the Vickers data show more variation is the small indentor can distinguish individual phase regions in the castings (some only a few micrometers across), rather than providing an average number. The finer resolution of the Vickers indentor is also able to distinguish the effects in the HAZ of the weld thermal cycle. The region between 1 and 2 mm into the casting was where the heat from the application of the PA-7 hardened the microstructure, with several values above 400 HV. These hard regions indicate an area more sensitive to cracking, and supports the need for a repair procedure that minimizes strain in this area. Finally, the hardness profile shows a hardness in the weld repair near 260 HV, which is a reasonably good match to the hardness of the casting.

Conclusions and Recommendations

Two products were found to produce the best performance with the cast iron in the shell of the Capitol dome.

The top performance came from PA-7, a nickel-based spray powder. PA-7 showed the lowest tendency for cracking in the castings and all joints exhibited good strength. In addition, mi-

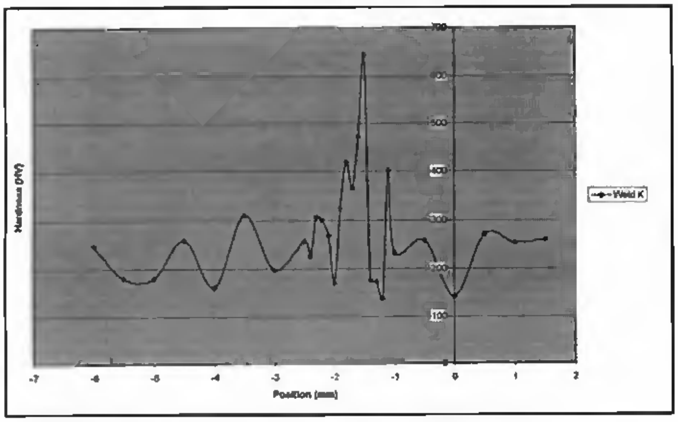


Fig. 4 — Vickers microhardness profile across the casting/weld interface for weld K. Negative position numbers signify measurements in the casting and positive numbers signify measurements in the weld (PA-7). The region between 1 and 2 mm into the casting was where the heat from the application of the PA-7 hardened the microstructure, with several values above 400 HV. The hardness profile shows a hardness in the weld repair near 260 HV. This hardness is a reasonably good match to the hardness of the bulk casting.

crostructural evaluations showed excellent wetting to the cast iron surfaces at each side and the least degradation of the HAZ of the casting. Because this product is not traditionally used with present-day cast irons, which are higher in strength and higher in ductility than those found in the dome, its suitability should be confirmed during development of the repair procedures.

The second best performance came from electrode J, a nickel-based composition, ENi-CI-A, that has been modified by eliminating carbon from the coating. The result is an electrode with lower strength (for lower residual stresses in the cast iron) but at the cost of poorer weldability. We suggest this is a good trade-off because of the desire to eliminate the tendency toward cracking found in previous repairs to the dome. In addition, we found it was best to butter the faces of the castings with the PA-7 powder before welding to further reduce the weld solidification stresses.

The traditional electrodes used to repair cast irons, ENi-CI-A and ENiFe-CI-A, produced some cracks in the heat-affected zones of evaluation welds, but could serve as backup electrodes if some problem was discovered with the electrodes described in our first recommendation. If this option is selected, the use of a buttering layer with PA-7 should be investigated as a way to reduce the solidification and shrinkage stresses that promote cracking.

A wide variety of other processes and electrodes were evaluated as part of this study, but all showed disadvantages, either cracking or poor weldability, that eliminated them from further consideration. Weld peening degraded the weld quality in all cases tried. A moderate preheat, 93–149°C, produced less cracking than no preheat, yet is still within a feasible preheat range for use on the dome.

The Next Steps

The final screening test was made under conditions thought to simulate the expected repair conditions as closely as possible, including the use of pieces of castings removed from the dome. However, further field trials are needed to evaluate these alternate procedures on a wider variety of shapes and by the welders who will perform the repair. They also need to be compared to more traditional procedures.

Further work is needed to evaluate all the positions that will be used and to develop a backing material for open root welds. Copper backing bars are often used in the welding of steel, but ceramic backing strips could be more practical for the dome joints.

A wide variety of welding procedures will continue to be developed and evaluated to be certain the optimum procedures will be ready for use for the upcoming second phase of the dome rehabilitation. Pending funding from Congress, the second phase is expected to begin in two years and last nearly three years. ◆

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The Auto Industry Gears Up for Aluminum

How well will established and new welding processes hold up under the challenge of the mass-produced aluminum automobile?

BY BOB IRVING

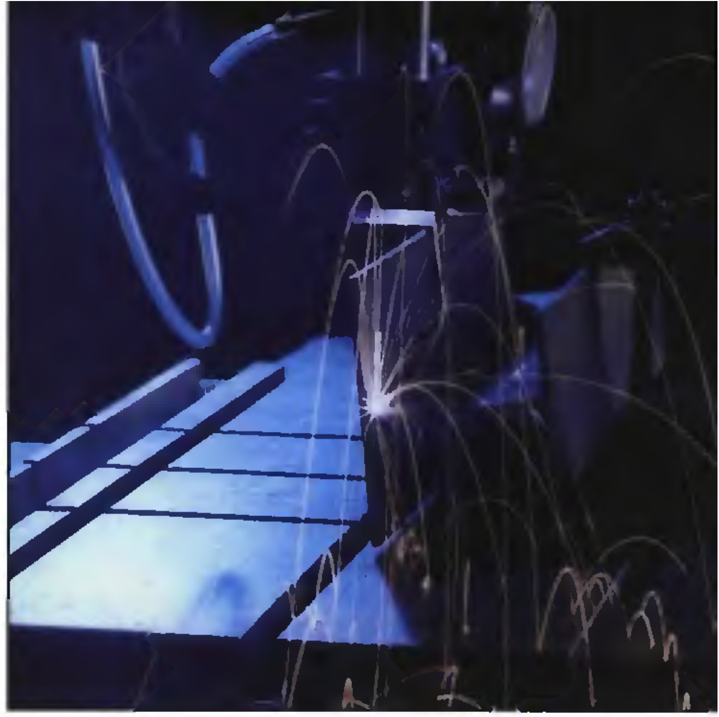

Fig. 1 — Fiber-optically delivered Nd:YAG laser beams can be used to make welds in aluminum structures. (Edison Welding Institute)

The shift within many automotive manufacturing plants from steel to aluminum is already happening. But the present concentration on aluminum is small compared to what will be expected in the years to come.

To the automotive industry, this new world is not without its trials and tribulations. For the most part, the welding engineers responsible for aluminum are presently experts in the welding of steel. So, whether the application calls for resistance spot welding or gas metal arc welding, the time has come to rethink these welding technologies. The time has also come to take a serious look at a number of new or different processes such as laser beam welding (Fig. 1), friction stir welding, hybrid welding and magnetic pulse welding. There are also a number of aluminum alloys to get to know — Table 1.

Aluminum is very different from steel. It has its metallurgical idiosyncrasies. It is a highly conductive metal that heats up very fast. The characteristic aluminum oxide on its surface is a difficult barrier to penetrate when welding and this must be addressed. In gas metal arc welding of aluminum, meltback can be a problem. Also, better joint fitup is required compared to welding steel. In resistance welding, much more power is needed. There is also a situation regarding electrode tips. Again, a new world.

Some Advice from Detroit

According to a welding engineer in the automotive industry, there are a number of issues facing the resistance welding (RW) and gas metal arc (GMA) welding of aluminum. These issues must be solved if aluminum is to be welded satisfactorily on the production line. The most important issue in resistance welding by far, he said, is the condition of the surface to be welded. Yes, there is the oxide surface to consider, but there are also the dirt, paint, sealants and die lubricants that can accumulate on the surface. The oxide coating on the surface will increase exponentially if the aluminum is stored outdoors. There, the stock is subjected to wide changes in temperature and such changes cause the oxide formation to increase more than normal.

Since most of the welding is performed robotically, automatic tip dressing and/or cleaning is a must. Also, the cooling water for the resistance welding guns must be closely controlled.

If cleanliness is an issue in resistance welding, it is even more important when the aluminum is joined by gas metal arc welding. Even when the aluminum is stored indoors, it is best to clean the surface of the metal within the week it will be welded. After cleaning, the components should be stored in the same area where they will be welded. The fitup requirements for aluminum, the engineer said, are at least twice as critical as the requirements for steel. Milling is a good way to provide consistency in weld preparation.

Other issues in GMA welding include fitup, termination of the welds and robotics. If not controlled properly, the terminations of welds can be quite a problem. If the crater is too deep, then cracking can develop. The weld controller for the robot can be set up to establish procedures that will eliminate this problem.

Progress Is Under Way

F. G. Armao, senior application engineer, The Lincoln Electric Co., Cleveland, Ohio, said aluminum is prominent in many of the newer cars, especially the more expensive ones. Among them will be new models from Jaguar and Ferrari. Corvette, he said, is expected to introduce a new model in the future that will be partly aluminum. Audi has taken the lead, however, in production line welding of aluminum automobiles.

In Audi's new Neckersulm plant in Germany, production has started on the all-aluminum A2 automobile. The

BOB IRVING is Contributing Editor to the Welding Journal.

Table 1 — Typical Aluminum Alloys Used for Automotive Applications

Inner and Outer Body Panels	2008, 2010, 2036, 3004, 5052, 5182, 5754, 6009, 6010, 6016, 6022, 6111
General Structural Components	6005, 6005A, 6009, 6061
Extrusions	6063, 6082, 7005
Luggage racks, air deflections	6463
Space tire carrier parts	6061
Bumper Components	
Ace bars	5052, 6009,
Reinforcements	6009, 6061, 7003, 7004, 7021, 7029
Brackets	6009, 7021
Seats	
Shells	7036, 6010
Headrest bars	7116, 7129
Tracks	6010, 5182, 5754, 6009
Load Floors	2036, 5182, 5754, 6009
Wheels	5454, 6061, A356.0
Suspension Parts	6061 (forging)
Drive Shaft	6061 (tube), Aluminum metal matrix alloys
Drive Shaft Yokes	6061 (forgings and impact extrusions)
Engine Accessary Brackets and Mounts	5454, 5754
Sub-Frames and Engine Cradles	5454, 5754, 6061, 6063
Miscellaneous	
Radiator tubes; heater cores; radiator, heater and evaporator fins; oil coolers; heater and air conditioner tubes	3003
Radiator, heater and evaporator fins	3005
Condenser tubes	3102
Condenser and radiator fins	7072

body consists of 60% aluminum panels, 18% extruded profiles and 22% castings. Each vehicle contains 30 m (98 ft) of laser beam welds and 20 m (65 ft) of GMA welds. Laser beam welding is performed inside sealed booths, and a welding operator controls the process via a video monitor from outside the booth.

The Audi A2 aluminum space frame consists of curved and straight extruded sections with vacuum die castings at the corners and intersections where the loads are highest (Ref. 1). The space frame is then clad with body panels. Laser beam welding is an essential part of the joining technology, allowing more and more aluminum applications.

On the Audi A8 car, which, like the A2 vehicle, is based on a space frame design, 60% of the joining is done using punch riveting. The balance is done using GMA welding. On the A2 vehicle, some of the GMA welding has been replaced by laser beam welding. Audi has purchased a number of 3-kW Nd:YAG lasers from Trumpf of Germany for that work. The ratio between punch riveting and welding on the A2 is close to 50-50. At the Neckersulm plant, all of the laser beam welding and 90% of the GMA welding is automated. Anticipated volume for the Audi A2 is expected to reach 60,000 vehicles per year. Production runs for the A8 car have been about 15,000 per year.

A Tried-and-True Method

In this country, there is considerable interest in resistance spot welding. "Much of the time," Armao said, "the automotive industry is more comfortable with resistance welding. It's a process the industry knows well. To them, resistance welding is a smaller leap from steel to aluminum."

Resistance welding is widely used in the production of the Lincoln Mercury division's Lincoln LS sedan. The process is used on the hood, the rear deck lid and the front fenders of the vehicle where body panels are made of aluminum. The Lincoln LS has been manufactured since April 1999 at the Wixom assembly plant in Wixom, Mich. Its competitors are cars such as the BMW, the Lexus and the Mercedes-Benz.

Mark White of Lincoln Mercury said it has been quite a challenge to weld aluminum for the Lincoln LS. However, he reports all is moving smoothly. At the Wixom plant, the engineers have chosen to use AC transformers. The transformers operate at relatively high currents.

Some Help from Aerospace

Engineers from the aerospace industry, who have considerable experience in the resistance welding of aluminum, are offering their assistance to the automotive industry. One of them, R. L. Szabo, the president of A-A Welding Engineering, Inc., Vacaville, Calif., previously "cut his teeth" on the resistance welding of aluminum while on the engineering staff at Convair. Szabo is convinced aluminum automotive components can be produced with the same quality as an aluminum missile resistance welded by Convair.

"One key to resistance welding of aluminum," Szabo said, "is the use of special starting weld current to weld through various aluminum surfaces. At Convair, we found that the development of an optimum starting current established weld formation from the center of the weld contact corona out. An excessive starting current, on the other hand, initiated expulsion. We believe that a starting current that is too low cooks the weld surface oxide, the adhesive or the protective metal surface coating, and that will cause weld formation near the outside of the weld corona. That condition can lead to irregular-shaped welds and often expulsion and blow holes."

Another potential technology transfer from aerospace to automotive is the use of decay weld current. "In aerospace," explained Szabo, "it is customary to follow a pulse of weld current with a decay current of about two-thirds of the weld current level. This decay current provides a slower cooling rate, one that will reduce internal defects resulting from aluminum shrinkage. Decay current is a useful technology for any resistance welding application involving aluminum, including automotive."

Weld Schedule Lobe Development

The use of weld schedule lobe development is often done in the automotive industry, but not to the extent it is done in aerospace. In aerospace welding of aluminum, for example, engineers have evaluated more weld lobe methods than are used in automotive. In aerospace, Szabo said, the following are evaluated:

1) Starting weld current vs. weld gun force.
2) Weld current vs. weld gun force.
3) Weld decay current vs. weld decay cycles.
4) Electrode hit count vs. weld current.

"Weld parameters for starting weld current," said Szabo, "weld current, weld cycles, weld gun force, decay current and decay cycles, all have a lobe or optimum range. A robust process results when a combination of these parameters is optimized from a lobe."

An associate of Szabo's, Thomas Croucher of Croucher & Associates, Paramount, Calif., has done considerable work with weld bonding, where a resistance weld is made through an adhesive. In aerospace, this method has been used successfully to join outside aluminum skins to internal cast structures. This involved the joining of a high-silicon casting alloy to an aluminum-zinc outer alloy. As a result, special weld lobe development was required. This technique would also apply to the joining of sheet aluminum to other castings, forgings and extrusions. It can also be applied to automotive applications such as aluminum impact door beam extrusions to aluminum door frames; cast aluminum structural frames to aluminum skin; and aluminum forged suspension mounting brackets to aluminum frame stampings.

Gas Metal Arc Welding

A. T. Anderson, technical services manager, AlcoTec Wire Corp., Traverse City, Mich., said, "Everybody associated with the automotive industry is quite excited about the move aluminum is making into structural components, like suspension frames, engine cradles, drive shafts and wheels. Most of the alloy is 6061 and 6063 aluminum. We are busy developing procedures for the automobile manufacturers. We are also training many of their welding engineers who were formerly just involved in the welding of steel."

When it comes to aluminum, gas metal arc welding is a well-established technology. The filler metals are in place, and the shielding gas (mostly argon) has been determined. "There have been innovations in power sources in recent years," said W. W. Hamilton, quality assurance manager at AlcoTec Wire, "whereby the interface has been improved between the welding machine and the robot. The process is already being used to weld wheels and driveshafts in mass production."

One difficulty remains, however, and that difficulty, a lack of a basic familiarity with the welding of aluminum, is being corrected. Alcotec, for example, operates a four-day seminar for engineers, line welders, and even people engaged in research and development in the automotive industry, on the fundamentals of aluminum welding. In AlcoTec's school, the mornings are devoted to lecture, while the afternoons are spent in actual "hands-on" welding. "It's important," Hamilton said, "that anyone involved with the welding of aluminum be aware of the issues."

As the gas metal arc process is beginning to be used more extensively in the automotive industry for the welding of aluminum, there appears to be a great need for some education. The engineers have to understand how quickly aluminum heats up and that it's necessary to weld the metal faster than steel. The stops and starts are different, and better fitup is required.

The Question of Robotics

Nick Dietzen, president of Gulf Wire Corp., New Orleans, La., cautions that anyone starting a new GMA aluminum project should look carefully at the metal's characteristics and how they differ from steel. One example is the expansion and contraction of aluminum when it is welded robotically. Aluminum's thermal expansion is about twice that of steel. This and other characteristics unique to aluminum make welding it a very different project compared to welding steel. Despite these differences, he said, information compiled by the Aluminum Association and the American Welding Society is available to help ensure a successful aluminum project.

Dietzen said the automotive industry is interested in working with larger packages of filler metal such as Gulf Wire's new 48-lb (21-kg) precision layer level wound spools and also in bulk reels up to 170 lb (76 kg).

M. J. O'Dell, automotive account manager for Miller Electric Manufacturing Co., Brighton, Mich., is seeing a trend among many automotive plants to use GMA welding in the manufacture of engine cradles, driveshafts and frames, and in relying on the relatively large $\frac{1}{16}$-in. (1.5-mm) diameter aluminum welding wires. Wires of that size, he said, handle more easily than other sizes. They can be run by simpler feed systems since they are easier to feed. Also, said O'Dell, because of the extreme demands in production, it is necessary to operate with water-cooled torches. The welding tips have to be kept as cool as possible. Another desirable convention is to maintain an electrode extension of $\frac{5}{8}$ in. (15.8 mm). Arc starting is also very important. Constant voltage should be run when starting the arc. The switch can then be made to a constant current mode.

Erzhi Wei, welding engineer, Ramco, Auburn, Ind., said his company currently manufactures between 1200 and 1300 aluminum engine cradles per day for General Motors' Chevrolet Impala 2000 and 2001. The cradles are being welded mostly by the robotic GMA process, using 4043 filler metal. The base metals are 6061 and 6063 aluminum, and weld joints consist mainly of lap joints. There are 40 Fanuc Arc Mate 100i robots in use in this operation.

Truck Radiator Supports

Michael Dumitrescu, general manager, Williamsburg Manufacturing, a division of Cosma International, Williamsburg, Iowa, discussed his company's GMA welding of truck radiator supports for the GMT800 program. The radiator supports, he said, consist of the following:

◆ Two (LH/RH) outer post subassemblies consisting of a 6063 aluminum extruded tube welded to two 5052 aluminum stampings for each assembly.

◆ A 6063 extruded aluminum upper tie bar and a 6063 extruded aluminum lower tie bar, which are welded to the LH/RH outer post assemblies and two extruded 6063 aluminum inner posts.

◆ A 6000 series aluminum cross brace with a 5000 series hood latch bracket welded to it is subassembled and installed on the final frame.

The radiator supports are welded on three separate lines, and there are 30 robots on each line. In addition, Williamsburg Manufacturing is using 130 power sources on this operation.

"We weld in the pulse mode on all applications," Dumitrescu said. "We also use a 5000 series filler metal."

Pursuits at Tower Automotive

R. E. Broman is in charge of an eight-person welding research team within the advanced technology laboratory of Tower Automotive, Milwaukee, Wis. "We have been working on aluminum for about five years in anticipation of greater use of aluminum by the automotive industry," Broman said. "It looks as if the production of aluminum components in volume is about ready to begin."

Tower Automotive is working especially hard to improve gas metal arc welding and friction stir welding. As far as GMA welding of aluminum is concerned, the need in the automotive industry is to make the equipment more robust to handle the huge production runs required by the industry. Broman said particular attention is being placed on arc starting, crater fill and wire feeding. Tower Automotive is working with certain vendors to help them improve their products for the automotive production line.

Friction stir welding (FSW) is also under evaluation by the company's welding team. Investigations have already been carried out over the past five years using a Tower Automotive developed robotic FSW system and modified milling machines. Initially, travel speeds of FSW were not competitive to GMAW, but developments have since allowed FSW to achieve travel speeds equivalent to GMAW. This has been accomplished through experimental trials and development of a three-dimen-

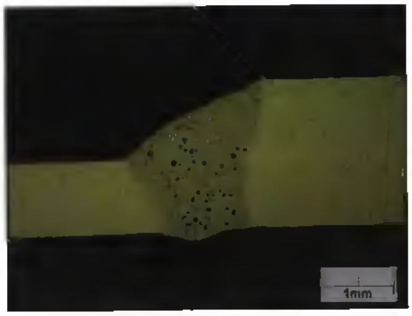

Fig. 2 — Cross section of an aluminum tailor-blank welded with the laser process. Note the typical porosity in the weld joint.

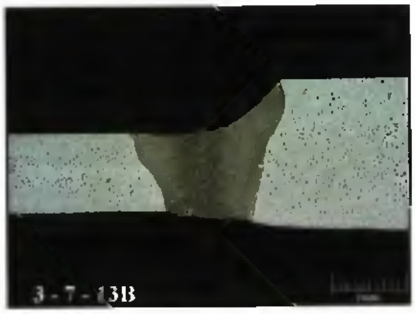

Fig. 3 — Cross section of an aluminum blank laser beam welded with modifications to the optics to control weld pool stability. Note the amount of porosity was controlled.

sional model. "Friction stir welding," Broman said, "is very viable for many applications. There is less heat input with friction stir welding." He believes Tower is the leader in implementing this new technology.

"Also," he added, "it can be used to weld most aluminum alloys, as well as welding 6000 series aluminum autogenously. Both resistance welding and laser welding have problems doing the same."

Manufacturing engineers in the automotive industry have always considered friction stir welding to be much too slow for their production lines. It is inexpensive, however, so the engineers still have hope the speed of this process can be increased, thus making it much more competitive with some of the more exotic welding processes. Considerable research is being conducted at Edison Welding Institute (EWI), Columbus, Ohio, and at The Welding Institute in the U. K. to bring the process up to production line speed.

Friction Stir Welding Gains Speed

T. J. Lienert, senior engineer at EWI, said, "Increases in speed are in the works. Present welding speeds on aluminum sheet, depending on the joint configuration, might exceed 60 in. (1.52 m) per minute." Conservatively, he believed that can be increased to 120 in. (3.04 m) per minute. But Lienert was also quick to point out there were many more aspects to consider with friction stir welding of aluminum than just speed. "Compared to the laser," he noted, "FSW has several very important advantages. For one thing, the latter process will handle the 6000 series without solidification cracking problems. It will also tolerate much looser fitup than laser beam welding. Also, welds made by friction stir welding do not lose magnesium by evaporation, which is likely to happen in laser beam welding. So, the mechanical properties are likely to be more consistent with FSW."

Lienert also cautions prospective users of friction stir welding "not to reinvent the wheel." FSW is a forge welding process and considerable information regarding deformation processing of aluminum alloys has been accumulated over the years. "Do not refer to weldability studies with this process. Instead, you should couch your understanding of FSW joinability of a given alloy based on its ease of forging," he said. "So, when it comes to friction stir welding, the key word is forgeability, not weldability."

In the U. S., cycle times for resistance spot welding are under one minute. Depending on the application, the design and the metal thickness, this requirement can be met by friction stir welding. Said Larry Holt, welding automation engineer, ESAB Welding Equipment AB, Belle Haven, Va., "We cannot sell the process based on speed alone. But, by adding additional weld heads and robotics, we can be competitive in speed. We have produced machines with cycle times of 47 seconds and are looking at faster times for other applications."

ESAB's headquarters for friction stir welding is in Laxa, Sweden. According to Holt, the organization has sold two FSW systems, one in Sweden and one in the United States, to first-tier suppliers to the automotive industry. Additional orders are pending.

In the automotive industry, the FSW process is competing head on with gas metal arc welding on 6000 series aluminum alloys. "With friction stir welding," Holt said, "there is no distortion, no filler metals, no shielding gases, no surface preparation. Also, the mechanical properties of welds made by the process are always better than those in GMA welds."

The Auto Aluminum Alliance

The recent Auto Aluminum Alliance was formed to accelerate the use of new and improved technologies for motor vehicles. One of the initial projects of the Alliance is the development of tailor welded blanks of aluminum. A number of welding technologies, including magnetic pulse welding, is being considered for this type of work.

At this point in time, and unlike the present situation in steel, there is no production in tailor welded blanks of aluminum. However, there is a considerable amount of effort under way evaluating prospective processes and alloys for this type of product. Alloy selection has been fairly well determined. According to Jo Ann Clarke, automotive applications engineer, Alcan Global Automotive Products, Farmington Hills, Mich., Alloys 5182 and 5754 are presently used as inners for closure panels. They are also candidates for tailor-welded blanks on inner panels. (There are no tailor-welded blanks on outer panels.) Alcan Alloy 6111 is already being used for outer panels and even some inner panels. This alloy may be used for tailor-welded blank inners. However, to laser beam weld Alloy 6111 on an automotive production line a filler metal, like 4043 or 4047, would have to be used.

As far as candidate welding processes are concerned, Alcan and others are looking at both YAG and CO_2 laser beam welding, nonvacuum electron beam welding, plasma arc welding, gas tungsten arc welding and, yes, even friction stir welding. At Edison Welding Institute, considerable research is being done through the modification of laser optics (Figs. 2, 3) to provide high-quality welds in tailor-welded aluminum blanks.

When laser welding aluminum, point out engineers from Volvo Cars in Sweden, a power density of at least 1 MW/cm^2 on the workpiece is required; otherwise, the laser beam will reflect on the surface of the metal (Ref. 2). For a stable welding process, and to perform keyhole welding, at least 2 MW/cm^2 is required, due to the high reflection and heat transfer of aluminum. Tailor welded blanks using the laser are being produced of both the 5000 and 6000 series of aluminum. This is normally done in a butt-joint configuration. Joints welded with filler metal generally display smoother transitions between the two base metals, thus reducing the sensitivity to fatigue failure. Another advantage in using filler metal is the lower sensitivity to cracks. Typically, root openings up to 0.3 mm (0.01 in.) can be bridged. Using filler metal, the tolerance can be increased to 0.5 mm (0.015 in.). In laser beam welding of aluminum, helium is the most frequently used shielding gas, but welding can also be performed without shielding. Without shielding gas, the process is more intense. One result is an increase in spatter. However, depending on metal thickness, welding speed can be increased by as much as 40%. Both CO_2 and Nd:YAG lasers have been used in tailor welded blanking operations in Sweden.

Lasers Are Active in Europe

Israel Stol, senior manufacturing specialist, Alcoa Technical Center, Alcoa Center, Pa., reports a number of automotive companies in Europe have been aggressively developing laser welding applications for the assembly of aluminum structures for several years. One of these companies, in addition to successfully adapting the process to welding parts for its present product line, plans to laser weld large portions of its future aluminum structures. This same company has also been pursuing a hybrid joining process, which combines the laser beam and GMA welding processes. In this process, a YAG laser beam precedes a welding arc along the joint. The YAG beam creates a keyhole and the GMAW process deposits the weld metal. This process has been demonstrated as being capable of depositing lap fillet joints comprised of 2.5-mm (0.075-in.) thick aluminum parts at 4 and 4.5 m/min (13 to 15 ft/min) speed of travel.

Both the YAG and the CO_2 lasers are viable candidates for automotive welding lines. Due to the short wavelength of the YAG lasers, the power with these systems can be transmitted through fiber optics. This makes YAG welding systems especially adaptable to welding with robots. The main drawback of YAG lasers is the maximum power output of about 4 kW in commercially available systems. The CO_2 laser, on the other hand, offers higher power output.

In the future, Stol sees increasing usage of laser beam welding, resistance welding and hybrid laser/GMA welding systems for automotive aluminum.

A proponent of the new hybrid welding process is Fraunhofer. According to Stephan Naegeler, director, Fraunhofer USA, Center for Surface and Laser Processing, Plymouth, Mich., the process is aimed at tailor-welded blanks and various structural components. The main alloys being welded include 5754 and 6111 aluminum. The hybrid welding process being promoted by Fraunhofer features a tandem arrangement involving two separate processes. They are the CO_2 laser and either gas metal arc or plasma arc welding. Naegeler confirms the process is being used in production in Europe.

Enter Magnetic Pulse Welding

D. P. Workman, senior engineer, Edison Welding Institute, Columbus, Ohio, is involved in the development of magnetic pulse welding. A derivative of magnetic forming, this process is intended to join closed sections, such as tubes to tubes. Workman describes the process as an extremely fast noncontact method that provides a solid-state bond or "cold weld" with minimal heat input. The fact the heat input is so low allows for the joining of such metallurgically incompatible metals as steel to aluminum. The magnetic pulse, he said, is very similar to an explosive weld except the driving forces are derived from magnetic energy rather than chemical energy.

Dana Corp. has an experimental magnetic pulse welding machine in its research laboratory in Toledo — Fig. 4. Through the demonstrated success of this machine, Dana has moved ahead and ordered a production machine to manufacture aluminum driveshafts in one of the Spicer plants. This second unit is expected to enter actual production between the second and third quarters of 2001.

Both machines are products of Manufacturing Technology,

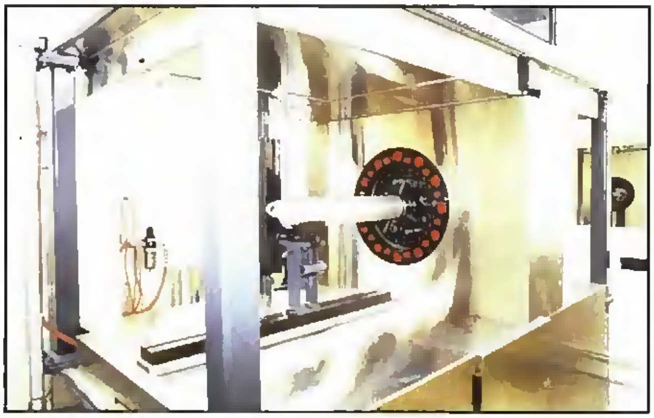

Fig. 4 — Experimental magnetic pulse welding machine at Dana Corp.'s research laboratory in Toledo, Ohio, has been used to demonstrate the ability to weld aluminum driveshafts. A second production unit is on order from the equipment builder, Manufacturing Technology, Inc.

Inc. (MTI), South Bend, Ind. MTI is best known, perhaps, as a builder of friction welding machines.

Work is also under way at Dana to develop the process so it can be used in the manufacture of aluminum space frames for future cars at Dana's Parrish Frame Division. Identified as the Rolling Space Frame™ module, this design incorporates the frame, the axle systems, driveshaft, suspension, steering gear, brakes and fuel tank of a motor vehicle.

The ultrahigh speeds with which magnetic pulse welding operates practically defy description. According to J. A. Duggan, chief engineer, Advanced Design for the Spicer Driveshaft Division, Dana Corp., Toledo, Ohio, the laboratory unit is capable of generating 5000 V and 1.5 million A in 100 microseconds. The weld can actually be made in 10 microseconds. With this process, he said, there is no heat input, no filler metal, no shielding gas.

When used to produce aluminum driveshafts, the work will be brought to the machine. The equipment now under development will contain highly automated features, thus enabling the process to work in union with high-speed automotive production lines.

Back to Resistance Welding

Another technology under development at EWI is a process called conductive heat resistance seam welding, where sacrificial steel sheets are used to generate heat and provide constraint to the molten nugget. Workman is also involved in this effort. In the resistance welding of aluminum, he said, as much as 30,000 A is required to make a weld using conventional methods. Using the sacrificial sheets, the amount of current needed to make the weld can be reduced to 15,000 A, which is similar to the amount of amperage required in making welds in galvanized steel. This permits conventional resistance welding equipment to be used for welding of aluminum.

In experiments conducted at EWI, the steel scavenger sheets, or "cover sheets," as they are called, consisted of 0.8- to 1.6-mm-thick bare steel. The aluminum alloys welded together in these experiments covered a range of alloys that included 5XXX, 6XXX and 7XXX alloys. Welds have also been made between dissimilar thickness sheets with excellent weld geometry. It is interesting to note 7075-T6 has always been considered a challenging aluminum alloy to weld while maintaining base metal strengths in the weld.

In the world of production, John Macdonald, divisional weld engineer, The Budd Co., Rochester, Mich., said aluminum fenders for a future model sport utility vehicle will soon be produced at one of the Budd plants. This part is scheduled to run at a yearly volume of about 400,000.

There are three basic power sources to choose from for the resistance welding of aluminum. They are conventional AC, rectified low-frequency DC and mid-frequency DC. Macdonald said AC offers low initial costs, but has the highest primary power demand. Rectified DC, he added, has lower primary power than AC, but weld controls have difficulty running in constant current mode. Mid-frequency, or MFDC, is the most expensive, but it has the lowest primary demand.

"We are looking at each job differently," he explained, "based on yearly volumes. This dictates how the tooling process is used. On low-volume jobs we are coming up with multiple guns for the transformer. I think there are applications where AC and rectified DC can be used to save money, but all of the factors, including power consumption, initial costs, duty cycle, weld quality, metal stack-ups and material, have to be considered. As industry starts to buy more MFDC equipment, then the cost should be driven down."

The Budd Co. chose MFDC because of the finer control of current and the low power consumption. MFDC operates at 1200 HZ; thus, the tuning of the welds can be more precise. Also, Macdonald said, MFDC has uninterrupted heat, which helps in overcoming the heat conductivity of aluminum.

"We are using a Weltronic MFDC weld control. This enables us to vary the frequency and to weld in 1/10 of cycles. We did not find," added Macdonald, "the polarity of the gun arms positive to negative to be a factor in weld surface quality or in tip life. The use of a dedicated weld chiller aided in preventing the tips from sticking to the metal surfaces. This also significantly pulled the heat from the gun tips and gun arms."

Improvements in Resistance Welding Electrodes

Huys Industries, Windsor, Ont., Canada, has been active in the design and manufacture of resistance welding electrodes for years. One of its main products is electrodes with tips impregnated with titanium carbide. Originally, this approach was aimed at galvanized steel to prevent pickup of zinc from the surface of the sheet metal being welded. This, in turn, extended tip life. Huys Industries uses a similar approach on electrodes for aluminum. The goal here is to prevent any of the aluminum to be picked up by the copper in the electrode. Again, the idea is to extend electrode tip life.

According to A. D. Kennedy, vice president of marketing at Huys, the average tip life on aluminum using mid-frequency current with uncoated resistance welding electrodes is only about 300 to 400 welds. Huys has developed a modified coating for the electrodes used on aluminum. In trials, the modified electrode is holding up through 2000 welds before tip dressing is required. Similar coatings are used on the tips employed to weld galvanized steel. There, 7000 to 8000 welds can be made before tip dressing is required. These electrodes are being used by Budd Automotive in the production of the fenders for the Ford Explorer.

In an attempt to extend tip life on aluminum even further, Huys, in conjunction with the Canadian government, is sponsoring research at the University of Waterloo and the University of Toronto to develop an even more effective coating for electrodes used on aluminum. This effort is a further modification of the titanium carbide approach. The goal here is 4000 to 5000 welds on aluminum using mid-frequency current before tip dressing is required.

Where We Are

In terms of materials, the automotive industry is in a sort of turmoil. It has been a rule of thumb that to improve gas mileage, it will be necessary to reduce the weight of the vehicle. Ergo, the aluminum-intensive automobile. But time is running out. Compared to steel, aluminum is very expensive, but it is also much lighter. When it comes to joining, the automotive industry wrote the book on resistance spot welding of steel. The aerospace industry has had experience in spot welding aluminum, but not in the enormous production quantities demanded by Detroit. So, R&D and education are needed to make resistance welding a cost-effective joining method for aluminum. It's much the same in gas metal arc welding, though, here, the need is greater for education.

Aluminum is beginning to be used in greater quantities. It's no longer just radiators and engines. We are now seeing frames and even the body in white. Automotive executives are looking at the new hybrid vehicles. If they catch on, there may not be any need for aluminum. The present trend, however, is toward the all-aluminum car, and the welding community is being called upon to help meet the challenge of fabricating it. ◆

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How to Select the Best Filler Metal for Welding Aluminum

These days, almost all aluminum welding is performed using GMAW or GTAW. With those two processes, flux entrapment, which could lead to corrosion problems, is not an issue.

Selection of a filler metal should be made only after analyzing the performance requirements of the welded component

BY TONY ANDERSON

Selecting the correct filler metal is a major factor in successfully welding aluminum, and is essential for the development and qualification of suitable welding procedure specifications.

Unlike steel, where a filler metal is usually matched with the tensile strength of the base metal alone, it is often possible to weld many of the aluminum base metals with any one of a number of filler metals — Fig. 1. Several filler metals will usually meet or exceed the tensile strength of the base metal in the as-welded condition. However, the selection of the filler metal is typically not based only on the tensile strength of the completed weld.

A number of variables need to be considered during the selection of the most suitable filler metal for a particular base metal and component operating condition. When choosing the optimum filler metal, both base metal and desired performance of the weldment must be of prime consideration. You need to know what the weld will be subjected to and what it is expected to do.

A reliable tool that can help you choose an aluminum filler metal is the filler metal selection chart from AlcoTec Corp., Traverse City, Mich. Each filler metal can produce unique characteristics in the finished weld, and the filler metal chart will help you make the most appropriate choice. The filler metal selection chart can be found in the AlcoTec technical brochure. To successfully use this, it is important to understand the numerous variables that govern the selection of a filler metal. In this article, we will examine each of the variables that need to be considered prior to the final selection of the most suitable filler metal for a particular application.

Ease of Welding or Relative Crack Sensitivity

Hot cracking typically results from a metallurgical weakness in the weld metal as it solidifies, and from transverse stress across the weld. The metallurgical weakness may result from the wrong mixture of filler metal and base metal, while the transverse stress may result from shrinkage during solidification of the weld. These cracks are called hot cracks because they occur at temperatures close to the solidification temperature.

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Fig. 1 — Various welded structural aluminum parts. Unlike steel, where the filler metal is usually matched with the tensile strength of the base metal, many aluminum alloys can be welded with any one of a number of filler metals.

To minimize the risk of hot cracking, we should consider the following guidelines regarding the reduction of transverse stresses across the weld and the avoidance of critical chemistry ranges in the weld.

Reduction of Stresses

Lower melting and solidification point. For base metals with a high susceptibility to hot cracking, such as many of the 2xxx series alloys, we may choose a 4xxx series filler such as 4145 that has an extremely low solidification temperature (970°F [521°C]). This low solidification temperature ensures that the 4145 weld metal is the last to solidify, thereby allowing the base metal to completely solidify and reach its maximum strength before the solidification/shrinkage stresses of the weld are applied to it.

Smaller freezing temperature range. By using a filler metal such as 4047, which freezes over a range of ten degrees Fahrenheit, welds can be made that solidify quickly. This provides less time for liquid metal to be subjected to shrinkage stresses during the solidification process.

Critical chemistry ranges. This issue is best addressed by use of the relative crack sensitivity curves as seen in Fig 2. The chart shows the crack sensitivity curves for the most common weld metal chemistries developed during the welding of the structural base metal materials.

The aluminum-silicon alloys (4xxx series) exist as nonheat treatable and heat treatable alloys with 4.5 to 13% silicon. They are used predominately for filler metals. Silicon in an aluminum filler metal/base metal mixture of between 0.5 and 2.0% produces a weld metal composition that is crack sensitive; a weld with this chemistry may crack during solidification. Care must be exercised if welding a 1xxx series (pure Al) base metal with a 4xxx series (Al-Si) filler metal, to prevent a weld metal chemistry mixture within this crack sensitive range.

The aluminum-copper alloys (2xxx series) are heat treatable, high-strength materials often used in specialized applications. As can be seen from the chart, they exhibit a wide range of crack sensitivity. Some of these base metals are considered poor for arc welding because of their sensitivity to hot cracking, but others are easily welded using the correct filler metal and procedure.

The aluminum-magnesium alloys (5xxx series) have the highest strengths of the nonheat treatable aluminum alloys, and for this reason are very important for structural applications. Magnesium in an aluminum weld, from 0.5 to 3.0%, produces a weld metal composition that is crack sensitive. Another issue relating to these base metals, which is not directly related to the crack sensitivity chart but is a very important factor for filler metal selection, must be addressed. As a rule, the Al-Mg base metals with less then 2.8% Mg content can be welded with either the Al-Si (4xxx series) or the Al-Mg (5xxx series) filler metals depending on weld performance requirements. The Al-Mg base metals with more than about 2.8% Mg typically cannot be successfully welded with the Al-Si (4xxx series) filler metals because of a eutectic problem associated with excessive amounts of magnesium silicide (Mg_2Si) developing in the weld structure, which decreases ductility and increases crack sensitivity.

The aluminum-magnesium-silicon alloys (6xxx series) are heat treatable. The 6xxx series base metals, typically containing around 1.0% magnesium silicide, cannot be welded successfully without filler metal. These alloys can be welded with 4xxx series (Al-Si) or 5xxx series (Al-Mg) filler metals depending on weld performance requirements. The main consideration is to adequately dilute the Mg_2Si percentage in the base metal with sufficient filler metal to reduce weld metal crack sensitivity.

Weld Strength

Groove Weld Tensile Strength

Typically, the heat-affected zone (HAZ) of the groove weld dictates the strength of the joint. Often many filler metals can satisfy this strength requirement. However, there are two factors to consider when developing welding procedures for nonheat treatable and heat treatable alloys.

For nonheat treatable alloys, the area adjacent to the weld will be completely annealed. These alloys are annealed by heating to 600–700°F, and the required time at this temperature is short. The welding procedure will have little effect on the transverse ultimate tensile strength of the groove weld because the annealed HAZ will typically be the weakest area of the joint. Welding procedure qualification for these alloys is based on the minimum tensile strength of the base metal in its annealed condition.

The heat treatable alloys require longer times at temperature to fully reduce their strength. This does not typically occur during welding, and the strength of the HAZ will only be partially reduced. In these alloys, the amount of strength loss is both time and temperature related. The faster the welding process and heat dissipation from the weld area, the less the heat effect and higher the as-welded strength. Excessive preheating, lack of interpass cooling and excessive heat input from slow, weaving weld passes all increase peak temperature and time at temperature. These factors by themselves, as well as the use of too small a specimen to provide adequate heat sink, can create sufficient overheating so that minimum strength values required to pass procedure qualification tests are not met.

Fillet Weld Shear Strength

Unlike groove welds, fillet weld strength is largely dependent on the composition of the filler metal used to weld the joint. The joint strength of fillet welds is based on shear strength, which can be affected considerably by filler metal selection. In structural applications, the selection between 5xxx series filler or a 4xxx series filler may not be so significant with regard to the tensile strength of groove welds. However, this may not be the case when considering the shear strength of fillet welds.

The 4xxx series filler metals typically have lower ductility and provide less shear strength in fillet welds. The 5xxx series filler metals typically have more ductility and can provide close to twice the shear strength of a 4xxx series filler metal in some circumstances. Tests have shown that a required shear strength value in a fillet weld in 6061 base metal required a ¼-in. fillet weld with 5556 filler compared to a 7/16-in. fillet with 4043 filler metal to meet the same required shear strength. The choice of filler metal can mean the difference between a fillet weld made with one pass and one that needs three passes to achieve the same strength.

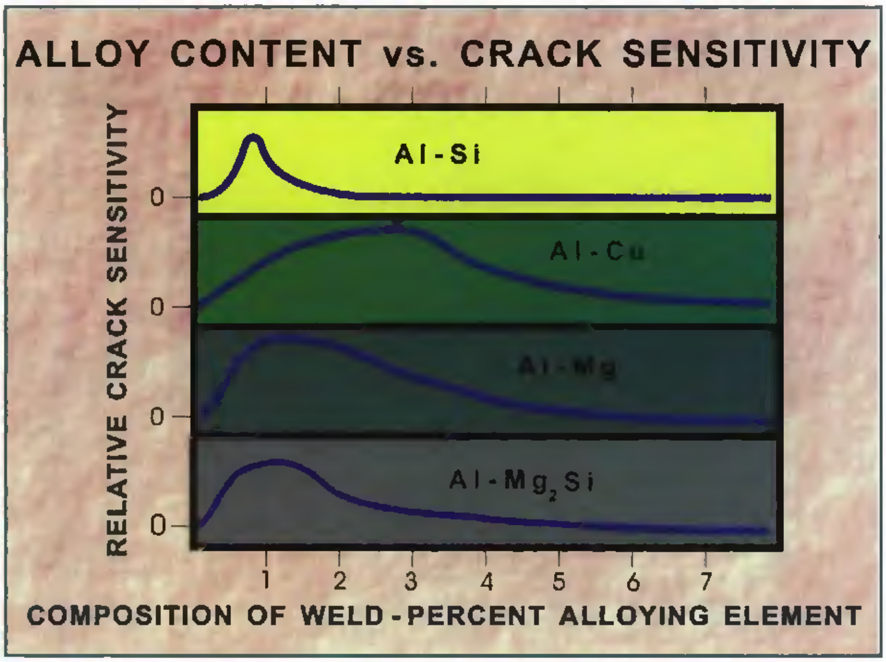


Fig. 2 — Crack sensitivity chart showing the most common aluminum weld metal chemistries.

Ductility

Ductility describes the ability of a material to plastically flow before fracturing. Fracture characteristics are described in terms of ability to undergo elastic stretching and plastic deformation in the presence of stress raisers (weld discontinuities). Increased ductility ratings for a filler metal indicate greater ability to deform plastically and to redistribute load and, thereby, to decrease the crack propagation sensitivity.

Ductility may be a consideration if forming is to be performed after welding or if the weld is going to be subjected to impact loading. Also, ductility is considered when conducting bend tests during procedure qualifications. The 4xxx series filler metals have relatively low ductility; this is addressed with special requirements within the code or standard relating to test sample thickness, bending radius and/or material condition.

Corrosion Resistance

The use of shielded metal arc welding (SMAW) electrodes with their flux coating gave concern for possible corrosion problems relating to entrapped flux within the welded joint. Today, almost all aluminum welding is performed using the gas metal arc welding (GMAW) or the gas tungsten arc welding (GTAW) processes, and flux entrapment is not an issue.

Developed primarily for use within a specific corrosive environment, 5654 filler metal was developed to weld storage tanks to hold hydrogen peroxide. This filler metal has a high purity with low copper and manganese content, which is required for this very active chemical.

Most unprotected aluminum base metal/filler metal combinations are quite satisfactory for general exposure to the atmosphere. In cases where a dissimilar aluminum alloy combination of base and filler metal is used and electrolyte is present, it is possible to set up a galvanic action between the dissimilar compositions. The difference in alloy performance can vary based upon the type of exposure. Filler metal chart ratings are typically based on fresh and salt water only. Corrosion resistance can be a complex subject when looking at service in specialized high-corrosive environments, and may necessitate consultation with engineers from within this specialized field.

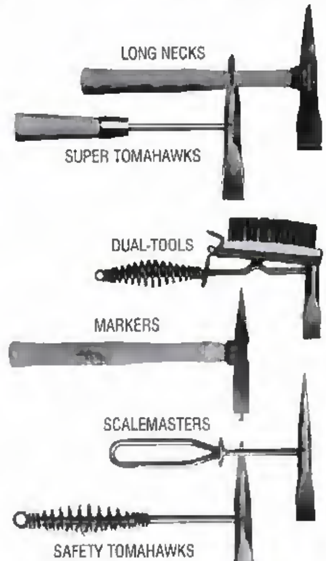
Service Temperature

Stress corrosion cracking is an undesirable condition that can result in premature failure of a welded component. One condition that can assist in the development of this phenomena is magnesium segregation at the grain boundaries of the material. This condition can be developed in alloys of more than 3% Mg through exposure to elevated temperature.

When considering service at temperatures above 150°F, we must consider the use of filler metals that can operate at these temperatures without any undesirable effects on the welded joint. Filler metals 5356, 5183, 5654 and 5556 all contain in excess of 3% Mg, typically around 5%; therefore, they are not suitable for temperature service. Alloy 5554 has less than 3% Mg and was developed for high-temperature applications. Alloy 5554 is used for welding of 5454 base metal, which is also used for these high-temperature applications. The Al-Si (4xxx series) filler metals may be used for some service temperature applications, depending on the weld performance requirements.

Postweld Heat Treatment

Typically, the common heat treatable base metals, such as 6061-T6, lose a substantial portion of their mechanical strength after welding. Alloy 6061-T6 typically has 45,000 lb/in.^{2} tensile strength prior to welding and 27,000 lb/in.^{2} in the as-welded condition. Consequently, on occasion it is desirable to perform postweld heat treatment to return the mechanical strength to the manufactured component. If postweld heat treatment is the option, it is necessary to evaluate the filler metal used with regard to its ability to respond to the heat treatment. Most of the commonly used filler



Most common filler metals will not respond to PWHT without substantial dilution with the heat treatable base metal.

metals will not respond to postweld heat treatment without substantial dilution with the heat treatable base metal. This is not always easy to achieve and can be difficult to control consistently. For this reason, some special filler metals have been developed to provide a heat treatable filler metal that guarantees the weld will respond to the heat treatment. Filler metal 4643 was developed for welding the 6xxx series base metals. It develops high mechanical properties in the postweld heat treated condition. This filler metal was developed by taking the well-known alloy 4043 and reducing the silicon and adding 0.10 to 0.30% magnesium. This chemistry introduces Mg_2Si into the weld metal and provides a weld that will respond to heat treatment.

Filler metal 5180 was developed for welding the 7xxx series base metals. It falls within the Al-Zn-Mg alloy family and responds to postweld thermal treatments. It provides very high weld mechanical properties in the postweld heat treated condition. This alloy is used to weld 7005 bicycle frames and will respond to heat treatment without dilution of the thin-walled tubing used for this high-performance application. Other heat treatable filler metals have been developed including 2319, 4009, 4010, 4145, 206.0, A356.0, A357.0, C355.0 and 357.0 for the welding of heat treatable wrought and cast aluminum alloys.

Final determination of the most suitable filler metal can only be made after a full analysis of the performance requirements for the welded components. Filler metal selection for welding aluminum is an essential part of the development and qualification of a successful welding procedure. ◆

Portable Video Probe Inspects Pipe Welds

Sound, contamination-free welds are a must in piping used in the manufacture of pharmaceuticals

The video monitor of this portable probe allows welds to be examined by multiple personnel for more positive identification of problems.

Pharmaceutical manufacturing poses the challenge of ensuring no materials are contaminated in any stage of production, which necessitates strict quality controls for all equipment that comes into contact with production materials. A single incident of contamination will cost a pharmaceutical manufacturer millions of dollars.

Pharmacia Corp., one of the world's leading pharmaceutical manufacturers, must ensure the purity of water used in production at its facility in Kalamazoo, Mich. Not only must the water be purified but the pipe lines through which it runs in the manufacturing process must be free of all contaminants. These pipes, which are 20 ft in length with diameters that range from 1½ to 6 in., must be welded together without any internal flaws. Internal inspection of each of these welds is necessary to ensure none are flawed.

Weld inspector H. James Moore is responsible for ensuring the internal welding of all pipe lines poses no threat of contaminating purified water. Each weld is inspected to ensure it is perfect, with no lips or concavities. Flaws in internal welding may result in the growth of bacteria and other pathogens. The water, whether fluid or steam, must also be free of mineral deposits. According to Moore, flawed welds expose the water to ions from metallic elements in the pipes.

To be rated USP Grade for pharmaceutical manufacturing, water is subjected to filtration, ionization and distillation to ensure it is free of all elements other than hydrogen and oxygen. Production equipment is inspected daily to ensure no contamination occurs.

If contamination does occur, production is suspended until the system is drained, cleaned and passivated; the cause of contamination is identified and corrected; and the system is tested for pharmaceutical production again. According to Moore, contamination can cease operations for as long as three weeks, costing the company millions of dollars.

Pharmaceutical manufacturing poses the challenge of ensuring no materials are contaminated

"The welding requires inspection by people who can recognize problems with the equipment," Moore said. "With frequent testing, we must be able to inspect accurately every time. There is no acceptable level of contamination."

The facility runs three different types of water lines: purified water; water for injectable pharmaceuticals, which is subject to additional distillation procedures; and sterile steam. To prevent internal pipe deterioration, as well as risk of contamination, the pipes are made from corrosion-resistant 316L stainless steel. Pharmacia is the only pharmaceutical manufacturer that takes the additional precaution of including a 10RA finish on the interiors of all pipes, fittings and valves.

The customary equipment used for weld inspections is a borescope. Moore was seeking a new borescope system that applied video technology, which would make the inspection process more efficient. The company chose View-A-Pipe® AR from Lenox Instrument Co., a flexible video probe with remote focus.

After struggling with mechanical instruments and eyepieces, a demonstration of the video probe showed Moore it was the equipment that was needed. A 55-deg field of view displays a large area of the pipe's interior, and the pipe's entire interior surface can be displayed.

On one project, Moore inspected more than 6000 ft of pipes. Even though video inspection equipment is notorious for requiring frequent repair, this equipment exhibited durability under adverse

Story based on information from Lenox Instrument Co., Inc., Trevose, Pa.

conditions. This project was constructed outdoors, and the equipment was used in unheated storage trailers in the winter, when the temperature was often well below freezing, and in the summer, when the storage trailers would be hotter than 100°F.

Moore will be assigned to the following phase of last year's project, which will require him to inspect and supervise the welding of more than 12,000 ft of pipes. Again, the construction of the system will be conducted outdoors and will include prefabricated piping in sections as long as 42 ft. "I must inspect every inch of every piece of welding," Moore said.

The video monitor is effective in demonstrating why welding was rejected by citing specific problems with the weld from the monitor image. In addition to being useful in training, this feature also contributes to decisions on whether to repair or replace defective systems.

"We can videotape the results of the inspection and use still images from the screen to document the inspection for comparison with future conditions," Moore said. "This documentation enables us to show the condition of the equipment." ◆

Hardness Testing

Hardness testing gives a relative indication of a metal's strength. The test also can provide information on metallurgical changes caused by welding. For example, a high hardness measurement in the heat-affected zone might indicate an untempered martensite condition, while a low hardness could indicate an overtempered condition.

The test uses an indentor of varying size and shape that is forced into the surface of a material at different loads. Depending on the type of test, either the depth or diameter of the indentation is measured. The most common hardness tests are Brinell, Rockwell and the Vickers or Knoop microhardness — Fig. 1.

The Brinell test (Fig. 2) uses a relatively large indentor. Before the test is started, the surface is ground or sanded to remove scale, rust or paint. There must be sufficient smoothness to accurately measure the indentation. The indentor is then forced into the surface at a prescribed load, and the diameter of the impression is measured with a special graduated magnifier. Depending on the size of the indentor, the diameter of the indentation and the load applied, the results are matched to an appropriate Brinell hardness number (BHN) from a table. For steels, the tensile strength in lb/in.^{2} is approximately 500 times the BHN.

A common indentor is a 10-mm hardened steel ball applied with a 3000-kg load. Other types of indentors are a 5-mm hardened steel ball and a 10-mm tungsten carbide ball. Loads as low as 500 kg might be used on soft metals.

The Rockwell test is similar to the Brinell in the use of indentors of various sizes applied at various loads. The loads are lower, ranging from 60 to 150 kg. Hardened steels balls of 1/16, 1/8, 1/4 and 1/2 in. are used. Based on the expected hardness range of the metal, a scale is chosen. The most common scales used for steels are designated A, B and C. The C scale is for the hardest materials; the B scale is for softer metals and the A scale is chosen when the alloy is unknown. The A scale includes a hardness range covered by both the B and C scale. The test piece is placed on an anvil and secured. The indentor is applied with load and the depth of indentation is then measured from a dial on the machine.

The microhardness test is so named because high magnification is required to read the impression. This test is beneficial to metallurgists since it can give hardness values to microstructure as small as a single grain of metal. Both the Knoop and Vickers, the most common microhardness tests, use diamond indentors. Typically, loads range from 100 to 500 kg (Fig. 3), although loads as low as 1 kg and as high as 1000 kg can be applied. Surface preparation is very important with the microhardness test since even minor irregularities can affect the reading. The test piece must also be tightly secured to ensure the accurate placement of the indentor.

Sometimes microhardness machines with a moving stage are used to place multiple indentations at exact intervals across an area — Fig. 4. The results are referred to as a microhardness traverse.

COMMERCIALLY USED HARDNESS TESTS

TEST	INDENTER	SHAPE OF INDENTATION
Brinell	10-mm sphere of steel or tungsten carbide	
Vickers	Diamond pyramid	
Knoop microhardness	Diamond pyramid	
Rockwell		
A, C, D	Diamond cone	
B, F, G	1/16 in. diameter steel sphere	
E	1/8 in. diameter steel sphere	

Fig. 1 — Types of indenters used with common hardness tests.

Excerpted from *Certification Manual for Welding Inspectors*

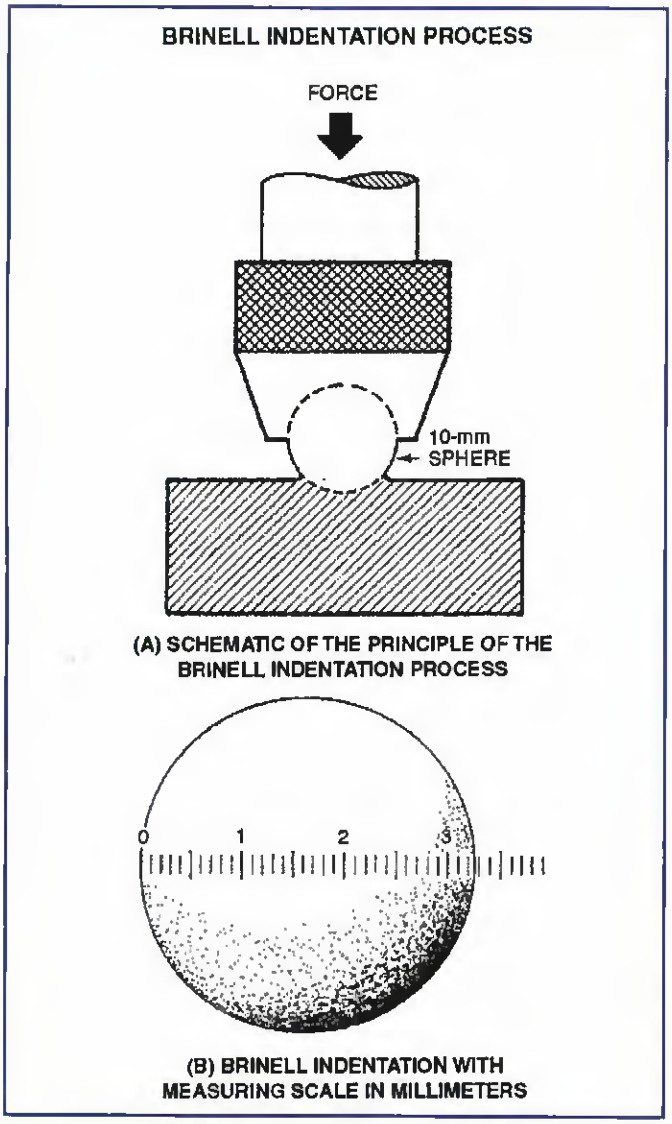


Fig. 2 — Brinell indentation process.

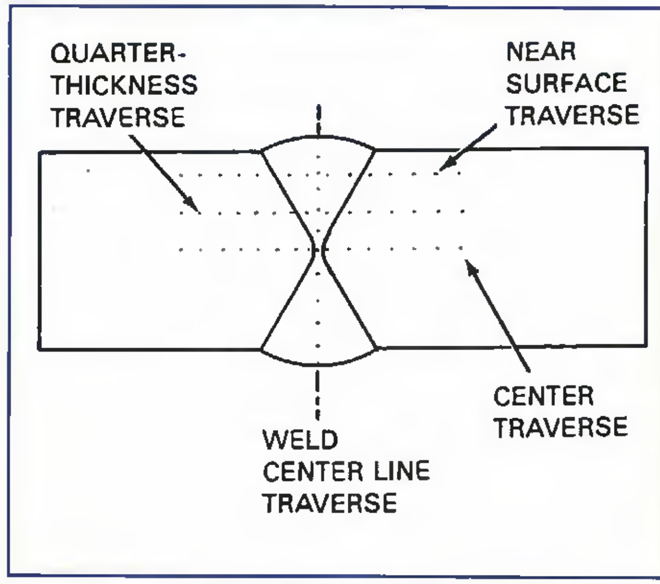


Fig. 4 — Hardness traverses on a double-V groove weld.

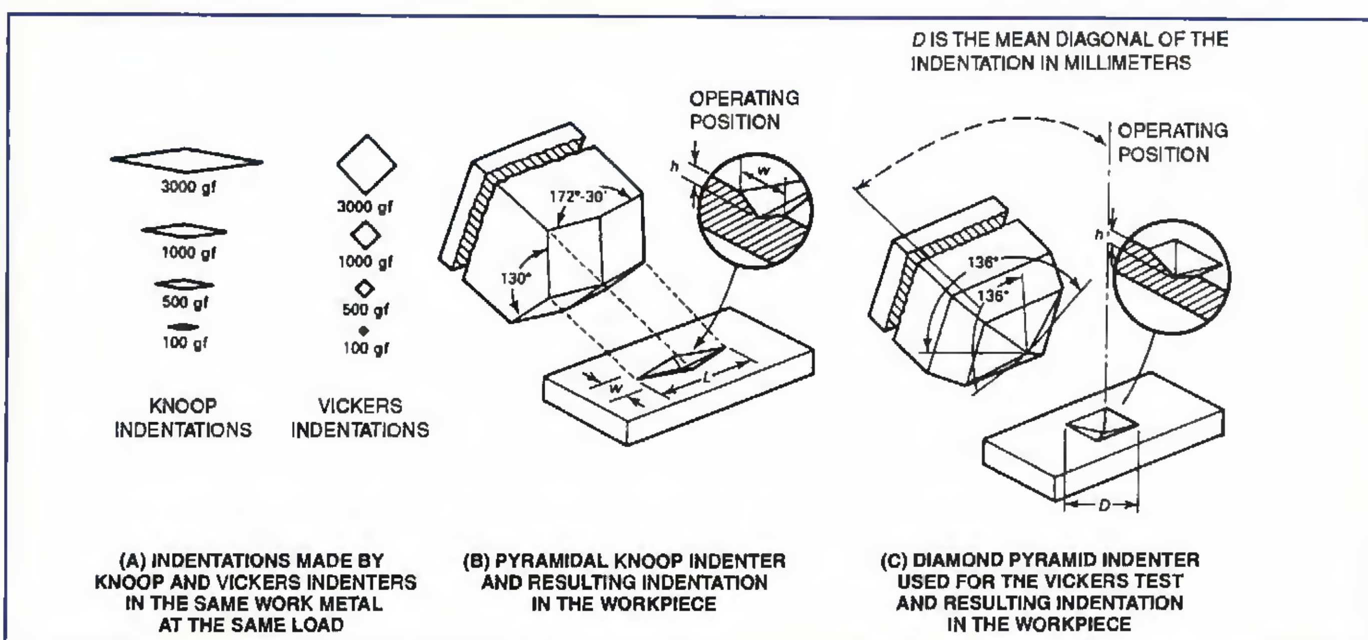


Fig. 3 — Microhardness testing.

Coming Events

Conferences and Exhibitions

NACE Northern Area Eastern Conference. November 5–7, The Sheraton Centre, Toronto, Ont., Canada. Sponsored by NACE International, the Corrosion Society. Contact: Antony Simcoe, conference chairman, (416) 531-3962, e-mail: Simcoe@Sympatico.ca.

◆ **How to Competitively Weld the 21st Century Ship.** November 8–9, Quality Inn Lake Wright Resort and Convention Center, Norfolk, Va. Sponsored by the American Welding Society. Contact: AWS Conference Dept., 550 NW LeJeune Rd., Miami, FL 33126, (800) 443-9353 ext. 223, FAX: (305) 443-1552.

FABTECH International 2000. November 14–16, I-X Center, Cleveland, Ohio. Cosponsored by the Fabricators and Manufacturers Association, International, and the Society of Manufacturing Engineers. Contact: SME Customer Service, One SME Dr., Dearborn, MI 48121, (800) 733-4763 or (313) 271-1500, FAX: (313) 271-2861.

Beijing Essen Welding Fair. November 14–17, Beijing, China. Sponsored by the German Welding Society (DVS) and the Chinese Mechanical Engineering Society. Contact: Messe Essen, Claus-Peter Regiani or Christina Kursawe, +49(0) 201-7244-227, FAX: +49(0) 201-7244-435, e-mail: regiani@messe-essen.de.

ICOMES 2000 — 6th International Conference of Mechanical Engineering Societies. November 18–22, Shanghai, China. Organized by the Chinese Mechanical Engineering Society (CMES). Contact: CMES, 46 Sanlihe Rd., Beijing 100823, P. R. China, 010 68511753, FAX: 010 68533613.

EuroBLECH 2000: 16th International Sheet Metal Working Technology Exposition. December 5–9, Hannover, Germany. Contact: Mack-Brooks Exhibitions Ltd., Forum Place, Hatfield Herts AL10 0RN, U.K., +44 (0)1707 275641, FAX: +44 (0)1707 275544.

◆ **ICAWT 2000, the International Conference on Advances in Welding Technology.** December 7–8, Grosvenor Resort, Orlando, Fla. Sponsored by the American Welding Society. Contact: AWS Conference Dept., 550 NW LeJeune Rd., Miami, FL 33126, (800) 443-9353 ext. 223, FAX: (305) 443-1552.

Second EPRI Corrosion and Degradation Conference. December 11–14, Wyndham's Casa Marina Resort & Beach House,

Note: A diamond (◆) denotes an AWS-sponsored event.

Key West, Fla. Cosponsored by EPRI and NACE. Contact: Brent Lancaster, CCM Conference Manager, EPRI, 1300 W.T. Harris Blvd., Charlotte, NC 28262, (704) 547-6017, FAX: (704) 547-6168.

Orlando 2001 Advanced Productivity Exposition. January 16–18, 2001, Orange County Convention Center, Orlando, Fla. Contact Laura Heidrich, (313) 271-1500 ext. 1853 or e-mail: *heidlau@sme.org*.

◆ **5th Robotic Arc Welding Conference and Exposition.** February 5–6, 2001, Grosvenor Resort, Orlando, Fla. Sponsored by the American Welding Society. Contact: AWS Conference Dept., 550 NW LeJeune Rd., Miami, FL 33126, (800) 443-9353 ext. 223, FAX: (305) 443-1552.

NACE Northern Area Western Conference. February 26–28, 2001, Hilton Hotel, Anchorage, Alaska. Sponsored by NACE International, the Corrosion Society. Contact: Dan Powell, Co-Chairman, (403) 235-6400, e-mail: dan.powell@corrpro.ca.

International Laser Safety Conference. March 5–8, 2001, Catamaran Resort Hotel, San Diego, Calif. Sponsored by the Laser Institute of America. Contact: LIA, 13501 Ingenuity Dr., Ste. 128, Orlando, FL 32826.

NACE International — Corrosion 2001, Conference and Exhibition. March 11–16, 2001, George R. Brown Convention Center, Houston, Tex. Sponsored by NACE International, the Corrosion Society. Contact: NACE Membership Services, (281) 228-6223, FAX: (281) 228-6329, *www.nace.org*.

WESTEC 2001: Advanced Productivity Exposition. March 26–29, 2001, Los Angeles Convention Center, Los Angeles, Calif. Sponsored by the Society of Manufacturing Engineers. Contact: SME Customer Service, One SME Dr., Dearborn, MI 48121, (800) 733-4763, (313) 271-1500, FAX: (313) 271-2861.

Educational Opportunities

Innovative Engineering and Inventive Problem Solving Course. November 6–7, Las Vegas, Nev.: February 26–27, 2001, Orlando, Fla. Conducted by the American Society of Mechanical Engineers. Contact: Shari Romar, Senior Education Specialist, ASME International, Three Park Ave., New York, NY 10016, (212) 591-7902, FAX: (212) 591-7143, romar@asme.org.

Practical Welding Technology Course. November 6–8, Las Vegas, Nev. Conducted by the American Society of Mechanical Engineers. Contact: Shari Romar, Senior Education Specialist, ASME International, Three Park Ave., New York, NY 10016, (212) 591-7902, FAX: (212) 591-7143, e-mail: romars @ asme.org.

Welding of Wire. November 7, Arlington Heights, Ill. Sponsored by the Society of Mechanical Engineers. Contact: SME Customer Service, One SME Dr., Dearborn, MI 48121, (800) 733-4763, FAX: (313) 271-2861.

Fundamentals of Brazing. November 8, Detroit, Mich. Sponsored by the Society of Mechanical Engineers. Contact: SME Customer Service, One SME Dr., Dearborn, MI 48121, (800) 733-4763, FAX: (313) 271-2861.

Educational Opportunities

AWS Schedule — CWI/CWE Prep Courses and Exams

Exam application must be submitted six weeks before exam date. For exam information and application, contact the AWS Certification Dept., (800) 443-9353 ext. 273. For exam prep course information, contact the AWS Education Dept., (800) 443-9353 ext. 229. Dates are subject to change.

Cities	Exam Prep Courses	CWI/CWE Exams
Anchorage, Alaska	EXAM ONLY	March 24, 2001
Atlanta, Ga.	Feb. 26–March 2, 2001 (API 1104 clinic also offered)	March 3, 2001
Beaumont, Tex.	Nov. 13–17 (API 1104 clinic/SCWI also offered)	Nov. 18
Birmingham, Ala.	EXAM ONLY	May 26, 2001
Buffalo, N.Y.	EXAM ONLY	Feb. 17, 2001
Charlotte, N.C.	Feb. 12–16, 2001	Feb. 17, 2001
Chicago, Ill.	EXAM ONLY	Nov. 18
Chicago, Ill.	April 30–May 4, 2001	May 5, 2001
Cleveland, Ohio	Dec. 4–8	Dec. 9
Columbus, Ohio	EXAM ONLY	March 3, 2001
Dallas, Tex.	Jan. 26–Feb. 2, 2001 (API 1104 clinic also offered)	Feb. 3, 2001
Denver, Colo.	Feb. 26–March 2, 2001	March 3, 2001
Des Moines, Iowa	Nov. 6–10	Nov. 11
Fresno, Calif.	EXAM ONLY	Jan. 13, 2001
Gulfport, Miss.	Feb. 19–23, 2001	Feb. 24, 2001
Houston, Tex.	March 5–9, 2001 (API 1104 clinic/SCWI also offered)	March 10, 2001
Knoxville, Tenn.	March 12–16, 2001 (API 1104 clinic also offered)	March 17, 2001
Las Vegas, Nev.	EXAM ONLY	Jan. 13, 2001
Las Vegas, Nev.	April 23–27, 2001	April 28, 2001
Long Beach, Calif.	Nov. 6–10	Nov. 11
Los Angles, Calif.	Jan. 22–26, 2001 (API 1104 clinic also offered)	Jan. 27, 2001
Miami, Fla.	Dec. 4–8	Dec. 9
Miami, Fla.	EXAM ONLY	Jan. 18, 2001
Miami, Fla.	EXAM ONLY	March 15, 2001
Minneapolis, Minn.	March 5–9, 2001	March 10, 2001
Mobile, Ala.	EXAM ONLY	Feb. 17, 2001
Newark, N.J.	EXAM ONLY	Jan. 27, 2001
Newark, N.J.	March 12–16, 2001	March 17, 2001
Oklahoma City, Okla.	Feb. 5–9, 2001	Feb. 10, 2001
Perrysburg, Ohio	EXAM ONLY	March 24, 2001
Portland, Maine	April 2–6, 2001	April 7, 2001
Phoenix, Ariz.	March 19–23, 2001	March 24, 2001
Rochester, N.Y.	Nov. 6–10	Nov. 11
Saint Louis, Mo.	EXAM ONLY	Nov. 4
Salt Lake City, Utah	Jan. 29–Feb. 2, 2001	Feb. 3, 2001
Shreveport, La.	Jan. 22–26, 2001	Jan. 27, 2001
Springfield, Mo.	March 19–23, 2001	March 24, 2001
Tampa, Fla.	Jan. 29–Feb. 2, 2001 (API 1104 clinic also offered)	Feb. 3, 2001
Tulsa, Okla.	EXAM ONLY	March 10, 2001

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I certify that the statements made above are correct and complete:
J. D. Weber, Publisher

New Literature

For more information, circle number on Reader Information Card.

Technical Guide to Aluminum Welding Published

A comprehensive technical guide to aluminum welding describes the effects of alloying elements on aluminum, how physical properties affect welding and the recommended procedures for welding aluminum. Since welding aluminum is so different than welding steel, the guide first goes through some basic metallurgy concepts on alloying elements

and temper designations so welders can find the aluminum base metal most suited to their needs. The guide also provides descriptions and tips for selection of electrodes and filler alloys. The next section of the guide deals with physical properties such as electrical conductivity, contact tip to work distance vs. arc length and causes and cures for weld porosity. How to properly clean the aluminum base material, setting welding parameters and joint geometry are all covered in the "Recommended Procedures" section of the guide. The literature also covers the company's latest technology for welding aluminum — pulsing and waveform manipulation. There is also a troubleshooting section to help correct some of the most common problems associated with aluminum welding such as porosity and weld cracking, among others.

The Lincoln Electric Co. 120
22801 St. Clair Ave., Cleveland, OH 44117-1199

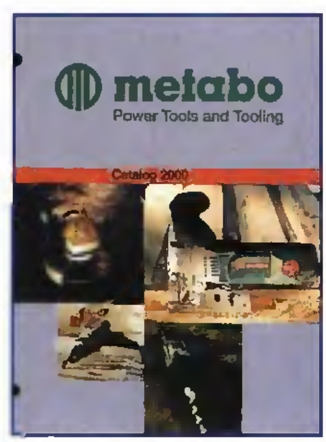
Guide Features Nickel, Cobalt and Their Alloys

The ASM *Specialty Handbook: Nickel, Cobalt, and Their Alloys* is a comprehensive 425-page guide to the compositions, properties, processing, performance and applications of nickel, cobalt and their alloys. The guide includes all the essential information contained in the 20-volume ASM *Handbook* series, as well as new or updated coverage. Included are an expanded corrosion discussion with guidelines for selecting the best alloy; data sheets covering the compositions, specifications, applications and properties for dozens of the most commercially important heat-, corrosion- and wear-resistant nickel and cobalt alloys; recent advances in superalloy development, including coatings to extend high-temperature service life; unique characteristics of nickel and cobalt that allow them to be used in specific purpose applications, *e.g.*, magnets, controlled-expansion devices, electronics and implants for the human body; and engineering applications for nickel and cobalt coatings produced by electroplating, electroforming, electroless coating, thermal spraying and weld surfacing. Prepublication price (through Nov. 30) for the ASM *Specialty Handbook: Nickel, Cobalt, and Their Alloys* is $151 for ASM members; $188 for nonmembers. After Nov. 30, $164 for members; $204 for nonmembers.

ASM International
Materials Park, OH 44073-0002

Catalog Showcases Power Tools and Tooling Products

The company showcases its complete line of portable electric tools for various industrial, construction and welding applications. Highlighted are several of the company's newest product lines including cordless drill/drivers and variable



speed jigsaws with orbital action. Also available is the company's tooling line, which features a wide variety of concrete bits, wood bits and bimetal saw blades to meet the needs of a range of applications.

Metabo Corp. 121
P.O. Box 2287, West Chester, PA 19380

Brochure Highlights Aluminum Rail Crane System

A brochure showing typical applications for a new aluminum enclosed rail

workstation crane is available. The company's systems are designed for low operator effort and precise load control. A variety of lifting devices can be fitted with an end effector for nearly any application. Components from other manufacturers can often be incorporated into the company's products. Products include extruded aluminum rail in four sizes.

EMH MovoMech Systems 122
550 Crane Dr., Valley City, OH 44280

Revised Laser Safety Standard Available

The revised ANSI Z136.1 (2000) *American National Standard for Safe Use of Lasers* has been published. The parent document and cornerstone of the Z136 series of laser safety standards, ANSI Z136.1 is the foundation of laser safety programs for industrial, military, medical and educational applications worldwide. The standard provides complete information on laser classifications, hazards, analysis and control measures needed for the development of a comprehensive laser program. Since the last revision in 1993, new developments in laser devices and applications have prompted research into the associated bio-effects. To incorporate these new findings, ANSI Z136.1 was revised. The revisions include the methods by which hazards evaluation and laser classifications are calculated for ocular exposure of small (intrabeam) viewing and extended source viewing, new tables on Maximum Permissible Exposures and changes in the design of warning signs. In addition, the "Control Measures" section specifically treats the safety issues associated with laser pointers and provides guidance for the safe use of these products. ANSI Z136.1 (2000) is priced at $70 for LIA members; $90 for nonmembers.

Laser Institute of America
13501 Ingenuity Dr., Ste. 128
Orlando, FL 32826

CD-ROM Gives Overview of Welding, Plasma Arc Cutting

The company's training systems has added an interactive CD-ROM to its popular series of training modules for welders: *Introduction to Welding*. The CD-ROM provides an overview of the basics of shielded metal arc welding, gas tungsten arc welding, gas metal arc welding and plasma arc cutting processes. The *Introduction* explains how each process works, discusses its advantages, applications, components and operator controls.

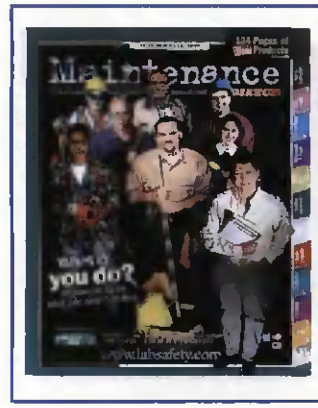
Live-arc videos and graphics illustrate concepts, while a glossary defines terms from arc blow to weld pool. Also available in the training series are *MIG Fun-*

damentals and *TIG Fundamentals*. Each CD-ROM in the series teaches in-depth process theory, applications and electrical theory. The CD-ROMs deliver training at a much lower cost compared to sending an employee to a remote workshop, and the interactivity delivers a higher level of learning than traditional techniques such as reading a textbook or sitting through a lecture. The cost of each CD-ROM training module is $29.95.

Miller Electric Mfg. Co.
1635 W. Spencer St., Appleton, WI 54912-1079

Maintenance Safety Catalog Offers Wide Array of Products

This 1232-page catalog offers a one-stop shop for virtually all maintenance-related professionals. The catalog contains a large selection of tools, ventilation products, industrial storage products, instrumentation, grounds maintenance supplies and more. Also included are 124 pages of new items with a full selection of valves, fittings and hoses for many different applications. Expanded product areas include hand tools, security hardware, electrical supplies and lighting.



Lab Safety Supply Inc. 123
P.O. Box 1368, Janesville, WI 53547-1368

Building and Construction Brochure Promotes Aluminum

This brochure for architects, developers, builders and contractors highlights aluminum as the material of choice for building and construction projects. The brochure includes detailed color photographs of several buildings that feature aluminum building or roofing components. Also included is information on aluminum wall cladding, which is ideal for recladding older structures and provides contemporary design options for many types of new buildings.

The Aluminum Assoc. 124
900 19th St., NW, Washington, DC 20006

NEW PRODUCTS

– *continued from page 30*

Palm-Held Gas Analyzer Performs Combustion Analysis, Emissions Monitoring

The UniGas 3000 is a compact, palm-held flue gas analyzer that permits combustion analysis, boiler tuning,

emissions monitoring and auxiliary tests and inspections. Two electrochemical sensors read the oxygen and carbon monoxide concentrations. Natural gas, LPG, gasoil and kerosene are the four most common fuels to be measured. A third sensor is used to measure the pollutants NO, NO^2 or SO^2, as required. Additional external probes allow the user to make ambient parameter measurements of room temperature and relative humidity, ambient CO safety checks and CH^4 analysis for leak detection.

TTI, Inc. 130
8 Leroy Rd., Box 1073, Williston, VT 05495

Improved GMAW Machine Offers Quick-Disconnect Feaure

Improvements have been made to the Fabricator® 130, and the Fabricator 180 has been introduced to

the company's line of GMAW packages that include built-in wire feeders. The improved Fabricator 130 now includes a quick-disconnect feature, as well as convenient cleaning of the torch and replacement of liner. This single-phase unit has a weld output of 30–130 A. The Fabricator 180 includes all the same features of the Fabricator 130, only with more power. This lightweight, portable unit runs on 230 V with an output range of 40–180 A.

Thermal Arc, A Thermadyne Co. 131
101 S. Hanley Rd., St. Louis, MO 63105

Welding Magnets Increase Speed and Efficiency

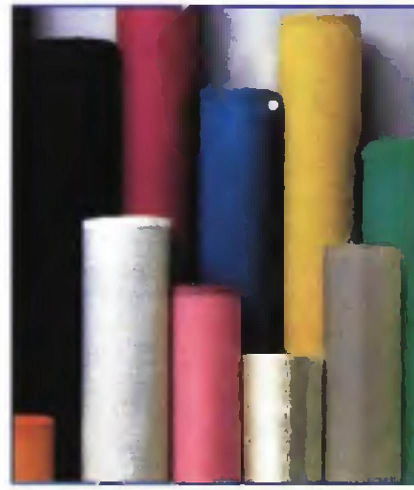
Three new magnetic products have been developed to increase operator speed and efficiency in welding operations, and eliminate the need for clamps and blocking methods during

the welding process. The Welder's Square has fast setup and accurate holding of ferrous sheet stock or tubing; the Welder's Magnetic Ground is a powerful magnet that attaches the operator's ground cable to the ferrous work surface; and the 90° Welding Square uses powerful magnets to hold steel when performing both 90-deg interior and exterior welds.

Mag-Mate Div. of Industrial Magnets, Inc. 132
P.O. Box 80, 1240 M-75 South, Boyne City, MI 49712

Line of Welding Fabrics Expanded

A full line of coated and uncoated welding fabrics is offered for a variety of high-temperature applications. Zetex Salmon is a lightweight 15-oz fabric in 38 and 60-in. widths. Z-Sil silica fabrics are available in weights of 18, 34 and 36 oz. Z-Pro and Z-Shield are coated fabrics designed for tough welding application, and are available in 40, 60

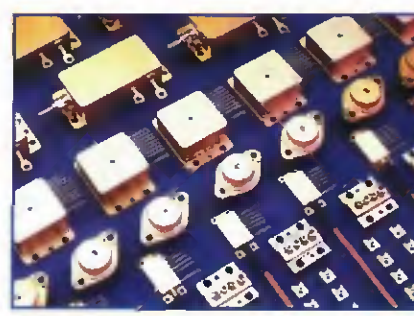


and 72 in. widths. Uncoated fabrics, with weights from 18 to 100 oz., can provide welding spark protection.

NewTex Industries, Inc. 133
8050 Victor-Mendon Rd., Victor, NY 14564

Laser Diodes for the Medical and Industrial Markets

These high-power laser diodes come in the 980-nm wavelength range. Consisting of 30-W bars and 25-W fiber array packages (FAP™), the laser family is suited for, along with other applications, direct-diode thermal applications that target the medical and industrial markets. The devices can be used on the company's microprocessor-controlled FAP-System™. Using the FAP device as its engine, the system allows users to swap



out laser diodes at different wavelengths to support a variety of applications. The system gives the user control of the operating temperature and current of the laser diode, as well as its mode of operation — cw, single shot or multishot. The system works with a front-panel user interface or a computer-controlled RS-232 interface.

Coherent, Inc. 134
5100 Patrick Henry Dr., Santa Clara, CA 95056

SOCIETY NEWS

By Susan Campbell

♦ AWS Foundation National Scholarship Applications Due in January

The AWS Foundation was established by the American Welding Society in 1989 to support programs that ensure the growth and development of the welding industry through strengthening research and educational opportunities in welding and related industries.

From giving children their first glimmer of excitement in learning about the natural sciences to providing funding for welding engineering undergraduates and fellowships for welding research, the AWS Foundation supports the welding industry.

The AWS Foundation has expanded its National Scholarship Program, which now includes nine individual scholarships each worth a minimum of $2500 annually. These scholarships are for students pursuing a welding engineering or engineering technology degree at an accredited four-year college or university. To take advantage of this program, students must plan now for the 2001–2002 school year. Professors and instructors at vocational schools, technical colleges, community colleges and universities are encouraged to share this valuable information with their staff and students. The deadline for applying is January 15, 2001.

Below is a list of the available national scholarships and a description of the requirements.

Howard E. Adkins Memorial Scholarship

This $2500 annual scholarship is awarded to a full-time junior- or senior-level student pursuing a minimum four-year bachelor's degree in welding engineering or welding engineering technology. Applicants must have a 3.2 or better GPA in technical subjects with a 2.8 overall GPA. Financial need is not required to qualify.

Roman F. and Lillian E. Arnoldy Scholarship

Full-time, undergraduate students enrolled in a welding-related program at an accredited four-year university may apply for this $2500 annual scholarship. Applicants must have a minimum 2.0 GPA and must be employed at least eight hours a week and/or participate in a university work/study program.

AWS Foundation, Inc.

A Foundation of the American Welding Society

Edward J. Brady Scholarship

Undergraduate students pursuing a minimum four-year bachelor's degree in welding engineering or welding engineering technology may apply for this $2500 annual scholarship. Applicants are required to have a minimum 2.5 overall GPA, provide a letter of reference indicating previous hands-on welding experience and complete an essay titled "Why I Want to Pursue a Career in Welding." Proof of financial need is a requirement for qualification.

Donald F. Hastings Scholarship

This $3000 annual scholarship is awarded to an undergraduate student pursuing a minimum four-year bachelor's degree in welding engineering or engineering welding technology. Applicants must have a minimum 2.5 overall GPA, and proof of financial need is required to qualify.

William B. Howell Memorial Scholarship

A $2500 annual scholarship, this scholarship is awarded to a full-time undergraduate student pursuing a minimum four-year degree in a welding program at an accredited university. Applicants must maintain a minimum 2.5 overall GPA, and proof of financial need is required to qualify.

John C. Lincoln Memorial Scholarship

An undergraduate student pursuing a minimum four-year bachelor's degree in welding engineering or welding engineering technology will be awarded this $2500 annual scholarship. Applicants must have a minimum 2.5 overall grade point average, and proof of financial need is required to qualify.

— continued on next page

AWS Foundation Scholarships

The Airgas-Terry Jarvis Memorial Scholarship

This $2500 annual scholarship is awarded to a full-time undergraduate pursuing a minimum four-year bachelor's degree in welding engineering or welding engineering technology. Applicants must have a minimum 2.8 overall GPA with a 3.0 GPA in engineering courses. Financial need is not required to qualify.

James A. Turner Jr. Scholarship

This $3000 annual scholarship is awarded to a student pursuing a minimum four-year bachelor of business degree, leading to a management career in welding store operations or a welding distributorship. Applicants must have at least a high school diploma and be employed by a welding store or distributorship a minimum of ten hours a week. Financial need is not a qualification requirement.

Praxair International Scholarship

This $2500 annual scholarship is awarded to an undergraduate student pursuing a minimum four-year bachelor's degree in welding engineering or welding engineering technology. Applicants must have a minimum 2.5 overall GPA, and proof of financial need is required to qualify.

The deadline for the National Scholarships is January 15, 2001, for the 2001-2002 academic year.

For a complete application package detailing eligibility requirements and other information, please check the Foundation Web site *www.aws.org* and click on "Foundation" or call the AWS Foundation office at (800) 443-9353 ext. 461.

The AWS International Scholarship Program

The purpose of the AWS International Scholarship Program is to provide financial assistance to international students wishing to pursue their education in welding and related joining technologies who are not assigned to an AWS section.

Eligibility Overview

International Scholarships are awarded to full-time international students pursuing a minimum of a bachelor's degree or equivalent in welding or a related field of study. Students must be in the top 20% of the institution's grading system and must provide proof of country citizenship. Applicants are encouraged to be an AWS member and financial need may be a deciding factor.

Eligibility Requirements

All applicants must meet the following eligibility requirements:

♦ Applicant must have completed at least one year of welding or related field of study at a Baccalaureate degree-granting institution.

♦ Student must be enrolled full time.

♦ Official proof of acceptance from the academic institution.

♦ Proof of country citizenship.

♦ Applicant must submit all required application information.

♦ Applicants may reapply; however, persons who have received this award may reapply and may be granted the award for a maximum of four times.

♦ Financial information regarding tuition and fees from the academic institution must be included with each application.

Submission

Deadline for submission of all application information is April 1, established by the postmark, for the following fall academic term.

Application Process

Students must submit all requested application information, in English, including the following:

♦ The International Scholarship Application Form.

♦ Copy of the proposed curriculum.

♦ Verification of enrollment by institution.

♦. Two letters of personal reference.

♦ Two-page Professional Goal Statement, including a brief biography.

♦ Grade transcript or equivalent from each college, university and/or trade/technical school listed on the application.

♦ AWS membership number, if member.

♦ Proof of country citizenship.

♦ Financial information regarding tuition and fees from the academic institution.

Awards

Scholarship funds are for tuition and fee expenses only, not to exceed $1000 (U.S. dollars/year.)

All funds are transferred, *e.g.*, wired/mailed, to the appropriate institution in U.S. currency. Any unused funds are required to be returned. No awards will be paid directly to the recipient.

International students remain eligible to apply for AWS District Scholarships, if attending an academic institution in the United States.

Applicants may reapply; however, persons who have received this award may reapply and be granted the award for a maximum of four years.

For further information on the AWS Foundation International Scholarships, visit the AWS Web site at *www.aws.org* and click on "Foundation" or call the AWS Foundation office at (800) 443-9353 ext. 461.

Other Available Funding

While reviewing the National and International scholarships, be sure to also check into AWS Section and District scholarships, the AWS Student Loan Program and the AWS Fellowship Program.

To receive a scholarship application or to further discuss AWS Foundation offerings with a Foundation representative, contact the AWS Foundation, 550 N.W. LeJeune Rd., Miami, FL 33126, telephone (800) 443-9353 ext. 461 or 576, or (305) 445-6628 outside the continental United State, FAX (305) 443-7559, e-mail found@aws.org.♦

♦ Volunteers Needed for the B4 Committee on Mechanical Testing of Welds

The American Welding Society (AWS) is looking for volunteers to serve on the Committee on Mechanical Testing of Welds.

The Committee is beginning the revision of AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. Experts in bend, tensile and toughness testing, as well as users of various weldability tests, are encouraged to participate. Members will participate in the revision of current test methods as well as the inclusion of new tests for weldability. In addition, the Committee will work to review and comment on international standards on the testing of welds.

If you are interested in participating in this work, please submit your application on the AWS Web site at *www.aws.org*, or contact the B4 Committee Secretary, Chris Pollock, at (800) 443-9353 ext. 304, or via e-mail at cpollock@aws.org. ♦

♦ Submit Your Technical Committee Reports

Committee Chairmen — We want to recognize the efforts of your committee and inform our readers of its accomplishments. Send a brief profile of its activities and recent accomplishments, along with a member roster and contact numbers, and we will publish it in the *Welding Journal*'s Society News section.

Send your submissions to

Susan Campbell, Assistant Editor
American Welding Society
550 N.W. LeJeune Rd.
Miami, FL 33126
Telephone, (305) 443-9353 ext. 244,
FAX: (305) 443-7404
e-mail: campbell@aws.org ♦

♦ CWI Test Held in Shanghai

Today, Shanghai is the commercial heart of China. It is a city situated on the country's central coastline and serves as a gateway to the fertile Yangtze River Valley. This city offers an unparalleled fusion of grand boulevards and old-world ways.

Shanghai has undergone one of the fastest economic expansions the world has ever seen. Inquiries in the American Welding Society's (AWS) Certified welding Inspector (CWI) program from Shanghai are suddenly becoming an almost weekly event. Nevertheless, the conducting of a CWI program in Shanghai last June was a difficult challenge. It was a challenge, however, that was successfully completed with the enthusiastic support of many individuals and the companies that sent their engineers to take part in this unprecedented program.

Although a cloud of uncertainty hangs over the international politics, the International Welding Technology Research Laboratory (IWTRL) in Taiwan, an official representative of AWS on certification programs in China, Taiwan and Korea, was determined to go ahead with the CWI program before the U.S. Senate rectifies China's permanent trade status and before China enters the World Trade Organization (WTO).

Training for the AWS CWI-Shanghai program was held from June 12 through 16. The CWI examination was given following the training course on June 17. Fourteen students participated in the training program and seventeen candidates took the test. Companies participating in the program included Shanghai Zhen Hua Port Machinery Co., Ltd.; Guangzhou Trust Steel Structure Co., Ltd.; Hudong Shipbuilding (Group) Co., Ltd.; Butler (Shanghai), Inc.; Shanghai CASCD-Kawasaki Heavy Industries Steel Structure Co., Ltd.; Deltak Co., Ltd.; and Moody International (test only).

The CWI-Shanghai program first seemed unthinkable due to great cultural differences and governmental regulations. However, through sheer determination, Yeh-Mei "May" Chen of IWTRL and Jason Tsai, vice president of Shanghai General Pneumatic Equipment Co., Ltd., took care of and paid close attention to each step toward the success of the program. This CWI-Shanghai program would not have been possible without the diligent and persistent hard work of these two dedicated individuals.

Credit must also be granted to Robert Kuo, executive vice president of Shanghai General Pneumatic Equipment Co., Ltd., for volunteering his staff for administrative support during the planning and program execution period. Qiangguo Tang, deputy general manager of Shanghai Zhen Hua Port Machinery Co., Ltd., lent his support to the logistic matters and thus saved the program substantial costs. Tang also provided valuable support that facilitated the training and test activities at the company's training facilities.

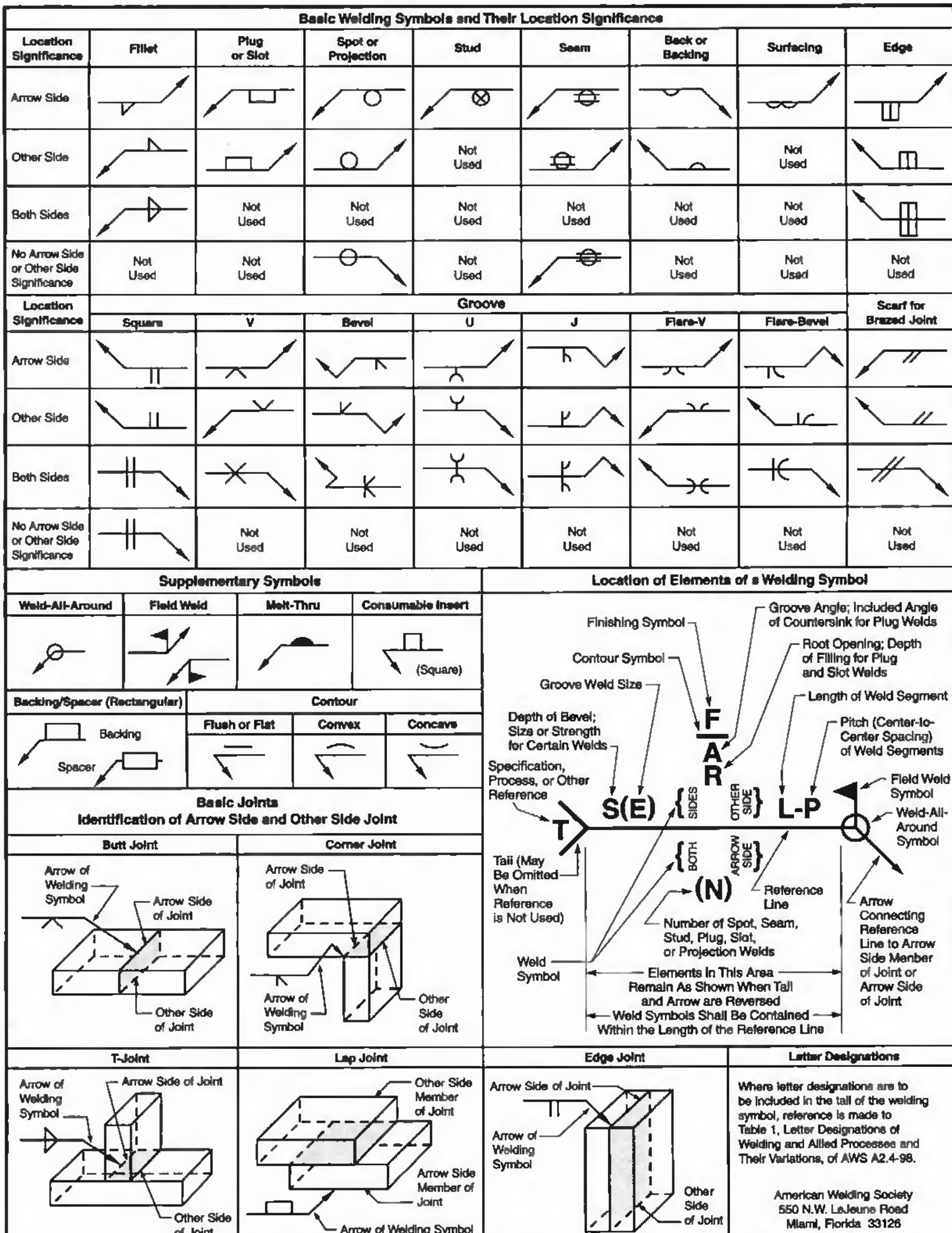
Special thanks must also be extended to the Shanghai Welding Association for cosponsoring the CWI-Shanghai program. Without the enthusiastic support of President Gen-Lin Jiang, Vice President I-Ming Tang, Vice Secretary-General Yu-Chuan Chen and Engineer You-Liang Hwang, the program would not have succeeded.

The official flower of Shanghai is the white magnolia, which has large, white petals and an eye that always looks toward the sky. This flower is the perfect symbol for the pioneering and enterprising spirit of the city. All indications are that the AWS CWI program will flourish in Shanghai and look toward other provinces and cities in China for even greater success in the future. ♦ — *Chon L. Tsai, professor, The Ohio State University, and director of the International Welding Technology Research Laboratory.*

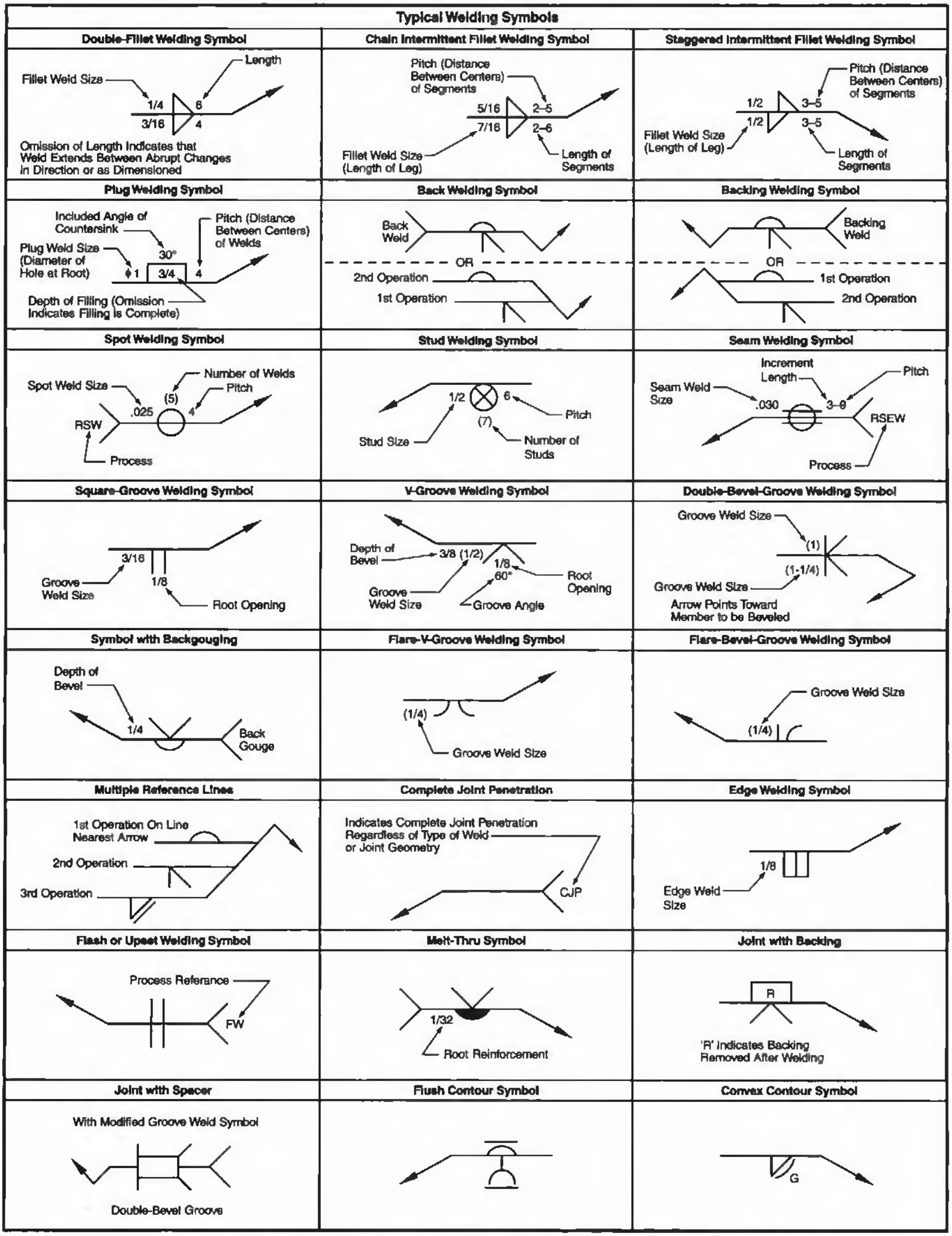
♦ Technical Topics

Errata For AWS A2.4, *Standard Symbols for Welding, Brazing and Nondestructive Examination.*

The following is the corrected Welding Symbol Chart for AWS A2.4, pages 106 and 107.♦



It should be understood that these charts are intended only as shop aids. The only complete and official presentation of the



standard welding symbol is in AWS A2.4-89, *Standard Symbols for Welding, Brazing and Nondestructive Examination.*

♦ Sustaining Company Member Dues Update

Effective June 1, 2000, the following adjustments have been implemented for AWS Sustaining Company Members:

Dues: The annual dues are $750, domestic; $850, international; plus a $500 initiation fee.

Benefits: The enhanced AWS Sustaining Company Member benefits package includes one of the following primary offerings: 1) the **complete library of AWS publications** ($5600 value), including 130+ specifications, with complimentary publication updates included; or 2) a **discount promotional package**, including a 5% discount on ads in the *Welding Journal* and a $4-per-sq-ft discount on booth space at the AWS/PMA Show; or 3) **ten *additional* AWS Individual Memberships** for company employees or customers.

In addition, AWS Sustaining Company Members enjoy the following:

♦ Ten free Individual Memberships for company employees or customers.

♦ Publicity of the company's name and product/service offerings in the *Welding Journal* and on the AWS Web site.

♦ Company recognition at the annual AWS/PMA Show.

♦ Usage of the AWS Sustaining Company Member logo on company letterhead and promotional material.

♦ AWS Sustaining Company engraved wall plaque.

♦ Free hyperlink from the AWS Web site to the member company's site.

For information on becoming an AWS Sustaining Company Member, contact the AWS Membership Dept. at (800) 443-9353 ext. 418, FAX (305) 443-5647 or write AWS, 550 N.W. LeJeune Rd., Miami, FL 33126. ♦

♦ Everything You Need to Know About GMAW

The American Welding Society (AWS) and Edison Welding Institute (EWI) have partnered to present a unique conference opportunity for welding professionals — Gas Metal Arc Welding (GMAW) for the 21st Century.

To be held December 6–8 at the Grosvenor Resort Hotel in Orlando, Fla., this conference will cover a wide variety of GMAW topics, including power supplies, process controls, cored wire welding and fume generation. Since GMAW is used in so many industries, this conference offers something for every welding professional.

Gas Metal Arc Welding for the 21st Century will be chaired by David Yapp, who has more than 25 years of welding experience. The conference will also feature sessions by experts from Miller Electric Mfg. Co., EWI, Panasonic Factory Automation, The Ohio State University and many more.

The conference registration fee is $660; $585 for AWS members. Registration for the conference is available by calling the AWS Conference Department at (800) 334-9353 ext. 449, (305) 443-9353 ext. 449 outside the United States or on the AWS Web site at *www.aws.org*. Hotel reservations can be made by contacting the hotel directly at (407) 828-444 and requesting the conference rate. A special exhibitors rate of $750 is also available. Contact the AWS Conference Dept. for details. ♦

AWS WELCOMES NEW SUPPORTING COMPANIES

New Supporting Companies

Precision Weld Company
1262 Lyell Avenue
Rochester, NY 14606

New Educational Institutions

Mountain Empire
Community College
P.O. Drawer 700
Big Stone Gap, VA 24219

♦ Member Dues Adjustment

The AWS Board of Directors, acting on the recommendations made by the Membership Committee, approved a dues adjustment to $75 for the "Regular Member" classification effective June 1, 2000.

Upon joining, and every third membership year, Regular Members dues will include an expanded publication choice of either the latest *Welding Handbook, Welding Metallurgy, Jefferson's Welding Encyclopedia, Soldering Handbook* or the *Design and Planning Manual for Cost-Effective Welding* upon request. In addition, AWS members receive a monthly subscription to the award-winning *Welding Journal*, as well as bimonthly issues of *The American Welder* supplement. AWS-certified personnel also receive quarterly issues of *Inspection Trends* magazine.

AWS members enjoy access to widely respected technical information in the materials-joining industry at discounted rates. Members-only discounts apply to AWS technical publications, as well as top-notch certifications, conferences and other educational offerings. Members also benefit from networking opportunities at local Section meetings and at the AWS/PMS Show. AWS members can choose between two value-added membership package offerings — the Gold and the Platinum membership packages — for modest fees. And, in the near future, AWS members will enjoy members-only access to special information and services on the AWS Web site, *www.aws.org*. ♦

SAFETY AND HEALTH

T O P I C S

♦ Confined Spaces

Fact Sheet No. 11

Introduction/Definition

Many different places require welding, cutting and heating work. Some of these places lack room and become "confined spaces." Confined spaces have the following characteristics:

♦ Limited space, entry or exit.

♦ Poor ventilation — lack of safe breathing air and possible buildup of hazardous gases, fumes and particles.

Examples of Confined Spaces

♦ Small rooms
♦ Process vessels
♦ Pits
♦ Tunnels
♦ Vats
♦ Reactor vessels
♦ Unventilated corners of a room
♦ Underground utility vaults
♦ Furnaces
♦ Storage tanks
♦ Pipelines
♦ Sewers
♦ Silos
♦ Degreasers
♦ Boilers
♦ Ventilation and exhaust ducts
♦ Ship compartments

Reasons for Deaths and Serious Injuries from Welding in Confined Spaces

♦ Fire
♦ Explosion
♦ Electric Shock
♦ Asphyxiation
♦ Exposure to hazardous air contaminants

Actions Required before Approving Start of Work in a Confined Space

♦ Open all covers and secure them from closing.

♦ Test confined space atmosphere for 1) suitable oxygen content, 2) no combustibles or reactives and 3) no toxics. *Note: The testing requires special equipment and training.*

♦ Isolate lines by capping or double valving and venting, if feasible. Keep vents open and valves leak-free.

♦ Lock out all systems not required during welding, cutting or heating.

♦ Provide means for readily turning off power, gas and other supplies from outside the confined space.

♦ Protect or remove any hazardous materials or materials that may become a physical or health risk when heated or exposed to an arc.

Required Actions during Work in a Confined Space

♦ Continuously ventilate and monitor confined space to ensure fumes and gases do not exceed safe exposure limits as found in Occupational Safety and Health Administration (OSHA) regulations Title 29, CFR Part 1910, 1000.

♦ Use National Institute for Occupational Safety and Health (NIOSH)/Mine Safety and Health Administration (MSHA) approved breathing devices when required by code, instruction or good practice.

♦ Keep unnecessary persons and equipment out of and away from the confined space.

♦ Do not allow equipment to block exits or possible rescue efforts.

♦ Place as much equipment as possible outside the confined space.

♦ Do not go into a confined space unless a watchperson, properly equipped and trained for rescue, is outside and maintaining continuous communications with workers inside.

♦ Provide means for turning off power, gases and fuel from inside the confined space, if possible, especially if outside turn-off means are not provided, feasible or certain.

Information Sources

National Institute for Occupational Safety and Health. *Criteria for a Recommended Standard — Working in Confined Spaces.* NOISH Publication No. 80-106. National Institute for Occupational Safety and Health, Cincinnati, Ohio.

Occupational Safety and Health Administration (OSHA). *Code of Federal Regulations*, Title 29 Labor, Chapter XVII, Parts 1901.1 to 1910.1450, Order No. 869-019-00111-5, Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

DeReamer, R. *Modern Safety and Health Technology*. John Wiley & Sons, New York, N.Y.

American National Standards Institute (ANSI). *Safety Requirements for Working in Tanks and Other Confined Spaces*, ANSI Z117.1. American National Standards Institute, 11 W. 42nd St., New York, NY 10036.

Mine Safety and Health Administration (MSHA). *Code of Federal Regulations*, Title 30 Mineral Resources, Parts 1-199. Superintendent of Documents, U.S. Government Printing Office, Washington DC 20402.♦

The Safety and Health Fact Sheets, *2nd ed., cover all aspects of safety and health applicable to welding and cutting. The* Fact Sheets *include 20 pages on subjects such as fumes and gases, radiation, noise and electrical hazards. Compiled in 1998. Price for AWS members is $27; nonmembers, $36. Copies of* Safety and Health Fact Sheets *can be ordered by calling AWS Publication Sales at (800) 334-9353, or (305) 443-9353 ext. 280 outside the United States, Monday through Friday, 8 a.m. to 5 p.m. Eastern Standard Time.*

SECTION NEWS

Posing with York-Central Pennsylvania Section members that attended the Section's Annual Golf outing are, left, Past President Shirley Bollinger, and, right, District 3 Director Claudia Bottenfield.

Boston Section outgoing Chairman Jim Reid, left, accepting a plaque of appreciation from incoming Chairman Glenn Myrick.

District 3 Director Claudia Bottenfield, right, with Maryland Section Chairman Dennis McCartney and AWS Past President Shirley Bollinger.

DISTRICT 1

Director: Geoffrey H. Putnam
Phone: (802) 439-5916

♦ **BOSTON**
AUGUST 28
Activity: Incoming Chairman **Glenn Myrick** presented a plaque of appreciation to outgoing Chairman **Jim Reid**.

DISTRICT 2

Director: Alfred F. Fleury
Phone: (732) 868-0768

♦ **DELAWARE**
SPEPTEMBER 20
Speakers: **Steve Shupe**, plant team leader, and **Jim Zakreski**, Human Resources/safety.
Affiliation: Cylinder Safety.
Activity: The Section toured the filling area, where emphasis was placed on safely filling cylinders.

DISTRICT 3

Director: Claudia Bottenfield
Phone: (717) 397-1312

♦ **MARYLAND**
AUGUST 10
Activity: Twenty-one members attended the Section's reorganization meeting. New Section officers were elected at the meeting, and **Ken Ellis** received the District Director's Award from District 3 Director **Claudia Bottenfield**.

♦ **YORK-CENTRAL PENNSYLVANIA**
AUGUST 18
Activity: The Section held its Annual Golf Outing at Cool Creek Country Club. Officers were elected for the 2000–2001 term.

DISTRICT 5

Director: Boris A. Bernstein
Phone: (787) 883-8383

♦ **SOUTH FLORIDA**
SEPTEMBER 14
Activity: The Section toured the Pipe Welders facility. Pipe Welders builds tuna towers for the South Florida charter and pleasure boat industries.

DISTRICT 11

Director: Scott C. Chapple
Phone: (913) 241-7242

♦ **NORTHERN MICHIGAN**
MAY 25
Activity: Spouse's Night was held along with a tribute to **Clyde "Art" Hedges**, who has been an AWS member for 54 years and a member of the Northern Michigan Section for 27 years. District 11 Director **Scott Chapple** attended the event.

♦ **DETROIT**
SEPTEMBER 14
Speakers: **James Ward**, **Aaron Hauschildt**, **Richarld Carlson** and **Eric Urbas**.
Affiliations: General Motors Corp, Ford Motor,Co., General Motors Corp. and Ford Motor Co., respectively.
Topic: Life (Work!) — the transformation to profitability.
Activity: The Section awarded $30,500 in academic scholarships to 15 outstanding students at Ferris State University and Washtenau Community College. **Wesley Doneth** of Ferris State was awarded the James W. Mitchell Scholarship and **Jeremy Purmala**, also a student at Ferris State, was awarded the Robert L. Wilcox Scholarship. The Section awarded more than $5300 in scholarships to the top finalists in the 2000 Detroit Area High School Welding Contest. Scholarship winners included **Jeff Albrecht**, **Joel Diller**, **Andrew Dake**, **Jerome Meldrum**, **Bill England**, **Jared Medler**, **Chris Soule**, **Chad Schondelmayer**, **Troy Bittner**, **Chris Knaffle**, **Keven Fleming** and **Kyle Dockery**.

Northern Michigan Section Chairman Scott Sinkule, right center, presenting Clyde "Art" Hedges, left center, with an award to honor his 54 years as an AWS member. Looking on are Publicity Chairman Bill Nell, far left, and District 11 Director Scott Chapple, far right.

Puget Sound Section member Chuck Daily, right, accepting the Outstanding Contributions Award from Section Chairman Ken Johnson.

DISTRICT 12

Director: Michael D. Kersey
Phone: (262) 650-9364

♦ **FOX VALLEY**

JANUARY 4 AND 5

Activity: The Section sponsored a two-day seminar on ASME Section IX. **Scot T. Forbes**, president of Tech Aid, was instructor of the seminar. The seminar included writing adequate and understandable Welding Procedure Specifications; reviews of the common manual, semiautomatic and automatic welding processes; how filler metals are addressed by the Code; planning, preparing, conducting and documenting procedure qualification tests; an overview of changes to ASME Section IX; basic steel metallurgy as addressed by the Code; and much more.

OCTOBER 7

Speaker: **Scot T. Forbes**, president.
Affiliation: Tech Aid.
Topic: Weld failures, bloopers and blunders.

DISTRICT 18

Director: J. M. Appledorn
Phone: (281) 847-9444

♦ **SAN ANTONIO**

AUGUST 19

Activity: The Section held its Annual AWS Picnic at Braun Hall in San Antonio. District 18 Director **Jim Appledorn** was on hand to present AWS Meritorious Service Awards to **Al Marin** and **Lawrence Schenk**. In addition, **Frances Guerrero** received the District Educator of the Year Award and **John Mendoza** received the District level Dalton E. Hamilton Memorial CWI of the Year Award. The Section extends special thanks to its many sponsors who contributed prizes and to the volunteers who worked long and hard.

Puget Sound Section Chairman Ken Johnson and his wife, Joan, at the dinner they hosted for 11 of the Section's board members.

DISTRICT 19

Director: Philip F. Zammit
Phone: (509) 468-2310 ext. 120

♦ **PUGET SOUND**

JULY 22

Activity: Chairman **Ken Johnson** and his wife, **Joan**, hosted a dinner at their home in Bellevue, Wash., for 11 board members. Quality Control Manager and CWI **Mike Slye** and Shop Superintendent **Brad Holm** of Graham Steel Corp. accepted a Certificate of Honor on behalf of the company.

SEPTEMBER 7

Speaker: **Wayne Barstow**.
Affiliation: MK Products.
Topic: Orbital GTA welding.
Activity: Section Chairman **Ken Johnson** presented a scholarship check to **Matt Greenwood** of Green River College, the CWI of the Year Award to **Chris Sundberg** and the Outstanding Contributions Award to **Chuck Daily**.

San Francisco Section Chairman Henry Rojas, left, presenting Gene Counts with a Lifetime Member Award.

♦ **ALASKA**

SEPTEMBER 29

Speaker: **Daniel Enz**
Affiliation: Victor Equipment Co.
Topic: Oxyfuel gas safety, gas cylinder construction, fuel gases, back flash arrestors and general operation of oxyfuel gas equipment.

DISTRICT 22

Director: Mark Bell
Phone: (209) 367-1398

♦ **SAN FRANCISCO**

SEPTEMBER 6

Speaker: **Douglas E. Williams**, metallurgical and welding engineer.
Topic: Structural steel quality as part of a fracture control plan.
Activity: The Section held Past Chairmen's Night. A Lifetime Member Award was presented to **Gene Counts** by Section Chairman **Henry Rojas**. ♦

♦Know Your District Director

♦ District 1
Geoffrey H. Putnam, Torch Designer
Thermal Dynamics
Industrial Park #2
West Lebanon, NH 03784
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E-mail: vtputnam@sover.net

♦ District 2
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A. F. Fleury & Associates
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Phone: (732) 868-0768

♦ District 3
Claudia B. Bottenfield, Manager
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E-mail: cbottenfield@dressel1.com

♦ District 4
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♦ District 5
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Techniweld Lab
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Phone: (787) 883-8383

♦ District 6
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E-mail: gerald.crawmer@ps.ge.com

♦ District 7
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♦ District 8
Harrell E. Bennett, Owner
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2764 S. Lee Highway SW
Cleveland, TN 37311
Phone: (423) 478-3624
E-mail: bscheb@vol.com

♦ District 9
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♦ District 10
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♦ District 11
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♦ District 12
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♦ District 13
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Heyworth, IL 61745
Phone: (309) 888-8956

♦ District 14
Hil Bax
Cee Kay Supply Inc.
5835 Manchester Avenue
St. Louis, MS 63110
Phone: (314) 644-3500, ext. 105

♦ District 15
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Spartan Sauna Heaters, Inc.
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♦ District 16
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♦ District 18
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♦ District 21
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♦ District 22
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♦ 2000–2001 Member-Get-A-Member Campaign

The format for recognizing participants in the AWS Member-Get-A-Member campaign has changed from a points system to that of a system where members are recognized for the actual number of members they sponsor. Campaign categories are outlined on page 97 of this issue.

If you have any questions regarding your member proposer points, please call the Membership Department at (800) 443-9353 ext. 270.

Winner's Circle

(AWS members sponsoring 20 or more new members beginning June 1, 2000.)

J. Compton, *San Fernando Valley* — 68
E. H. Ezell, *Mobile* — 35
B. A. Mikeska, *Houston* — 24
W. L. Shreve, *Fox Valley* — 22
J. Merzthal, *Peru* — 21
R. Wray, *Nebraska* — 21

President's Guild

(AWS Individual members sponsoring 20 or more new Individual members between June 1, 2000, and May 31, 2001.)

J. Merzthal, *Peru* — 21

President's Roundtable

(AWS members sponsoring 11–19 new members between June 1, 2000, and May 31, 2001.)

A. O. Smith III, *Tulsa* — 12

President's Club

(AWS members sponsoring 6–10 new Individual members between June 1, 2000, and May 31, 2001.)

J. Compton, *San Fernando Valley* — 9
W. R. Beck, *Rochester* — 8
G. Taylor, *Pascagoula* — 6
R. Buse, *Mobile* — 6

President's Honor Roll

(AWS members sponsoring 1–5 new members between June 1, 2000, and May 31, 2001. Only those sponsoring 2 or more AWS Individual Members are listed.)

H. E. Cable, Sr., *Pittsburgh* — 4
F. Soto, *New Jersey* — 4
C.-L. Tsai, *Columbus* — 4
J. Rosado, *Puerto Rico* — 3
J. T. Blank, *Northern Michigan* — 2
J. Craft, *Louisville* — 2
D. S. Dodds, *Pittsburgh* — 2
E. Ezell, *Mobile* — 2
J. Gump, *Maryland* — 2
R. Hannan, *JAK* — 2
D. Hatfield — 6
J. Koster, *Western Michigan* — 2
F. Larzabal, *Corpus Christi* — 2
M. Mott, *Florida West Coast* — 2
L. C. Pierre, *New York* — 2
G. Teague, *Eastern Carolina* — 2
R. Teuscher, *Colorado* — 2
M. Weeks, *Sabine* — 2
G. Williams, *Sangamon Valley* — 2
D. Wright, *Kansas* — 2

Student Sponsors

(AWS members sponsoring 3 or more AWS Student Members are listed.)

G. Woomer, *Johnstown/Altoona* — 20
P. Baldwin, *Peoria* — 16
T. Strickland, *Arizona* — 13
C. Alonzo, *San Antonio* — 7
B. Patchett, *Northern Michigan* — 7
D. Hatfield — 6
D. Nelson, *Puget Sound* — 5
R. Rux, *Wyoming* — 5
M. Tait, *Los Angeles* — 4
J. T. Blank, *Northern Michigan* — 3
W. L. Galvary, Jr., *Long Beach* — 3
R. Grays, *Kern* — 3
J. D. Sanders, *Houston* — 3
J. H. Smith, *Mobile* — 3
W. R. Beck, *Rochester* — 2♦

SECTION EVENTS CALENDAR

♦ NEW JERSEY

NOVEMBER 21
Praxair.
Topic: Metal cored wires.

DECEMBER 19
Activity: Manufacturers' Night. All major manufacturers will be in attendance.

JANUARY 16
Miller Electric.
Topic: To be announced.

FEBRUARY 20
Thermal Dynamics.
Topic: Simple automation for plasma arc cutters.♦

DISTRICT CONFERENCE

On June 16, members of District 3 held their District Conference at Rutters Restaurant in York, Pa. Attending were Past President Shirley Bollinger, front row, second from left, and District 3 Director Claudia Bottenfield, front row, second from right.

STANDARD NOTICES

Standards for Project Initiation Notification System (PINS)

Development work has begun on the following new or revised standards. Directly and materially affected individuals are invited to contribute to the development of such standards. Those wanting to participate may contact the staff engineer listed with the document.

Participation on AWS Technical Committees and Subcommittees is open to all persons.

B5.2:200X, *Specification for the Qualification of Welding Inspector Specialists and Welding Inspector Assistants.* This specification defines the requirements and program for an employer (company) to qualify Welding Inspector Specialists and Welding Inspector Assistants to contract or industry-specific inspector standards. The qualification program is developed and controlled by an employer. The qualification requires documentation of experience, training and satisfactory completion of an examination. The examination tests knowledge of welding processes, welding procedures, welder qualification, destructive testing, nondestructive testing, terms, definitions, symbols, reports, records, safety and responsibility as specifically applied by the contract or industry standards applicable to the employer. Engineer: John Gayler, (305) 443-9353 ext. 472.

Standards for Public Review

AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. This column also advises of ANSI approval of documents. The following standards are submitted for public review. A copy may be obtained by sending the amount shown to AWS Technical Dept., 550 N.W. LeJeune Rd., Miami, FL 33126, or by calling (800) 334-9353.

A3.0:200X, *Standard Welding Terms and Definitions.* Revised standard. $53.50. [ANSI Public Review expires November 7, 2000.]

B5.2:200X, *Specification for the Qualification of Welding Inspector Specialists and Welding Inspector Assistants.* New standard. $4.50. [ANSI Public Review expires December 5, 2000.]

D10.11M/D10.11:200X, *Welding for Root Pass Welding of Pipe without Backing.* Revised standard. $10.00. [ANSI Public Review expires November 21, 2000.]

ISO Standards for Public Review

ANSI, the U.S. member of the International Organization for Standardization (ISO), has accredited AWS to administer U.S. Technical Advisory Groups (TAGs) that act as counterparts to ISO's technical committees for welding and Allied Processes. These AWS-administered TAGs are the mechanism to convey U.S. technical positions on a wide variety of international welding activities. The "DIS" status denotes an international standard in the draft mode. To order, forward amount shown to AWS Technical Department, 550 N.W. LeJeune Rd., Miami, FL 33126, or by calling (800) 334-9353. For further information on AWS participation in ISO activities, contact Andrew Davis at (800) 443-9353 ext. 466, or e-mail adavis@aws.org.

ISO/DIS 8205-1, *Water-cooled secondary connection cables for resistance welding – Part 1: Dimensions and requirements for double-conductor connection cables.* Standard. $2.25. [ANSI Public Review expires December 3, 2000.]

ISO/DIS 8205-2, *Water-cooled secondary connection cables for resistance welding – Part 2: Dimensions and requirements for single-conductor connection cables.* Standard. $2.25. [ANSI Public Review expires December 3, 2000.]

New Standard Approved by ANSI

B4.0M:2000, *Standard Methods for Mechanical Testing of Welds.* Approval date: July 25, 2000.

Revised Standard Approved by ANSI

D10.7M/D10.7:2000, *Guide for the Gas Shielded Arc Welding of Aluminum and Aluminum Alloy Pipe.* Approval date: August 16, 2000. ♦

TECHNICAL COMMITTEE MEETINGS

All AWS technical committee meetings are open to the public. Persons wishing to attend a meeting should contact the staff secretary of the committee as listed below at AWS, 550 N.W. LeJeune Rd., Miami, FL 33126; telephone (305) 443-9353.

November 15, 2000, C4 Committee on Oxyfuel Gas Welding and Cutting, Clearwater Beach, Fla. Standards preparation meeting. Staff contact: M. O. Kulp. ♦

♦ Errata for AWS D1.1:2000

♦ AWS D1.1:2000, Structural Welding Code — Steel

Annex M (page 342) - Bottom row, under "Electrode Classification," change "E10018-X" to "E11018-X." ♦

2000 DISTRICT AND SECTION AWARDS

♦ Meritorious Awards

♦ 2000 District Meritorious Awards

Dist.	Name	Section
2	Gary Atherton	Philadelphia
3	Bruce Mays	Reading
4	Gary Stiltner	Charlotte
4	James E. Hollowell	Northeastern Carolina
5	Darryl Jardine	Florida West Coast
6	Kenneth A. Phy	Syracuse
8	Jeffrey Ross	Nashville
8	Ronald "Pappy" Abner	Nashville
9	Johnny Dedeaux	Mobile
9	Charles Lewis, Jr.	Acadiana
10	Ken Jones	Mahoning Valley
12	Theodore Huebbe	Lakeshore
12	Scott Rafaelli	Upper Peninsula
13	Jesse Hunter	Peoria
13	John DeVries	Chicago
14	Joe Daumeyer	Indiana
14	Richard Howard	Louisville
15	Mace Harris	Northwest
15	Tim Schwanz	Northern Plains
17	Johnny Day	Oklahoma City
17	Charlotte Benke	North Texas
18	R.W. "Tac" Edwards	Lake Charles
18	Al Marin	San Antonio
19	Gordon Robertson	Puget Sound
20	Galen Altman	Colorado
20	Kelly Niswender	Wyoming
22	Robert Milliron	Sacramento Valley
22	Doug Williams	San Francisco

♦ 2000 Section Meritorious Awards

Dist.	Name	Section
2	Dominic Colasanto	New York
2	Brian Cassidy	Long Island
2	Gene Sanquini	Long Island
3	Bruce Mays	Reading
4	Sam Glass	Carolina
4	Russell Wahrman	Triangle
4	Greg Fredericks	Charlotte
6	Kenneth A. Phy	Syracuse
8	Bill Brooks	Chattanooga
8	Joe Smith	Greater Huntsville
8	Richard Daffron	Chattanooga
9	Byron Landry	New Orleans
9	John Pajak	New Orleans
9	Jerry Betts	Mobile
9	Robert Wells	Mobile
9	Ken Jobes	Birmingham
9	Frank Smith	Central Alabama
9	Prohal Banerjee	Central Alabama
9	William Carter	Pascagoula
9	David Hackler	Pascagoula
9	Kim Brown	Pascagoula
9	Sammy Wells	Pascagoula
9	Judy Saucier	Pascagoula
9	Cody Allen	Pascagoula
10	Charles Moore	Mahoney Valley
10	Gary Lazarus	Stark Central
10	Harry Sadler	Cleveland
13	Chuck Hubbard	Chicago
13	Joann Piotrowski	Illinois Valley
13	Bonnie Parker	Peoria
14	Paul Thompson	St. Louis
14	Tully Parker	St. Louis
14	Roger Greer	Lexington
14	Kevin Lynn	Indianapolis
14	Don Stickle	Sangamon Valley
14	Dick Bowman	Sangamon Valley
14	Charles Ford	Sangamon Valley
14	Bob Silliman	Louisville
14	Jim Gillespie	Louisville
14	Joe Craft	Louisville
15	Tim Schwanz	Northern Plains
15	Mace Harris	Northwest
15	Jack Heikkinen	Arrowhead
15	Lisa Glendower	Northwest
17	Dave Thomas	Tulsa
18	John Hill	Houston
18	Alton Wolf	Sabine
18	Lawrence Schenk	San Antonio
20	Jeff Strahan	Utah
20	Terry McClelland	Colorado
22	Sandy Carreiro	Sacramento
22	Sharon Jones	San Francisco
22	Fred Mattern	Fresno

♦ Educator Awards

♦ 2000 Private Sector Educator District Awards

Dist.	Name	Section
4	Walt Sperko	Carolina
5	Wayne Engeron	Atlanta
8	Delbert Butler	Chattanooga
9	James Ivy	Pascagoula
9	Gerald McCranie	Mobile
10	Dennis Klingman	Cleveland
10	Bill West	Cleveland
13	Nick Leavy	JAK
13	Victor Hunter	Blackhawk
14	Don Davis	Indianapolis
15	David E. Lynnes	Northern Plains
17	Sandra Green	North Texas
17	Dr. Edmund Rybicki	Tulsa
18	Jose Vargas	Houston
18	David Savoy	Lake Charles
22	Phil Aguilar	San Francisco

♦ 2000 District Educator Awards

Dist.	Name	Section
4	Randy Owens	Carolina
5	James Fasting	Florida West Coast
6	Jean Paul Martin	Syracuse
8	Joe Livesay	Nashville
8	Jim Thompson	Greater Huntsville
8	David Hamilton	Chattanooga
8	Don Dillon	Northeast Tennessee
9	James Sullivan	Mobile
9	Andrew Sessions	Mobile
10	Chet Wesley	Northwestern Pennsylvania
10	Art Baughman	Stark Central
12	Daniel Roland	Upper Peninsula
13	John Fialko	JAK
13	Norman F. King	Blackhawk
13	Mike Spangler	JAK

— continued on next page

2000 AWARDS

♦ 2000 District Educator Awards — *continued*

Dist.	Name	Section
14	Mike Casper	Sangamon Valley
14	Brian Huff	Sangamon Valley
15	Raymond Leiviska	Arrowhead
15	Dean Odette	Northwest
15	Robert Mracek	Northern Plains
15	Dale Szabla	Northwest
17	Charles Credicott	North Texas
17	Frank Wilkins	Central Texas
18	Frances Guerrero	San Antonio
18	Dr. Angie Price	Houston
20	Donny Ray Smith	Wyoming
20	Leland Vetter	Wyoming
22	Dale Rogers	Sacramento Valley
22	Durella Combs	Santa Clara Valley

♦ 2000 Section Educator Awards

Dist.	Name	Section
4	Randy Owens	Carolina
4	Ted Alberts	Southwest Virginia
4	Anver Claussens	Charlotte
6	Jean Paul Martin	Syracuse
8	Joe Smith	Greater Huntsville
8	Jeff Hankins	Northeast Tennessee
8	Dion Frady	Nashville
8	Dr. John Berry	Northeast Mississippi
9	Joe Golemi	New Orleans
9	Bruce Hallila	New Orleans
9	Bill Jordan	Pascagoula
9	Jerold Shepard	Pascagoula
9	Darren Haas	Pascagoula
9	Charlie Hill	Pascagoula
9	William Harris	Pascagoula
9	Brenda Blackman	Acadiana
9	Gerrell Baker	Birmingham
10	Daniel Harrison	Cleveland
13	Mearle Longnecker	Blackhawk
13	Curt Rippey	Peoria
13	Al Tomnitz	JAK
14	Larry Stradler	St. Louis
14	Robert Palovcsik	St. Louis
14	Paul Donald Kimbrell	St. Louis
14	Tim Pinson	Lexington
14	Ed Wyatt	Indianapolis
14	Steve Hoff	Sangamon Valley
14	Bob West	Sangamon Valley
14	Larry Owens	Sangamon Valley
14	Dr. Marvin Copes	Louisville
15	Raymond Leiviska	Arrowhead
15	Robert Mracek	Northern Plains
15	Brain Buson	Northwest
17	Keith Theissen	Oklahoma City
18	Wayne Knuppel	Houston
18	Drew Fontenot	Lake Charles
20	Dale Mortensen	Eastern Idaho/Montana
20	Paul Hasty	Colorado
20	Eric Warren	Colorado
20	Dr. Paul O'Leary	Eastern Idaho/Montana
22	Joseph Johnson	Santa Clara Valley
22	Michael Urioste	San Francisco

♦ CWI of the Year Awards

♦ 2000 District CWI of the Year Awards

Dist.	Name	Section
1	Thomas H. Cormier	Maine
1	Thomas Ferri	Boston
4	Anver Classens	Charlotte
4	Russell Wahrman	Triangle
5	Kenneth D. Erickson	Florida West Coast
6	William Beck	Rochester
8	James A. Thompson	Greater Huntsville
8	Jeff Ross	Nashville
9	C. Levon Mills	Mobile
9	Lenis Doiron	New Orleans
9	John Brown	Pascagoula
10	Chip Rathwell	Cleveland
12	Dale Hange	Upper Peninsula
13	Dan McCarty	Blackhawk
13	Don Gutman	JAK
13	James Peters	Peroia
13	Zach Awad	JAK
14	Steve Brown	St. Louis
15	John Cox	Northern Plains
15	Bob Sands	Northwest
15	Bruce Danielson	Northwest
16	Eric Peterson	Central Iowa
17	Randy Walker	North Texas
17	Harry T. Timmerman	Central Texas
18	Ron Theiss	Houston
18	John Mendoza	Sabine
20	Fred Castle	Colorado
20	Jim Corbin	Colorado
22	Karlton Windhorst	Sacramento Valley
22	Jose Bohorquez	Santa Clara Valley

♦ 2000 Section CWI of the Year

Dist.	Name	Section
4	Anver Classens	Charlotte
4	Russell Wahrman	Triangle
4	Walt Sperko	Carolina
5	Lyndsey Deckard	Atlanta
5	David Ortigoza	South Florida
6	Neil Chapman	Syracuse
6	William Beck	Rochester
8	Jeff Ross	Nashville
8	Joe Livesay	Nashville
8	Jim Thompson	Greater Huntsville
9	Alvin Leake	New Orleans
9	Travis Moore	New Orleans
9	Pradeep Mallenahalli	Acadiana
9	Robert Delavega	Birmingham
9	Ron Phillips	Mobile
13	Mearle Longnecker	Blackhawk
13	Mike Festa	Chicago
13	Richard Polanin	Peoria
14	Brad Hicks	St. Louis
14	Billy Wilson	Lexington
14	Dave Graves	Indianapolis
14	Gary Lane	Sangamon Valley
14	Richard Howard	Louisville
15	John Cox	Northern Plains
15	Ken Rand	Northwest
16	Eric Peterson	Central Iowa
17	Jay Johnson	Oklahoma City
18	James Bobo	Lake Charles
18	D. P. Cordell, Jr.	Sabine
20	Ray Zampedri	Wyoming
20	Norman Winn	Utah
22	John Van Dyke	Sacramento
22	Mel Smith	Santa Clara Valley

GUIDE TO AWS SERVICES

550 N.W. LeJeune Rd., Miami, FL 33126
Phone (800) 443-9353; Telex 51-9245; (888) WELDING
FAX (305) 443-7559; *Internet: www.aws.org*
Phone extensions appear in parentheses.

AWS PRESIDENT

L. William Myers, Welding Engineer
Dresser-Rand
Olean Operations
P.O. Box 560, Paul Clark Dr.
Olean, NY 14760

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Frank G. DeLaurier, CAE (210)

Deputy Executive Directors
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Jeffrey R. Hufsey (264)
John J. McLaughlin (235)

Assistant Executive Director
Debbie A. Cadavid (222)

Director of Quality Management Systems
Linda K. Williams (298)

Corporate Director of Finance/Comptroller
Frank R. Tarafa (252)

INFORMATION SERVICES

Corporate Director
Joe Cilli (258)

HUMAN RESOURCES

Director
Luisa Hernandez (266)

INTERNATIONAL INSTITUTE OF WELDING

Information (294)

Provides liaison activities involving other professional societies and standards organizations, nationally and internationally.

GOVERNMENT LIAISON SERVICES

Hugh K. Webster
Webster, Chamberlain & Bean
Washington, D.C.
(202) 466-2976
FAX (202) 835-0243

Identifies sources of funding for welding education and research & development. Monitors legislative and regulatory issues important to the industry.

WELDING EQUIPMENT MANUFACTURERS COMMITTEE

Associate Executive Director
Richard L. Alley (217)

INDUSTRY ACTION COMMITTEE

Associate Executive Director
Charles R. Fassinger (297)

COMMUNICATIONS

Corporate Director, Communications
Nannette M. Zapata (308)

Corporate Director of Administrative Services
Jim Lankford (214)

Corporate Director of Marketing
Technical Services Division
Debrah C. Weir (279)

Promotes Society programs and activities to AWS members, the welding community and the general public.

CONVENTION & EXPOSITIONS
Exhibiting Information (221, 256)

Managing Director
Tom L. Davis (231)

Organizes the week-long annual AWS International Welding and Fabricating Exposition and Convention. Regulates space assignments, registration materials and other Expo activities.

PUBLICATION SERVICES
Division Information (348)

Managing Director
Jeff Weber (246)

WELDING JOURNAL

Publisher
Jeff Weber (246)

Editor
Andrew Cullison (249)

National Sales Director
Rob Saltzstein (243)

WELDING HANDBOOK

Welding Handbook Editor
Annette O'Brien (303)

Publishes AWS's monthly magazine, the *Welding Journal*, which provides information on the state of the welding industry, its technology and Society activities. Publishes the *Welding Handbook* and books on general welding subjects.

MEMBER SERVICES

Department Information (261)

Managing Director
Cassie R. Burrell (253)

Assistant Director
Rhenda A. Mayo (260)

Serves as a liaison between Section members and AWS headquarters. Informs members about AWS benefits and other activities of interest.

CERTIFICATION PROGRAMS/ BUSINESS DEVELOPMENT

Director of Int'l Business Development
Walter Herrera (475)

For customized certification and educational programs to industry and government.

EDUCATION

Director
James R. Cunningham (219)

Information on education products, projects and programs. CWI, SCWI and other seminars designed for assistance in Certification. Responsible for the S.E.N.S.E. beginning welder program and dissemination of education information on the Web.

CONFERENCES

Director
Giselle I. Rodriguez (278)

Responsible for national and local conferences/exhibitions and seminars on industry topics ranging from the basics to the leading edge of technology.

CERTIFICATION OPERATIONS
Information and application materials on certifying welders, welding inspectors and educators. (273)

Managing Director
Wendy S. Reeve (215)

Awards & Fellows

Managing Director
Wendy S. Reeve (215)

Coordinates awards and AWS Fellow nominees.

TELEWELD

FAX: (305) 443-5951

For information about AWS technical publications, contact the Technical Services personnel listed below.

TECHNICAL SERVICES

Department Information (340)

Managing Director
William R. Oates (299)

Leonard P. Connor (302) Standards Activities Director, Qualification, Inspection, Food Processing Equipment

Andrew R. Davis (466) International Standards Program Manager, Welding in Marine Construction

Stephen P. Hedrick (305) Safety and Health Manager, Symbols and Definitions

Engineers

Hardy H. Campbell III (300) Structural

Rakesh Gupta (301) Filler Metals

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Melvin O. Kulp (314) Oxyfuel Gas Welding & Cutting, Arc Welding and Cutting, Machinery and Equipment, Welding Iron Castings

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Senior Publications Coordinator

Rosalinda O'Neill (451)

AWS publishes more than 160 volumes of material, including standards that are used throughout the industry.

With regard to technical inquiries, oral opinions on AWS standards may be rendered. However, such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

It is the intent of the American Welding Society to build the Society to the highest quality standards possible. We welcome any suggestions you may have.
Please contact any of the staff listed on the previous page or AWS President L. William Myers, Welding Engineer, Dresser-Rand, Olean Operations, P.O. Box 560, Paul Clark Dr., Olean, NY 14760.

AWS FOUNDATION, INC.

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The AWS Foundation is a not-for-profit corporation established to provide support for educational and scientific endeavors of the American Welding Society. Information on gift-giving programs is available upon request.

♦ Nominees for National Office

Only Sustaining Members, Members, Honorary Members, Life Members or Retired Members who have been members for a period of at least three years shall be eligible for election as a Director or National Officer.

It is the duty of the National Nominating Committee to nominate candidates for national office. The committee shall hold an open meeting, preferably at the Annual Meeting, at which members may appear to present and discuss the eligibility of all candidates.

To be considered a candidate for positions of President, Vice President, Treasurer or Director-at-Large, the following qualifications and conditions apply:

President: To be eligible to hold the office of President, an individual must have served as a Vice President for at least one year.

Vice President: To be eligible to hold the office of Vice President, an individual must have served at least one year as a Director, other than Executive Director and Secretary.

Treasurer: To be eligible to hold the office of Treasurer, an individual must be a member of the Society, other than a Student Member, must be frequently available to the National Office and should be of executive status in business or industry with experience in financial affairs.

Director-at-Large: To be eligible for election as a Director-at-Large, an individual shall previously have held office as Chairman of a Section; as Chairman or Vice Chairman of a standing, technical or special committee of the Society; or as District Director.

Interested parties are to send a letter stating which particular office they are seeking, including a statement of qualifications, their willingness and ability to serve if nominated and elected and 20 copies of their biographical sketch.

This material should be sent to Robert J. Teuscher, Chairman, National Nominating Committee, American Welding Society, 550 N.W. LeJeune Rd., Miami, FL 33126.

The next meeting of the National Nominating Committee is currently scheduled for May 1, 2001, in Cleveland, Ohio. The terms of office for candidates nominated at this meeting will commence June 1, 2002. ♦

♦ Honorary-Meritorious Awards

The Honorary-Meritorious Awards Committee has the duty to make recommendations regarding nominees presented for Honorary Membership, National Meritorious Certificate, William Irrgang Memorial and the George E. Willis Awards. These awards are presented in conjunction with the AWS Exposition and Convention held each spring. The descriptions of these awards follow, and the submission deadline for consideration is July 1 prior to the year of presentation. All candidate material should be sent to the attention of John J. McLaughlin, Secretary, Honorary-Meritorious Awards Committee, 550 N.W. LeJeune Road, Miami, FL 33126.

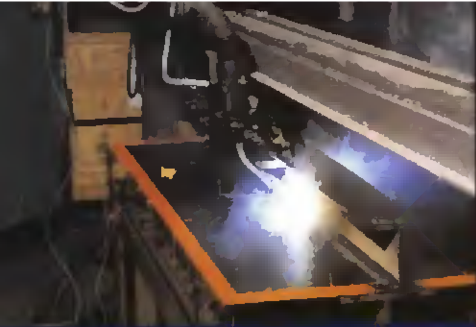
National Meritorious Certificate Award: This award is given in recognition of the candidate's counsel, loyalty and devotion to the affairs of the Society, assistance in promoting cordial relations with industry and other organizations, and for the contribution of time and effort on behalf of the Society.

William Irrgang Memorial Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Company to honor the late William Irrgang. It is awarded each year to the individual who has done the most to enhance the American Welding Society's goal of advancing the science and technology of welding over the past five-year period.

George E. Willis Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Company to honor George E. Willis. It is awarded each year to an individual for promoting the advancement of welding internationally by fostering cooperative participation in areas such as technology transfer, standards rationalization and promotion of industrial goodwill.

International Meritorious Certificate Award: This award is given in recognition of the candidate's significant contributions to the worldwide welding industry. This award should reflect "Service to the International Welding Community" in the broadest terms. The awardee is not required to be a member of the American Welding Society. Multiple awards can be given per year as the situation dictates. The award consists of a certificate to be presented at the award's luncheon or at another time as appropriate in conjunction with the AWS President's travel itinerary, and, if appropriate, a one-year membership to AWS.

Honorary Membership Award: An Honorary Member shall be a person of acknowledged eminence in the welding profession, or who is accredited with exceptional accomplishments in the development of the welding art, upon whom the American Welding Society sees fit to confer an honorary distinction. An Honorary Member shall have full rights of membership. ♦



A comprehensive two-and-one-half day conference logically sequenced into five challenging sessions:

- Power Supplies and Process Optimization
- High Productivity and Process Variants
- Process Control and Monitoring
- Cored Wire Welding and Applications
- Materials and Fume Generation

This is the complete conference experience for GMAW users: continuous access to U.S. and international experts, panel discussions, exhibits, receptions, and take-home materials for a quick reference.

An International Conference on Advances in Welding Technology (ICAWT)

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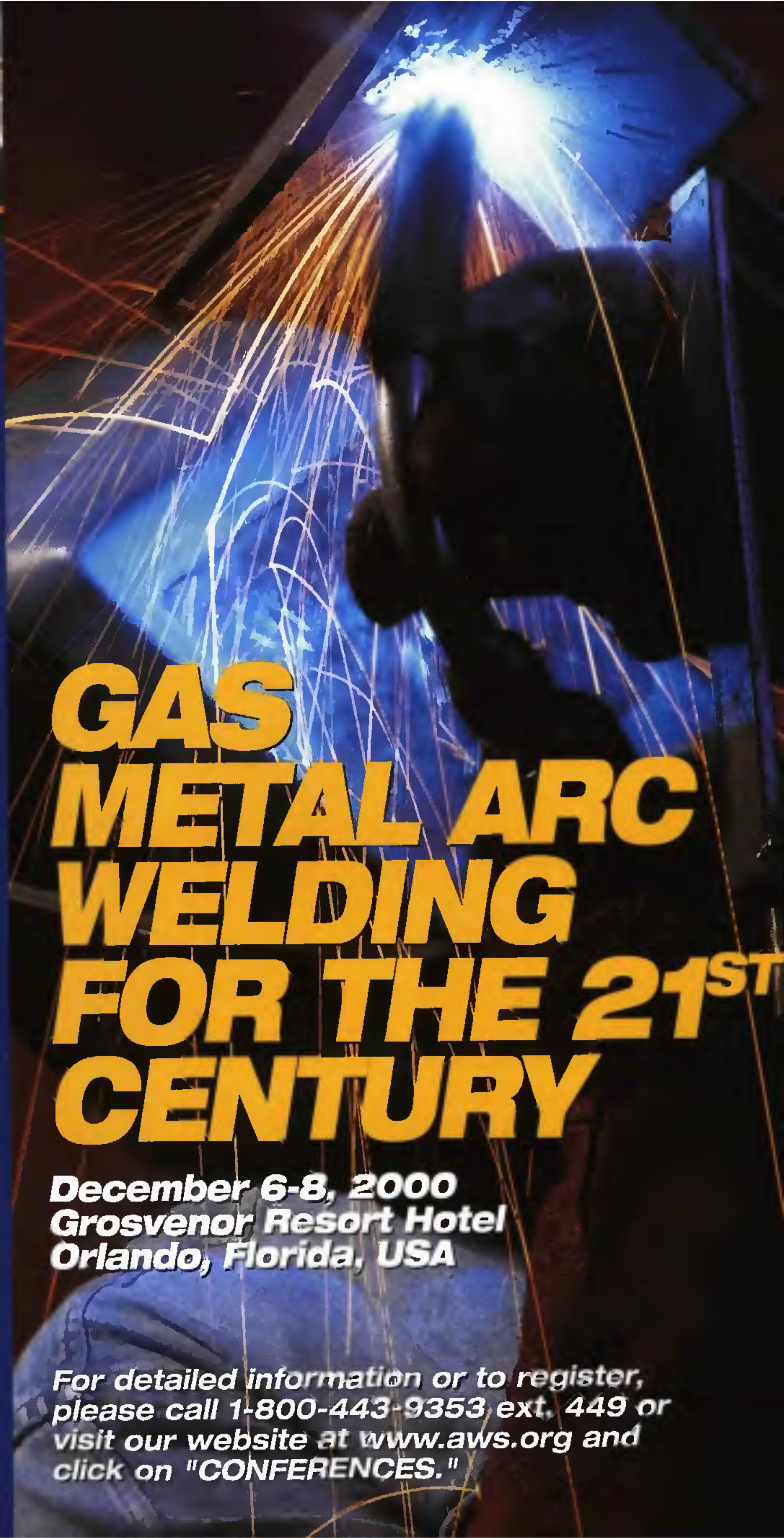

AWS Foundation, Inc.

A Foundation of the American Welding Society

Year-End Recognition

THE MISSION OF THE AWS FOUNDATION

Is to meet the needs for education and research in the field of welding and related joining technologies.

The Foundation is honored to recognize the many individuals and companies who support the future industry by contributing to the Foundation's education funds. These funds are awarded to students pursuing a career in welding in welding or related materials joining science.

HIGHLIGHTS OF 1999-2000

You helped the Foundation surpass $300,000 in scholarship and fellowship funding serving over 175 students.

The student loan program was initiated to assist students in need of financial support with low interest rate loans.

Three new national scholarships were established. The Roman F. and Lillian E. Arnoldy Scholarship, the William H. Howell Scholarship, and the Airgas-Terry Jarvis Memorial Scholarship award $2,500 to students pursuing a 4-year degree in a welding-related program.

This year, new programs were initiated to enhance the Foundation's current programs and assist students with critical educational funds. These programs include:

First International Scholarship

Matsuo Bridge Scholarship, Japan

Foundation trustees approved the establishment of an estate planning program to be launched in 2000-2001.

Services and Opportunities Offered by the AWS Foundation

National Scholarship Program

Airgas-Terry Jarvis Memorial Scholarship
Howard E. Adkins Memorial Scholarship
The Roman F. and Lillian E. Arnoldy Scholarship
Edward J. Brady Scholarship
Donald F. Hastings Scholarship
John C. Lincoln Memorial Scholarship
James A. Turner, Jr., Memorial Scholarship
Praxair International Scholarship
William B. Howell Memorial Scholarship

Other Scholarships

Miller Electric International Youth Skills Competition Scholarship
Carol J. DeLaurier Memorial Scholarship

Scholarship programs in development

Malcolm T. Gilliland Scholarship
Hypertherm Scholarship
Ted B. Jefferson Scholarship
Robert L. O'Brien Memorial Scholarship
Jerry Robinson Scholarship
Thermadyne Industries Scholarship

Graduate Research Fellowships

Glenn J. Gibson Fellowship
Miller Electric Fellowship
Navy Joining Fellowship
AWS Fellowship

Educational Tools

Engineering Your Future
Image of Welding Project

Donor Recognition

Diamond Donors
Innovators for Tomorrow
Leaders in Excellence
Partners in Progress

Other Recognition

Visionary Club (Estate Planners)
Memorials and Honorariums
AWS Foundation Major Corporate Sponsors

AWS Foundation Major Sponsors

The AWS Foundation recognizes the following partners for their long-term commitments and significant contributions. Through their generous support and concern, the AWS Foundation continues to provide opportunities for welding and related education.

Major Corporate Sponsors

AirGas
Air Liquide America Corporation
Air Products and Chemicals, Inc.
American Welding Society
Chemalloy Company, Inc.
ESAB Welding & Cutting Products
Eutectic Castolin
The Fibre-Metal Products Company
Gibson Tube, Inc.
Malcolm T. Gilliland, Inc.
Gullco International, Inc.
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High Purity Gas
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NASCO, Inc.
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National Welding Supply Association
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Major Individual Sponsors

Wilma J. Adkins in memory of Howard E. Adkins*

Richard Amirikian in memory of Arsham Amirikian*

Roman F. Arnoldy

D. Fred Bovie

Jack and Jo Dammann

Frank G. DeLaurier

William T. DeLong

Glenn J. Gibson

Donald F. Hastings

Robb F. Howell and Deborah H. Kurd in memory of William B. Howell*

Ronald C. Pierce

Jerome L. Robinson

Charley Stoody

James A. Turner, Jr.*

Pictures not shown
Debbie A. Cadavid
Richard D. French

*Deceased

1999-2000 District Scholarship Recipients

In its commitment to improve industry's productivity, the AWS Foundation provides funding assistance to help students wishing to pursue vocational, community college, or a degree program in a welding or related field of study. These scholarships are awarded locally within the 22 AWS districts nationwide. In addition to the $5,000 AWS gives each district, local sections within the districts also award separate scholarships.

Scholarship recipients are selected annually at AWS District Conferences.

The students who received awards granted for the 1999-2000 academic year through the AWS Foundation are as follows:

DISTRICT 1

Nathan A. Fontaine ... Hobart Welding Institute of Technology
Anthony N. Jean ... Eastern Maine Technical College
Jesse J. Roy ... Santa Fe Community College
Mark Sciacca* ... Pennsylvania College of Technology
Shain Smith ... Eastern Maine Technical College

DISTRICT 2

Frank T. Grudzien ... Bergen Work Force Center
Laura Lee Hildebrandt ... Union County Vocational Technical School
Jesse W. Vornhold ... Pennsylvania College of Technology

DISTRICT 3

Jennings W. Bird* ... Pennsylvania College of Technology
Peter J. G. Boone ... Pennsylvania College of Technology
Russell N. Downey III ... Pennsylvania College of Technology
Mark Sciacca* ... Pennsylvania College of Technology
Christopher R. Wessel ... Pennsylvania College of Technology

DISTRICT 4

Thomas L. Anderson ... Pitt Community College
James E. Boyd III* ... Greenville Technical College
Tavarus L. Cobb ... Wilson Technical Community College
Andrew J. Favre ... New River Community College
Brandon L. Harrell ... Pitt Community College
Donald A. Harrell ... Wilson Technical Community College
Samuel P. Holmes I* ... Greenville Technical College
Scott Kersey* ... Greenville Technical College
Randy N. Sanderson ... Wilson Technical Community College
Colin Smith* ... Greenville Technical College
David E. Telfair, Jr. ... Pitt Community College
David L. Tripp, Jr. ... Pitt Community College
Dominic Tyson ... Pitt Community College
Derek A. Weeks ... New River Community College
Brandon L. Wilson ... Pitt Community College

DISTRICT 5

Brandon Bellamy ... Tuskegee Institute
James E. Boyd III* ... Greenville Technical College
Tran Dien ... Pinellas Technical Education Center
Daniel Fisher ... First Coast Technical Institute
Samuel P. Holmes I* ... Greenville Technical College
Jill Isbell ... Gwinnett Technical Institute
Scott Kersey* ... Greenville Technical College
Nick Maggio ... Pinellas Technical Education Center
Andrew C. Martin ... University of South Florida
Teresa A. Martin ... Savannah Technical Institute
Edward A. Menees, Jr. ... Pinellas Technical Education Center
Colin Smith* ... Greenville Technical College
David G. Taylor ... Pinellas Technical Education Center
Robert B. Thompson ... Trident Technical College
Lenorris Williams, Jr. ... Savannah Technical Institute
Shannon M. Wilson ... Pinellas Technical Education Center

DISTRICT 6

Timothy M. Adams ... Alfred State College
Jennings W. Bird* ... Pennsylvania College of Technology
Jeffrey D. Crowley ... Triangle Tech

DISTRICT 7

Jason W. Bigham ... The Ohio State University
Adam J. Geary ... Belmont Technical College
Christopher Ray ... The Ohio State University
Brandon A. Robinette ... Hobart Institute of Welding Technology
Matthew M. Robinson ... The Ohio State University
Joseph E. Steel ... Westmoreland County Community College
Eric S. White ... West Virginia University of Parkersburg
Clint Whysong ... University of Pittsburgh at Johnstown

DISTRICT 8

William Bable ... Tennessee Technical Center at Crossville
Aprile L. Carter ... Northeast State Technical Community College
Jason Clouse ... Northeast State Technical Community College
Kenneth P. Eason* ... Wallace State Community College
Dustin Kunkel ... Tennessee Technical Center at Crossville
Jonathan N. Kyker ... Northeast State Technical Community College
Daniel K. Matthews ... Itawamba Community College

Drew L. Porterfield....Northeast State Technical Community College
Ricky L Rogers....Tennessee Technical Center at Crossville
Charles Whitehead....Hazard Technical College

DISTRICT 9

Jason W. Boles*....Gulf Coast Commercial Diving Academy
Jeremy L. Boulware....Mississippi State University
Stephen P. Bourgeois....Louisiana Technical College
Kenneth P. Eason*....Wallace State Community College
David W. Kirksey, Jr.....University of Southern Alabama
Johnny L. Lee, Jr.....Auburn University
Paul Wittenbach....Auburn University Graduate School

DISTRICT 10

Francis V. Carbasho....Hobart Institute of Welding Technology
Jesse L. Copley....Triangle Tech
Ryan S. Copley....Pennsylvania College of Technology
Daniel R. DeVore....Triangle Tech

DISTRICT 11

Lori L. Kuiper....Ferris State University
Douglas J. Marsh....Ferris State University
William L. Stellwag, Jr.....Ferris State University
Nathan E. Stroven....Ferris State University
Zachary C. Wenzel....Ferris State University
Joshua Williamson....Ferris State University

DISTRICT 12

Jeff T. Albrecht....Ferris State University
Brice L. Cherubini....Bay de Noc Community College
Gary Duensing....Milwaukee Area Technical College
Dwayne E. Haschker....University of Wisconsin - Stout
Melissa B. Meier....Madison Area Technical College
Joshua H. Reed....Bay de Noc Community College
Dion J. Williamson....Northeast Wisconsin Technical College
Scott Woida....Milwaukee Area Technical College

DISTRICT 13

Thomas P. Cass*....University of Illinois at Urbana-Champaign
Sarah B. Grycko....Lewis University
Timothy L. Hunter....Illinois State University
George Iftimie....Derry Institute of Technology
Nicholas R. Jones....Illinois State University

DISTRICT 14

Walter W. Bohn III....Belleville Area College
Thomas P. Cass*....University of Illinois at Urbana-Champaign
Jonathan Dawson....Central Kentucky Technical College
Jason A. Eckstein....East Central College
William D. Friend....Central Kentucky Technical College
John J. Hammond....Purdue University
Jeffrey A. Jager....Hobart Institute of Welding Technology
Matthew L. Mattingly....Tulsa Welding School
Nathan W. Peters....Belleville Area College
David W. Smith, Jr.....Central Kentucky Technical College
Paul West*....Moberly Area Technical Center

DISTRICT 15

Ryan D. Becker....North Dakota State College of Science
Nathan R. Brown....North Dakota State College of Science
Randy L. Knott....Alexandria Technical College
Chad R. Luedke....Anoka-Hennepin Technical College
Ryan Njos....Eastern Wyoming College
David W. Otto....Central Lakes College
Rozella M. Vahl....Northwest Iowa Community College
Virgil R. Vahl....Northwest Iowa Community College

DISTRICT 16

Neil R. Formanek....Southeast Community College
Jason Hill....Southeast Community College
Kasey Prochaska....Southeast Community College
Emmett D. Wemp*....McPherson College
Paul West*....Moberly Area Technical Center

DISTRICT 17

Milton Coker....LeTourneau University
Daniel W. Dieter....Westark College
Joe Johnson....Ozark Technical Community College
Jay Jones....Texas A & M Commerce
Loren Kirchner....Texas State Technical College
Christopher M. Newton....Tulsa Welding School
Jeremy W. Pebley....Southwestern Oklahoma State University

DISTRICT 18

Chris J. Bartlett....University of Texas San Antonio
Stephen L. Bettis....Texas A & M University at Kingsville
Jason W. Boles*....Gulf Coast Commercial Diving Academy
Henry Hall....Texas Engineering Extension Service
Harriet I. Kalio....Lamar University
Mandy K. Upton....Texas A & M University at Galveston

DISTRICT 19

Arthur C. Bastian....South Puget Sound Community College
Timothy N. Falk....Linn Benton Community College
Nicholaus W. Hale....Spokane Community College
Robert A. Jamtaas....Grays Harbor College
Teri L. Lacey....Portland Community College
Randy Page....Mt. Hood Community College
Daniel G. Trotter....University of Alaska Anchorage
Daniel R. Wittekind....Linn Benton Community College

DISTRICT 20

Casey A. Foltz....Eastern Wyoming College
Eldeen Johnson, Jr.....New Mexico Junior College
Ryan R. Morris....Utah State University
Russell J. Shelby....Montana Tech of the University of Montana
Rick L. Sheridan....Montana Tech of the University of Montana
Jared Tennant....Utah State University
Dan Yantis....College of Southern Idaho

DISTRICT 21

Stephen Baker....College of Oceaneering
Rhonda Clemons....Southwestern College
Benjamin G. Ellsworth....Arizona Western College
Jared Henley....Santa Rosa Junior College
Reginald W. Miller....Honolulu Community College
William E. Mundkowsky....California State Polytechnic University
Melissa Parker....Palomar College
Crystal Lee Sibley....Allan Hancock College
Jason Wood....Palomar College

DISTRICT 22

James R. Coppa....Sierra College
Jennifer L. Cottingham....Fresno State University
Kip B. Goff....Dixie College
Kyle Jenkins....Truckee Meadows Community College
Emmett D. Wemp*....McPherson College

*Total 161 Recipients. * Indicates awards from more than one district. Recipients reported as of March 23, 2000.*

"A Challenge to the Industry"

YOU DID IT!

You were challenged and you responded without hesitation. Last year, as part of the AWS Foundation's Annual Support Campaign, ESAB Welding & Cutting Products and The Lincoln Electric Company challenged the industry to match their $100,000 grants.

That means every dollar you gave to support welding education was matched up to the total challenge of $200,000. Together with these two world-premier, welding equipment manufacturers, you made it happen. What a great way to finish the Foundation's 10th anniversary with $914,000 to advance the endowment!

More important, because of your enthusiasm and contributions to provide scholarships for deserving students and maintain the growth of the welding industry, you surpassed the goal by $714,000. The Foundation is proud to recognize the many companies, individuals, AWS volunteers and staff, and AWS Sections who responded to the challenge and marked year 2000 as the beginning of the next great welding millennium. You made the difference! On behalf of future welding students and the industry, THANK YOU!!

ESAB

LINCOLN ELECTRIC

They made the $200,000 Challenge. You met it. Now, there's $914,000 More for students.

ADK Controls Engineering, Inc.
AWESCD
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Abicor Binzel
Accurate Arc Industrial Construction
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Carl Adams
Francis E. Adams
Wilma J. Adkins
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Air Liquide America Corporation
Air Products and Chemicals, Inc.
Aladdin Welding Products, Inc.
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Douglas M. Allan
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American Welding Society
Andersen Machine & Welding
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Jim Appledorn
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Boris A. Bernstein
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Irving G. Betz
Gail Beyer, II
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Ronald L. Vann
Juan Vazquez-Rivera
Martica Ventura
Michael S. Veszpremi
Welding Engineering Supply Company, Inc.
Nelson C. Wall
C. T. Ward
David E. Weart
Jeffrey Weber
Webster, Chamberlain & Bean
Debrah Weir
Bruce D. Weisman
Welding Metals, Inc.
Weldstar Company
Michael L. Weller
Emmett Wemp
Leonard D. Wert
Weslor Enterprises, Inc.
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Thomas White
J. Frank Wilson
Amos O. Winsand
Robert B. Witherell
Paul Wittenbach
Wolverine Bronze Company
Mark Wood
Howard Woodward
David Wurtz
Wyandotte Welding Supply, Inc.
Yard Enterprises
Nannette Zapata
Nydia Zeno
Zimkor Industries, Inc.
Michael W. Zimmerman
Life Member

AWS Sections that Participated

Alaska
Arrowhead
Atlanta
Chattanooga
Dayton
Delaware
East Texas
Eastern Idaho/Montana
- Nancy M. Carlson
Greater Huntsville
Green & White Mountains
Houston
Inland Empire
Lakeshore
Lehigh Valley
Long Beach/Orange County
Louisville
Maine
Mobile
New Jersey
New Orleans
Northeast Mississippi
Northwest
Olean-Bradford
Academy Fabricators - Ozark
Peoria
Philadelphia
Pittsburgh
Portland
St. Louis
San Antonio
San Fernando Valley
Louis De Freitas - Santa Clara Valley
Shreveport
South Carolina
South Florida
Southeast Nebraska
Southeast Nebraska Student Chapter
Southern Colorado
Southwest Virginia
Spokane
Upper Peninsula

Section Investment Agreements

This program is a Foundation service to help AWS sections realize maximum return on their investments, which are used to further educational opportunities in their local areas.

The following AWS Sections and members are recognized for their participation in the Section Investment Program.

Atlanta
Baton Rouge
Boston
Chattanooga
Chicago
Cleveland
Colorado
Columbus
Connecticut

Dayton
Detroit
Eastern Idaho/Montana
Green & White Mountains
Hawaii
Indiana
Lehigh Valley
Long Beach/Orange County
Long Island

Maryland
Milwaukee
Mobile
New Orleans
Niagara Frontier
North Texas
Northwest
Olean-Bradford
Pascagoula

Philadelphia
Pittsburgh
Portland
Puget Sound
Reading
Richmond
St. Louis
San Fernando Valley
San Francisco

Santa Clara Valley
South Florida
Willamette Valley

As of March 2000
39 Sections
Approximately $1,000,00

Honorariums and Memorials

The following donors are recognized for their gifts on behalf of another individual in supporting educational opportunities within the industry.

Colleen Beem
in memory of
Carol J. DeLaurier

Cassie Burrell
in memory of
Carol J. DeLaurier

Debbie Cadavid
in memory of
Carol J. DeLaurier

Sharon Campbell
in memory of
Carol J. DeLaurier

Susan Campbell
in memory of
Carol J. DeLaurier

Zaida Chavez
in memory of
Carol J. DeLaurier

Joseph Cilli
in memory of
Carol J. DeLaurier

Jim Cunningham
in memory of
Carol J. DeLaurier

Lisa de la Torre
in memory of
Carol J. DeLaurier

Frank G. DeLaurier
in memory of
Carol J. DeLaurier

Jamie DeLaurier
in memory of
Carol J. DeLaurier

Federation of Materials Societies
in memory of
Elizabeth Key

Fray Welding Co., Inc.
in memory of
William Fray

John M. Gerken
in memory of
Carol J. DeLaurier

John M. Hercher
in memory of
Elizabeth Key

Neida Herrera
in memory of
Carol J. DeLaurier

Cynthia Jenney
in memory of
Robert L. O'Brien

Mary Ruth Johnsen
in memory of
Carol J. DeLaurier

Mr. and Mrs. Robert C. Johnson
in memory of
Carol J. DeLaurier

Bud Kinnebrew
in memory of
Carol J. DeLaurier

Kirk Foundation,
Jim Kirk
in memory of
James A. Turner, Jr.

James I. Lankford
in memory of
Carol J. DeLaurier

Gene E. and
Bette M. Lawson
in memory of
Carol J. DeLaurier

Peter, Ellen, Dorle and
Barbara Lekisch
in memory of
Elizabeth Key

Marilyn Levine
in memory of
Robert L. O'Brien

Andre M. Lopez
in memory of
Michael D. Lopez

Tania Lyter
in memory of
Carol J. DeLaurier

Rhenda Mayo
in memory of
Carol J. DeLaurier

John J. McLaughlin
in memory of
Carol J. DeLaurier

Doris A. Moore
in memory of
Carol J. DeLaurier

Thomas M. Mustaleski
in memory of
Warren F. Savage

Glenn M. Nally
in memory of
Carol J. DeLaurier

William Oates
in memory of
Carol J. DeLaurier

Mary A. O'Brien
in memory of
Robert L. O'Brien

Nelly Perez
in memory of
Carol J. DeLaurier

Gladys Santana
in memory of
Carol J. DeLaurier

James A. Seydel
in memory of
Elizabeth Key

Christine Tarafa
in memory of
Carol J. DeLaurier

Frank Tarafa
in memory of
Carol J. DeLaurier

Linda Williams
in memory of
Carol J. DeLaurier

Nannette Zapata
in memory of
Carol J. DeLaurier

Arco
in honor of
David Noble

Miller Electric Mfg. Co Sponsor of the VICA World Skills Competition Scholarship

The AWS Foundation is grateful to the Miller Electric Manufacturing Company who is the proud sponsor of this $40,000 scholarship. This award recognizes and provides financial assistance to contestants representing the United States in the World Skills Competition.

To become eligible for this scholarship, the applicant must compete in the national VICA USA Skills Competition for welding, and advance to the AWS Weld Trials at the AWS International Welding and Fabricating Exposition and Convention, which is held on a bi-annual basis.

1999 Recipient
RAY CONNOLLY
Gold Medal Winner

1997 Recipient
GLENN KAY, III
Silver Medal Winner

1995 Recipient
BRANDEN MUEHLBRANDT
Bronze Medal Winner

1993 Recipient
NICHOLAS J. PETERSON
Silver Medal Winner

Student Loan Program

This program is funded by Gibson Tube, Inc. to honor Mr. Glenn J. Gibson's desire to advance educational opportunities within the welding industry. Student Loan Program funds are presented to individuals nationwide who wish to enter the welding field but do not have the resources to start. These low interest rate loans are repayable following the recipients leaving their training program.

2000-2001 National Scholarship Recipients

Howard E. Adkins Memorial Scholarship
Award sponsored by Wilma Adkins in the memory of her husband, Howard Adkins

Rick L. Sheridan
Montana Tech. of the University of Montana
Welding Engineering Technology

AirGas - Terry Jarvis Memorial Scholarship
Award sponsored by AirGas in memory of devoted employee Terry Jarvis.

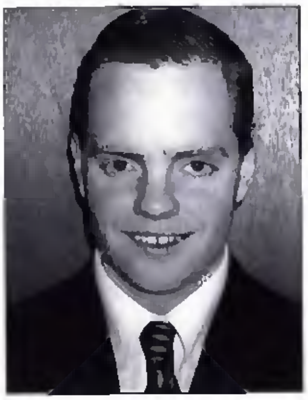
Brian F. Muenchau
Ferris State University
Welding Engineering Technology

Roman F. and Lillian E. Arnoldy Scholarship
Award sponsored by Roman F. and Lillian E. Arnoldy to promote welding education for participants in a university work/study program.

Darin C. Nielsen
Utah State University
Welding Engineering Technology

Edward J. Brady Scholarship
Award sponsored by ESAB Welding & Cutting Products and D. Fred Bovie, retired president of Alloy Rods, in honor and recognition of Ed Brady, founder of Alloy Rods.

Jonathan M. Stewart
Utah State University
Welding Engineering Technology



Donald F. Hastings Scholarship
Award sponsored by The Lincoln Electric Foundation, in honor and recognition of Don Hastings, retired CEO of The Lincoln Electric Company.

Joshua D. Fielding
The Ohio State University
Welding Engineering

Praxair International Scholarship
Award sponsored by Praxair of Canada to recognize superior leadership abilities in a welding student.

Wesley W. Doueth
Ferris State University
Welding Engineering Technology

John C. Lincoln Memorial Scholarship
Award sponsored by The Lincoln Electric Foundation, in memory of John C. Lincoln, founder of the Lincoln Electric Company.

Joshua A. Dudley
The Ohio State University
Welding Engineering

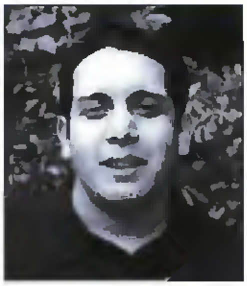
2000-2001 Fellowship Recipients

Each year the AWS Foundation awards graduate fellowships to students attending a welding science or engineering related program in an area of research. A fellowship award consists of funding up to $25,000, which is matched in-kind by the institution of higher learning where the student is engaged in post-graduate work.

Students who received awards this past year through the AWS Foundation are:

Glenn J. Gibson Fellowship
Nathan E. Nissley
The Ohio State University

"An Investigation of Ductility Dip Cracking in Austenitic Alloys"



Miller Electric Fellowship
Toby M. Padilla Colorado School of Mines

"Static and Dynamic Analysis of Wire Feeding Mechanisms in Gas Metal Arc Welding"

Navy Joining Center Fellowship
Chad S. Kusko Lehigh University

"A Fundamental Study of Fatigue Crack Propagation along the Fusion Line in Dissimilar Metal Welds"

Navy Joining Center Fellowship
Jason E. Mitchell
Vanderbilt University

"An Investigation of the Forces Produced During Friction Stir With an Objective of Improved Control"

AWS Fellowship
Manuel MaryaColorado School of Mines

"Science and Engineering in the Magnesium Alloy Welding"

Visionary Club

The Visionary Club is a an exclusive group of individuals who have provided support to the AWS Foundation through one of the various estate planning programs .

Objective: To encourage individuals who believe in the importance of our industry, the continued growth of the United States in the world market, and who will invest in its future by making a gift through their estate plan to the AWS Foundation.

The Visionary Club program provides a method of a lifetime commitment for the donor, and perpetuates the educational needs of the industry. Also, it provides the donor recognition and the assurance that the gift will support the industry indefinitely.

Current members are:
James F. Key
John G. Lincoln
Jerome L. Robinson

Hybrid Laser Welding under Development for Fabrication of Ship Structural Components

The Navy Joining Center (NJC) has been awarded a project to develop and deploy hybrid laser welding for fabrication of ship structural components. This project is part of the Shipbuilding Initiative, a cooperative effort between the Office of Naval Research (ONR) and the National Shipbuilding Research Program (NSRP.) The Shipbuilding Initiative applies the technical capabilities of the Navy MANTECH Centers of Excellence to directly support the technology needs of the shipbuilding industry.

The hybrid laser welding project includes participation from iMAST; Newport News Shipbuilding; Bender Shipbuilding; Ingalls Shipbuilding; Meyer Werft; Caterpillar, Inc.; Edison Welding Institute; Convergent Energy; and the University of Aachen.

This project will compare the advantages and disadvantages of hybrid laser welding to both conventional arc welding and laser welding processes for fabrication of typical stiffened panels. The project is intended to demonstrate the process can meet U.S. Navy requirements for welded structures using typical ship structural materials. The following deliverables from the project will aid in determining the value of using hybrid laser welding for shipyard applications:

- processing rates
- material performance
- distortion of the weld joints
- capital requirements and operating/ownership issues.

Laser welding of ship structural components and similar heavy fabrications have the potential to increase productivity and decrease distortion. While laser welding of ship steels and structural configurations has been demonstrated, requirements for joint fit-up and the need to add filler metal have limited shipyard applications of laser welding. Successful implementation of conventional laser welding processes requires fundamental changes in design or major improvements in cutting and other first operations in order to meet joint fit-up criteria.

Recent work in both Europe and the United States has demonstrated a new welding approach that unites arc welding and laser welding technology into hybrid laser welding. The hybrid approach combines the deep penetration of laser welding with the inherent robustness of the arc welding process. Additional advantages of the hybrid approach include the following:

- Less laser power is required for hybrid laser welding than for conventional laser beam welding, permitting the use of more widely available and lower cost commercial equipment.
- The technology can be integrated into existing shipyard welding operations, allowing arc welding processes to sustain current production.
- The process potentially allows greater control over weld bead geometry, which could improve fatigue properties and overall structural life.

The advantages of hybrid laser welding make it an attractive alternative to help shipbuilders improve productivity and reduce construction costs.

For more information, contact Paul Denney, EWI, at (614) 688-5239; paul_denney@ewi.org, or Larry Brown, NJC, at (614) 688-5080; larry_brown@ewi.org.

NJC Presenting at DMC 2000

Visit the NJC booth at the Defense Manufacturing Conference (DMC 2000) "Foundation for Global Security" to be held November 27–30, 2000, at the Tampa Convention Center, Tampa, Fla.

Technical presentations and information on NJC projects will include the following:

- Transient Thermal-Tensioning Methods to Reduce Distortion in "Thin" Ship Panels — James Dydo
- Knowledge-Based Inspection System — Tim Trapp
- Friction Stir Welding (FSW) of 2519 Aluminum for AAAV — Tim Trapp.

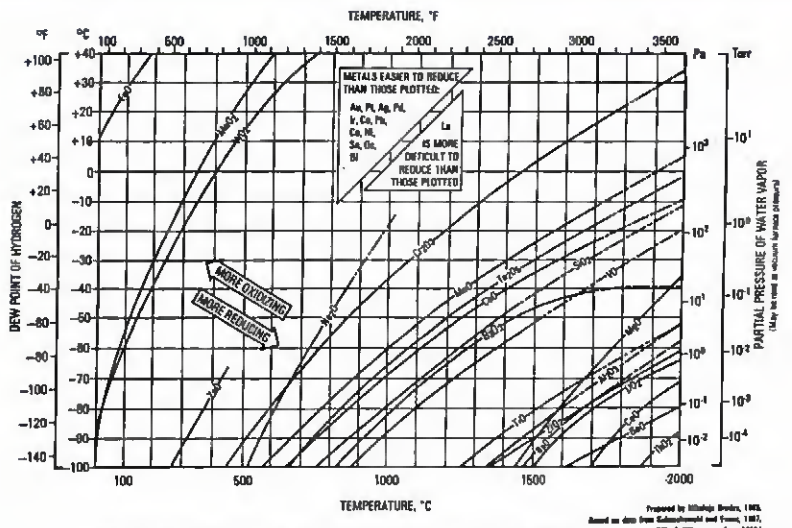
For more information on DMC '00 visit the MANTECH Web site *www.dmc2000.utcdayton.com*.

NJC Operated by EWI
The Navy Joining Center
1250 Arthur E. Adams Dr.
Columbus, OH 43221
Phone: (614) 688-5010
FAX: (614) 688-5001
e-mail: NJC@ewi.org
www: *http://www.ewi.org*
Contact: Harvey Castner

Brazing Q&A

BY R. L. PEASLEE

Q: The specialized heat exchanger we are making is made from 1-in. carbon steel tubing in a flat, rectangular form with several cross tubes. The heating media will be water. It is currently welded, but, because production must be increased and costs reduced, we would like to go to furnace bracing. Can a continuous furnace be used, or is a vacuum furnace required? Also, what filler metal should be used for this application? Can BNi-6, BNi-7 or the 25% chromium version similar to BNi-7 be used?



Metal-Metal Oxide Equilibria In Pure Hydrogen Atmospheres

A: First, let's look at the furnace. If there is a small quantity of parts to process, a batch furnace with a gas atmosphere or vacuum may be more economical. If you plan to have a high production, then a continuous furnace would be more economical. Contact the furnace manufacturers and they will calculate the size and production rate to match your requirements.

Next, let's look at the brazing filler metal. The BNi-6 filler metal Ni-P is very insensitive to the atmosphere quality, which in this range is essentially controlled by the moisture in the atmosphere and is measured as the dew point. A +70 dew point will suffice.

The change to the BNi-7 or the 25% Cr-Ni-P filler metals is a big jump in atmosphere requirements and in furnace design. These filler metals contain a substantial chromium content, 14% and 25%, respectively. When examining the Metal-Metal Oxide Equilibrium graph, iron is in the upper left corner and chromium is in the center of the graph. To dissociate (reduce) the chromium oxide, the atmosphere dew point must be a distance below the chromium oxide equilibrium graph line. In the best brazing range of 1950 to 2050°F (1066 to 1121°C) the dew point should be below –50°F (–46°C) to assure dissociation of the chromium oxide.

Next is the atmosphere requirement to keep carbon steel bright and clean. An exothermic atmosphere having a +70 dew point will suffice. This dew point matches very well with the requirements of the BNi-6 filler metal. The exothermic atmosphere would be suitable, as would the cryogenic nitrogen +2% hydrogen atmosphere. Moisture could be added to raise the dew point, but this is not necessary, as the filler-metal-paste binder will vaporize off clean.

For the BNi-7 and the 25% Cr-Ni-P filler metals, an atmosphere of nitrogen +20% or greater hydrogen with a –50°F (–46°C) or lower dew point will be required. It is obvious the chromium is more sensitive to the atmosphere partial pressure of oxygen (measured dew point).

I expect you will be using demineralized water with a corrosion inhibitor added to prevent attack of the iron tubing. Chlorine in tap water will increase the corrosion and some demineralizing equipment will not remove it. There is a special filter that will remove chlorine and organic compounds; check with the supplier of the demineralizing equipment to be sure you have the proper equipment. It is possible the corrosion inhibitor could neutralize this problem.◆

R. L. PEASLEE is Vice President, Wall Colmonoy Corp., Madison Heights, Mich. This article is based on a column prepared for the AWS Detroit Brazing and Soldering Division's newsletter. Reader questions may be sent to Mr. Peaslee c/o Welding Journal, 550 N.W. LeJeune Rd., Miami, FL 33126.

Stainless Q&A

BY DAMIAN J. KOTECKI

Q: I am attempting to qualify a welding procedure for joining 2¼ Cr–1 Mo steel plate clad with nickel Alloy 625 to 304H stainless. I am using 309 covered electrodes. The welding is fine while joining the CrMo steel to the 304H, but when I tie in to the 625 cladding, there is a lot of centerline cracking. What is the problem, and what can be done about it?

A: Your problem stems from dilution from the Alloy 625 cladding into the stainless steel weld metal. There are two contributing factors — the nickel and the niobium (a.k.a. columbium) in the Alloy 625. The high nickel of the Alloy 625 (more than 60%) tends to make the diluted weld metal fully austenitic. Even as little as 15% dilution from the Alloy 625 will mean the weld metal will contain about 20% nickel, so that it is virtually impossible to use a stainless steel filler metal and still get ferrite in the weld metal (Table 1). The niobium (more than 3%) in the Alloy 625 makes the diluted weld metal contain on the order of 0.5% Nb. That niobium level, coupled with a virtually ferrite-free deposit due to the nickel pickup, makes the weld metal extremely sensitive to hot cracking. A pretty good rule of thumb in ferrite-free compositions is that no niobium is good, and a lot of niobium (on the order of 3%) is good, but low niobium (on the order of 0.5%) is very bad as regards sensitivity to hot cracking. Your centerline cracks are undoubtedly hot cracks.

Type 312 filler might be tempting since it can produce some ferrite when diluted with Alloy 625. But 312 is very dangerous in a joint to be given a postweld heat treatment (PWHT), as yours undoubtedly is, given you are welding in part on 2¼ Cr–1 Mo steel. The high ferrite in 312 weld metal transforms very rapidly to sigma phase during PWHT, which severely embrittles the weld.

There are a couple of ways to fix the problem. Assuming the properties of the 309 weld metal in the CrMo steel to 304H stainless part of the joint are acceptable (more about that later), you can choose a nickel-based alloy filler metal just for the weld passes that tie in to the Alloy 625 and all subsequent passes. Another good rule here is that once you have a nickel-based alloy upon which to weld, you can never back up to stainless steel filler metal. The nickel pickup from the substrate will always push the stainless weld metal into ferrite-free compositions that tend to hot crack. So you could fill the joint with 309 filler metal until you get close to the Alloy 625, then finish the joint with AWS A5.11 covered electrodes of the class ENiCrFe-3 (nominally 70% Ni, 15% Cr, 7% Mn, 5% Fe and 2% Nb), or with GMA wire of the AWS A5.14 class ERNiCr-3 (nominally 20% Cr, 70% Ni, 7% Mn and 2.5% Nb). Both of these nickel-based-alloy filler metals have high resistance to hot cracking.

There is a danger in using 309 filler metal for most of the joint and then finishing with nickel-based-alloy filler metal for the weld passes once weld metal contact with the 625 cladding begins. The danger is that, during PWHT and service at high temperatures, carbon from the 2¼ Cr–1 Mo steel migrates into the 309 stainless deposit, causing carbide precipitation in the filler metal along the weld interface, and causing carbon depletion in the CrMo steel heat-affected zone (HAZ). This carbon depletion in the HAZ, along with the rather large mismatch in thermal expansion between the 309 filler metal and the CrMo steel base metal, has been known to cause premature failure in high-temperature service, especially when thermal cycling is frequent. Normally, both CrMo steel and 304H stainless steel are chosen for high-temperature service, so I suspect this to be the case in your situation. If so, you should consider a second way of making the joint.

Instead of filling most of the joint with 309 filler metal, and only using nickel-based-alloy filler metal for the passes once the Alloy 625 cladding is reached, you might want to consider making the entire joint with the nickel alloy filler metals ENiCrFe-3 or ERNiCr-3. Their hot cracking resistance in joining CrMo steel to 304H stainless steel is very good, carbon migration during PWHT and high-temperature service is reduced with nickel-based alloy filler metals in place of 309 stainless filler and the thermal expansion of the nickel-based alloys is closer to matching that of the CrMo steel, so thermal stresses are lessened compared to using 309 filler metal. It is rather common, today, to use these nickel-based-alloy filler metals for an entire joint such as yours for these reasons. However, it should be noted the nickel-based-alloy filler metals are more costly than 309 stainless electrodes.

Q: For numerous years, I have purchased stainless steel covered electrodes classified as E308L-16 . In the last few years, the electrodes, with the same trade designation, have now become classified as E308L-17. The electrode manufacturer assures me the electrodes are unchanged, but this classification change makes me nervous. Can you explain this classification change?

A: The AWS standard for classifying stainless steel covered electrodes is A5.4. The most recent version, published in 1992, is the one that introduced the –17 coating type. This is a coating type suitable for all-position welding using either AC or DC current. While the previous version of AWS A5.4, published in 1981, did not contain the –17 coating type, it did contain the –16 coating type, which is also suitable for all-position welding using either AC or DC current. At first glance, these requirements appear to be identical, so you may wonder why the AWS Filler Metal Committee introduced the –17 coating type in 1992.

Prior to the 1981 publication of AWS A5.4, there was a single more-or-less standard way in the United States of making stainless steel electrode coatings for AC and DC welding. The coating formulations were very high in the mineral rutile, which is essentially titanium dioxide. The slag of these electrodes freezes quite fast, so welding in the uphill position is rather easily accomplished with a narrow weave technique. But about the time of this publication, a different form of a coating, suitable for AC or DC welding, began to become popular with welders in the United States. This coating substituted silica for some of the rutile. The resulting welding operation tended to include a smoother arc action, with less spatter and a more attractive weld surface appearance, than was normally obtained with the classic U.S. –16 coating type. These electrodes originated from Europe, so they came to be called "European-style AC-DC electrodes." Since these electrodes welded both AC and DC, and since the AWS A5.4 standard at that time only contained two coating types (-15 for DC only, and –16 for AC and DC), the European suppliers used the –16 identification for them. They became very popular in the United States, so, of course, they were copied by the U.S. electrode manufacturers. But they were, and are, truly different from the classic U.S. –16 coated electrodes. In particular, while these European-style electrodes can be used in all welding positions, they generally require a wider weave in the uphill position to make an acceptably flat fillet weld. The testing for classification of a stainless steel covered electrode, as a –16 coating type, includes producing uphill fillet welds with a maximum allowable fillet size and a maximum allowable convexity. It proved to be difficult to meet these requirements consistently with the European-style –16 coating, so the 1992 revision of AWS A5.4 introduced the –17 coating type, with a wider allowable uphill weave in the fillet weld test than for the –16 coating type, to more properly describe these electrodes.

The 1992 publication of AWS A5.4 did not put the matter to rest. No manufacturer of electrodes, so far as I know, started using the –17 coating designation until the change was incorporated into the ASME Code as SFA5.4, which did not happen until the 1994 Winter Addenda to the Code. Even then, there were further delays, as electrode manufacturers had money invested in warehouse stocks that were already imprinted and labeled with the –16 designation. The manufacturers also had trade literature, price books and advertising that included the –16 coating designation. So it took some time for U.S. manufacturers to work through these factors and make the switch to the more accurate –17 coating designation. In addition, some manufacturers have not made the switch, despite their electrode coatings using formulations that include the silica substitution for some rutile. This may be due in part to concerns such as the one you expressed. It may also be due in part to the fact the Canadian W48.2 standard for stainless steel covered electrodes, which largely mirrors the AWS A5.4 standard, has never accepted the –17 coating type, and this somewhat complicates marketing of these electrodes in North America. So you can't always be sure, from the classification, that the electrode you buy with a –16 coating type

— continued on page 131

Table 1 – Typical Compositions of Alloy 625, 309 Filler Metal and Diluted Weld Metal

Typical Composition	Cr, %	Ni, %	Mo, %	Nb, %	FN(a)
Alloy 625	21.0	60	9	3.5	0
309 Filler Metal	23.5	13	—	—	11
309 Filler with 15% Dilution from 625	23.1	20	1.35	0.53	0

(a) FN = Ferrite Number, calculated from the WRC-1992 Diagram

Red Ball Oxygen Announces Appointments

Ralph Thomas was appointed chief financial officer and secretary/treasurer

Thomas

of Red Ball Oxygen Co., Inc., Shreveport, La. He will oversee development of financial, accounting and administrative systems. Most recently, Thomas held vice president of finance and vice president of operations positions with Federal Home Products, Inc. Previously, he worked 18 years with Thiokol Corp. in several senior financial management assignments. Thomas earned a B.S. degree in accounting and an M.B.A. from Louisiana Tech University.

Kennedy

Henderson

The company also announced the election of **Gary Kennedy** as president and **John Henderson** as director of the Buying and Information Group (BIG). The Buying and Information Group is a nationwide industry trade association of prominent welding and industrial/medical gas distributors. Kennedy has served as president of Red Ball Oxygen since 1987. Henderson, who serves as product manage, has been with the company for three years.

BOC Group Selects Board Member

Dick Grant, chief executive of the BOC Gases, Murray Hill, N.J., Process Gas Solution Business, was named to the Board of Directors of The BOC Group plc, based in London, England. He is also a member of the Executive Management Board for The BOC Group.

As part of a recent reorganization, BOC combined two of its global lines of business — Process Systems and Applied Gas Solutions — to form Process Gas Solutions, and named Grant as its chief executive. Grant also heads BOC's

Technology Center and the company's activities in Latin America. Grant, who joined BOC in 1972, holds a degree in engineering from Leeds University in Yorkshire, England.

DE-STA-CO Names Vice President

DE-STA-CO Industries, Madison Heights, Mich., named **Steve Marcus** as vice president-operations. In his new position, he is responsible for all company operations in the Detroit area. He will also coordinate the manufacturing activities at all of the company's business units. Prior to joining DE-STA-CO, Marcus served as chief operating officer for LMI Aerospace in St. Charles, Mo.

Robotic Workspace Technologies Announces V.P.

Robotic Workspace Technologies, Ft. Myers, Fla., named **Joyce Malinowski** as vice president administration, corporate secretary and officer of the company. For the past three years, Malinowski served as principal assistant to the company's president and chief executive officer. In addition to overall administrative responsibilities and financial management reporting, her other duties include human resources, shareholder relations and legal and accounting functions.

Malinowski

Wall Colmonoy Selects General Manager

John P. Husko has been promoted to general manager of the Wall Colmonoy, Madison Heights, Mich., San Antonio facility. He joined the company in 1996 as a technical sales representative for the West Coast. Husko holds a B.S. from Northrop Institute and an M.B.A. from California Baptist University. He has 30 years of experience in the aviation industry.

Obituaries

Thomas A. McKearney

Thomas A. McKearney (AWS), American Welding Society Life Member and past chairman of the Philadelphia and Washington, D.C., Sections, died of cancer on July 25.

McKearney began his welding career at Westinghouse in the Steam Turbine and Heat Transfer Divisions. While at Westinghouse, he was a member of the team that developed the first automatic tube welding machine. After leaving Westinghouse, McKearney joined Midvale-Heppenstall Steel Company and M.L. Bayard in Philadelphia, Pa.

McKearney

McKearney was hired by General Dynamics/Electric Boat Division as supervisor of welding engineering in the QA/QC Department at the start of the Polaris submarine program. He was responsible for welding engineering on the entire Polaris submarine with the exception of the reactor compartment.

In 1967, McKearney joined Lukens Steel Company, where he was responsible for welding engineering at both the U.S. and Canadian shops.

In 1980, McKearney moved to Johannesburg, South Africa, to help open an office for Gilbert Associates. He joined Bechtel Corp. in its Houston office when he returned to the United States. McKearney retired from Bechtel in 1995 after holding a series of increasingly important positions and advancing to manager of materials and quality services. After his retirement, McKearney provided welding, NDE and QA/QC consulting services to companies in the United States and abroad.

McKearney is survived by his wife, Lois; daughter, Beverly; son-in-law, Michael; and grandson, Max.

Donald W. Darrone

Donald W. Darrone [AWS], a Life Member of the American Welding Society, passed away on November 30, 1999.

Darrone retired as president in 1984 from Allen Tool Corp. He had served the company since 1954. He graduated in 1937 from Syracuse University's College of Forestry.

Darrone was a past director of the Manufacturers' Association of Syracuse and past president and trustee of the National Tooling and Machine Association. In 1986, Darrone was named Outstanding Man in Industry by the *Herald Journal*.

Darrone is survived by his wife, Doris, and his children.

Charles Thomas Williamsen

Charles ("CT" or "Tom") Thomas Williamsen [AWS] died on July 8 in Texas.

Williamsen retired from Grumman Aerospace, Long Island, N.Y., in 1974. His accomplishments while at Grumman included pioneering clean room practices used in assembly of the lunar excursion module that first landed on the moon in 1969. His more than 60 years of industrial experience also included metallurgical and related engineering positions with employers such as Bendix Aviation, General Motors, U.S. Naval Ordnance and Eutectic Welding Alloys. In 1944, Williamsen established Technical Consulting and Photography, through which he did failure analysis work into his late seventies for Houston area clients including Anderson & Associates and Captain Derrick Marine Surveyors.

Williamsen is a 1933 chemical engineering graduate of the University of Notre Dame. He regularly pursued continuing technical studies and, in 1975, at the age of 66, he acquired his Texas Professional Engineer license.

Throughout his career, Williamsen made leadership contributions to numerous metallurgical, welding and contamination control technical societies. He also volunteered extensively in support of community activities.

Williamsen is survived by his son, Charles Williamsen III, and his wife, Paula; daughter, Barbara Bowes, and her husband, William; four grandchildren; and six great grandchildren.

— continued on page 132

Participate in the
82nd Annual AWS Convention
Poster Session
Cleveland, Ohio May 6–10, 2001

Students, educators, researchers, engineers, technical committees, consultants, and anyone else in a welding- or joining-related field are invited to participate in the world's leading annual welding event by visually displaying their technical accomplishments in a brief graphic presentation, suitable for close, first-hand examination by interested individuals.

Posters provide an ideal format to present results that are best communicated visually, more suited for display than verbal presentation before a large audience; new techniques or procedures that are best discussed in detail individually with interested viewers; brief reports on work in progress; and results that call for the close study of photomicrographs or other illustrative materials.

Two Categories

There are two categories: Student and Commercial.

Professional category is available to display recent advances in welding technology. Blatant advertisement or sales-oriented posters will not be accepted. Prizes will be awarded for first, second, third, and honorable mention where warranted. No prize will be awarded solely because of number (or lack thereof) of entries in a category.

Awards

Judging is based equally on presentation/clarity and technical merit. Awards are made, where warranted, in two categories; Student and Commercial. All first place winners will be recognized at the following year's AWS Authors' Breakfast and Awards Luncheon.

	Professional	Student (in each of 3 levels)
First Place	Plaque	$200 + Plaque
Second Place	Ribbon	$100 + Ribbon
Third Place	Ribbon	$50 + Ribbon
Honorable Mention	Ribbon	Ribbon

Expenses: Up to a maximum of $1,000 travel expenses will be reimbursed for the top student winner in each level to attend and be recognized at the following year's AWS Authors' Breakfast and Awards Luncheon. (NO travel expenses will be paid for the top winner in the Professional Division.)

Rules

1. Complete the Poster Session Application on the back of this page and mail it with a 200-word description (*i.e.*, abstract) of your poster topic by **December 1, 2000,** to Technical Papers Coordinator, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126, or electronically to <dorcas@aws.org>.
2. You will be notified in February it your proposed Poster Session topic has been accepted. If so, you should do the following:
   - Mount your material on either 22 x 28-in.-wide or 44 x 28-in.-wide (maximum) poster board, or prepare your material so that it can be mounted for you on one of those sizes of poster board. Laminated digital prints, or digital prints already mounted on backing, may be 40 X 30 in. wide (maximum).
   - plan to use a flat display format that is large enough to read from 6 to 8 ft away.

POSTER APPLICATION
82nd Annual AWS Convention
Cleveland, Ohio May 6–10, 2001

Complete form and mail with 200-word abstract by December 1, 2000, to Technical Papers Coordinator, American Welding Society, 550 N.W. LeJeune Rd., Miami, FL 33126, or e-mail to <dorcas@aws.org>
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CATEGORY: (Check One) ❐ Professional ❐ A – Certificate or 2-year degree student
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Abstract	Poster Presentation
The 200-word abstract should include the following; ◆ Overall significance to welding (or, in Category A *only*, materials science) community. ◆ Newness or originality of poster content ◆ What your illustrations (if any) show ◆ Important points stressed in poster ◆ Where relevant, potential economic impact of the work described by the poster	The presence of a personal representative in Cleveland is not mandatory.

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September 19 and 20, 2001 — Columbus, Ohio

This is the eleventh in a series of computer conferences designed to provide the welding industry with the latest information regarding the use of computers for welding. This conference, jointly sponsored by the American Welding Society, The Welding Institute and the National Institute of Standards and Technology, will be held September 19 and 20, 2001, in Columbus, Ohio. Authors from around the world are strongly encouraged to submit an abstract, as attendance from an international audience will be encouraged.

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STAINLESS STEEL

— *Continued from page 124*

designation really has a –16 coating.

There is a pretty easy way to detect if a particular electrode, designated by the manufacturer as having a –16 coating type, is really a –17 coating in disguise. Look at the weld metal silicon content, either by your own analysis or by the electrode manufacturer's certified analysis. Most stainless steel electrode manufacturers will provide a Certified Material Test Report (CMTR), for a given lot of electrodes, on request. A real –16 coating type will produce typically 0.5% Si in the deposit, or less. But the silica in a real –17 coating type will cause silicon pickup by the weld metal, so that the deposit silicon will typically be 0.6%, or more.

Due to this silicon pickup, and the known tendency to increased hot cracking difficulties in ferrite-free stainless steel weld metal with higher silicon, fully austenitic compositions are not generally made with the –17 coating type. (See the Stainless Q&A column in the February 2000 *Welding Journal*.) But the common ferrite-bearing alloys, such as 308, 308L, 308H, 309, 309L, 316, 316L and 347, are perfectly acceptable with either coating type. Please note there is nothing inherently inferior about a –17 coating type as compared to a –16 coating type, for ferrite-bearing compositions, but they are really different. The –17 coating type tends to be more welder-friendly for flat position welding. The –16 coating type tends to be more welder-friendly for uphill or all-position welding. Take your pick.♦

Correction

In the September *Welding Journal*'s Stainless Q&A column, the wrong image was inadvertently printed for Figure 3. The correct Figure 3 appears here. We apologize for the error.

DAMIAN J. KOTECKI is Technical Director for Stainless and High-Alloy Product Development for The Lincoln Electric Co., Cleveland, Ohio. He is a member of the AWS A5D Subcommittee on Stainless Steel Filler Metals; AWS D1 Structural Welding Committee, Subcommittee on Stainless Steel Welding; and a member and past chair of the Welding Research Council Subcommittee on Welding Stainless Steels and Nickel Base Alloys. Questions may be sent to Mr. Kotecki c/o Welding Journal, 550 N.W. LeJeune Rd., Miami, FL 33126.

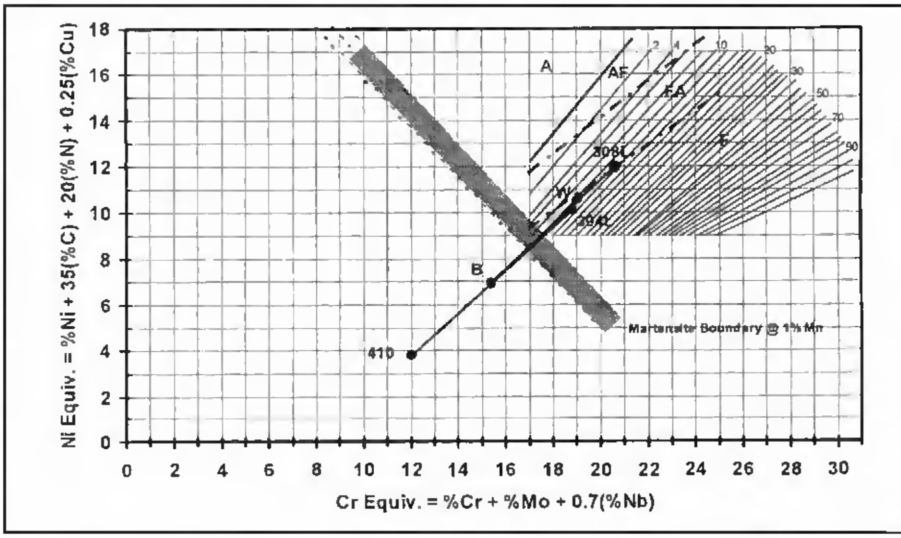

Fig. 3 — Analysis for ER308L filler metal on the WRC-1992 Diagram with martensite boundary.

PERSONNEL

— *Continued from page 126*

Lincoln Names Manager of Welding Technology Center

The Lincoln Electric Co., Cleveland, Ohio, named **Duane K. Miller** to the position of manager - Welding Technology Center. In this role, Miller will be responsible for all traditional aspects of the Center, including application engineering, engineering services and technical training, as well as the Customer Service Sales Support Group. Miller, who joined the company in 1978, has held a number of positions including technical sales representative, applications engineer, welding design engineer and manager-engineering services. For the past six years, he has been involved with the technical and legal developments that grew out of the Northridge earthquake, assisting in the achievement of the complete defense verdict, which was recently announced. Miller earned his B.S. degree with a double major of welding and mechanical engineering from LeTourneau University and an M.S. in materials engineering from the University of Wisconsin-Milwaukee. He was awarded an Honorary Doctor of Science degree from Le Tourneau University. Miller publishes frequently in the industry press and on three occasions has been awarded the coveted Silver Quill Award from the American Welding Society for the excellence of his published work, most recently in 1998. He currently serves as second vice chair of the AWS D1 Committe on Structural Welding and chair of the Seismic Welding Subcommittee.

Miller

Thermal Dynamics Appoints District Manager

Don Mapes joined Thermal Dynamics Corp., St. Louis, Mo., as district manager. In his new position, he is responsible for the company's business in Central, West and East Texas and the lower half of New Mexico. Mapes joins the company with more than 20 years of engineering, manufacturing and plant operations experience in the welding industry. He is an ASME

Mapes

subcommittee member for the Boiler and Pressure Vessel Industry, AWS Certified Welding Inspector and former U.S. Navy nuclear power plant welder. Mapes holds a bachelor of business administration degree from LeTourneau University.

BOC Gases Names Vice President

Ned Galbally has been appointed senior vice president, global operations, for the Process Gas Solutions of BOC Gases, Murray Hill, N.J. Galbally is responsible for leading the company's global operations organization to produce, schedule and deliver liquid/bulk and pipeline industrial gases. He previously served as senior vice president of operations for BOC Gases' Tonnage and Applied Gas Solutions Business in North America. Galbally holds a bachelor of science degree in business from LaSalle College in Philadelphia, Pa.

NEWS OF THE INDUSTRY

— continued from page 24.

Five Companies Create Laser Blanking Consortium

Five companies recently formed an alliance called Laser Blanking Central that will focus on laser-cut sheet metal blanking technologies.

Following are the companies that make up the consortium and their areas of expertise:

◆ DCT, Inc., Sterling Heights, Mich., system integration and material handling automation.

◆ Gen Systems, Inc., Callery, Pa., decoiling and coil leveling equipment under the Herr Voss brand.

◆ L.A.S.E. Inc., Jensen Beach, Fla., an automotive industry consulting firm.

◆ Alabama Laser Systems, Inc., Munford, Ala., production of high-speed laser cutting systems.

◆ GE Fanuc Automation NA, Inc., Cincinnati, Ohio, industrial lasers, linear motors and control systems.

More information on the consortium is available at *www.laserblankingcentral.com*.

Industry Notes

◆ Edison Welding Institute (EWI), Columbus, Ohio, has opened its first regional office in Houston, Tex. The office will provide EWI customers with direct access to services such as on-site consulting, applied engineering project work and welding procedure development and optimization. John Talkington, senior engineer in the Arc Welding and Automation team at EWI, has relocated to Houston. Talkington will serve as a link between the Columbus office and Gulf Coast customers. Contact the office at P.O. Box 1598, Spring, TX 77383-1598, telephone (281) 251-5124 or e-mail john_talkington@ewi.org.

◆ F&M Mafco Inc., Cincinnati, Ohio, recently opened a wire rope and sling facility in Oklahoma City, Okla. "The investment in this new facility provides F&M Mafco an opportunity to expand our global presence in hoists and specialty rigging, as well as an ideal opportunity to increase safety awareness for ourselves and our customers," Mike McKenna, vice president of sales, said. The company is a distributor of construction tools and equipment, industrial supplies, welding products and cranes, hoists and derricks.

◆ BOC Gases, Murray Hill, N.J., was recently awarded a three-year contract to supply welding hard goods and cylinder gases to American Cast Iron Pipe Co., one of Alabama's largest welding supply users. The contract is valued at $2.7 million a year.

◆ General Dynamics Electric Boat, Groton, Conn., was recently awarded a $77.8 million contract for Virginia-class submarine lead-yard services from the Naval Sea Systems Command. The contract provides funding for design-yard services in support of R&D efforts for the baseline Virginia design, and technology insertion and upgrades for follow-on ships of the class. It also provides for design-yard support for construction of the 30 planned Virginia-class submarines. Currently, Electric Boat and Newport News Shipbuilding are working on a $4.2 billion contract to build the first four ships of the class.

◆ HI TecMetal Group (HTG), Cleveland, Ohio, recently acquired Industrial Brazing, Troy, Mich., to improve its position as a provider of copper brazing services in Michigan. The company will consolidate this newly acquired facility with HTG Copper Brazing Industries in Warren, Mich., which specializes in low carbon and stainless steel high-production furnace brazing and is a major supplier of copper-brazed torque converters and brazed tubular assemblies to the automotive industry.

◆ Gullco International Ltd. recently completed construction of a 30,000-sq-ft corporate headquarters and manufacturing facility in Newmarket, Ont., Canada. The new facility enables Gullco to increase production of its automated welding and cutting equipment and accessories.

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WELDING RESEARCH

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Oxygen Equivalent Effects on the Mechanical Properties of Titanium Welds

Understanding the effects of carbon, oxygen, nitrogen and cooling rate on weld properties will help in the development of a nondestructive test method for titanium

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ABSTRACT. This investigation evaluated the use of an oxygen equivalent equation to predict the effects of the factors that control weld mechanical properties. These factors include solid-solution strengthening, grain size and microstructure. The latter two factors are related to the weld cooling rate below the beta transus. Full-penetration welds were made on commercially pure titanium and Ti-6Al-4V using argon-based shielding gases with small additions of either air or CO_2. These welds were made on sheet material using the autogenous GTAW process. Longitudinal weld metal tensile, macrohardness, microhardness, and interstitial composition specimens were removed from each weld. Bend tests also were performed to assess the effects of surface oxidation.

Weld color was shown to be a poor indicator of weld properties and only indicated some surface contamination occurred during solid-state cooling at high temperatures. Oxygen equivalent formulas and weld cooling rate were used to relate weld metal mechanical properties to weld alloy content. An oxygen equivalent formula (based on a formula developed by Ogden and Jaffee in 1955 for wrought alpha titanium alloys) was found to work well on weld metal for commercially pure (CP) titanium. An oxygen equivalent formula was developed for Ti-6Al-4V, but the relationship to weld properties did not relate strongly to variations in interstitial composition.

For CP titanium, Rockwell B hardness testing on the weld face can be used to correlate weld alloy content to mechanical properties, and may be used to assess welds for contamination.

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KEY WORDS

Oxygen Equivalent Formulas
CP Tatanium
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GTAW
Interstitial Composition
Rockwell B Testing
Cooling Rate

Introduction

Contamination of titanium weld metal by interstitial elements (oxygen, nitrogen, carbon and hydrogen) reduces ductility and toughness, while increasing strength and hardness (Refs. 1–10). Contamination can be caused by poor cleaning of the joint and filler materials prior to welding, poor shielding of the weld zone or impurities in the shielding gas. Titanium forms a stable oxide layer that provides excellent corrosion resistance of the material at temperatures below 500°C (930°F) (Ref. 11). However, at temperatures above 500°C, the oxidation resistance of titanium decreases rapidly and the metal becomes susceptible to embrittlement by oxygen, nitrogen and hydrogen. The weld pool is the most vulnerable to contamination since diffusion of interstitial elements is very rapid in molten titanium. Contamination of the solidified weld bead or heat-affected zone (HAZ) usually only affects the material near the surface. Excessive contamination produces welds with poor properties. In addition, the high solubility of oxygen and nitrogen in titanium makes heating in air a problem. Heating titanium to high temperatures in air results not only in surface oxidation but also in solid-solution hardening as a result of inward diffusion of oxygen. The surface-hardened layer is known as alpha case. Because titanium oxide changes the color of the titanium surface, color is commonly used to visually inspect titanium components for contamination. Thick titanium oxide and alpha case layers must be removed before service because their presence reduces fatigue strength and ductility.

Accepted welding practice requires titanium welds to be bright and shiny with only slight discoloration. If normal practices are followed, the appearance of colors may indicate a problem with shielding equipment. Typically, welds that have colors of blue, purple or white are con-

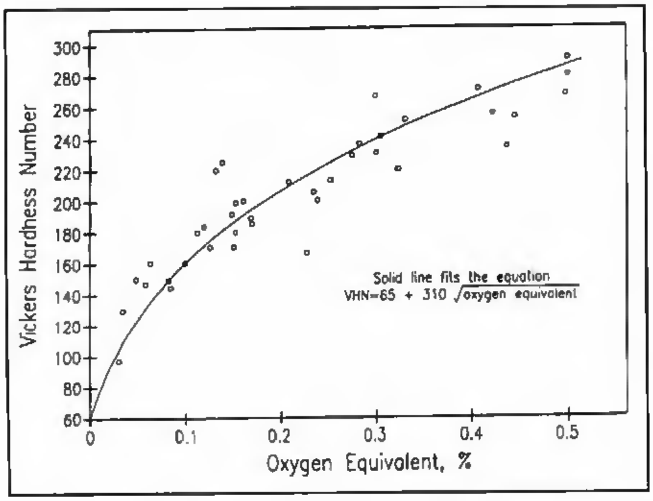


Fig. 1 — Effect of total interstitial content, expressed in terms of an oxygen equivalent, on the hardness of CP titanium base material (Ref. 10).

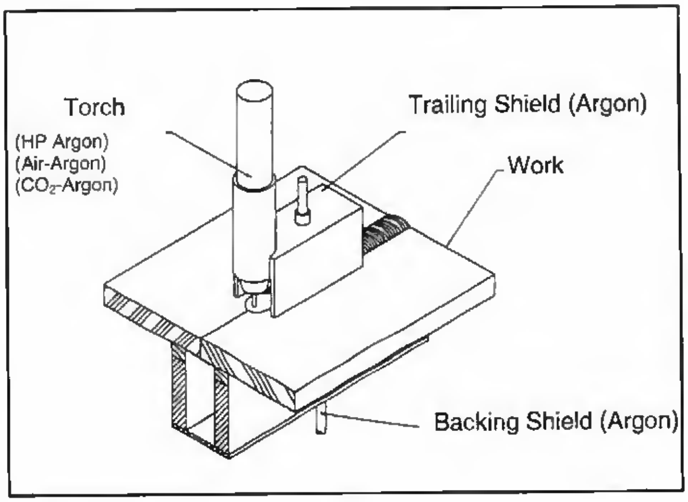


Fig. 2 — Setup for titanium weld tests.

sidered unacceptable and must be removed. Review of the literature reveals color is not always a reliable acceptance criteria (Ref. 8). Discoloration may only indicate the formation of an oxide on the surface of the weldment and may not directly relate to contamination that may have occurred in the molten weld pool. The bulk weld pool may have acceptable properties if the contamination occurred after solidification even though the titanium oxide may have unacceptable color. There is no currently acceptable method to determine if a discolored weld was properly shielded during solidification. Conversely, an unacceptable silver weld can be produced if a contaminated weld pool is well shielded after it solidifies since the surface oxide can dissolve into the subsurface.

The effect of welding procedure cleanliness on CP titanium weld properties has been characterized by numerous investigators (Refs. 3–9). In these investigations, titanium weldability was rated to be good due to solidification and solid-state cracking resistance with exceptional wetting, which promotes smooth weld beads. Solid-solution embrittlement of the HCP alpha phase by the interstitial elements carbon, nitrogen and oxygen was a primary source for manufacturing problems. Nitrogen is the most potent strengthener, followed by oxygen and carbon. Ogden and Jaffee determined nitrogen to have approximately twice the strengthening effect of oxygen (Ref. 10). An oxygen equivalent was formulated by these researchers to relate the effects of the interstitial elements on wrought CP titanium where

$$\text{oxygen equivalent, } OE_{CP} = (2/3 \times \text{wt-\% C}) + \text{wt-\% O} + (2 \times \text{wt-\% N}).$$

This equation was based on the properties of binary alloys and was used to relate the combined effects of the interstitial elements found in CP titanium to hardness — Fig. 1. Hydrogen and iron were not included in this formula because they are 8CC beta phase stabilizers and have very low solubility in alpha-phase titanium. Hydrogen embrittles titanium by precipitation of hydride particles, which significantly lower impact strength (Refs. 4, 5, 11, 12). In CP titanium, 100 ppm (0.01 wt-%) of hydrogen has been reported to cause a loss of toughness and notch resistance but not to significantly affect strength and ductility. A small amount of beta (Ref. 13) (approximately 5%) is normally present in CP titanium from iron content and is believed to getter hydrogen and improve toughness (Ref. 12). Hydrogen is also believed to be responsible for porosity in titanium welds (Refs. 11,14). The effect of iron content on CP titanium welds was not reported.

Research data that relates titanium weld strength, hardness or ductility to an oxygen equivalent formula was not found. Several investigators (Refs. 6, 8, 9) reported titanium weld properties as a

Table 1 — 8ase Material Data

Ti Grade	Nitrogen Max (wt-%)	Carbon max (wt-%)	Oxygen max (wt-%)	Hydrogen max (wt-%)	Iron max (wt-%)	Ultimate stress min (ksi)	Yield min (ksi)	Elongation min (%)
Grade 1 (CP Ti)	0.03	0.08	0.18	0.015	0.20	35	25	24
Grade 2 (CP Ti)	0.03	0.08	0.25	0.015	0.30	50	40	20
Grade 3 (Cp Ti)	0.05	0.08	0.35	0.015	0.30	65	55	18
Grade 4 (CP Ti)	0.05	0.08	0.40	0.015	0.50	80	70	15
Grade 5 (Ti-6Al-4V)	0.05	0.08	0.20	0.015	0.40	130	120	10
Grade 23 (Ti-6Al-4V ELI)	0.03	0.08	0.13	0.0125	0.25	120	110	10
Heat No. 452141 0.079-in. (2-mm) thick, CP Ti	0.013	0.009	0.10	0.0010	0.06	69.1	46.2	27
Heat No. 420053 0.118-in. (3-mm) thick, CP Ti	0.007	0.01	0.15	0.0019	0.03	73.1	48.6	28
Heat No. 24-620 0.080-in. (2.03-mm) thick, Ti-6Al-4V	0.0091	0.013	0.16	0.0077	0.089	138	128	10
Heat No. W52H1B-RI 0.125-in. (3.17-mm) thick, Ti-6Al-4V	0.017	0.035	0.15	0.0054	0.19	148	140	19

function of contamination level introduced into their welding environment, such as dew point effects, but this data cannot be correlated to other welding applications. No oxygen equivalent equation has been found in the literature for the Ti-6Al-4V alloy (Refs. 15–29). In addition, the effects of weld cooling rate have not been related to alloy and interstitial content and weld properties. Titanium strength and hardness can be correlated to grain size and interstitial content using Hall-Petch relationships (Ref. 30). Weld cooling rate controls the grain size of the weldment. The effects of cooling rate need to be considered along with alloy and interstitial content to accurately predict the properties of titanium welds.

This investigation was initiated to improve the understanding of the effects of interstitial elements on the properties of welds in CP titanium Grade 2 and Ti-6Al-4V since these two alloys are the most commonly used in industry. Nondestructive testing of titanium welds for contamination is currently limited to visual examination of weld color. Many welds are repaired in industry based on weld color criteria since a better method does not exist. A future goal of industry is to develop nondestructive test methods to quantitatively evaluate the interstitial content (or contamination) of titanium welds. In a prior investigation (Ref. 1), the oxygen and nitrogen content of CP titanium welds was related to weld strength, hardness and ductility using the oxygen equivalent relationship developed by Ogden and Jaffee. This relationship was expanded in this investigation by evaluating the effects of carbon, oxygen, nitrogen and cooling rate on CP Grade 2 and Ti-6Al-4V alloy weld properties.

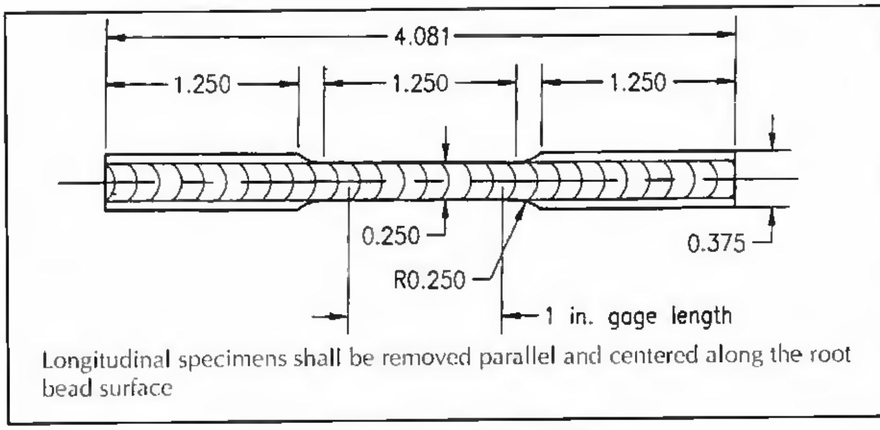


Fig. 3 — Longitudinal tension test specimen.

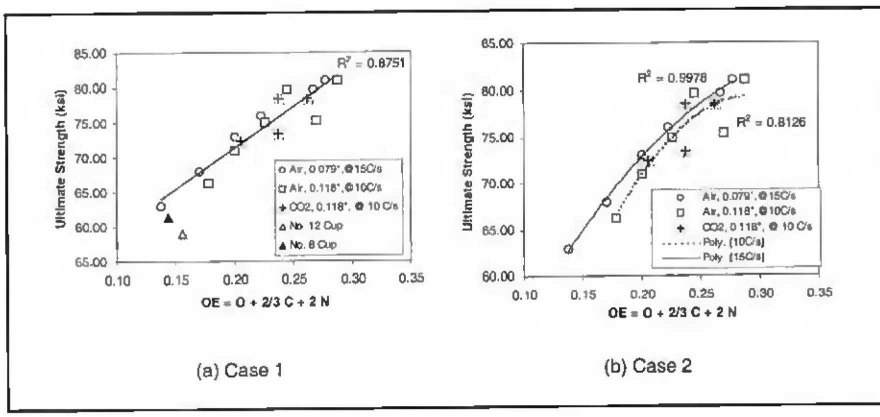


Fig. 4 — OE_{CP} effects on longitudinal ultimate strength.

Experimental Procedure

Two thicknesses of CP titanium Grade 2 and two thicknesses of Ti-6Al-4V (Table 1) were used to make full-penetration bead-on-plate welds in the flat position. These welding tests used argon-based shielding gases that had controlled levels of either air or carbon dioxide (CO_2). For CP titanium, only air-argon mixtures were evaluated on the 0.079-in. (2-mm) material. Both air-argon and CO_2-argon shielding gases were evaluated on the other heats of material. The air-argon and CO_2-argon shielding gases were used to separately evaluate the effects of oxygen and nitrogen, and oxygen and carbon alloy additions. These shielding gases (Table 2) were only used in the welding torch so the interstitial elements would be absorbed primarily by the weld pool. Approximately 24 different shielding gas conditions were used for CP titanium and 20 different shielding gas conditions were used for Ti-6Al-4V, as shown in Table 3. This test matrix was developed to produce a range of weld metal compositions and cooling rates.

The gas tungsten arc welding (GTAW) process was used to make the test welds — Fig. 2. Most welds were made with a trailing shield attached to a No. 12 torch shield cup. Several welds were made just using shielding from either a No. 12 or No. 8 torch cup without a trailing shield. The inside diameters of the No. 12 and No. 8 cup were ¾ and ½ in. (19.05 and 12.7 mm), respectively. Twenty-four-inch (609.6-mm) long weld test coupons were sheared parallel to the rolling direction from each heat and thickness. The weld test coupon (Fig. 2) was clamped in a fixture that provided argon gas backing. Prior to welding each day, a 5 to 10 ft^3/h argon purge was applied for a minimum of 30 minutes and maintained between tests for both the torch and trailing shield. The titanium base metal was thoroughly cleaned using acetone and lint-free paper towels. Surface oxides were removed by wire brushing with a clean stainless steel wire brush, which was attached to an electric grinder and was only used on titanium. The weld joint area and weld fixture were wiped with acetone that was a minimum of 99.5% pure to remove wire brushing debris. An

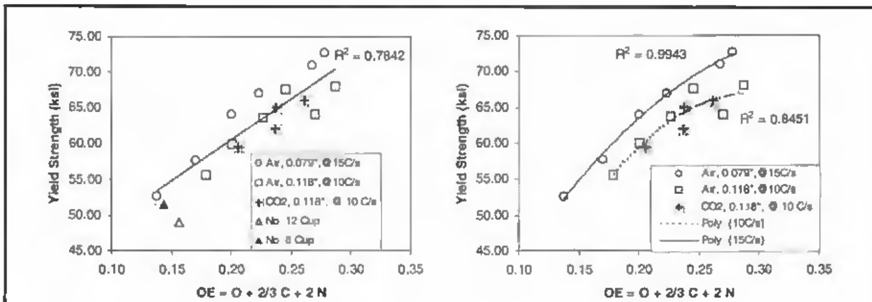
Table 2 — Shielding Gas Test Conditions for GTA Welds

Torch Shield	Trailing Shield	Backing Shield
High-purity (HP) argon	Argon	Argon
High-purity argon w/no trail shield	—	Argon
Air-contaminated argon mixtures	Argon	Argon
–0.21% air		
–0.43% air		
–0.60% air		
–0.79% air		
–0.97% air		
CO_2-contaminated argon mixtures	Argon	Argon
–0.26% CO_2		
–0.52% CO_2		
–0.77% CO_2		
–1.00% CO_2		

Table 3 — Interstitial Composition Results for Autogenous Titanium and Ti-6Al-4V

Weld Condition	Test Condition	Avg C (wt-%)	Avg N_2 (wt-%)	Avg O_2 (wt-%)	Avg H_2 (wt-%)	Oxygen Equivalent
	HP-Argon	0.0205	0.014	0.115	0.00095	0.156
0.079 in. (2 mm)	0.21% Air	0.0205	0.028	0.12	0.0012	0.189
CP Ti	0.43% Air	0.023	0.0365	0.12	0.0011	0.208
Single pass	0.60% Air	0.0185	0.0555	0.11	0.00145	0.233
11°C/s cooling rate	0.79% Air	0.017	0.0625	0.125	0.00085	0.261
3.5 in./min TS	0.97% Air	0.0195	0.098	0.145	0.00085	0.354
	No. 12 cup	0.018	0.017	0.11	0.0010	0.156
	No. 8 cup	0.019	0.103	0.11	0.0011	0.149
	HP-Argon	0.018	0.0095	0.11	0.0007	0.141
0.079 in. (2 mm)	0.21% Air	0.022	0.021	0.12	0.0012	0.175
CP Ti	0.043% Air	0.020	0.033	0.12	0.0004	0.199
Single pass	0.60% Air	0.015	0.046	0.12	0.007	0.222
15°C/s cooling rate	0.79% Air	0.017	0.057	0.135	0.007	0.259
7.75 in./min TS	0.97% Air	0.021	0.061	0.145	0.008	0.278
	HP-Argon	0.011	0.0067	0.16	0.0018	0.181
0.118 in. (3 mm)	0.21% Air	0.011	0.015	0.165	0.0014	0.202
CP Ti	0.43% Air	0.012	0.021	0.175	0.0017	0.225
Single pass	0.60% Air	0.013	0.039	0.180	0.0016	0.265
10°C/s cooling rate	0.79% Air	0.010	0.055	0.170	0.0014	0.287
7.75 in./min TS	0.97% Air	0.015	0.051	0.175	0.0017	0.287
0.118 in. (3 mm)	0.26% CO_2	0.018	0.0068	0.18	0.0016	0.206
CP Ti	0.52% CO_2	0.031	0.0080	0.20	0.0012	0.237
Single pass	0.77% CO_2	0.032	0.0080	0.20	0.0015	0.237
10°C/s cooling rate	1.0% CO_2	0.039	0.0077	0.22	0.0004	0.261
7.75 in./min TS						
	HP-Argon	0.013	0.0110	0.16	0.0063	0.0001
0.080 in. (2.03 mm)	0.21% Air	0.020	0.0180	0.17	0.0053	0.2105
Ti-6Al-4V	0.43% Air	0.016	0.0300	0.17	0.0050	0.2205
Single pass	0.60% Air	0.018	0.0490	0.18	0.0060	0.4201
12.5°C/s cooling rate	0.79% Air	0.016	0.0590	0.19	0.0052	0.4663
9.0 in./min TS	0.97% Air	0.016	0.0810	0.19	0.0054	0.5775
0.080 in. (2.03 mm)	0.26% CO_2	0.024	0.0075	0.18	0.0053	0.2221
Ti-6Al-4V	0.52% CO_2	0.026	0.0068	0.18	0.0056	0.2583
Single pass	0.77% CO_2	0.042	0.0068	0.22	0.0050	0.6316
12.5°C/s cooling rate	1.0% CO_2	0.046	0.0022	0.24	0.0051	0.6992
	HP-Argon	0.046	0.0150	0.13	0.0036	0.1029
0.125 in. (3.17 mm)	0.21% Air	0.047	0.0330	0.14	0.0031	0.2738
Ti-6Al-4V	0.43% Air	0.050	0.0340	0.14	0.0028	0.3441
Single pass	0.60% Air	0.041	0.0590	0.14	0.0034	0.3512
11.8°C/s cooling rate	0.79% Air	0.047	0.0540	0.14	0.0031	0.4373
8.5 in./min TS	0.97% Air	0.039	0.0880	0.15	0.006	0.5452
0.125 in. (3.17 mm)	0.26% CO_2	0.049	0.0059	0.14	0.0039	0.1045
Ti-6Al-4V	0.52% CO_2	0.058	0.0085	0.16	0.0027	0.3323
Single pass	0.77% CO_2	0.060	0.0081	0.18	0.0029	0.3908
11.8°C/s cooling rate	1.0% CO_2	0.065	0.0086	0.19	0.0037	0.5089
8.5 in./min TS						

(a) $OE_{CP} = 2/3C + O + 2N$, $OE_{Ti-6-4} = 20.8C + 7.8N + 0 = 5.8Fe$
Test Temperature, 75°F.
Test condition was as-welded.



(a) Case 1 (b) Case 2

Fig. 5 — OE_{CP} effects on longitudinal yield strength.

argon backpurge was started in the backing chamber to provide at least a 20 to 1 dilution by volume before welding. The weld parameters developed for the autogenous welds used travel speeds from 3.5 to 9.0 in./min (1.48 to 3.81 mm/s) so that heat inputs would be typical of manual welding (Table 4). A minimum root bead width criteria of 0.25 in. (6.35 mm) was produced to permit the removal of all weld metal tensile specimens. Weld cooling rate was measured by immersing a tungsten-rhenium type C thermocouple that was 0.020-in. (0.5-mm) diameter into the weld pool. The cooling rate was determined between the temperature range of 500 to 800°C (1472 to 932°F). After welding, the weld assemblies were then sectioned into test specimens.

Three longitudinal weld metal tensile specimens were removed from each weld and the dimensions are shown in Fig. 3. Tensile specimens were tested in the as-welded condition where the face and root surface of the weld was as-welded (as-cast) and the edges of the flat tensile specimen were milled. The tensile tests were performed to ASTM E8 using a displacement rate of 0.05 in./min (0.02 mm/s). Specimens were also removed for microhardness testing, macrohardness testing, metallographic analysis and interstitial composition analysis. Microhardness and metallographic cross-sections were prepared by mounting the specimens in bakelite and polishing with up to 4000-grit sandpaper. A final polish was then performed using a colloidal silica suspension on an automatic cloth wheel. This step was repeated until all of the scratches were removed. The specimens were etched using a mixture of 88% distilled water, 10% hydrogen peroxide and 2% hydrofluoric acid. Composition of the welds was measured for interstitial elements oxygen, nitrogen and carbon using the ASTM E-1019 combustion method. Hydrogen was measured using the ASTM E-1447MOD combustion method. Vickers microhardness measurements were taken using a load of 500 g for 15 s on a mounted cross section. An average Vickers microhardness was calculated from nine measurements. All measurements were made in the fusion zone and were intragranular. Rockwell macrohardness measurements were made on the surfaces of the welds in the fusion zone, HAZ and base metal.

Tensile strength, ductility and hardness data were plotted as a function of oxygen equivalent. Statistical analysis was used to best fit the relationship between that property and the oxygen equivalent equation. For CP titanium, the data fit was analyzed for two cases:

1) A direct relationship between that property and OE.

2) An indirect relationship between that property and OE as a function of cooling rate.

The coefficient of multiple determination was calculated for each data fit for both cases. In the case of Ti-6AL-4V, a complete regression analysis was performed to derive a new oxygen equivalent equation that maximized the relationship between Ti-6Al-4V weld properties and alloy content.

Regression Analysis for Ti-6Al-4V OE

The objective of the regression analysis was to find the best relationships between mechanical properties and the oxygen equivalent. To reach this objective, regression analysis must find the best fit of oxygen equivalent coefficients and minimize the total error estimation. The approach was as follows:

First, an oxygen equivalent was established by parameterizing the coefficients of the chemical compositions. This oxygen equivalent was fit to each of the mechanical properties using the least-squared error method. The average R-squared value was then calculated and minimized over the parameterized chemical composition coefficients to guarantee a best fit. This procedure is summarized by the following equations:

Let A_i = chemical compositions of run i $= [a_{1i}\ a_{2i} \ldots a_{r,i}]^T$. That is $A_i = [\%C_i\ \%N_i\ \%O_i\ \%Fe_i]^T$.

C = chemical composition coefficients $= [c_1\ c_2 \ldots c_r]$.

z_i = oxygen equivalent of run i $= CA_i$, i = 1,... , n.

$Z = [Z_1\ \ Z_2\ \ \ldots\ Z_n]^T$ That is $z_i = c_1{*}(\%C)_i + c_2{*}(\%N)_i + c_3{*}(\%O)_i + c_4{*}(\%Fe)_i$.

x_{ij} = design matrix, i = 1,...,n, j = 1,...,p-1.

$$X = \begin{bmatrix} 1 & x_{11} & x_{12} \\ 1 & x_{21} & x_{22} \\ \mathbf{M} & x_{ij} & \mathbf{M} \\ 1 & x_{n1} & x_{n2} \end{bmatrix}$$

$$= \begin{bmatrix} 1 & Z & Z^2 \end{bmatrix} = \begin{bmatrix} 1 & Z_1 & Z_1^2 \\ 1 & Z_2 & Z_2^2 \\ \mathbf{M} & & \\ 1 & Z_n & Z_n^2 \end{bmatrix}.$$

y_{ik} = mechanical property (response) k from run i = 1,..., n, k = 1,..., m.

$Y_k = [y_{1k}\ y_{2k} \ldots y_{nk}]^T$, k = 1,..., m.

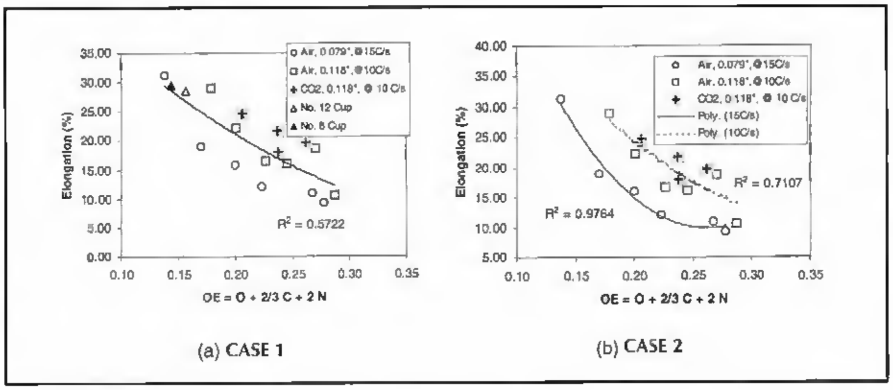


Fig. 6 — OE_{CP} effects on longitudinal tensile elongation.

Table 4 — Autogenous Welding Parameters

Thickness (in.)	Weld Condition	Current (amps)	Voltage (volts)	Travel Speed in./min	Travel Speed mm/s	Cooling Rates (°C/s)
0.079 (2.0 mm) CP Ti	single pass (autogenous)	70	8.0	3.5	1.48	11
0.079 (2.0 mm) CP Ti	single pass (autogenous)	120	9.0	7.75	3.28	15
0.118 (3.0 mm) CP Ti	single pass (autogenous)	200	10.0	7.75	3.28	10
0.080 (2.03 mm) Ti-6Al-4V	single pass (autogenous)	125	13.0	9.0	3.80	12.5
0.125 (3.17 mm) Ti-6Al-4V	single pass (autogenous)	225	11	8.5	3.60	11.8

The model used was $Y_k = X\,B_k + \varepsilon_k$, k = 1,..., m, where $B_k = [ß_{0k}\ ß_{1k}\ ß_{2k}]$, k = 1,..., m, and $ß_{jk}$ was the regression coefficient. The error term ε in the model was assumed to have $E(\varepsilon) = 0$ and $V(\varepsilon) = \sigma^2$, and the $\{\varepsilon_i\}$ were uncorrelated random variables. Let L represent the sum of the squared errors, ε_{ik}, $y_{ik} - \hat{y}_{ik}$, where $\hat{y}_{ik}$ was the estimated y_{ik}, $\varepsilon_{ik} = y_{ik} - \hat{y}_{ik}$, i = 1,...,n, k = 1,...,m, or $\varepsilon_k = [\varepsilon_{1k}\ \varepsilon_{2k} \ldots \varepsilon_{nk}]^T$.

$$L = \sum_{k=1}^{m}\sum_{i=1}^{n}\left(y_{ik} - \left(\beta_{0k} + \sum \beta_{jk}x_{ijk}\right)\right)^2$$

$$= \sum_{k=1}^{m}\left(Y_k'Y_k - 2B_k'X'Y_k + B_k'X'XB_k\right).$$

The least squares method takes the partial differential of L with respect to $ß_{jk}$, j = 0,1,2, k = 1,..., m, and set it to zero. Solving the least square normal equations derived the coefficient $ß_{jk}$, which minimizes the sum of the squared errors.

$$\left.\frac{\partial L}{\partial B}\right|_{\hat{\beta}_k} = 0 \text{ or } -2X'Y_k + 2X'X\hat{B}_k = 0, k = 1,\ldots,m.$$

Solving the normal equations above derived the regression coefficients $\hat{\beta}_k$, the relationship of mechanical properties to the oxygen-equivalent equation,

$\hat{\beta}_k = (X'X)^{-1}X'Y$. The estimated y_{ik} for the fitted regression model was

$$\hat{Y}_k = X\hat{B}_k.$$

Further, the residual sum of squares (SS_E), the regression sum of squares (SS_R) and the total sum of squares (SS_T) were estimated to identify the coefficient of multiple determination R^2 and the adjusted R^2 for each relationship of X and Y_k per the definitions as defined in Design and Analysis of Experiments (Ref. 31).

The chemical coefficient matrix C was estimated such that it gave the least squared error fit to each of the regression coefficients $\hat{B}_k$. Thus, nonlinear programming was used to maximize the total $R^2_{adj,k}$, which indicates how good the fits were taking into account the number of variables and the number of runs (n) in each Y_k. The formulation of the nonlinear program was as follows:

$$\underset{C}{Max} \sum_{k=1}^{m} R^2_{adj,k}$$

Subject to $c_3 = 1$.

The only constraint was set to prevent multiple sets of solutions that would give

Table 5 — Color of Titanium Welds Made with Different Shielding Conditions (a)

Thickness (in.)	Shield Gas	HAZ Color	Weld Color
0.079 (2 mm)	100% Argon	Silver	Silver
0.079 (2 mm)	HP-Argon(b)	Silver	Silver
0.079 (2 mm)	0.21% Air	Silver/Some Straw	Silver
0.079 (2 mm)	0.21% Air	Dark Blue/Some Straw	Silver
0.079 (2 mm)	0.43% Air	Silver	Silver
0.079 (2 mm)	0.43% Air	Silver/Some Straw	Silver
0.079 (2 mm)	0.60% Air	Straw/Dark Blue	Silver
0.079 (2 mm)	0.60% Air	Straw/Dark Blue	Silver/Straw
0.079 (2 mm)	0.60% Air	Straw/Dark Blue	Straw
0.079 (2 mm)	0.79% Air	Straw/Dark Blue	Silver/Some Straw
0.079 (2 mm)	0.79% Air	Straw/Dark Blue	Silver/Some Straw
0.079 (2 mm)	0.97% Air	Straw/Dark Blue	Silver/Some Straw
0.079 (2 mm)	0.97% Air	Straw/Dark Blue	Silver/Some Straw
0.079 (2 mm)	HP-Argon (No. 12 Cup)(c)	Blues	Light Blue/Burgundy
0.079 (2 mm)	HP-Argon (No. 12 Cup)(c)	Blues	Light Blue/Burgundy
0.079 (2 mm)	HP-Argon (No. 8 Cup)(c)	Burgundy/Blues	Burgundy
0.079 (2 mm)	HP-Argon (No. 8 Cup)(c)	Burgundy/Blues	Burgundy

(a) All welds were made at 3.5 in./min travel speed, 11°C/s cooling rate.
(b) HP-Argon = high-purity Argon ≥ 99.998% pure by volume, 100% Argon ≥ 99.985% pure by volume.
(c) An argon gas trail shield was not used to protect the cooling weld bead after solidification; trail shield length = 3 in. (76.2 mm).

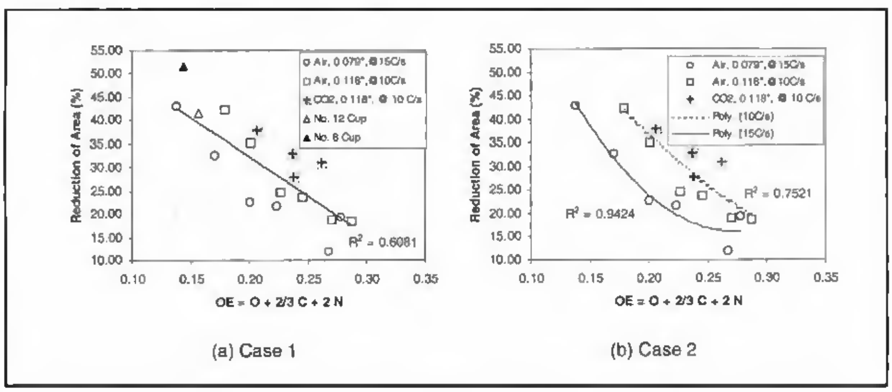


Fig. 7 — OE_{CP} effects on longitudinal tensile reduction of area.

the same solution or performance in fitting the regression model. Besides, it was more conventional to let other C varies as the proportion of oxygen coefficient while keeping the oxygen coefficient to the value of 1. Solving the above problem yielded the oxygen equivalent coefficient matrix, C.

Results and Discussion

Weld Color Observations

The color of the titanium weld varied between tests depending on the welding parameters, sheet thickness and alloy type (CP or Ti-6AL-4V). Welds made using contaminated torch shielding gas used pure argon backing and trailing shields to protect the molten metal from further contamination. As a result, welds made on the 0.079-in. (2.0-mm) CP Grade 2 titanium using air-argon torch shielding gases of up to 0.60% air were essentially silver — Table 5. Straw-colored welds were made with the 0.79 and 0.97% air-argon shielding gases. The HAZ color changed through a spectrum of colors from silver to straw to dark blue as the air content of the torch shielding gas increased from zero to 0.43% to 0.97%, respectively. The weld color of the autogenous welds made on the 0.118-in. (3.0-mm) CP Grade 2 titanium was straw or darker because the 3-in. (76.2-mm) long trailing shield was too short to provide complete trailing gas coverage during cooling of the thicker section, which was also welded at a higher travel speed. The same problem was observed on the two thicknesses of Ti-6Al-4V. The operator witnessed the color change as the hot weld metal left the protection of the trailing shield.

The color of titanium welds is related to the oxidizing conditions of the torch and trailing shield during welding, the peak temperature and the weld metal cooling rate. Higher air contents in the shielding gas were more likely to contaminate the trailing shield gas and promote darker weld colors. Slower cooling rates also promoted darker colors since the weld metal was at higher oxidation temperatures as it left the protection of the argon trailing shield. The silver welds produced with air-argon shielding gases were probably a result of the weld pool absorbing the majority of the air contaminates and the slower weld travel speed, which permitted cooling below the oxidation temperature range before the weld metal left the protection of the trailing shield. Therefore, a silver weld can be contaminated when the majority of the contamination is absorbed by the weld pool area at very high temperatures, any surface oxides that form are dissolved into the subsurface, and the trailing shield is long enough to assure argon coverage to weld metal temperatures below 840°F (449°C). However, the weld craters of the welds made with air-contaminated shielding gases were discolored due to prolonged exposure during torch shielding postpurge. In addition, the tungsten electrodes were degraded by the contaminated shielding gases. Oxide whiskers grew on the end of the electrodes and the size of the whiskers increased with increasing air or CO_2 content in the torch shielding gas.

Autogenous welds also were made on the 0.079-in. (2.0-mm) thick CP titanium with just a No. 8 and a No. 12 cup using HP argon and no trailing shield. Table 5 shows these welds were very discolored. The weld face color of the No. 8 cup test was burgundy. The HAZ color was a rainbow of color where the far HAZ was straw and the color sequence went from burgundy to blues to silver hiatus (Ref. 8) and then repeated the sequence near the weld interface. The weld crater and adjacent material on these welds were silver from the shielding gas postpurge, indicating adequate gas shielding over the weld pool area. Therefore, the color seen on the No. 8 and No. 12 cup welds was primarily due to surface oxides that formed after solidification.

CP Titanium Weld Properties

Transverse tensile tests were initially performed on the autogenous 0.079-in. (2-mm) thick welds, but the results did not relate to the effects of air contamination since all of the specimens broke in the softer HAZ where grain coarsening had occurred. The ultimate strength of these transverse tests varied from 56.7 to 63.0 ksi (390.9 to 434.4 MPa). This was slightly less than the base metal ultimate strength, which averaged near 70 ksi (482.6 MPa) but was greater than the ASTM requirements of 50 ksi (344.7 MPa) for Grade 2 — Table 1.

Longitudinal tensile tests provided a better measurement of weld metal strength (Figs. 4 and 5) and ductility (Figs. 6 and 7). An autogenous weld made at 15°C/s cooling rate with 0.97% air-argon torch shield had the highest strength and lowest ductility. The properties were 73.0 ksi (503.3 MPa) yield strength, 81.0 ksi (558.5 MPa) ultimate strength, 9.2% elongation and 19.3% RA. Welds made with high-purity argon had the lowest strength and highest ductility. The range of tensile properties for these welds was 53 to 56 ksi (365.4 to 386.1 MPa) yield strength, 63 to 66 ksi (434.4 to 455.0 MPa) ultimate strength, 29 to 31% elongation and 42 to 43% RA.

Welds made without trailing shields using just the No. 12 or No. 8 cup had essentially the same tensile properties as welds made with high-purity argon. It appeared the oxide and alpha-case layers on the No. 12 and No. 8 cup test welds, which were left in the as-welded condition, were not thick enough to affect tensile properties. Table 3 confirms the composition of these welds was essentially the same as welds made with high-purity argon and an argon trailing shield. The properties exceeded ASTM requirements for Grade 2 base material — Table 1.

Oxygen equivalents for welds made with high-purity argon shielding gas varied from 0.141 to 0.181 wt-% for the 0.079- and 0.118-in. (2- and 3-mm) thicknesses, respectively. The latter material heat had a higher as-received oxygen content and strength. The OE of the No. 8 and No. 12 weld tests, which were made on the 0.079-in. titanium, was 0.149 and 0.156 wt-%, respectively. It was concluded no appreciable contamination occurred in the welds made without trailing shields because mechanized GTAW was employed under very controlled conditions where proper torch shielding protected the weld pool.

Longitudinal weld metal tensile results for CP titanium welds were compared to the oxygen equivalent equation, OE = 2/3C + O + 2N. As expected, strength increased (Figs. 4 and 5) and ductility decreased (Figs. 6 and 7) as the oxygen equivalent increased for CP titanium welds. In each of these figures, the data is graphed two ways: a best fit of all the data (Case 1) and two curves to fit data as a function of cooling rate (Case 2). The two case approach to analysis was used to determine if weld metal cooling rate over a range from 10 to 15°C/s had an effect on properties. The cooling rate between 800 to 500°C (1472 to 932°F) was determined to be approximately 10 and 15°C/s for the 0.118- and 0.079-in. (3- and 2-mm) welds, respectively. These cooling rates are representative of manual GTA welds.

Ultimate strength (Fig. 4) varied from 63 to 81 ksi (434.4 to 558.5 MPa) over the

Table 6 — Average 95% Confidence Intervals (+, –) for Data Points from Weld Property Tests

Property	Commercially Pure Titanium 0.079-in. (2-mm) thick	Commercially Pure Titanium 0.118-in. (3-mm) thick	Titanium 6Al-4V 0.080-in. (2.03-mm) thick	Titanium 6Al-4V 0.125-in. (3.17-mm) thick
Yield (ksi)	1.21	1.54	3.23	3.30
Ultimate(ksi)	1.49	1.26	3.24	2.70
Elongation (%)	2.24	4.57	1.29	1.00
ROA (%)	6.66	9.22	3.81	4.44
Rockwell	1.19 (R_B)	1.62 (R_B)	1.11 (R_C)	1.43 (R_C)
Vickers (VHN)	7.65	9.21	7.97	9.70

Table 7 — R^2 Comparison of OE Relationships

	CP Ti Case 1	CP Ti Case 2 f(cooling rate)	Ti-6Al-4V OE = 20.8C + 7.8N + 0 – 5.8 Fe
Yield Strength	0.7842	0.9943 (15 c/s) 0.8451 (10 c/s)	0.507
Ultimate Strength	0.8751	0.9978 (15 c/s) 0.8126 (10 c/s)	0.2843
Elongation	0.5722	0.9764 (15 c/s) 0.7107 (10 c/s)	0.4882
Reduction of Area	0.6081	0.9424 (15 c/s) 0.7521 (10 c/s)	0.1474
Rockwell B/C	0.8804	0.9949 (15 c/s) 0.8198 (10 c/s)	0.403
Vickers	0.8817	0.9754 (15 c/s) 0.8665 (10 c/s)	0.5023
Average R^2	0.7602	0.8898	0.3887

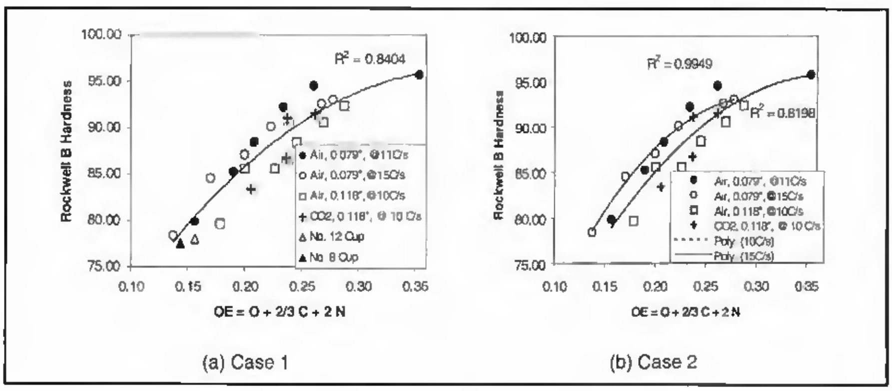


Fig. 8 — OE_{CP} effects on weld face hardness (Rockwell B).

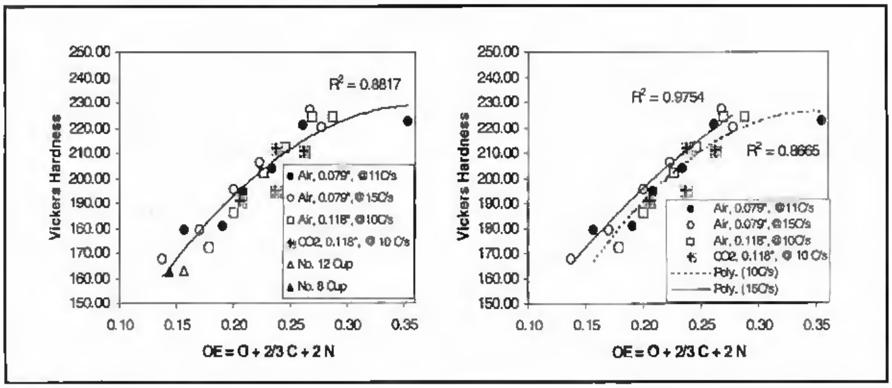


Fig. 9 — OE_{CP} effects on weld microhardness.

OE range of 0.14 to 0.30 wt-%. For ultimate strength, the coefficient of multiple determinations (R^2) was determined to be 0.87 for Case 1 and 0.99 and 0.81 for Case 2 cooling rate curves. The Case 2 analysis did not show significant benefit for improving the relationship between OE and ultimate strength since the Case 1 R^2 value was sufficiently high.

The Case 2 relationship was stronger when evaluating the other CP titanium weld properties, like weld metal yield strength as shown in Fig. 5. Here the R^2 was 0.78 for Case 1 and 0.99 and 0.85 for Case 2. The yield strength ranged from 53 to 73 ksi (365.4 to 503.3 MPa) over the oxygen equivalent range. A cooling rate effect was observed where the slower cooling 0.118-in. (3-mm) thick welds had a yield strength approximately 4 ksi (34.5 MPa) lower than the 0.079-in. (2-mm) thick welds as a function of oxygen equivalent — Fig. 5.

The relationship between oxygen equivalent and tensile ductility was dependent on cooling rate for the CP titanium welds (Figs. 6 and 7). In general, weld ductility decreased as the oxygen equivalent increased for CP titanium welds. Elongation ranged from 31% to 8% over the OE range of 0.14 to 0.30 wt-%, respectively. Reduction in area ranged from 43% to 10% over the same OE range. The OE_{CP} formula produced a good trend for both elongation and reduction of area for the Case 2 analysis where the R^2 values for elongation were 0.57 for Case 1 and 0.98 and 0.71 for Case 2 cooling rates. The welds made with the lower cooling rate (10°C/s) had approximately 7% more elongation and 10% more reduction in area than welds made at comparable oxygen equivalents at the higher cooling rate.

Most CP titanium welding applications require the weld ductility to be greater than 12% to 20% elongation depending on the application. Based on the welds made here, the minimum OE corresponding to these ductility levels would be approximately 0.24 to 0.18 wt-%, respectively. The latter oxygen equivalent was equal to the oxygen equivalent of the 0.118-in. (3-mm) CP base metal. Therefore, care should be exercised when procuring CP titanium when high ductility is required in the weld metal. Since oxygen has been reported to affect toughness, especially at cryogenic temperatures, the effects of oxygen equivalent on toughness and corrosion resistance is another area for future work.

The tensile ductility of the single-pass welds made without trailing shields was essentially the same as the welds made with trailing shields using proper torch argon shielding. These tests were conducted with the alpha case left in the as-welded condition. Even though the tensile ductility of these tests was acceptable, mixed results were obtained in a prior investigation of bend tests (Ref. 1) that were performed on as-welded longitudinal test specimens. In this investigation, bend tests performed at 2T bend radii (20% strain) passed, but one of four bend tests performed at 4T bend radii (12% strain) failed due to two small cracks that formed on one side of the weld interface. This bend failure was hard to explain, but reinforces the risk a fabricator would take if welds are put in service with thick oxide and alpha case. Based on previous bend test results on single-pass welds, it did appear that some thickness of oxide and alpha case could be tolerated before bend ductility is unacceptable. The effects of oxide and alpha case on fatigue performance may be more severe and is another area that needs to be quantified for weldments. The alpha case that formed on the CP titanium welds made without trailing shields was not obvious in metallographic cross sections.

Rockwell B hardness measurements were made on the weld face and root on each welding test so data generated here could support the use of portable hardness testers that are being considered for weld inspection. The difference in hardness between the weld face and root was small but, in general, the weld face was slightly harder. This indicated the contamination introduced into the weld pool was mixed through the weld thickness. The weld face probably had a slightly higher concentration of interstitial elements. The weld face Rockwell B hardness (Fig. 8) averaged about 78 R_B for the single-pass welds made with high-purity argon shielding gas with or without a trailing shield. The 0.079-in. (2-mm) thick base material used on these tests had a hardness of approximately 81.5 R_B. The 0.118-in. (3-mm) thick base material had a hardness that averaged 86 R_B. The cast grain structure of the weld metal was believed to cause the lower hardness between the weld metals and base materials, which were wrought. Hardness measurements on the HAZ were always lower than the base metal due to grain coarsening of the single-phase HCP alpha.

Weld metal Rockwell B hardness increased as the oxygen equivalent increased for these autogenous welds — Fig. 8. The hardness ranged from 78 to 95 R_B over an OE range of 0.14 to 0.35 wt-%, respectively. The 0.079-in. (2-mm) thick welds made with 0.97% air (0.354 oxygen equivalent) had the highest macrohardness of approximately 95 R_B. The 0.118-in. (3-mm) thick welds were approximately 2 R_B softer than the 0.079-in. (2-mm) thick welds as a function of oxygen equivalent due to the lower cooling rate. The cooling rate effect did not appear to be as strong for Rockwell B hardness. The R^2 values for the curves shown in this figure was 0.84 for Case 1, and was 0.99 at 15°C/s and 0.82 at 10°C/s for the Case 2 cooling rates.

AWS D10.6-91 notes that a satisfactory weld should have a hardness that does not exceed the base metal hardness by 5 R_B (which is equivalent to about 30 H_V) and peak hardness should not exceed 100 R_B. The macrohardness of the 0.079-in. (2-mm) thick base material in this investigation averaged about 81.5 R_B. Based on AWS recommendations, welds with a hardness of up to 86.5 R_B with an oxygen equivalent of 0.20 wt-% should be acceptable. This oxygen equivalent correlated to approximately 16% elongation, which should be acceptable on applications with a 4T bend criteria. Likewise, a hardness of 91 R_B should be acceptable for the 0.118-in. (3-mm) thick material based on the +5 R_B rule. This

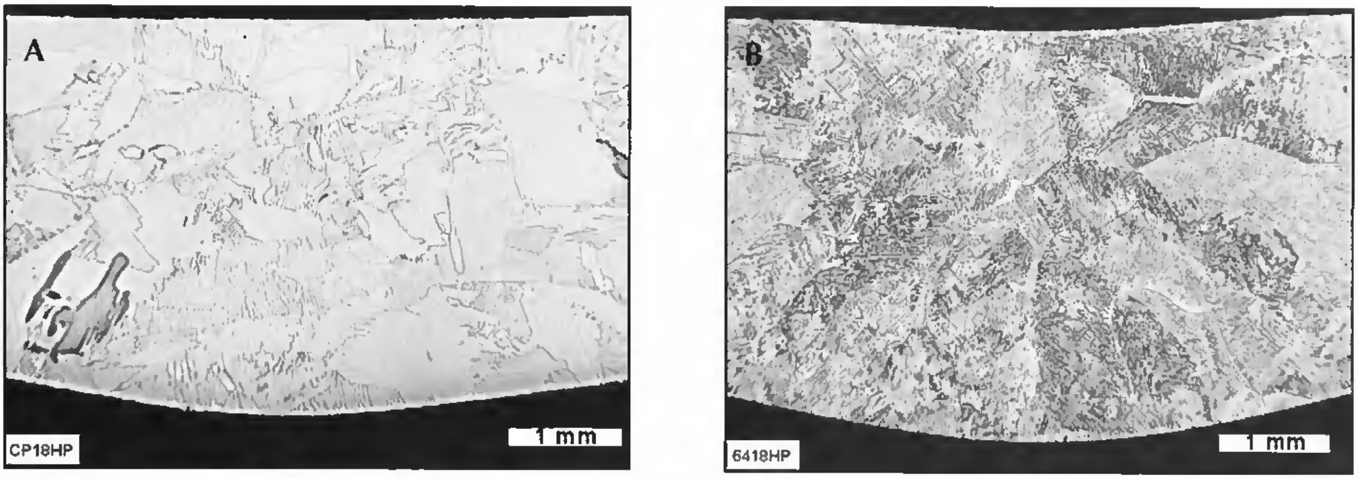


Fig. 10 — Macrostructure of autogenous welds. A — Serrated Alpha in CP titanium; B — Acicular Alpha and Beta with Alpha on prior Beta grain boundaries in Ti-6Al-4V.

hardness correlated to an oxygen equivalent of 0.30 wt-% and an elongation of 10%. Based on the results here, the +5 R_B rule provided as a recommendation in AWS D10.6-91 will be sensitive to the starting composition of the base material, the contamination absorbed during welding and the weld cooling rate. The rule should probably be used with caution depending on interstitial content of the base material and the ductility required on the welding application.

Vickers microhardness measurements (Fig. 9) were made on a metallographic cross section from each CP titanium weld. Microhardness averaged less than 165 H_V for the welds made with high-purity argon shielding both with and without trailing shields. For the welds made with contaminated shielding gas, the microhardness increased as the oxygen equivalent of the weld metal increased to a maximum of 225 H_V at 0.29 wt-%. The 0.118-in. (3-mm) thick welds had a microhardness that was approximately 5 H_V lower than the 0.079-in. (2-mm) thick welds as a function of oxygen equivalent due to the lower cooling rate. The R^2 value for the curves shown in Fig. 9 was 0.88 for Case 1, and was 0.98 at 15°C/s and 0.87 at 10°C/s for the Case 2 cooling rates. As with Rockwell B hardness, the effects of cooling rate on Vickers hardness was not as great as for tensile strength or ductility.

The average 95% confidence level band was calculated for each data point on Figs. 4 through 9, as shown in Table 6. For Vickers hardness, the average variation in a group of measurements was ±7.5 H_V. Microhardness testing required an average of at least six to nine intragranular measurements to account for the scatter caused by grain orientation. A bimodal hardness distribution was typically observed on Vickers hardness data and was believed to be due to the anisotropic mechanical behavior of alpha HCP titanium. The operator believed this hardness distribution could be correlated to the etching of the sample (*i.e.*, light vs. dark etching grains). Based on these results, an average of a large group of microhardness measurements is recommended when assessing the hardness of titanium welds.

Overall, the oxygen equivalent formula produced a uniform relationship for most of the weld metal test conditions evaluated in this investigation for CP titanium. A comparison of R^2 values between Case 1 (which evaluated a direct relationship to the OE) and Case 2 (which evaluated an indirect relationship to OE as a function of cooling rate) was performed as shown in Table 7. The average R^2 value calculated by averaging the sum of all the individual R^2 calculations was 0.76 for Case 1. This was significantly lower than 0.89 for Case 2, which factored the effects of cooling rate. Based on this analysis, it appeared CP titanium weld properties were sensitive to cooling rate. Most of the variability observed in the Case 2 analysis was from the tests performed at 10°C/s cooling rate on the 0.118-in. (3-mm) material where both air-argon and CO_2-argon contamination was evaluated. This additional variability could be attributed to either the accuracy of the OE equation to account for the interactive effects of each interstitial element, carbon, oxygen and nitrogen; or the effects of iron additions that varied from 0.03 to 0.06 wt-% between the two heats of CP titanium material that was evaluated here. Future work should perform a more systematic evaluation of the factors that control properties in CP titanium welds. These factors should include interstitial and iron content, and weld metal cooling rate based on this investigation.

Metallographic analysis of the CP titanium test welds was performed to characterize any differences in microstructure due to air or CO_2 contamination. In general, the welds had a serrated alpha grain structure — Fig. 10. Some areas had some Widmanstätten structures. The Widmanstätten structure is reported to become more dominant in CP titanium as the oxygen and nitrogen content increase (Refs. 2, 3). The intragranular areas had a platelike substructure where the interplate boundaries are probably rich in iron and may have some beta phase present. The iron content was low, approximately 0.03 and 0.06 wt-% in the 0.118- and 0.079-in. (3- and 2-mm) materials, respectively. The low iron content of these heats would probably provide enhanced corrosion resistance and toughness. Iron is considered a solid-solution strengthener in CP titanium. Heats too low in iron are possibly more susceptible to hydride precipitation (Ref. 11). Hydrides have been observed to precipitate in commercial heats containing iron near 0.3 wt-% at hydrogen levels near 100 to 150 ppm. High-purity titanium was found to precipitate hydrides at 40 ppm hydrogen (Ref. 11). No hydride needles were observed in these metallographic cross sections and the welds made here typically had less than 20 ppm hydrogen. No differences were observed in substructure due to differences in carbon, nitrogen or oxygen content under optical metallographic examination.

Ti-6Al-4V Weld Properties

Several differences were observed when comparing the welding characteristics and weld properties of CP titanium and Ti-6Al-4V. The first difference was there were almost no changes in weld metal cooling rate in the Ti-6Al-4V welds

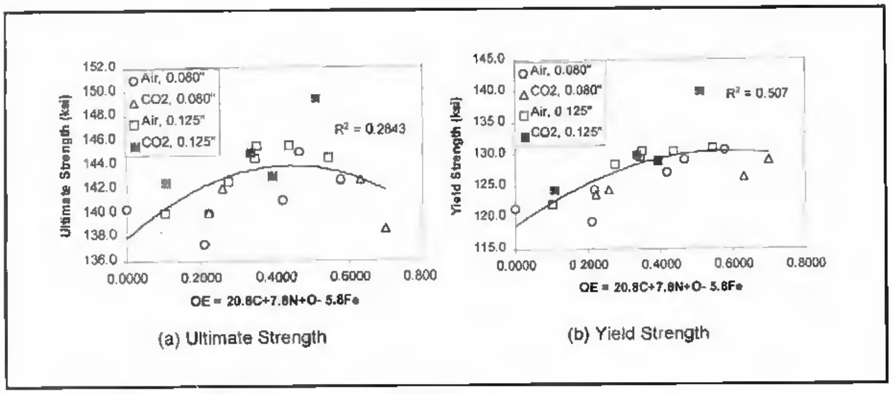


Fig. 11 — $OE_{Ti\text{-}6Al\text{-}4V}$ effects on longitudinal weld strength.

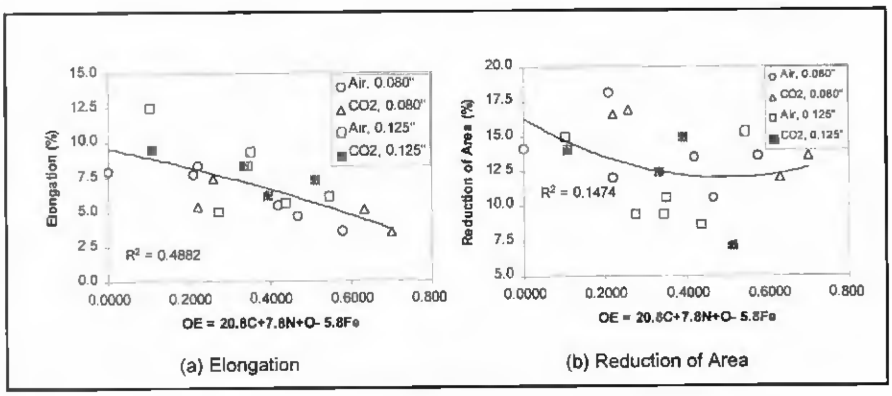


Fig. 12 — $OE_{Ti\text{-}6Al\text{-}4V}$ effects on weld ductility.

due to welding different thickness materials. In CP titanium, the cooling rate was either 15 or 10°C/s for full-penetration welds that had a ¼-in. (6.35-mm) root bead width at 7.75 in./min (3.28 mm/s) travel speed as the thickness was changed from 0.079- to 0.0118 in. (2 to 3 mm), respectively. For Ti-6Al-4V full-penetration welds with ¼-in. (6.35-mm) root bead width, there was only a slight variation in cooling rate for the two thicknesses of materials, 0.080 and 0.125 in. (2.03 and 3.17 mm), that were evaluated. The 0.080-in. (2.03-mm) material was welded at 8.5 in./min (3.6 mm/s) travel speed and the weld metal cooling rate between 800 and 500°C (1472 and 932°F) was 12.5°C/s. For the 0.125-in. (3.18-mm) material welded at 9.0 in./min (3.81 mm/s) travel speed, the cooling rate was 11.8°C/s. The low thermal conductivity of Ti-6Al-4V was believed to nullify the effects of thickness on the tests performed here. The backing fixture used in this investigation had a 2-in. (50.8-mm) wide gap to minimize tooling effects and simulate non-backed welding applications. Therefore, for this investigation the effect of cooling rate on Ti-6Al-4V weld properties was considered negligible and was not related to the oxygen equivalent. Literature suggests the effects of cooling rate are much stronger in Ti-6Al-4V compared to CP titanium due to the solid-state phase transformation that occurs with changes in cooling rate. Future investigations may consider comparing different weld processes to produce stronger changes in weld metal cooling rate, use materials with greater thickness differences, or force cool the weld metal to study cooling rate effects on OE relationships.

The second observation was that a new OE equation needed to be developed for Ti-6Al-4V weld metals to better relate the factors that affect weld properties. The Ti-6Al-4V weld metal properties measured here were first related to the oxygen equivalent equation that was used for CP titanium, $OE_{CP} = 2/3C + O + 2N$, but the data fit was poor and unacceptable. In general, the welds contaminated with carbon and oxygen (from CO_2-argon contamination) were observed to have higher strength and hardness and lower ductility than welds made using air-argon contamination at the same relative OE_{CP} level. It was apparent carbon was a more potent strengthener in Ti-6Al-4V than in CP titanium. A statistical regression analysis was performed to derive a new oxygen equivalent formula to best fit the Ti-6Al-4V data. The new OE equation was determined by maximizing the R^2 value for each weld metal property and was the following:

$$OE_{Ti\text{-}6Al\text{-}4V} = 20.8C + 7.8N + O - 5.8Fe \text{ (wt-\%)}$$

This equation indicates carbon has 20.8 times the effect on weld metal properties as does oxygen. Nitrogen is 7.8 times and iron is negative 5.8 times more potent than oxygen. Due to the larger factors, the oxygen equivalent range calculated by this equation is much larger than produced by the OE_{CP} equation. The most significant change relative to the OE_{CP} equation is the increase in the carbon factor from 2/3 to 20.8. Nitrogen was increased from 2 to 7.8 and a factor was added for iron, which has a negative effect. Iron was not measured in the composition analysis of each weld metal test. The iron factor was determined by assuming constant base metal content for each material heat per the levels shown in Table 1. The maximized R^2_{AVG} was 0.39 and was calculated by averaging the R^2 values for each property shown in Table 7. This was considered a weak fit overall and indicated the oxygen equivalent relationships for Ti-6Al-4V, based on interstitial content, do not work since these elements had such a small effect on strength, hardness and ductility. Other factors that were not controlled in these tests, such as the actual iron, aluminum and vanadium content, and prior beta grain size (Ref. 15), may need to be studied to properly characterize all the factors that affect Ti-6Al-4V weld metal properties.

Even though correlation was poor for the relationships measured, there were small trends between $OE_{Ti\text{-}6Al\text{-}4V}$ and the different weld properties. The relationship between $OE_{Ti\text{-}6Al\text{-}4V}$ and tensile strength (Fig. 11), tensile ductility (Fig. 12) and hardness (Fig. 13) were graphed for analysis. The relationship between ultimate strength and $OE_{Ti\text{-}6Al\text{-}4V}$ was fairly weak as shown in Fig. 11A where the R^2 value was only 0.28. The ultimate strength of the cast weld metal varied from 137 to 146 ksi (944.6 to 1006.7 MPa) over an OE range of 0.10 to 0.70 wt-%. Ultimate strength slowly increased with increasing OE but appeared to slightly decrease at $OE_{Ti\text{-}6Al\text{-}4V}$ greater than 0.50 wt-%.

The Ti-6Al-4V oxygen equivalent relationship was slightly better for weld metal yield strength (Fig. 11B) where the R^2 value increased to 0.51. Yield strength increased as the oxygen equivalent increased as expected. The yield strength varied from 120 to 130 ksi (827.4 to 896.3 MPa) as the oxygen equivalent increased from 0.10 to 0.70 wt-%. No difference in yield strength was observed between the 0.080- and 0.125-in. (2.03- and 3.17-mm) thicknesses of material since the welds had approximately the same cooling rate. Weld metal yield strength was lower than the base materials when comparing the weld properties from the high-purity argon shielding tests. The yield strength of the base material was 132 and 140 ksi (910.1 and 965.3 MPa) for the 0.080- and 0.125-in. (2.03- and 3.17-mm) thicknesses, respectively. The heat treatment condition for the 0.125-in. (3.17-mm) Ti-6Al-4V sheet was not reported. The 0.080-in. (2.03-mm) base metal was supplied in the annealed condition where the heat treatment parameters were 770°C (1418°F) for 10 minutes then air-cooled.

Weld metal elongation decreased with increasing oxygen equivalent — Fig. 12A. The weld metal elongation varied from approximately 10 to 4% as the oxygen equivalent increased from 0.10 to 0.70 wt-%. The R^2 value for the curve in this graph was 0.49, which again indicated the relationship was weak. The high-purity argon shielding test had the highest elongation of 12.5%. The lowest elongation was 4% and was produced using the 1.0% CO_2-argon shielding gas. Tensile ductility measurements on Ti-6Al-4V welds were believed to be sensitive to the coarse-grain structure, which can behave anisotropically, and the limited ductility of the high strength Ti-6AL-4V weld metals. The data fit was worse for reduction of area (RA) (Fig. 12B) where the R^2 value decreased to 0.15, indicating a poorer relationship. The high-purity shielding gas tests averaged between 14 and 15% RA at $OE_{Ti\text{-}6Al\text{-}4V}$ values of approximately 0.1 wt-%. At higher $OE_{Ti\text{-}6Al\text{-}4V}$ values greater than 0.20 wt-%, the RA ranged from 8 to 15% and showed almost no relationship to OE.

Rockwell C hardness measurements were made on the weld face of each test weld — Fig. 13. Hardness increased from approximately 30 to 36 Rockwell C over the range of oxygen equivalents tested. This was a small hardness range and showed the hardness of this titanium alloy was more dependent on microstructure than interstitial content. The 95% confidence level for this data (Table 6) was about the same as the CP titanium data, but there was more variation as a function of oxygen equivalent. The R^2 value for curve in Fig. 13A was 0.40. The hardness of the welds made with high-purity argon was 30 to 32 R_C. The same trend was found in Fig. 13B, which shows the Vickers hardness data where the R^2 value was 0.50. The Vickers hardness ranged from 327 to 358 over the $OE_{Ti\text{-}6Al\text{-}4V}$ range. Welds made with high-purity argon had a Vickers weld metal hardness of 332 to 335. The limited range of hardness in the Ti-6Al-4V welds is closely related to the range of ultimate strength, which was also small in this high-strength material over the range of compositions evaluated here. The use of hardness testing to assess the quality level of Ti-6Al-4V welds appears not feasible, based on the variance in data.

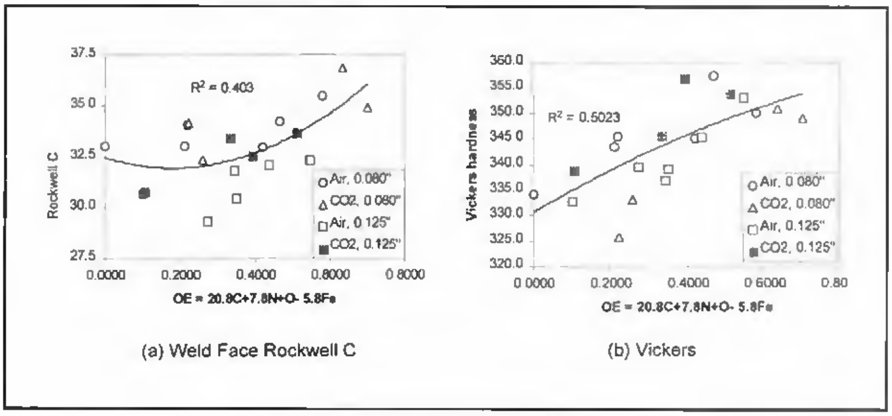


Fig. 13 — $OE_{Ti\text{-}6Al\text{-}4V}$ effects on weld hardness.

Metallographic analysis of the Ti-6Al-4V test welds was performed to characterize any differences in microstructure due to air or CO_2 contamination. In general, all the welds had acicular alpha and beta substructure with alpha on prior beta grain boundaries — Fig. 10. This microstructure was not believed to contain any alpha prime, which is a martensitic transformation product. These welds had a low cooling rate of about 12°C/s, so the transformations should have been due to nucleation and growth processes. Hydrides are difficult to form in Ti-6Al-4V due to the high content of beta stabilizers and are not likely in these microstructures due to their low hydrogen content.

Overall, Ti-6Al-4V is a high-strength material that has low to moderate ductility. The high strength can be related to its high hardness. The properties of Ti-6Al-4V welds are largely influenced by prior beta grain size, microstructure, solid-solution strengthening primarily by aluminum, and by second phase effects induced through transformations. It appears from the data measured here interstitial strengthening had a small effect and minimizes the benefit of using oxygen equivalent relationships. Future work is needed to better characterize all the factors that control the properties of Ti-6AL-4V weld metal.

Conclusions

1. Oxygen equivalent formulas were used to relate weld metal mechanical properties to interstitial content and cooling rate for CP titanium. The mechanical property relationships that were characterized for CP titanium appeared to be dependent on weld metal cooling rate.

2. Macrohardness (Rockwell B) testing can be used to correlate weld face hardness of CP titanium to other weld mechanical properties and interstitial content via the oxygen equivalent formula, and could be used to assess for contamination. A hardness standard as a function of oxygen equivalent should be developed for each weld application and cooling rate.

3. The oxygen equivalent equation developed for Ti-6Al-4V could not be used to relate the effects of interstitial elements on weld metal properties.

Acknowledgments

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Structural Characterization of C-Mn Steel Laser Beam Welded Joints with Powder Filler Metal

Weld quality of butt-joint welds with beveled and square edges is investigated

BY S. MISSORI AND A. SILI

ABSTRACT. The possibility of performing successfully sound welds on steel using the laser beam welding (LBW) process with powder filler metal has been used to investigate possible advantages regarding an easier control of the composition of the welded zone. In this work, LBW joints were carried out on C-Mn steel plates with prepared square and beveled edges. Ni filler powder was used as a tracer of the powder penetration inside the joints. The examination of welds included metallographic work by optical and scanning electron microscopy (SEM), with microanalysis by energy-dispersive spectroscopy, to obtain indications on powder distribution. Mechanical properties were evaluated by Vickers microhardness tests.

Introduction

Welding with powder filler metal, using conventional techniques such as arc welding (Ref. 1) and submerged arc welding (Refs. 2–4), could enable enhanced deposition rates. Moreover, the powder addition can offer advantages in the chemical composition of the filler material, particularly where a controlled composition of the welded zone (WZ) is required or when welding materials are not easily combinable. Powder filler metal should allow an improvement of process stability as compared to the risks of incomplete fusion and sticking when using a wire filler material.

In this work, the LBW process has been used to verify the possibility of utilizing powder filler metal. The industrial application of this method could be of interest in the construction of vessels, equipment of large dimensions, ships, etc., thanks to the peculiar characteristics of laser beam welding, *i.e.*, easy automation of the process, reduction of the heat-affected zone and minimizing distortions and residual stresses.

The results of metallurgical investigations on C-Mn steel butt-joint welds, with two different preparations (square and beveled edges) are given. Observations by optical and scanning electron microscopy with microanalysis, by energy dispersive spectroscopy (EDS), were performed to evaluate the depth of powder penetration and the contribution of powder to the formation of a melted pool. The mechanical properties were measured by Vickers microhardness tests.

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Materials and Methods

Materials

Laser beam welding tests were performed on low-alloy C-Mn steel plates, 10 mm thick, specified as L24N (corresponding to a steel type AISI 15XX with an extra-low content of P and S impurities), having the chemical composition reported in Table 1. The plates were supplied in the normalized condition with a ferritic-pearlitic microstructure.

Commercially pure Ni powder (particle sizes in the range 20–50 μm), transported by an Ar flow, was employed as filler material. The Ni powder was utilized as a tracer because it allows an easy investigation into the distribution of the filler material and the evaluation of the penetration depth along the joint thickness.

KEY WORDS

C-Mn Steel
Powder Filler Metal
Laser Beam Welds (LBW)
Ni Powder Tracing
Welded Zone (WZ)
Heat-Affected Zone (HAZ)

Laser Beam Welding Procedure

The laser system was a continuous CO_2 unit, type TLF12000, with 9 kW of net power on the workpiece. The focusing device was a water-cooled, copper paraboloid mirror. The high power density, focused on a spot of dimension of the order of 0.5 mm, leads to the keyhole mechanism of energy transfer to the workpiece.

A sketch of the process is shown in Fig. 1. The system worked in robotic style with the plates placed in the flat position on a moving table that, translating below the laser head, allows the bead formation in a single pass.

A nozzle with three tubes, arranged as shown in Fig. 1, was utilized for the various gas flows. The welded zone protection was obtained by a primary Ar flow (25 L/min) through tube 3; the powder transportation by a secondary Ar flow (5 L/min) through tube 1; and the plasma control was performed by a He flow (10 L/min) through tube 2.

Many preliminary experiments were performed to optimize the geometric parameters that have a remarkable influence on the powder penetration inside the melted metal (Ref. 5). The nozzle was directed just above the interaction zone of the laser beam and workpiece, in proximity of the melted pool, with an inclination angle of 37 deg. This value was assumed in the middle of the range 30–45 deg in which plasma control and stability can be optimized. Moreover, the powder flow interaction with the workpiece

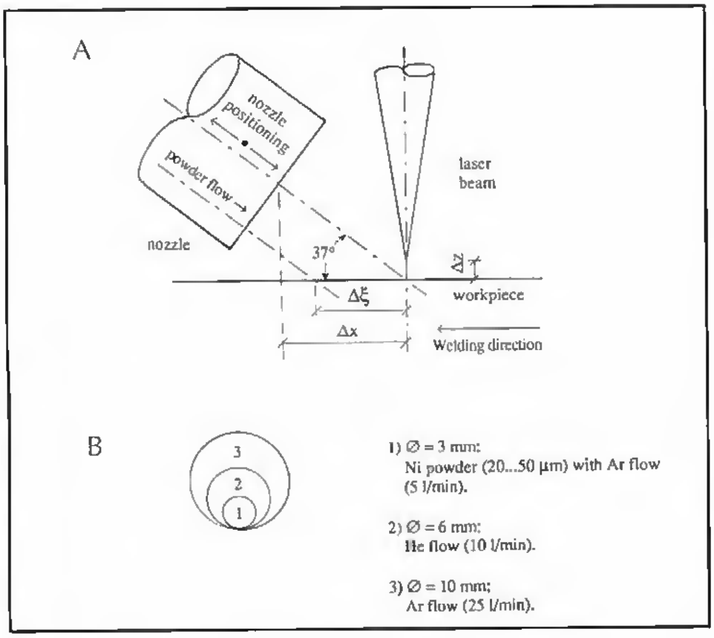


Fig. 1 — A — Sketch of the LBW process; B — nozzle section.

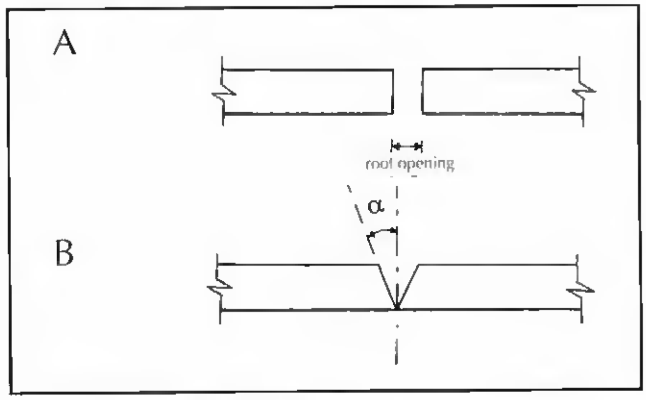


Fig. 2 — Plate preparation of butt-joint welds: A — square edges; B — beveled edges.

and the powder penetration inside the melted pool depend on nozzle and laser beam focus positions. With reference to Fig. 1, the powder trajectory, if approximated by the axis of the smaller tube intersects the workpiece surface at distance $\Delta\xi$ from the laser beam axis, has an optimized value equal to 5.8 mm. The distance Δz between the laser beam focus and workpiece surface has an optimized value equal to 1 mm, and the distance Δx between the nozzle center and the laser beam axis equal to 8 mm. In any case, according to the process sketched in Fig.1, an adjustment of nozzle positioning can be done by a little translation along its axis that changes the distance Δx, but keeps constant the distance $\Delta\xi$ between the powder impingement point and the laser beam axis.

Preliminary bead-on-plate tests were permitted to optimize the process parameters, such as the powder rates in the range 20–60 g/min or the welding speed in the range 0.5–1 m/min.

Butt-joint welds were performed on plates with square edges, with a root opening in the range 0–0.4 mm (preparation A), or beveled edge preparation, with bevel angle α = 3, 6, 9 deg and no opening at the root (preparation B), as reported in Fig. 2. The welding speed and powder rate values are given in Table 2.

Experimental Work

The welded plates were cut transversely to the bead to obtain samples of the welded sections. The samples were metallographically prepared by abrasive paper, polished by fine alumina and then etched by 2% Nital.

The following experimental work was performed on the metallographic samples.

A) Visual and macrographic inspections were performed. A minimum number of three macrographic samples per each procedure were cut and examined. The WZ area was measured for each sample.

B) Optical/SEM observations and microanalysis by EDS were performed on metallographic samples taken from each of the welding procedures in order to analyze WZ morphology and assess the Ni content along the thickness of the welds. The Ni content was measured along the centerline of the WZ by an electron probe in a SEM type JSM-35 CF, equipped with an energy-dispersive spectrometer model EDAX 711, at an accelerating voltage of 15 kV. The depth and diameter of the interaction pair were estimated at about 0.5 and 1 μm, respectively. The distance between two microanalysis measurements was equal to about 0.5 mm.

c) Vickers microhardness tests were performed to evaluate the mechanical properties in the welded joints. Measurements were extended to the entire thickness along the centerline of the WZ and to the heat-affected zone (HAZ). Vickers tests were performed with a load of 5 N and a loading time of 10 s.

Results

Visual and Macrographic Inspection

The samples submitted to visual and macrographic inspections confirmed the possibility of having sound welds with a good repeatability (Figs. 3, 4) for both joint preparations. In almost all cases, the penetration was complete along all the plate thickness, and the welds were free from cracks or other defects. However, occasional microcracks in the WZ were revealed. The average values of the WZ area, measured in each sample, are given in Table 3.

Samples welded with square edge preparation show inhomogeneities in the solidification structure, characterized by irregular banding in the WZ — Fig. 3.

Samples welded with beveled edge preparation show the best appearance of the WZ at visual and macrographic examination; the WZ is alloyed enough in Ni to be only weakly etched by Nital — Fig. 4.

Generally, the size and shape of the ferritic steel HAZ is regular and clearly distinct, even if some mismatch (step) of the edges is present, thus demonstrating a good bridgeability of the process. In the macrographs of Figs. 3 and 4, for both joint preparations, the HAZ is clearly observable. The width is gradually varied along the thickness in the range of 1–2 mm, being, in general, larger at the side exposed to the laser beam, corresponding to a wider melted zone.

Microanalysis by EDS

The profiles of Ni concentration along the centerline of the welded sections, which characterize the powder penetration, are reported in Fig. 5 for samples welded with both joint preparations. These diagrams report the best fit of the experimental results and show a Ni penetration along all the weld thickness with a content that, in general, is decreasing along the thickness, starting from the laser beam side. Moreover, the Ni concentration increases when the root opening or the bevel angle values increase.

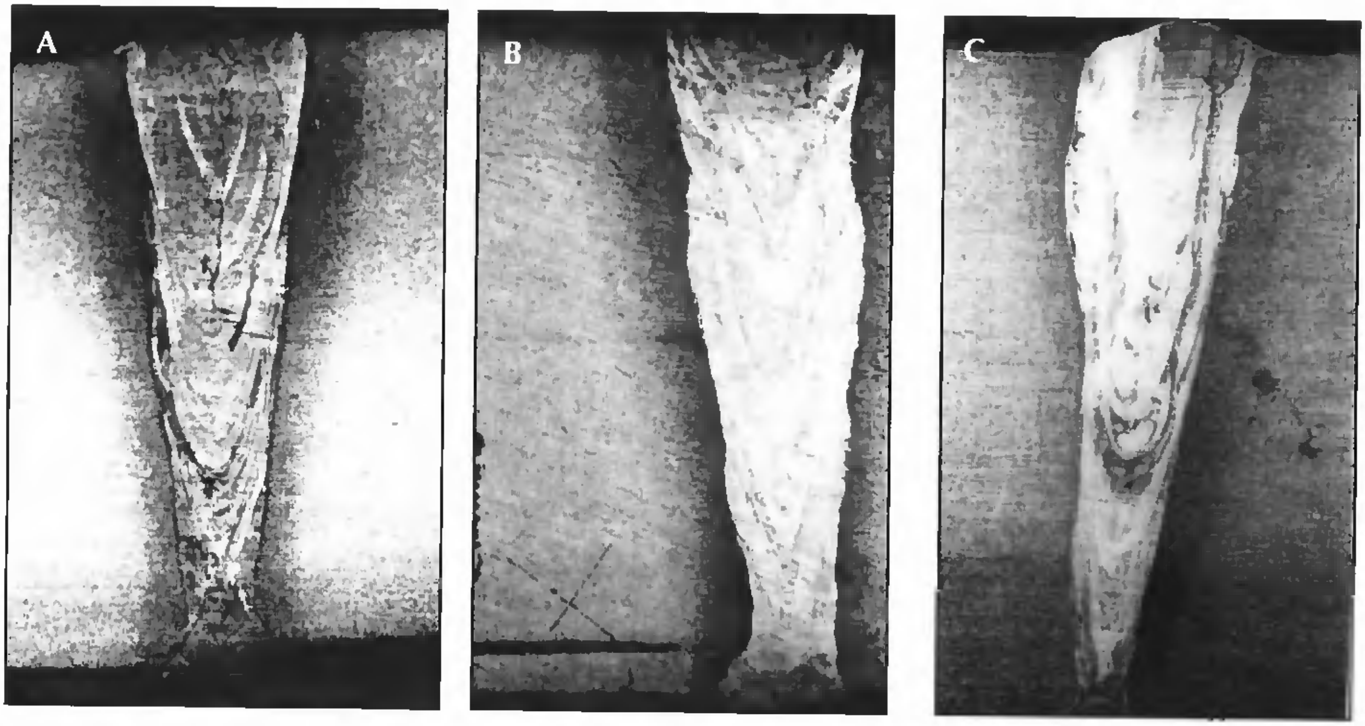


Fig. 3 — Macrograph of welds with square edge preparation: A — root opening = 0; B — root opening = 0.2 mm; C — root opening = 0.4 mm.

Table 1 — Base Material Composition

	C	Si	Mn	P	S	Cr	Ni	Ti	V	Nb	Al
L24N	0.13	—	1.05	0.009	0.002	0.030	0.030	—	—	—	0.041

For samples welded with joint preparation A, the Ni content is in the range 5–3% in weight (0–0.2 mm root opening) and in the range 14–6% in weight (0.4 mm root opening), with higher values at the outer surface (laser beam side).

The most satisfactory results, in terms of powder penetration, are obtained with joint preparation B. In these cases, the Ni content is substantially higher and better distributed along the weld thickness. With a bevel angle of 3 deg, the Ni content profile decreases along the weld thickness from about 22% at the outer surface (laser beam side) to about 10% in weight on the opposite side. With higher bevel angles — 6 and 9 deg — the Ni content is in the range from about 28% at the outer surface (laser beam side) to 20% in weight on the opposite side.

Table 2 — Welding Parameters

Joint preparation	Bevel angle α	Root opening (mm)	Power rate (g/min)	Welding speed (mm/min)
A) square edges		0	20	1000
A) square edges		0.2	20	1000
A) square edges		0.4	35	1000
B) beveled edges	3 deg		40	1000
B) beveled edges	6 deg		60	700
B) beveled edges	9 deg		60	500

Table 3 — Average Values of the WZ Area

Joint preparation	Bevel angle α	Root opening (mm)	WZ area (mm²)
A) square edges		0	21.2
A) square edges		0.2	21.9
A) square edges		0.4	19.4
B) beveled edges	3 deg		21.4
B) beveled edges	6 deg		28.8
B) beveled edges	9 deg		43.4

Optical / SEM Observations

A sample with beveled preparation (α = 3 deg) was taken as representative of the metallographic constituents obtained. The metallographic appearance of the WZ at low magnification is shown by the optical micrograph in Fig. 6; details of the solidification structures are

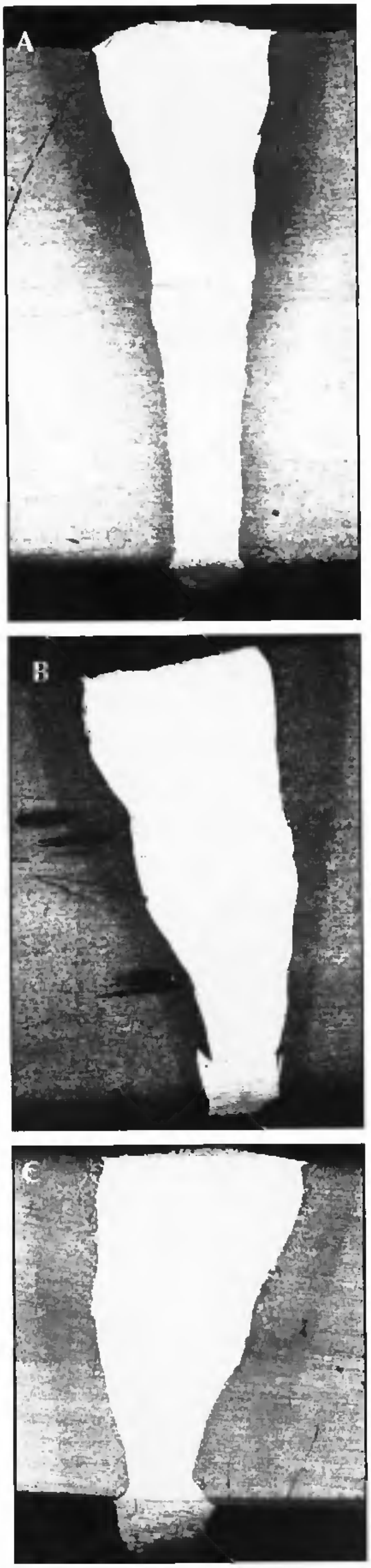


Fig. 4 — Macrograph of welds with beveled edges preparation: A — α = 3 deg; B — α = 6 deg; C — α = 9 deg;

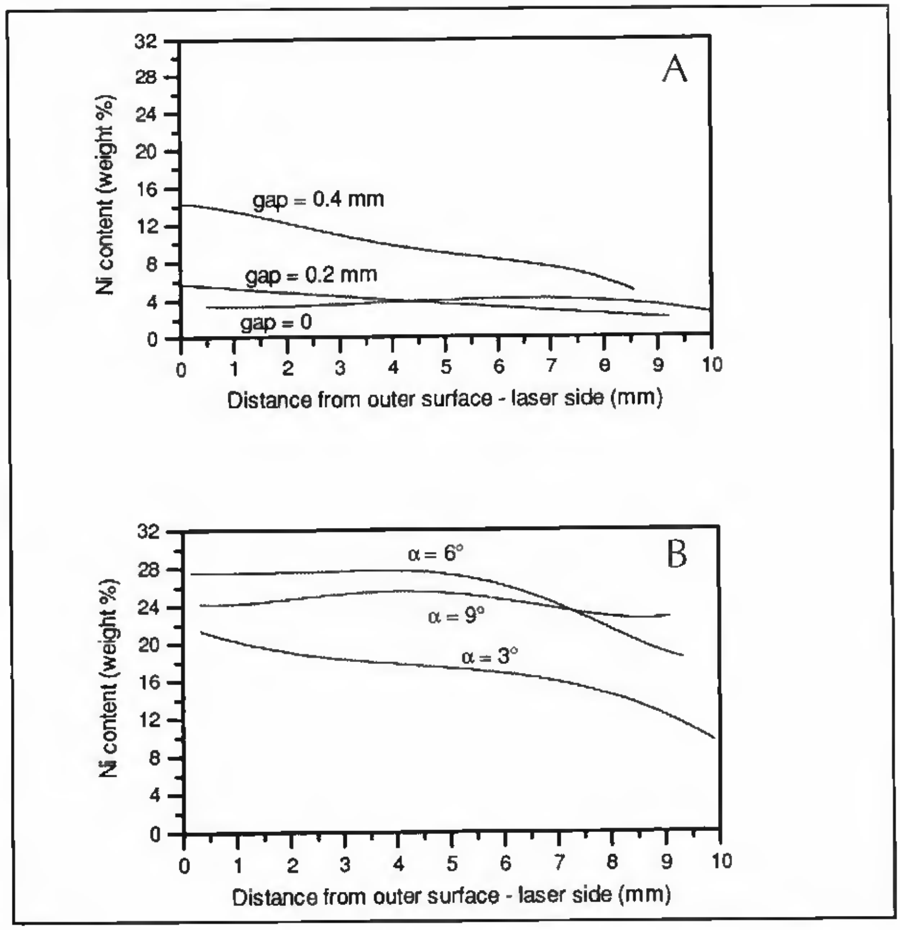
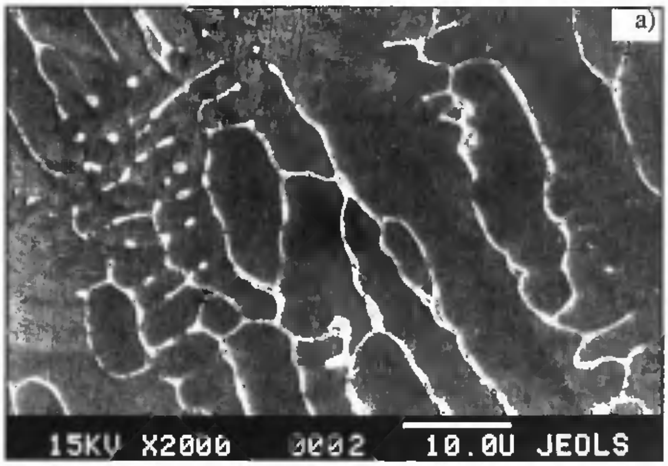


Fig. 5 — Profiles of Ni concentration along the centerline of the welded sections: A — square edge preparation; B — beveled edge preparation.

Fig. 6 — Optical micrograph at low magnification of the WZ for a sample with beveled edge preparation and α = 3 deg.



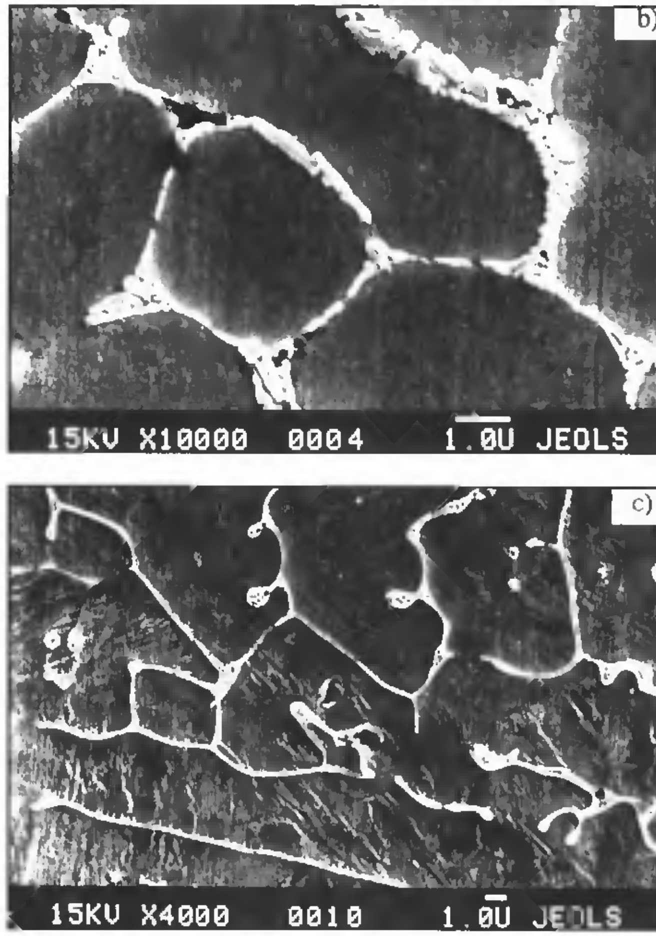


Fig. 7 — SEM images of the WZ for a sample with beveled edge preparation (α = 3 deg): near the outer surface at the laser beam side (a, b); at the opposite side (c).

given in the SEM micrographs of Fig. 7. The dendritic solidification structures of the matrix grain are surrounded by an intergranular constituent, whose nature was not identified.

Near the outer surface on the laser beam side (Fig. 7A), the matrix is supposed to be austenitic, according to the high Ni content, which gradually decreases from a value of around 22%, near the outer surface on the laser beam side, to a value of about 10%, on the opposite side — Fig. 5.

Local microanalysis measurements on the intergranular constituent gave a Ni content comparable to the one present in the matrix. On this basis, the interpretation of this constituent as the $FeNi_3$ intermetallic compound has to be excluded. Moreover, in this zone (Fig. 7B) some micropores of dark appearance and rounded elongated shape, having about 1 mm size, are present. These micropores have a morphology similar to that observed in materials produced by powder metallurgy (Ref. 6).

At the opposite side (Fig. 7C), the matrix is characterized by an acicular structure, suggesting the possible presence of martensite, according to the microhardness measurements. Here again, the intergranular constituent surrounding the dendritic matrix grains and some micropores are visible.

The same acicular structure can be observed in the samples welded with the square edge preparation (root opening = 0.4 mm) in the region with the highest values of microhardness — Fig. 8.

Vickers Microhardness Test

For samples welded with joint preparation A, the Vickers microhardness values, measured along the centerline of the welded section, are given in Fig. 9. The hardness fluctuations can be related to solidification structure inhomogeneities, as resulting from the distinct banding revealed by the macrographic inspection — Fig 3. The higher hardness values (above 450 HV) recorded for samples welded with 0.4 mm root openings confirm, on the basis of the Ni content measurements and SEM observations, the presence of martensitic structures.

For joint preparation B with the lower bevel angle (α = 3 deg), the measured values were in the range 200–480 HV — Fig. 10A. The relatively high microhardness values (average value 350 HV) in the zone distant 1–3 mm from the outer surface, laser beam side, are reasonable when taking into account the hardening effects of the high Ni content — Fig. 5. The peak value of 480 HV suggests the presence of martensitic structures, as supported also by the acicular morphology observed in the zone far from the laser beam side — Fig. 7C.

With the other values of bevel angle

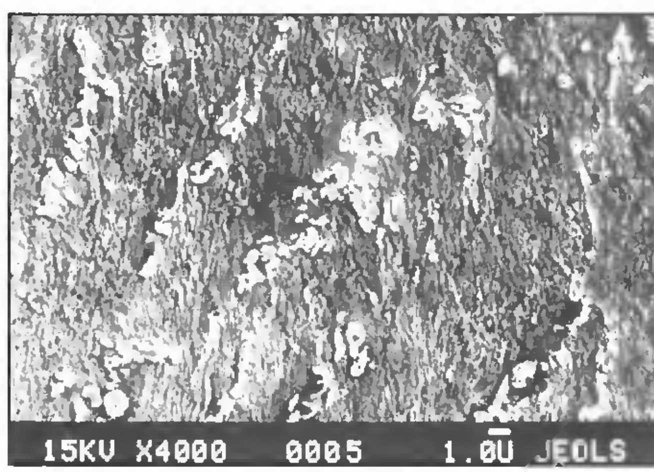


Fig. 8 — SEM images of the WZ for a sample with square edge preparation and root opening = 0.4 mm.

Table 4 — Expected and Experimental Average Ni Content

Joint preparation	Bevel angle α	Root opening (mm)	Expected Ni content (wt-%)	Average Experimental Ni content (wt-%)
A) square edges		0	11	4
A) square edges		0.2	11	4
A) square edges		0.4	22	10
B) beveled edges	3 deg		23	17
B) beveled edges	6 deg		36	25
B) beveled edges	9 deg		34	24

(α = 6 and 9 deg), the hardness profiles along the centerline of the welded sections are characterized by values around 200 HV and by the absence of relevant fluctuations — Fig. 10. Considering the high Ni content (a range of 20–28% in weight) recorded by microanalysis measurements, these low hardness values can be ascribed to austenitic structures, which are present along all the weld thickness.

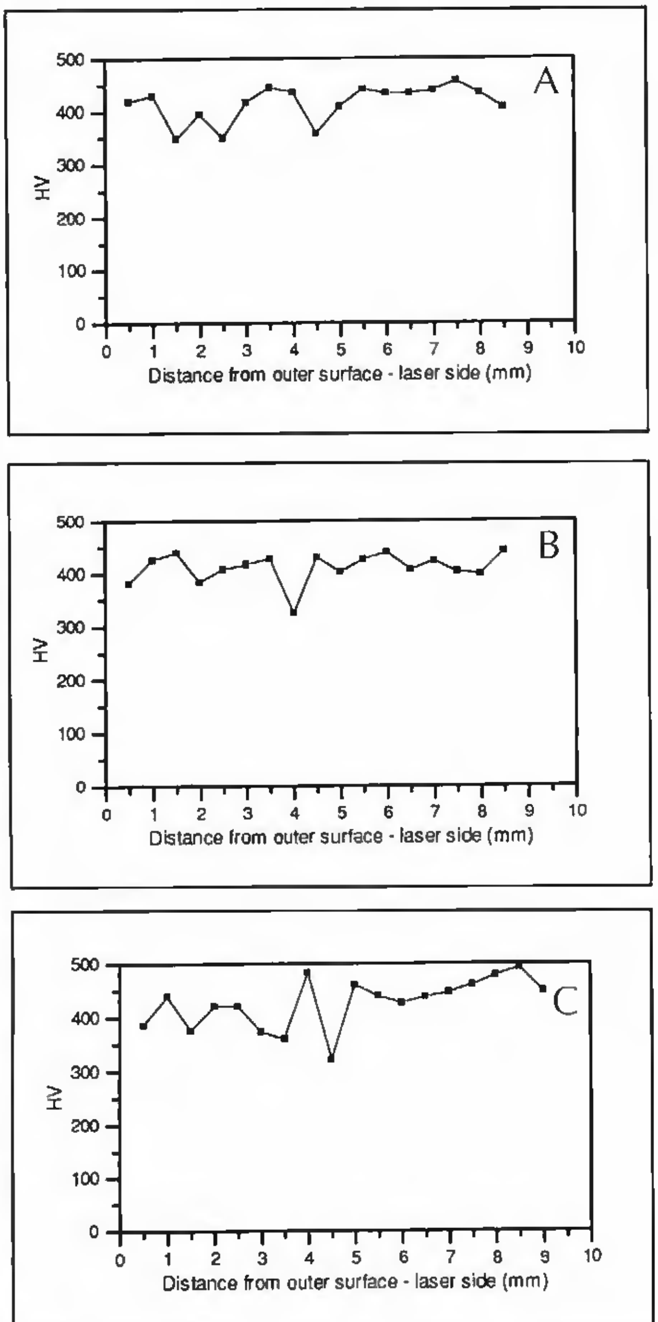


Fig. 9 — Vickers microhardness profiles along the centerline of the welded sections for samples with square edges preparation: A — root opening = 0; B — root opening = 0.2 mm; C — root opening = 0.4 mm.

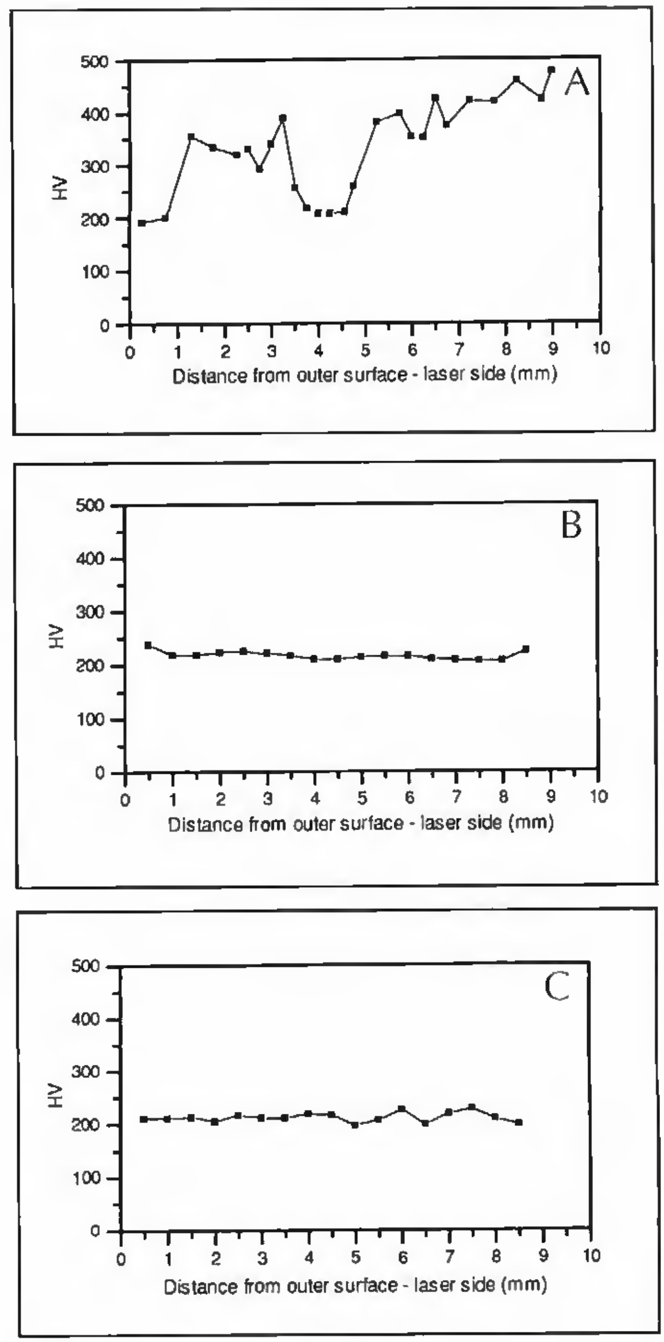


Fig. 10 — Vickers microhardness profiles along the centerline of the welded sections for samples with beveled edges preparation: A — α = 3 deg; B — α = 6 deg; C — α = 9 deg.

Discussion

In order to estimate which is the best geometry to convey the powder flow into the melted pool, the expected Ni content, calculated on the basis of the welding parameters and of the measured WZ area, was compared with the Ni content along the welded sections experimentally obtained by microanalysis.

As a result of microanalysis measurements, the contribution to the joint formation is given by the base metal, with density δ_{Fe}=7.87 10^{-3} g/mm^3 and concentration C_{Fe} (weight fraction), and by the Ni powder, with density δ_{Ni}=8.9 10^{-3} g/mm^3 and concentration C_{Ni} (weight fraction). So, for a welded volume having as base the WZ area A_S (mm^2) and a height of 1 mm, considering the powder rate p (g/min) and the welding speed v_S (mm/min), the expected Ni content is given by the following expression:

$$C_{Ni} = p/[(\delta_{Ni}C_{Ni} + \delta_{Fe}C_{Fe}) \times v_S \times A_S] \qquad (1)$$

The average value of the Ni content experimental profile along the welded section, obtained by microanalysis measurements, was considered representative of the Ni content along the welded sections.

In Table 4, expected and experimental average Ni content are compared for both joint preparations. The experimental average values are, in any case, lower than the expected ones, due to probable powder loss. From data reported in Table 4, the ratio of the experimental average Ni content to the expected Ni content results are about 0.4 for joint preparation A and about 0.7 for joint preparation B. So, the best results appear to be those obtained in the samples welded with a beveled joint, in which the experimental average Ni content shows the best approximation to the expected one.

With the beveled joint preparation, the powder conveyed by the gas flow is "funneled" and forced to melt into the space between the edges. On the contrary, when welding using square edges with little or no root opening, the possibility of the powder penetrating between the edges is drastically reduced and part of the filler powder is blown away with the process gas.

Generally, samples butt-joint welded with square edges gave rise to a low contribution of the powder filler metal to the formation of the WZ, revealed by the lean content of nickel and, occasionally, with presence of cracks observed on macrographs and micrographs.

In some welded sections of joints with beveled edge preparation, the presence of rounded and elongated micropores (representative size of 1 mm) were observed. These micropores are similar to those often found in materials produced by powder metallurgy.

Conclusions

The experimental work contributed to the setup of the laser beam welding process with a single pass by utilization of filler metal powder. The obtainable distribution of the filler metal and its alloy elements along the thickness of butt-joint welds was considered for two different preparations — square and beveled edges.

- The powder penetration along the weld thickness decreased starting from the outer surface at the laser beam side.
- For square edge preparation, the Ni content increased at the increasing of the root opening between plate edges, but it is always very low in respect to the expected value.
- The highest contribution of the filler powder to the formation of the weld zone was obtained with the beveled joint preparation, reaching about 70% of the Ni expected content.
- In some welded sections, particularly those for joints with beveled edge preparation, the presence of rounded and elongated micropores, similar to those often found in materials produced by powder metallurgy, were observed.

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Visualization of Marangoni Convection in Simulated Weld Pools Containing a Surface-Active Agent

Marangoni convection is reversed to go inward along the pool surface and downward toward the pool bottom, and deeper laser beam welds are produced when the agent is present

BY C. LIMMANEEVICHITR AND S. KOU

ABSTRACT. The theory that a surface-active agent can cause weld pool Marangoni convection to reverse itself – to go inward along the pool surface and downward toward the pool bottom and result in deeper weld penetration — was proposed by Heiple and Roper in 1982 and studied worldwide since then. To actually observe such a flow pattern, a simulated transparent weld pool of $NaNO_3$ (10 mm in diameter) was heated with a defocused CO_2 laser beam to induce Marangoni convection, and C_2H_5COOK was used as a surface-active agent to cause flow reversal. A laser light-cut technique was used to reveal convection in the pool. With pure $NaNO_3$, convection was outward along the free surface and downward along the pool wall. However, when C_2H_5COOK was present (e.g., at 0.5 and 1 mole-%), convection slowed down. When more C_2H_5COOK was present (e.g., at 1.5 and 2 mole-%), convection was reversed to go inward along the pool surface and downward along the pool axis. Since this is in the opposite direction of gravity-induced buoyancy convection, Marangoni convection clearly dominated in the pools. In stationary laser beam welding, $NaNO_3$ containing 1 mole-% C_2H_5COOK showed deeper weld pools and inward surface flow, while pure $NaNO_3$ showed shallower weld pools and outward surface flow. This is consistent with the reversal of Marangoni convection caused by C_2H_5COOK observed in the flow visualization.

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KEY WORDS

Marangoni Convection
Surface-Active Agent
Laser Beam Welding
Weld Pool
Gravity-Induced
Buoyancy Convection
Flow Visualization

Introduction

Marangoni convection, also called surface-tension-driven convection or thermocapillary convection, can have a dramatic effect on the penetration depth of the resultant weld. This was described in the well-known work by Heiple and Roper (Ref. 1).

Marangoni convection in a weld pool is illustrated in Fig. 1. The top view of the weld pool in Fig. 1A shows convection is outward along the pool surface. The front view of the pool in Fig. 1B shows the outward surface flow turns around at the pool edge, and the return flow below the pool surface is downward and inward.

The presence of the heat source near the center of the weld pool induces a negative temperature gradient along the pool surface, that is $\partial T/\partial s < 0$, where T is temperature and s is the outward distance along the pool surface. In the absence of a surface-active agent, the surface tension γ decreases with increasing temperature, that is, $\partial\gamma/\partial T < 0$ (Ref. 2).

As shown in Fig. 1B, a positive surface-tension gradient $\partial\gamma/\partial s$ is present along the pool surface. Consequently, the liquid is pulled along the pool surface from the center (where temperature is high and the surface tension is low) to the edge (where temperature is low and the surface tension is high). Mathematically, $\partial\gamma/\partial s = \partial T/\partial s \times \partial\gamma/\partial T$. In other words, the surface-tension gradient $\partial\gamma/\partial s$ (>0) is induced both by the temperature gradient along the pool surface $\partial T/\partial s$ (<0) and the temperature dependence of the surface tension $\partial\gamma/\partial T$ (<0).

The presence of a very small amount of a surface-active agent can make the weld pool much deeper (Ref. 1). The surface-active agent of a liquid, e.g., S in liquid steel, is a material that can significantly reduce the surface tension of the liquid and even change its temperature dependence. It has been shown by thermodynamics (Ref. 3) and by experimental data (Refs. 4, 5) that in the presence of such an agent, the surface tension can, in fact, increase with increasing temperature, that is, $\partial\gamma/\partial T > 0$. This makes the surface-tension gradient along the pool surface negative, that is, $\partial\gamma/\partial s < 0$. As illustrated in Fig. 1C, the liquid is pulled along the pool surface from the edge (where temperature and the surface tension are both low) to the center (where temperature and the surface tension are both high). With the direction of flow reversed to favor convective heat transfer from the heat source to the pool bottom, a much deeper pool can be produced, as shown in Fig. 1D. General information about Marangoni convection in the weld pool is available elsewhere (Refs. 6, 7).

Marangoni convection cannot be studied in arc welding because of the interference by the electromagnetic force in the weld pool and by the aerodynamic drag force of the arc. To avoid this problem, the arc can be substituted with a laser beam defocused to the size of the

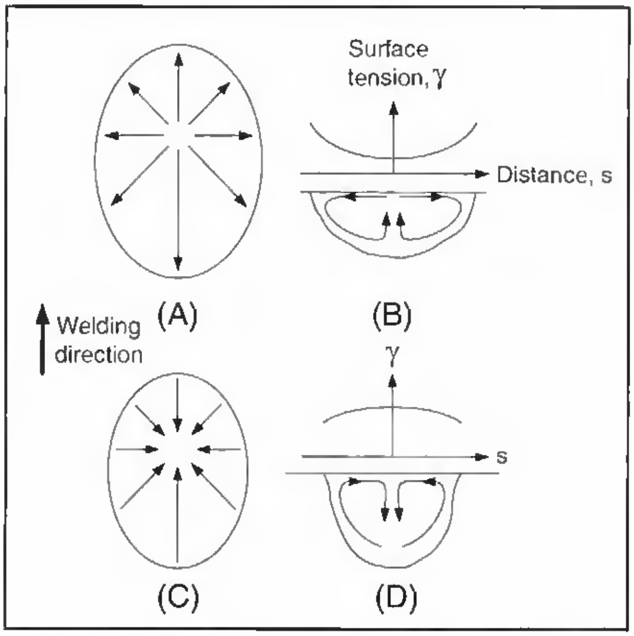

Fig. 1 — Marangoni convection in weld pools. A — Top view, convection outward; B — front view, outward convection turns and flow below surface is downward and inward; C — liquid pulled from pool edge to center; D — flow reversed to the pool bottom.

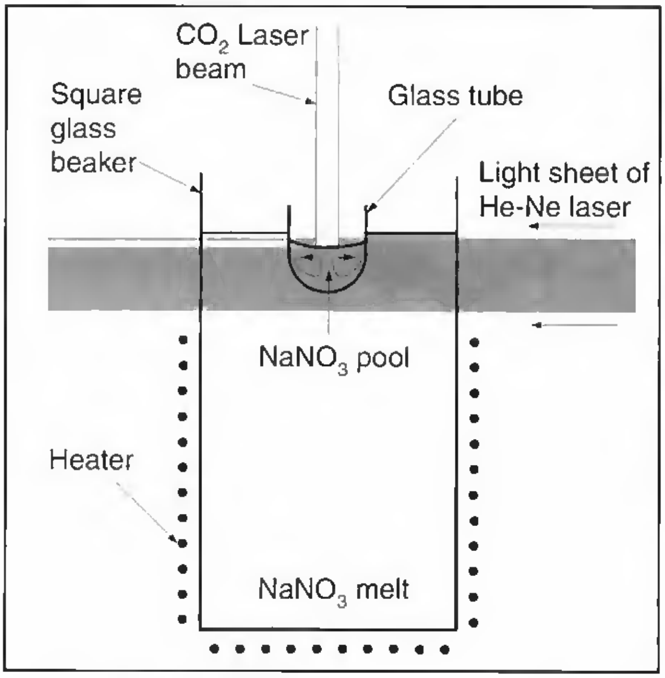

Fig. 2 — A transparent system for flow visualization of Marangoni convection in a simulated weld pool.

arc. As in arc welding, melting is through heating from the top surface (the so-called conduction mode), and no vapor hole is produced in the weld pool by the laser beam (the so-called keyholing mode). The Marangoni convection induced by such a defocused laser beam should be similar to that induced by a welding arc.

Flow visualization in a weld pool is limited to the pool surface because the molten metal is opaque. In fact, even at the pool surface such observation can still be difficult because of the brightness of the arc. Ishizaki, *et al.* (Ref. 8), observed Marangoni convection in a slice of molten paraffin heated by a soldering iron in contact with its top surface. Since paraffin is often a mixture of several organic compounds, its physical properties are not defined. Furthermore, it is not known if a surface-active agent is available for paraffin.

Recently, the authors have conducted physical simulation of weld-pool Marangoni convection by using a transparent pool of $NaNO_3$ and heating it with a defocused laser beam (Ref. 9). The physical properties of $NaNO_3$ are well documented, as will be shown later. The Marangoni number Ma for the simulated weld pool of $NaNO_3$ was close to those for steel and aluminum weld pools (Refs. 10–14). According to the similarity law of hydrodynamics, similarity in Marangoni convection between two fluid systems can be expected if the Marangoni numbers are close to each other (Ref. 15).

In the present investigation, Marangoni convection in weld pools is simulated again using $NaNO_3$ but with C_2H_5COOK as a surface-active agent. The objectives are 1) to observe reversed Marangoni convection caused by a surface-active agent, and 2) to study the effect of the surface-active agent on the weld shape. Since the focus is on the observation of flow reversal and its effect on the weld shape, no attempt was made to measure the temperature and composition distributions along the pool surface and determine the Marangoni numbers.

Experimental Procedures

Materials

Sodium nitrate, $NaNO_3$, is a low-melting-point oxide and its physical properties are shown in Table 1 (Refs. 16–21). It has a transmission range of 0.35 to 3 μm and is, therefore, opaque to the CO_2 laser (10.6 μm) just like a weld pool is opaque to the heat source. Potassium propionate, C_2H_5COOK, decomposes at 330°C (Refs. 10, 16). The purity levels were above 99.99 and 99% for $NaNO_3$ and C_2H_5COOK, respectively.

Flow Visualization

The apparatus for flow visualization, shown in Fig. 2, is identical to the one used previously for flow visualization in pure $NaNO_3$ (Ref. 9). It consisted of a Pyrex glass tube (10 mm ID) holding an essentially hemispherical pool of $NaNO_3$ and a square Pyrex glass beaker (40 x 40 mm inside) holding a $NaNO_3$ melt.

A defocused CO_2 laser beam shone at the center of the pool surface to induce Marangoni convection. The characteristics of the CO_2 laser have been described (Ref. 9). The beam power was measured with a power meter having a 0.1-W resolution. The beam diameter was measured with a micrometer-mounted device developed recently (Ref. 9).

The $NaNO_3$ melt in the square beaker served to correct the optical distortion caused by the lens effect of the pool and to keep the pool from freezing and becoming opaque. The refractive index of $NaNO_3$ (1.46) is practically identical to that of Pyrex glass (1.47). A thermocouple was placed in the glass beaker near the bottom and hooked up to a temperature controller set at 330°C. In the absence of a CO_2 laser beam, this gave a temperature of 323.4°C at the bottom of the outer surface of the glass tube.

The amount of $NaNO_3$ in the glass tube was 630 mg. The tube was placed in the glass beaker to melt the $NaNO_3$ in the glass tube. A small amount of C_2H_5COOK, ranging from 2.5 to 10 mg, was added to the $NaNO_3$ pool at the pool temperature below 320°C. An electronic balance with 0.1-mg resolution was used for weighing. After the addition, the glass tube was removed from the beaker and shaken for two seconds before it was put back to the beaker. After checking alignment, the CO_2 laser was shone on the

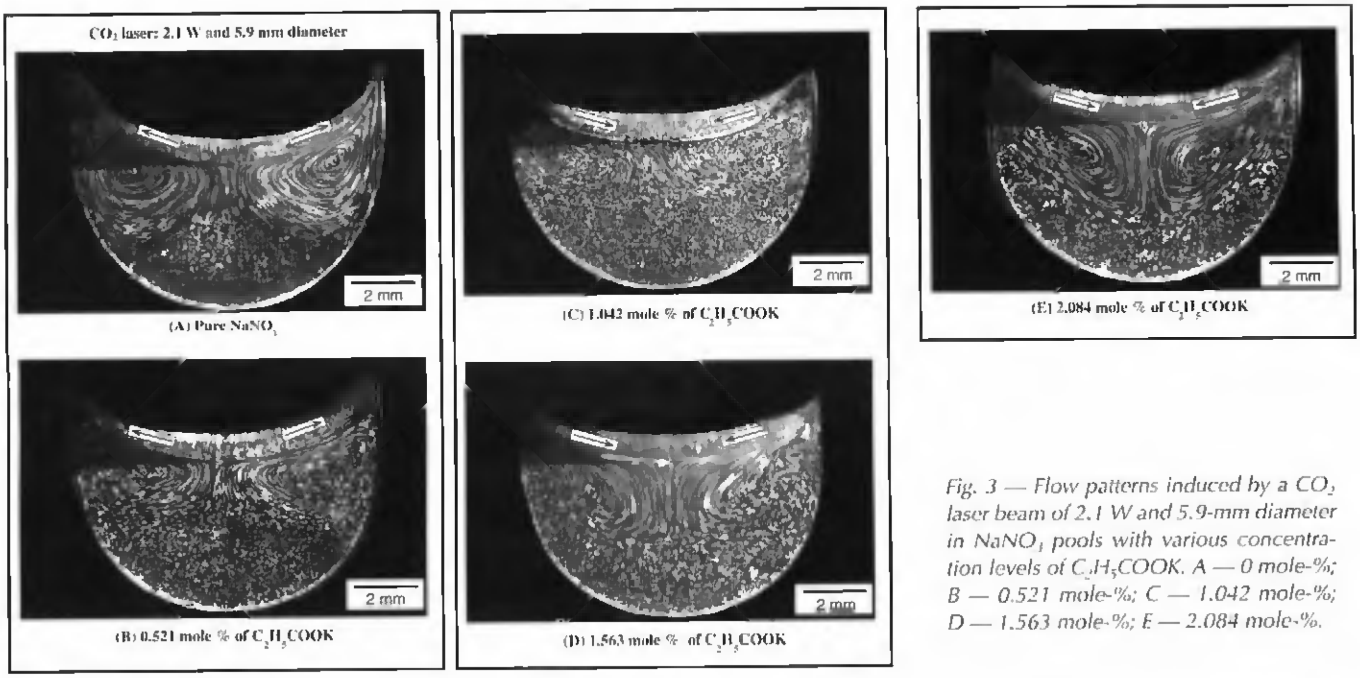

Fig. 3 — Flow patterns induced by a CO_2 laser beam of 2.1 W and 5.9-mm diameter in $NaNO_3$ pools with various concentration levels of C_2H_5COOK. A — 0 mole-%; B — 0.521 mole-%; C — 1.042 mole-%; D — 1.563 mole-%; E — 2.084 mole-%.

pool surface and flow visualization was started. All photographs were taken within 20 to 40 s.

A laser light-cut technique was used for flow visualization. The laser light sheet was produced with the help of a 20-mW He-Ne laser and optical lenses. It cut through the meridian plane of the pool to illuminate to the tracer particles in the melt and reveal the flow pattern. Aluminum particles 5 μm in diameter were used as a tracer. The density of aluminum (2.7 g cm^{-3}) is greater than that of the $NaNO_3$ melt (1.9 g cm^{-3}). From Stokes' law (Ref. 7), however, the settling velocity is much slower than Marangoni convection in view of the small particle diameter. In fact, aluminum particles are often used for flow visualization in water (Ref. 22), which is even lighter than $NaNO_3$. A certain amount of aluminum particles gradually settled to the pool bottom over extended periods of time. Photographs of the flow patterns were taken with Kodak Technical Pan films and an exposure time of 0.625 s. The reflex mirror of the camera was locked to reduce vibration.

Similar photographs were taken with a much shorter exposure time of 0.05 s with high-speed Kodak T-MAX P3200 films. The negatives were developed and scanned into the computer with a high-resolution scanner (maximum resolution 3200 dpi). The lengths of the velocity vectors were determined by using the x and y coordinates in the Info Palette displays in Adobe Photoshop 5.5 (Ref. 23). From the lengths of the flow lines and the exposure time, the velocity vectors in the pool were determined. The velocity vectors were interpolated using the inverse-distance interpolation function in Tecplot (Ref. 24) on a 27 x 28 grid that fits the free surface, wall and centerline of the pool.

Laser Beam Welding

Blocks of $NaNO_3$ were prepared for welding by melting and casting. The top and bottom surfaces were ground flat and cleaned before welding. The dimensions of the samples were 10 x 10 x 2 cm.

Stationary welds were made with a defocused CO_2 laser beam. The welding time was up to three minutes. The melt was then decanted from the pool instantaneously. Since the melt solidifies slowly, there was enough time for decanting.

The shape of the emptied pool was determined by using a digital x-y stage with a resolution of 0.01 mm and a fine-tip dial indicator with a resolution of 0.025 mm. The depth of the pool was measured every 0.25 mm along the diameter, in two directions perpendicular to each other.

Results and Discussion

Flow Pattern

Figure 3 shows the flow patterns induced by a CO_2 laser beam of 2.1 W power and 5.9 mm diameter. The melt wets the glass tube and forms a meniscus that makes the pool surface concave, though the pool surface can often be concave in conduction-mode laser beam welding for other reasons (Refs. 14, 25, 26).

The arrows above the pool surface indicate the directions of flow along the pool surface. A dark shadow is present below the left-hand edge of the pool surface because this part of the pool surface reflects the laser light sheet coming from the right. The front half of the concave free surface faces the camera and acts as a mirror to show the illuminated meridian plane to the camera. This produces a bright image above the entire pool surface. The arrows are shown inside the range of this image.

Figure 3A shows the flow pattern in a pool of pure $NaNO_3$. Fluid flow is steady, axisymmetric and unicellular, somewhat similar to the shape of a doughnut. In the meridian plane of the pool, however, the flow pattern appears as a clockwise cell on the right and a counterclockwise cell on the left. In other words, the melt at the center of the pool surface flows outward along the pool surface, turns downward at the pool edge to fall along the pool wall, and then returns to the center of the pool surface. The flow lines are most closely spaced near the pool surface and become more widely separated below the pool surface and in the interior. This is consistent with the fact the surface flow is much faster than the return flow. There is little flow in the area near the bottom of the pool. The centers of the cells are close to the pool edge. These characteristics of Marangoni convection are confirmed by the videotape movie recorded during flow visualization (Ref. 27).

Figure 3B shows the flow pattern for a $NaNO_3$ pool containing 0.521 mole-% of C_2H_5COOK (25 mg). Convection is still outward along the pool surface and downward along the pool wall. However, as compared to the case of pure $NaNO_3$, convection is significantly slower. This is evident from the fact the flow lines are shorter than those in Fig. 3A.

As shown in Fig. 3C, when the C_2H_5COOK concentration is increased to 1.042 mole-% (50 mg), convection is reversed — the surface flow is now inward toward the center of the pool surface. Convection is weak, as indicated by the short flow lines. The flow pattern is not steady but changes slowly with time. However, the direction of convection remains unchanged, that is, always inward along the pool surface.

Figure 3D shows the case in which the C_2H_5COOK concentration is further increased to 1.563 mole-% (75 mg). As shown in Fig. 3D, the inward surface flow becomes faster. The downward flow along the pool axis penetrates deeper, about halfway to the pool bottom.

The case of the highest C_2H_5COOK concentration of 2.084 mole-% (100 mg) is shown in Fig. 3E. As compared to the previous case in Fig. 3D, convection is stronger, the liquid penetrates closer to the pool bottom and the flow lines are longer. This convection is in the opposite direction of gravity-induced buoyancy convection, and this indicates Marangoni convection dominates in the pool.

Higher C_2H_5COOK concentrations than 2.084 mole-% were also attempted, but there was a tendency for a film to form on the pool surface and for bubbles to form suddenly.

The flow patterns shown in Figs. 3C through 3E all change slowly with time. The flow cells move slowly without a clear frequency or amplitude. This is why some flow lines in Fig. 3E appear to cross each other. Within the 0.625-s exposure time, the flow pattern has changed slightly. The flow pattern in Fig. 3A for pure $NaNO_3$ is stable, as already mentioned. It is not suggested, however, that Marangoni convection with a strong outward surface flow is always stable. In fact, Marangoni convection in pure $NaNO_3$ becomes oscillatory when the laser power is increased beyond a certain point.

According to Table 1, C_2H_5COOK reduces the surface tension of $NaNO_3$ significantly, the concentration dependence of the surface tension being −22 dyne/(cm mole-%). Above 330°C, C_2H_5COOK decomposes as follows (Refs. 15, 21):

$$2C_2H_5COOK \rightarrow CH_3COOK + C_2H_5CHO \uparrow + C + KOH \qquad (1)$$

where C_2H_5CHO (propionaldehyde, boiling point 49°C), just escapes as a gas.

Unlike C_2H_5COOK, CH_3COOK does not reduce the surface tension of $NaNO_3$ much and can, therefore, be neglected for simplicity of discussion. The concentration dependence of the surface tension for CH_3COOK, −4 dyne/(cm mole-%), is less than one-fifth of that for C_2H_5COOK, −22 dyne/(cm mole-%) (Table 1). C and KOH are not known to have a significant effect on the surface tension of $NaNO_3$.

The way C_2H_5COOK can cause Marangoni convection in a laser-heated pool of $NaNO_3$ to be reversed is illustrated in Fig. 4. C_2H_5COOK in the pool decomposes upon heating by the laser beam. This makes the C_2H_5COOK concentration lower at the center of the pool surface and higher at the pool edge. Since C_2H_5COOK reduces the surface tension of $NaNO_3$ significantly, the surface tension can be higher at the center of the pool surface and lower at the pool edge. Consequently, Marangoni convection can be reversed to go inward along the pool surface and downward along the pool axis.

However, it should be cautioned that composition and temperature gradients are present along the pool surface at the same time and they can

Table 1 — Physical Properties of $NaNO_3$ Melt (Refs. 16–21)

Properties	$NaNO_3$
Melting point, T_m, °C	306.8
Decomposition temperature, T_d, °C	380
Autoignition point, T_a, °C	538
Heat of Fusion, ΔH, J/g	182
Temperature coefficient of surface tension, $\partial\gamma/\partial T$, dyne/(cm °C)	−0.056
Surface tension, γ, dyne/cm	119.96 at T_m
Dynamic viscosity, μ, g/(cm s)	0.0302 at T_m
Density, ρ, g/cm³	1.904 at T_m
Specific heat, C_p, J/(g °C)	1.71 at T_m
Thermal conductivity, k, W/(cm °C)	5.65×10^{-3} at T_m
Thermal expansion coefficient, β, °C⁻¹	6.6×10^{-4}
Thermal diffusivity, $\alpha = k/(\rho C_p)$, cm²/s	1.74×10^{-3} at T_m
Prandtl number, $Pr = C_p\mu/k$	9.12 at T_m
Refractive index, n	1.46
Emissivity, ε	0.3
Transmission range, λ, cm	$0.35 \times 10^{-4} - 3 \times 10^{-4}$
Concentration dependence of surface tension for C_2H_5COOK, dyne/(cm mole-%)	−22
Concentration dependence of surface tension for CH_3COOK, dyne/(cm mole-%)	−4

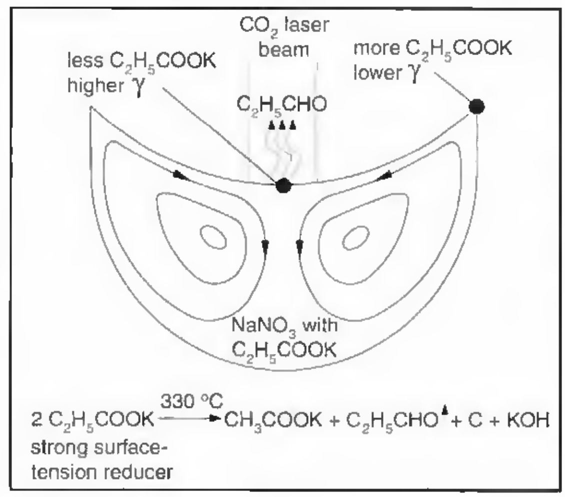

Fig. 4 — Reversed Marangoni convection in a $NaNO_3$ pool containing C_2H_5COOK, which decomposes upon heating by the laser beam.

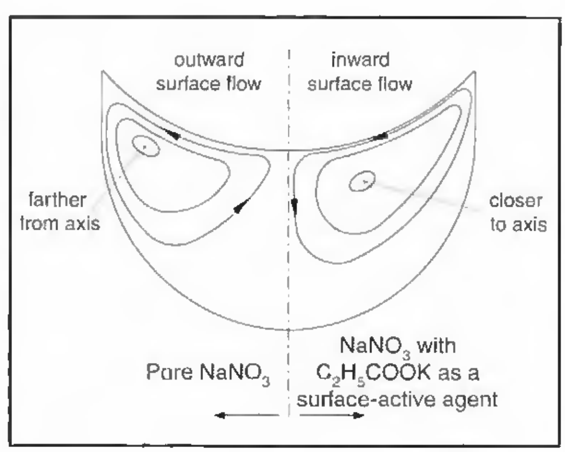

Fig. 5 — Effect of C_2H_5COOK on the flow pattern.

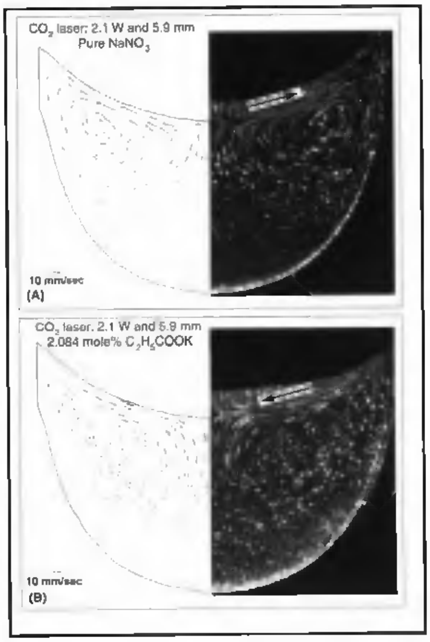

Fig. 6 — Velocity vectors measured in pools of the following: A — $NaNO_3$; B — $NaNO_3$ containing 2.084 mole-% C_2H_5COOK.

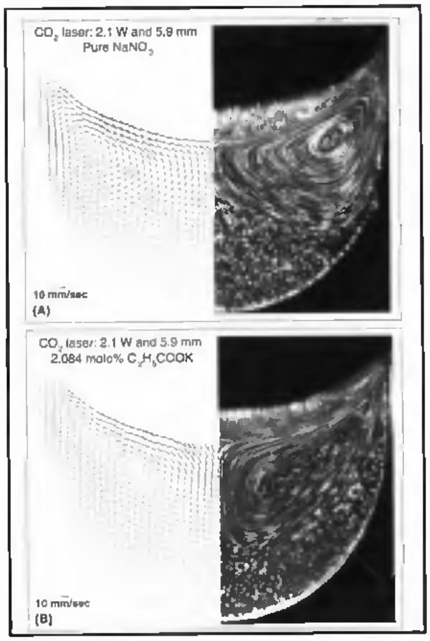

Fig. 7 — Velocity fields interpolated from measured velocity vectors. A — $NaNO_3$; B — $NaNO_3$ containing 2.084 mole-% C_2H_5COOK.

have opposite effects on Marangoni convection. The surface tension of $NaNO_3$ decreases with increasing temperature because $\partial\gamma/\partial T < 0$ (Table 1). Consequently, the temperature gradients are in favor of a lower surface tension at the center of the pool surface and a higher surface tension at the pool edge, that is, an outward surface flow. This is just the opposite of the composition gradients along the pool surface. If the effect of composition gradients prevails over that of the temperature gradients, convection will be inward along the pool surface and vice versa.

Let s be the distance along the pool surface from the center of the pool surface, γ the surface tension, C the concentration of the surface-active agent, and T temperature. Since γ is a function of both C and T, the variation of the surface tension along the pool surface is as follows:

$$\frac{d\gamma}{ds} = \underbrace{\frac{\partial\gamma}{\partial T}}_{<0}\underbrace{\frac{dT}{ds}}_{<0} + \underbrace{\frac{\partial\gamma}{\partial C}}_{<0}\underbrace{\frac{dC}{ds}}_{<0} \qquad (2)$$

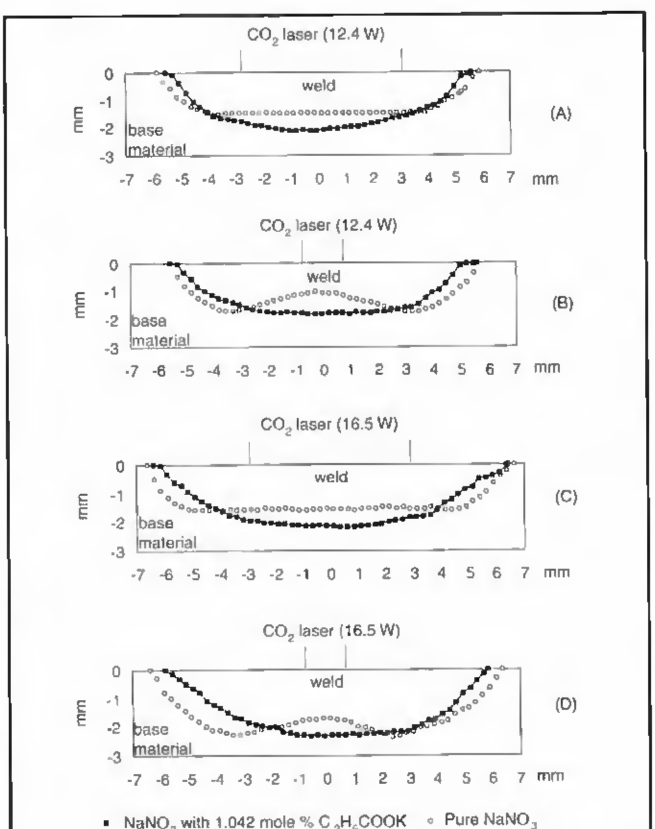

Fig. 8 — Shapes of stationary welds in solid $NaNO_3$ containing 1.042 mole-% C_2H_5COOK (squares) and pure $NaNO_3$ (open circles) produced by CO_2 laser beams. A — 12.4 W and 5.9 mm diameter; B — 12.4 W and 1.5 mm diameter; C — 16.5 W and 5.9 mm diameter; D — 16.5 W and 1.5 mm diameter. Welding time: 3 min.

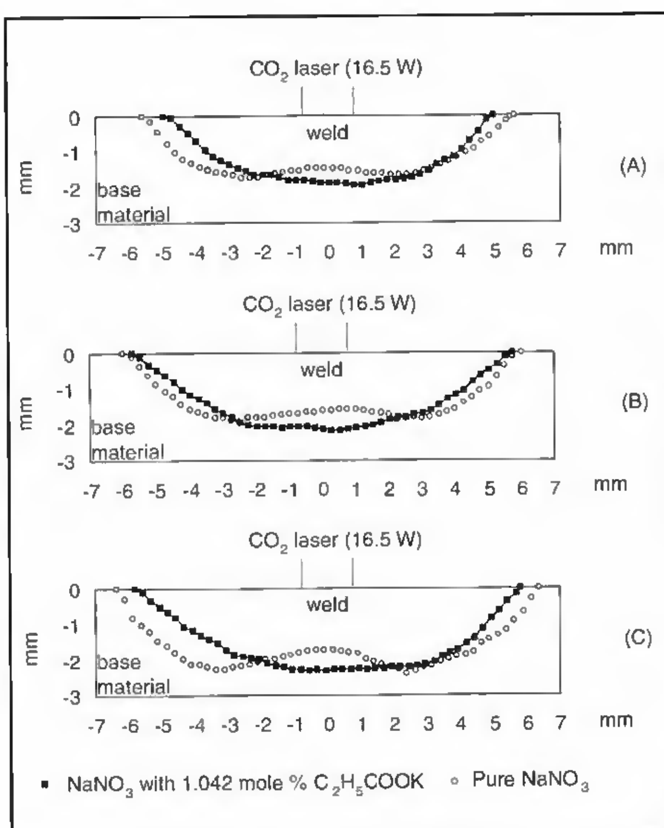

Fig. 9 — Shapes of stationary laser welds in solid $NaNO_3$ containing 1.042 mole-% C_2H_5COOK after at a welding time of: A — 1 min; B — 2 min; C — 3 min. Beam power: 16.5 W; beam diameter: 1.5 mm.

For $NaNO_3$, the surface tension decreases both with increasing temperature and increasing C_2H_5COOK concentration, that is, $\partial\gamma/\partial T < 0$ and $\partial\gamma/\partial C < 0$. When moving outward along the pool surface, temperature decreases but the C_2H_5COOK concentration increases, that is, $dT/ds < 0$ but $dC/ds > 0$. As such, the first term on the RHS of Equation 2 is positive but the second term is negative, and the sum of the two can either be positive or negative. If the surface tension varies along the pool surface more with temperature than with composition, the sum is positive and the surface flow is outward — Fig. 3A, B. On the other hand, if the surface tension varies along the pool surface more with composition than with temperature, the sum is negative and the surface flow is inward — Fig. 3C – E.

The effect of C_2H_5COOK is summarized in Fig. 5. When the levels of C_2H_5COOK concentration and heat source power are such that the surface tension decreases outward along the pool surface, Marangoni convection is reversed. Convection becomes inward along the pool surface and downward along the pool axis, and the centers of cells move away from near the pool edge toward the pool axis.

Velocity Fields

The right-hand side of Fig. 6 shows the short flow lines obtained by photographing with the short exposure time of 0.05 s. The left-hand side shows the velocity vectors measured from the flow lines. The flow lines are longer and have a greater tendency to overlap at the pool surface than in the interior, and their lengths are thus more difficult to measure.

The velocity vectors shown in Fig. 6A for pure $NaNO_3$ are outward near the pool surface and inward in the interior while those shown in Fig. 6B for $NaNO_3$ with 2.084 mole-% C_2H_5COOK are opposite in direction. On the average, the velocity vectors are longer in $NaNO_3$ than in $NaNO_3$ with 2.084 mole-% C_2H_5COOK. This is consistent with the observation of stronger convection in the former and weaker convection in the latter during flow visualization. The flow is weaker in the latter because composition and temperature gradients along the pool surface act in the opposite directions.

The velocity vectors in Fig. 6 are interpolated and shown in Fig. 7, along with the corresponding flow patterns photographed with the exposure time of 0.625 s. Unlike the velocity vectors in Fig. 6, these velocity fields cover the whole pool. From Fig. 7A, the maximum velocity for pure $NaNO_3$ is 16.9 mm/s, outward and pointing along the pool surface. It is located at a radius of 2.76 mm along the free surface. From Fig. 7B, the maximum velocity for $NaNO_3$ with 2.084 mole-% C_2H_5COOK is 10.7 mm/s, inward and pointing along the pool surface. It is also located at a radius of 2.76 mm along the free surface. In general, the velocities at the pool surface are not as accurate as those below it because of fewer available flow lines at the pool surface — Fig. 6.

Pool Shapes

Figure 8 shows stationary laser welds made in solid blocks of $NaNO_3$ and $NaNO_3$ with 1.04 mole-% C_2H_5COOK. The laser powers are 12.4 and 16.5 W, the beam diameters are 5.9 and 1.5 mm, and the welding time is 3 min. The solid squares represent the welds in $NaNO_3$ blocks containing 1.04 mole-% C_2H_5COOK that are made in the present study. The open circles indicate the welds in pure $NaNO_3$ blocks that were made in a previous study (Ref. 28). As shown in Fig. 8, the presence of C_2H_5COOK in $NaNO_3$ increases the weld depth at the pool axis and decreases the average weld width.

The laser powers of 12.4 and 16.5 W for welding are much higher than the laser power of 2.1 W for inducing Marangoni convection in the 10-mm pool. This is because in welding the laser beam has to be powerful enough to heat and melt the solid material to form a weld pool. As such, decomposition of C_2H_5COOK at the center of the pool surface and hence the composition gradients along the pool surface are expected to be more significant than those in the 10-mm-diameter pool. At the same time, however, temperature gradients along the pool surface also become more significant.

Since solid $NaNO_3$ is opaque, the flow pattern in the weld pool cannot be observed by the light-cut technique. However, the surface bubbles produced by the decomposition of C_2H_5COOK can still show the direction of the surface flow. They move inward along the weld pool surface before bursting near the center of the pool surface, and this indicates the surface flow is inward. As already shown by flow visualization, when the surface flow is inward, the flow, and hence convective heat transfer along the pool axis, are downward toward the pool bottom. This explains why the depth/width ratios in the welds containing 1.04 mole-% C_2H_5COOK are higher than those in the welds of pure $NaNO_3$.

The flat and convex bottoms of the pure $NaNO_3$ welds have been explained previously (Ref. 28). In short, outward surface flow dominates heat transfer in the pool and the pool bottom is, therefore, flat. As the beam diameter is reduced from 5.9 to 1.5 mm, however, the power density, and hence the temperature at the center of the pool surface, increase significantly. The increased surface-tension gradients along the pool surface make the outward surface flow strong enough to turn downward at the pool edge and carry heat downward. Consequently, the pool is deeper near the pool edge than at the pool axis, that is, the pool bottom becomes convex. In the weld pools of $NaNO_3$ containing 1.04 mole-% C_2H_5COOK, however, the outward surface flow no longer exists, and the pool bottom is no longer convex.

As C_2H_5COOK decomposes with time, its concentration in the weld pool decreases. It is possible that beyond a certain point of time the pool depth actually begins to decrease because of little C_2H_5COOK left in the pool. In other words, strong outward surface flow takes over and the pool bottom starts to turn convex just like in a pure $NaNO_3$ pool. Figures 9A, B and C show the weld pool shapes in $NaNO_3$ containing 1.042 mole-% C_2H_5COOK after a welding time of 1, 2 and 3 min, respectively. As shown, the pool depth continues to increase within the 3 min period of time. This suggests that the 3 min welding time for the welds shown previously in Fig. 8 is appropriate.

Conclusions

Reversed Marangoni convection, caused by the presence of a surface-active agent to go inward along the pool surface and downward toward the pool bottom, can be observed in a simulated weld pool of $NaNO_3$ containing C_2H_5COOK as a surface-active agent and heated from above by a defocused CO_2 laser beam. Flow visualization can be achieved by using a laser light-cut technique to reveal convection in the pool. With pure $NaNO_3$, convection is outward along the free surface and downward along the pool wall. However, when C_2H_5COOK is added, convection slows down. With further addition of C_2H_5COOK, convection can be reversed to become inward along the pool surface and downward along the pool axis. Since this is in the opposite direction of gravity-induced buoyancy convection, Marangoni convection clearly dominates in the pool. In each pool, the laser light sheet intersects the doughnut-shaped flow cell twice and "two" counterrotating cells appear in the meridian plane of the pool. The centers of the cells are near the

RESEARCH/DEVELOPMENT/RESEARCH/DEVELOPMENT/RESEARCH/DEVELOPMENT/RESEARCH/DEVELOPMENT/RESEARCH/DEVELOPMENT pool edge in the case of pure $NaNO_3$ but move toward the pool axis as the C_2H_5COOK content is increased. Stationary laser welding shows the pool is deeper in $NaNO_3$ containing about 1 mole-% C_2H_5COOK than in pure $NaNO_3$. This is consistent with reversal of Marangoni convection by C_2H_5COOK observed in flow visualization. The downward flow along the pool axis carries heat from the laser beam to the pool bottom and makes it deeper.

Acknowledgments

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Prediction and Optimization of Weld Bead Volume for the Submerged Arc Process — Part 2

Analytic models were developed to establish a relationship between process parameters and weld bead quality

BY V. GUNARAJ AND N. MURUGAN

ABSTRACT. As a part of a study and analysis on the effects of process parameters on weld bead volume in submerged arc welding (SAW) of pipes, mathematical models were developed to relate the process parameters and the weld bead quality parameters. Further, the optimization of weld bead volume was carried out using the optimization module available in the *MATLAB* version 4.2b software package. The mathematical models thus developed for optimization are also helpful in predicting the weld bead quality parameters and in setting process parameters at optimum values to achieve the desirable weld bead quality at a relatively low cost with a high degree of repeatability and increased production rate. Total volume of the weld bead, an important bead parameter, was optimized (minimized), keeping the dimensions of the other important bead parameters as constraints, to obtain sound and superior quality welded pipes. Sensitivity analysis was also carried out to predict the direct and few interaction effects of important bead parameters on the total volume of the weld bead, and the results are presented in graphical form. The results of the sensitivity analysis are very useful in understanding the interdependence of various weld bead quality parameters in controlling the volume of the weld bead, to improve weld quality, to increase productivity with the available welding facilities and to minimize the total welding cost.

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KEY WORDS

SAW
Weld Bead Volume
Optimization
Constraints
Sensitivity Analysis
Heat Input
Dilution
Penetration
Reinforcement
Bead Width

Introduction

Submerged arc welding is widely employed as one of the major fabrication processes in industry due to its inherent advantages of deep penetration, smooth bead and superior quality (Ref. 1). In SAW of pipes, engineers are often faced with the problems of relating the process variables to the weld bead quality and optimization of the bead parameters. Also, welding is done with the aim of achieving a sound joint at a low cost. But without optimization, it is impossible to achieve low-cost welding. The design and optimization process is iterative, requiring the repeated use of the same set of calculations (Refs. 2, 3). Until recently, cost and time-intensive trial and error methods were used to determine the optimum process parameters for a required bead quality. Since any welding process is a multi-objective problem (maximum penetration, minimum reinforcement, minimum heat input, minimum width, minimum dilution, low cost, maximum production rate), the optimum solution is a compromise (Ref. 4). Selection of an appropriate weld bead parameter is also equally important because if the selected parameter is the one determined and controlled by most of the other important bead parameters, then the optimization of that parameter will obviously include all the other parameters. Total volume of the weld bead is one of those important bead parameters controlled by most of the other bead parameters. Hence, the total volume, if optimized (minimized), obviously minimizes most of the other bead quality parameters such as heat input, dilution, reinforcement, bead width and penetration. But for a sound and strong weld, bead penetration should be maximized. Hence, in optimizing the total volume of the weld bead, the penetration, included as a constraint, should be set at its maximum value.

Minimizing the size of the weld bead reduces the welding cost through 1) reduced consumption of consumables such as electrodes and flux; 2) reduced heat input and energy consumption and 3) increased welding productivity through a high welding speed. Because of these advantages, the total volume of the weld bead should be optimized, having other bead parameters as constraints, rather than optimizing all the bead parameters individually. The total volume of the weld bead is the area of the weld bead cross section multiplied by the length of the weld bead. To reduce the complexity of the problem, the length of the bead is assumed as unity, which simplifies the equation. Now the total vol-

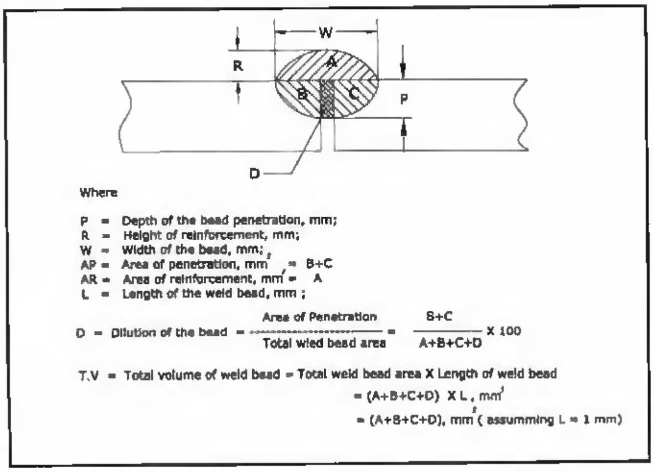

Fig. 1 — Cross section of a weld bead.

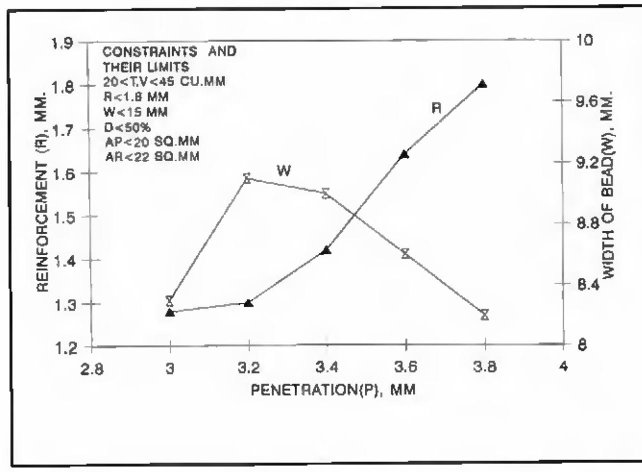

Fig. 2 — Direct effect of penetration (P) on reinforcement (R) and bead width (W).

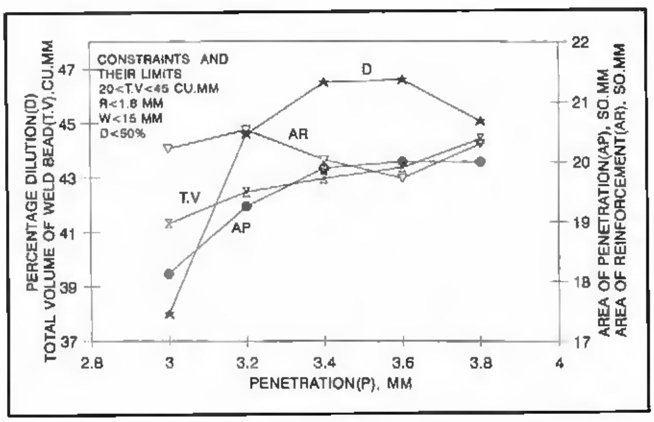

Fig. 3 — Direct effect of penetration (P) on percentage of dilution (D), area of penetration (AP), area of reinforcement (AR) and total weld bead volume (T.V.).

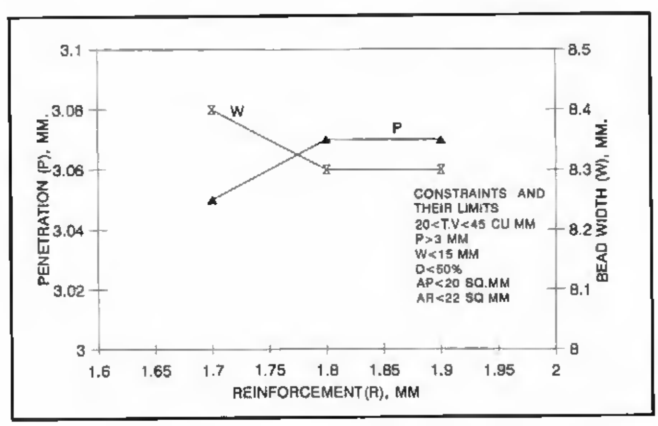

Fig. 4 — Direct effect of reinforcement(R) on penetration (P) and bead width (W).

ume is equal to the total area of the weld bead. Hence, the optimization of the total area of the weld bead cross section, subject to minimum reinforcement, minimum bead width, minimum dilution and maximum penetration, is the objective of this study. In order to do this, mathematical models were developed to establish the relationship between process parameters and the weld bead quality parameters. To achieve these objectives, the following three steps of methodology were used (Ref. 5):

1) Development of mathematical models, involving several steps to relate the response and the process parameters.

2) Model building, which involves selection of the objective function, along with one or several constraints with limits. This facilitates the optimization process.

3) Optimization, which includes the actual minimization or maximization of the objective function, subject to the constraints already specified.

As the amount of data generated in the iterative process for optimization were enormous and each design cycle requires substantial calculations, the optimization module available in the tool box of the *MATLAB* version 4.2b software package was used.

To achieve the objective, a study of the SAW process used for longitudinal welding of pipe was conducted to determine the effects of SAW process parameters on the dimensions of the important weld bead quality parameters. Statistically designed experiments based on the factorial technique (Ref. 6) were used to reduce the cost and time, as well as to obtain the required information about the main and interaction effects of the process variables on the weld bead quality parameters. The cross section of a weld bead showing important weld bead quality parameters is given in Fig. 1.

The mathematical models developed and optimized for weld bead parameters are very useful to predict the optimum weld bead geometry for the proposed input variables, to select the optimum combination of input variables for the desired weld bead quality and to atomize the SAW process through the development of a computer program. Also, this will be helpful in setting the process variables at the correct and optimum levels to obtain superior quality welded joints at a relatively high production rate with low manufacturing cost. Also, it is very important to study the benefit of relaxing the constraints associated with the total volume in understanding the influence of one bead parameter on the other. So, sensitivity analysis was also carried out.

Experimental Work

The experiment was conducted at M/s. Sri Venkateswara Engineering Corporation, Coimbatore, India, with the following setup: ADORE semiautomatic welding equipment joined IS 2062 carbon steel plates 300 x 150 x 6 mm thick; ESAB SA1

(E8) copper-coated wire 3.15 mm in diameter and ESAB basic fluoride type (equivalent to DIN 8557) granular flux were used. The plates were joined in the flat position using a narrow square-groove butt joint with 1-mm root opening.

Development of Mathematical Models

The detailed step-by-step procedure of the development of mathematical models was presented in Part 1, Mathematical Modeling to Predict Weld Bead Quality for SAW of Pipes, published in the October 2000 issue of the *Welding Journal*. A central composite rotatable design (Ref. 7), a factorial design, was used to develop mathematical models. The selected process control parameters with their limits and levels are shown in Table 1. The final mathematical models developed with all process parameters in coded form are given below.

$$\text{Penetration, mm} = 3.57 - 0.113V + 0.33F - 0.217S - 0.001N + 0.048V^2 + 0.1F^2 + 0.03S^2 - 0.01N^2 - 0.05VF + 0.03VS + 0.04VN - 0.01FS - 0.01FN + 0.08SN \quad (1)$$

$$\text{Reinforcement, mm} = 1.27 - 0.08V + 0.16F - 0.18S - 0.03N + 0.03V^2 + 0.07F^2 + 0.15S^2 + 0.01N^2 + 0.03VF + 0.03VS - 0.014VN - 0.001FS - 0.02FN + 0.03SN \quad (2)$$

$$\text{Width of weld bead, mm} = 10.76 + 1.19V + 0.45F - 1.9S + 0.23N + 0.41V^2 - 0.17F^2 + 0.29S^2 + 0.12N^2 - 0.04VF - 0.64VS - 0.15VN - 0.35FS + 0.091FN - 0.29SN \quad (3)$$

$$\text{Area of penetration, mm}^2 = 21.56 + 1.05V + 1.85F - 1.61S - 0.212N + 0.041V^2 + 0.29F^2 - 0.097S^2 + 0.15N^2 + 0.14VF - 0.21VS + 0.056VN - 0.24FS - 0.16FN - 0.16SN \quad (4)$$

$$\text{Area of reinforcement, mm}^2 = 21.44 + 0.44V + 0.187F - 1.76S + 2.11N + 1.39V^2 - 0.39F^2 + 1.22S^2 + 0.62N^2 + 0.41VF - 0.047VS + 0.14VN - 0.94FS + 0.77FN - 0.33SN \quad (5)$$

$$\text{Percentage of dilution} = 47.27 + 0.74V + 2.51F - 0.25S - 2.23N - 1.31V^2 - 0.71F^2 - 1.31S^2 - 0.44N^2 - 0.09VF - 0.3VS - 0.31VN + 0.43FS - 0.90FN + 0.17SN \quad (6)$$

$$\text{Total weld bead volume, mm}^3 = 45.78 + 1.58V + 2.2F - 3.5S + 2.0N + 1.67V^2 + 0.17F^2 + 1.34S^2 + 0.97N^2 + 0.28VF - 0.21VS + 0.48VN - 0.87FS + 0.64FN - 0.77SN \quad (7)$$

Optimization

Selection of Function and Constraints

The objective function selected for optimization was the total volume of the weld bead. The area in which the solution for the function lies decreases as the number of constraints increases. Therefore, only the parameters penetration, reinforcement, bead width and percentage of dilution were given as constraints in their equation form. In optimization, generally the constraints with their upper limits should be given in such a way that their value will be less than or equal to zero. Also, the function, as well as the constraint functions, will usually be minimized. To obtain a strong weld in any application, it is always desirable to have maximum depth of penetration with minimum reinforcement, width and dilution without sacrificing other bead qualities. To maximize a function, the function should be multiplied by –1. The process

Table 1 — Process Parameters and Their Limits

Parameters	Units	Notation	Limits: –2	–1	0	+1	+2
Welding voltage	volts	V	24	26	28	30	32
Wire feed rate	m/min	F	0.70	0.93	1.16	1.39	1.62
Welding speed	m/min	S	0.43	0.51	0.59	0.67	0.75
Nozzle-to-plate distance	mm	N	30.00	32.50	35.00	37.50	40.00

Table 2 — Results of the Sensitivity Analysis

S. No	Parameters varied and their limits	Optimum Process Variables: V volts	F m/min	S m/min	N mm	Optimum Values of the Bead Parameters: P mm	R mm	W mm	AP mm^2	AR mm^2	D %	T.V mm^3
1	R = 1.7 mm	28	0.69	0.64	34.5	3.05	1.28	8.4	18.07	20.19	37.9	41.31
2	R = 1.8 mm	28	0.70	0.64	34.6	3.07	1.28	8.3	18.13	20.21	38.0	41.33
3	R = 1.9 mm	28	0.70	0.64	34.6	3.07	1.28	8.3	18.13	20.21	38.0	41.33
4	R = 2.0 mm	28	0.70	0.64	34.6	3.07	1.28	8.3	18.13	20.21	38.0	41.33
5	P = 3.0 mm	28	0.70	0.64	34.6	3.07	1.28	8.3	18.13	20.21	38.0	41.33
6	P = 3.2 mm	28	1.02	0.66	33.6	3.20	1.28	9.1	19.25	20.53	44.6	42.48
7	P = 3.4 mm	28	1.17	0.68	33.3	3.40	1.42	9.0	19.89	20.03	46.5	42.98
8	P = 3.6 mm	27	1.28	0.71	33.5	3.60	1.64	8.6	20.00	19.72	46.6	43.38
9	P = 3.8 mm	27	1.40	0.72	34.7	3.80	1.80	8.2	20.00	20.30	45.1	44.44
10	W = 8 mm	27	0.70	0.67	35.6	3.07	1.38	8.0	17.54	21.37	36.3	41.58
11	W = 8.5 mm	28	0.70	0.64	34.6	3.07	1.28	8.5	18.13	20.21	38.0	41.33
12	W = 9 mm	28	0.70	0.64	34.6	3.07	1.28	9.0	18.13	20.21	38.0	41.33
13	W = 10 mm	28	0.70	0.64	34.6	3.07	1.28	9.0	18.13	20.21	38.0	41.33
14	D = 35%	28	0.70	0.63	35.3	3.04	1.47	7.9	17.14	22.00	35.0	42.51
15	D = 36%	27	0.70	0.60	35.4	3.05	1.40	8.0	17.40	21.64	36.0	41.68
16	D = 37%	27	0.70	0.66	35.1	3.06	1.34	8.1	17.74	20.89	37.0	41.43
17	D = 38%	28	0.70	0.64	34.7	3.07	1.28	8.3	18.13	20.21	38.0	41.33
18	AP = 18 mm^2	29	0.70	0.65	34.8	3.06	1.30	8.2	18.00	20.16	37.7	41.33
19	AP = 20 mm^2	28	0.70	0.64	34.7	3.07	1.28	8.3	18.13	20.21	38.0	41.34
20	AR = 20 mm^2	28	0.70	0.63	34.6	3.07	1.27	8.5	18.27	20.00	38.3	41.33
21	AR = 22 mm^2	28	0.70	0.64	34.7	3.07	1.28	8.3	18.13	20.21	38.0	41.34

For the values of the bead parameters P, R, W, AP, AR and D, other than that tabulated above, it was found that the value of objective function, namely, total volume of the weld bead, is either unaltered or it had no feasible solution.

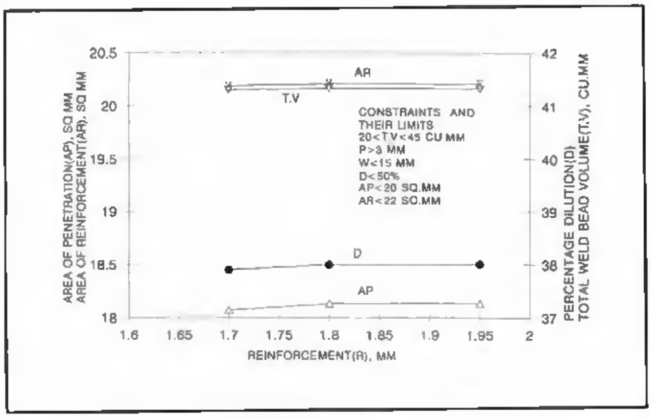

Fig. 5 — Direct effect of R on D, AP, AR and T.V.

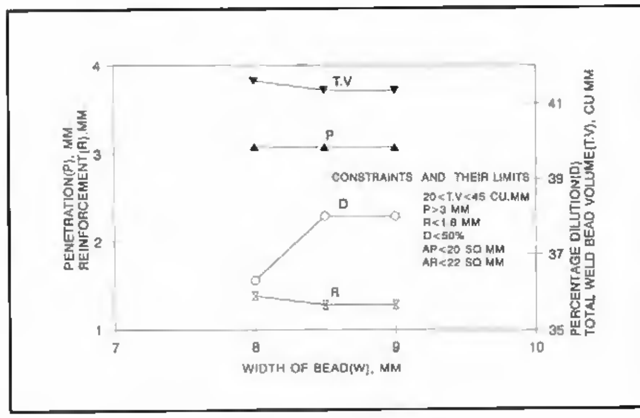

Fig. 6 — Direct effect of W on P, R, D and T.V.

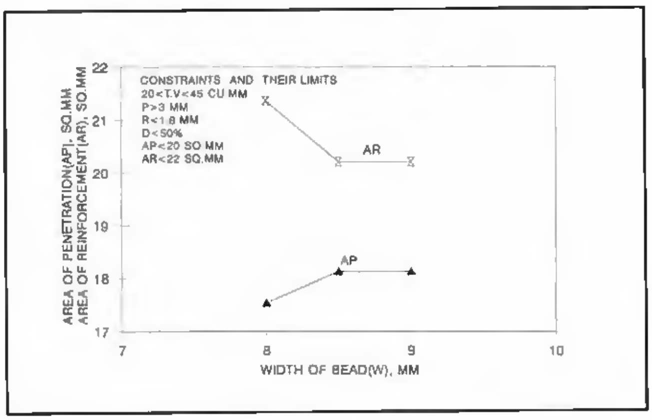

Fig. 7 — Direct effect of W on AP and AR.

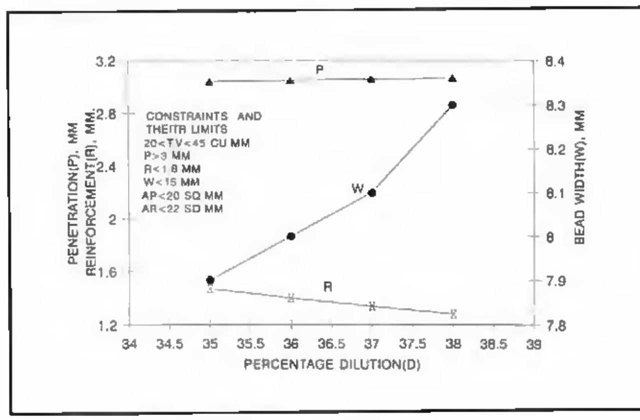

Fig. 8 — Direct effect of D on P, R and W.

variables and their notations used in writing the M-file using *MATLAB* software are given below.

X (1) = welding voltage (V)
X (2) = wire feed rate (F)
X (3) = welding speed (S)
X (4) = nozzle-to-plate distance (N).

Optimization of the Objective Function

The main purpose of this study is to minimize the total volume of the weld bead using other important bead parameters with their limits as constraints. The model is a nonlinear equation with constraints. The step-by-step procedure of minimization of total volume using the optimization module available in the tool box of the *MATLAB* version 4.2b software package is given below. The constrained minimum of a scalar function of several variables at an initial estimate, which is referred as "constrained nonlinear optimization," is mathematically stated as the following:

Minimize f(X) subject to

$$G(X_1, X_2, X_3, \ldots X_n) < 0$$

where, X and G(X) represent the matrices of the objective and constraint functions, respectively, and f(X) is a scalar function. In optimization, the value of the constraints should be < 0 (Ref. 8). To satisfy this condition, the upper limit of each of the constraints, except for penetration, is included in the constraint equation so that each of the constraints is kept below or equal to the limit. But the penetration of the weld bead has to be fixed at the maximum possible value. Therefore, the penetration is specified as a constraint in such a way that it is multiplied by –1 and its minimum limit is included so that it becomes –P + 3 <0 (where 3 mm is its minimum value). Therefore, the value of the penetration as a constraint will be above 3 mm. The limits of the other constraints (*i.e.*, reinforcement, width, area of penetration, area of reinforcement and the dilution of the weld bead) were established by data obtained from past experience with a view that they should provide a sound and defect-free welded joint along with a feasible solution to the objective function. Also, the constraints were given in the form of equations. Several numerical methods are available for optimization of nonlinear equations with constraints. A quasi-Newton method is the most efficient and quickest one, and this method was used to determine the optimum total weld bead volume (Ref. 9).

Step 1: Writing M-file: Function (f, g) = f(x)

f(X) = 45.78 + 1.58*X(1) + 2.2*X(2) – 3.5*X(3) + 2.0*X(4) + 1.67*X(1)^2 + 0.17*X(2)^2 + 1.34*X(3)^2 + 0.97*X(4)^2 + 0.28*X(1)*X(2) – 0.21*X(1)*X(3) + 0.48*X(1)*X(4) – 0.87*X(2)*X(3) + 0.64*X(2)*X(4) – 0.77*X(3)*X(4); Total weld bead volume.

g(1) = 1.27–0.08*X(1) + 0.16*X(2) – 0.18*X(3) – 0.03*X(4) + 0.03*X(1)^2 + 0.07*X(2)^2 + 0.15*X(3)^2 + 0.01*X(4)^2 + 0.03*X(1)*X(2) + 0.03*X(1)*X(3) – 0.014*X(1)*X(4) – 0.001*X(2)*X(3) – 0.02*X(2)*X(4) + 0.03*X(3)*X(4) – 1.8; Reinforcement and its upper limit in mm.

g(2) = –[3.57 – 0.113*X(1) + 0.33*X(2) – 0.22*X(3) – 0.001*X(4) + 0.05*X(1)^2 + 0.1* X(2)^2 + 0.03*X(3)^2 – 0.01*X(4)^2 – 0.05*X(1)*X(2) +

Table 3 — Comparison of Observed and Predicted Values of Conformity Test

S. No.	Process parameters V Volts	F m/min	S m/min	N mm	Penetration, mm Observed Value	Predicted Value	Error %	Dilution, % Observed Value	Predicted Value	Error %	Total Volume, mm³ Observed Value	Predicted Value	Error %
1	27	0.70	0.67	36	3.00	3.08	+2.60	36.48	35.45	+2.91	41.66	41.50	2.21
2	27	1.39	0.75	35	3.70	3.75	−1.33	46.23	44.98	+2.84	44.34	44.11	2.85
3	28	0.70	0.61	35	3.20	3.10	+3.20	39.17	38.05	+2.94	42.25	43.14	2.06
						Average	2.38			2.89			2.40
			Error =										

$$\% \text{ Error} = \frac{\text{Observed value-predicted value}}{\text{Predicted value}} \times 100$$

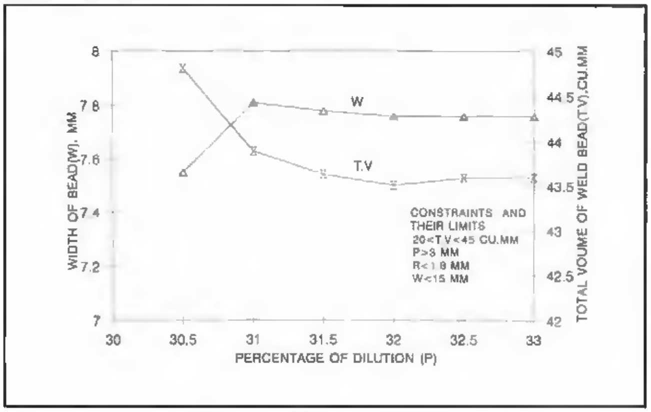

Fig. 9 — Direct effect of P on W and T.V.

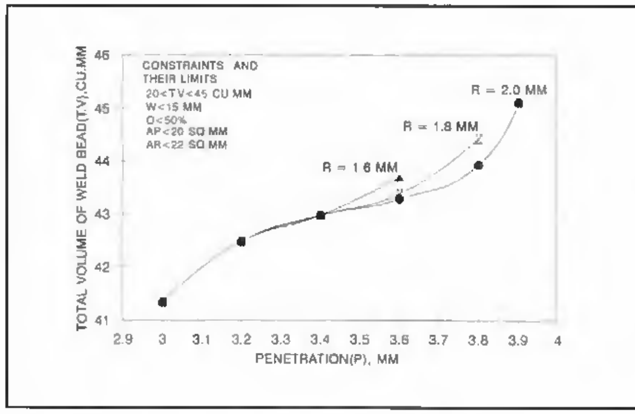

Fig. 10 — Interaction effect of P and R on T.V.

0.03*X(1)*X(3) + 0.04*X(1)*X(4) − 0.01*X(2)*X(3) − 0.01*X(2)*X(4) + 0.08*X(3)*X(4)] + 3.0; Penetration and its lower limit in mm.

g(3) = 10.76 + 1.19*X(1) + 0.45*X(2) − 1.9*X(3) + 0.23*X(4) + 0.41*X(1)^2 − 0.17*X(2)^2 + 0.29*X(3)^2 + 0.12*X(4)^2 − 0.04*X(1)*X(2) − 0.64*X(1)*X(3) − 0.15*X(1)*X(4) − 0.35*X(2)*X(3) + 0.091*X(2)*X(4) − 0.29*X(3)*X(4) – 15.0; Bead width and its upper limit in mm.

g(4) = 47.27 + 0.74*X(1) + 2.51*X(2) − 0.25*X(3) − 2.23*X(4) − 1.31*X(1)^2 − 0.71*X(2)^2 1.31*X(3)^2 − 0.44*X(4)^2 − 0.09*X(1)*X(2) − 0.3*X(1)*X(3) − 0.31*X(1)*X(4) + 0.43*X(2)*X(3) − 0.90*X(2)*X(4) + 0.17*X(3)*X(4) − 50; % Dilution and its upper limit.

g(5) = 21.56 + 1.05*X(1) + 1.85*X(2) − 1.61*X(3) – 0.212*X(4) + 0.041*X(1)^2 + 0.29*X(2)^2 − 0.097*X(3)^2 + 0.15*X(4)^2 + 0.14*X(1)*X(2) − 0.21*X(1)*X(3) + 0.056*X(1)*X(4) − 0.24*X(2)*X(3) − 0.16*X(2)*X(4) − 0.16*X(3)*X(4) – 20; Area of penetration and its upper limit.

g(6) = 21.44 + 0.44*X(1) + 0.187*X(2) − 1.76*X(3) + 2.11*X(4) + 1.39*X(1)^2 − 0.39*X(2)^2 + 1.22*X(3)^2 + 0.62*X(4)^2 + 0.41*X(1)*X(2) − 0.047*X(1)*X(3) + 0.14*X(1)*X(4) − 0.94*X(2)*X(3) + 0.77*X(2)*X(4) − 0.33*X(3)*X(4) – 22; Area of reinforcement and its upper limit.

g(7) = f – 45; upper limit of total weld bead volume is 45 mm³.

g(8) = – f + 20; lower limit of total weld bead volume is 20 mm³.

Step 2: Invoke an optimization routine (R-file)

X_0 = [−1, −1,1,1] (guess of initial solution)

Options = [ ] (change in the default setting if any)

V_{lb} = [−2, −2, −2, −2] (lower boundaries of the variables)

V_{ub} = [2, 2, 2, 2] (upper boundaries of the variables)

X = Constr ('f(X)' X0; options; V_{lb}, V_{ub})

Step 3: Running the M-file.

After running the M-file and retrieving the constraints, the optimum values of the process variables are the following:

X(1) = welding voltage (V) = 28 volts;
X(2) = wire feed rate (F) = 0.7 m/min;
X(3) = welding speed (S) = 0.64 m/min
X(4) = nozzle-to-plate distance (N) = 34.6 mm.

The results of optimization are given below.

T.V. = total volume of the weld bead = 41.33 mm³
R = reinforcement = 1.28 mm;
P = penetration = 3.07 mm;
W = width of the bead = 8.33 mm;
D = dilution of the bead = 38%;
AP = area of penetration = 18.13 mm²;
AR = area of reinforcement = 20.21 mm².

Sensitivity Analysis

Sensitivity analysis, also known as the post optimality analysis, is the study of what happens to the value of the objective function if the limit of each of the constraints is changed from optimum value. Optimum solution for any function lies in a boundary or zone and, hence, it is not a single constant value (Ref. 10). This provides a flexibility in fixing the limits for the constraints. Also, for every value of each of the constraints there is a possibility for change in the value of the objective function as well as other constraints.

Therefore, it is very important to know the impact of relaxing the limits of each constraint on the value of the objective

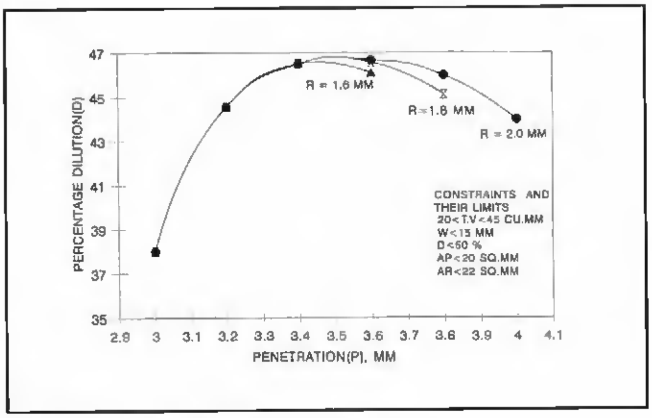

Fig. 11 — Interaction effect of P and R on D.

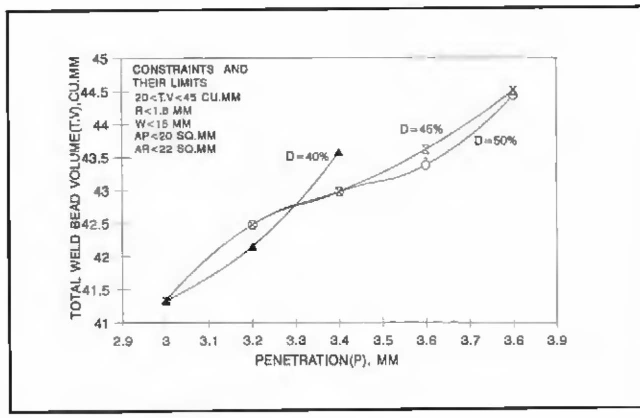

Fig. 12 — Interaction effect of P and D on T.V.

function and other constraints before fixing the correct limits for the constraints to produce a sound and strong weld at relatively low cost with a high degree of repeatability. Sensitivity analysis was carried out for the total volume of the weld bead by varying the limit of one of the constraints at a time, and the effect of the change in the constraint limit on the value of the total volume and other constraints were recorded and given in Table 2. To find the interaction effect of the constraints, limits of two constraints were changed and their effects were also noted.

Confirming Test

To check and confirm the validity of the optimization results, test runs were conducted in a manufacturing facility with the same experimental setup. The process parameters were assigned values nearest to the optimum values selected from Table 2 after confirming the equipment could produce them and the results were recorded. For the same set of parameters, optimization of T.V. was done with other bead parameters as constraints with the same limits. The objective function, as well as the constraints, were substituted in their natural scale. A comparative study between the actual and predicted results with a percentage of deviation of the results was carried out. The results of this comparative study are presented in Table 3.

Results

The mathematical models furnished above can be used to predict the weld bead geometry by substituting the values, in coded form, of the respective factors. Also, knowing the weld bead volume is very useful 1) to minimize the various weld defects due to high heat input, 2) to increase productivity and 3) to minimize the total welding cost for the required quality. The sensitivity analysis improves the understanding of the direct and interaction effects of various bead parameters on weld bead size and volume. The responses calculated for each set of coded welding variables are represented graphically in Figs. 2–12.

For bead parameter values, P, R, W, AP, AR and D, other than that tabulated above, it was found the value of the objective function, namely, total volume of the weld bead, is either unaltered or has no feasible solution.

Discussion

The main effects of each of the weld bead parameters on the other bead parameters and on the total weld bead volume predicted from the sensitivity analysis using the mathematical models developed are depicted in Figs. 2–12.

Direct Effects of Bead Parameters

Direct Effect of Penetration on the Other Bead Parameters

Figure 2 shows the effect of increasing the lower limit value of the penetration (P), a constraint, on reinforcement (R) and bead width (W) in the process of optimizing the total volume of weld bead. For the given constraints and limits, the maximum penetration is 3.8 mm. For all values of P greater than 3.8 mm, no feasible solution was possible and for P less than 3 mm, the values of R and W remain unchanged. From Table 2, it is noted that as P is increased from 3 to 3.2 mm, V and S increase marginally but N drops from 34.6 to 33.6 mm and F increases considerably from 0.7 to 1.02 m/min. As F has a positive effect on all the bead parameters and N has a negative effect on R but a positive effect on W, the increase in P from 3 to 3.2 mm results in an increase in R from 1.28 to 1.30 mm and W from 8.3 to 9.1 mm. The increase in P beyond 3.2 mm results in a drop in V from 28 to 27 V, an increase in F from 1.02 to 1.40 m/min, an increase in S from 0.66 to 0.7 m/min and an increase in N from 33.6 to 34.7 mm. This shows the increase in R from 1.30 to 1.80 mm as P is increased beyond 3.2 mm is mainly due to an increase in F. Therefore, F has the predominant effect on R for all values of P compared to that of other bead parameters. The decrease of W is mainly due to an increase in S as P is increased beyond 3.2 mm. Therefore, S has the predominant effect on W for all values of P >3.2 mm compared to other bead parameters.

Figure 3 shows the effect of P on other bead parameters, namely, area of penetration (AP), area of reinforcement (AR), total weld bead volume (T.V.) and percentage of dilution (D). From the figure, it is clear AP generally increases with the increase in P. But this increase of AP decreases gradually because of a decrease in W as P is increased beyond 3.2 mm — Fig. 2. AR has a mixed trend with the increase in P. As P is increased from 3 to 3.2 mm, AR increases from 20.21 to 20.53 mm^2 because both R and W increase for this range of values of P. As P is increased from 3.2 to 3.6 mm, AR decreases from 20.53 to 19.72 mm^2. This is mainly due to the drop in W for this range of values of P. For further increase in P, AR increases from 19.72 to 20.30 mm. This may be due to the predominant effect of an increase in R rather than the decrease in W on AR. T.V. also generally increases with an increase in P. The increasing rate of T.V. is not steady. This is because of a mixed trend of R in spite of an increasing trend of AP. D increases from 38% to 46.6% as P is increased from 3 to 3.6 mm. D drops from 46.6% to 45.1%. This is because the increasing rate of AP compared to T.V. with the increase in P from 3 to 3.6 mm is more. Therefore, D increases. For the increase in P from 3 to 3.6 mm, AP remains at the same value of 20 mm^2 but T.V. increases from 43.38 to 44.44 mm^3. Therefore, D drops. For all the other values of P, the values of R, W, D, AP, AR and T.V. either remained unaltered or no feasible solution is possible.

Direct Effect of Reinforcement on the Other Bead Parameters

Figures 4 and 5 show the effect of changing the value of R, a constraint in optimization, on bead parameters P, W, AP, AR, T.V. and D. From Fig. 4, it is apparent as R is increased from 1.7 to 1.8 mm, P increases from 3.05 to 3.07 mm, but W drops from 8.4 to 8.3 mm. These effects are mainly due to the increase in the value of F as R increases. As F has a positive effect on P and W, they increase with the increase in R. For a further increase in R beyond 1.8 mm, there is no change in the values of the process parameters, and hence, in the values of P and W. For other values of R, no feasible solution was possible.

From Fig. 5, it is clear as R is increased from 1.7 to 1.8 mm, V and F increase, and, therefore, AP, AR, T.V. and D increase. For a further increase in R beyond 1.8 mm, all the bead parameters remain unaltered. For other values of R <1.7 mm, no feasible solution was possible.

Direct Effect of Bead Width on the Other Bead Parameters

Figure 6 shows the effect of varying the value of the upper limit of W on other bead parameters, namely, P, R, D and T.V. From the figure, it is apparent the range of values of W for which a feasible solution is possible is very narrow and is 8 to 8.5 mm only. For all the other values of W, the values of bead parameters were either unaltered or no feasible solution was possible. As W is increased from 8 to 8.5 mm, P remains at the same value of 3.07 mm, but R drops from 1.38 to 1.28 mm. The decrease in R is due mainly to increase in S and N as W is increased. As S and N have a negative effect on R, R decreases. As P is unaltered and R decreases, T.V. drops when W is increased. Because T.V. drops, D increased from 36.3% to 38% as W increased.

From Fig. 7, it is noted AP increases from 17.54 to 18.13 mm^2 with the increase in W. This is because P is unaltered when W is increased from 8 to 8.5 mm. Also, as W increases from 8 to 8.5 mm, R drops from 1.38 to 1.28 mm, and AR drops from 21.37 to 20.21 mm^2. For the other values of W, the values of AP and AR either remain unaltered or no feasible solution was possible.

Direct Effect of Percentage of Dilution on the Other Bead Parameters

Figure 8 shows the effect of D on P and R and W. The figure shows P increases slightly from 3.04 to 3.07 mm but R decreases gradually from 1.47 to1.28 mm and W increases from 7.9 to 8.3 mm as D is increased from 30% to 38%. The increase in P is mainly due to the decrease in N as D increased — Table 2. The decrease in R is due to the increase in S. The decrease in R is compensated by the increase in W as D increases. For the other values of D, the value of P, R and W are either unchanged or no feasible solution was possible.

Figure 9 shows the effect of changing the value of D, a constraint in optimization of T.V., on AP, AR and T.V. From the figure, it is apparent AP increases but both AR and T.V. decrease as D increases from 35% to 38%. The increase in AP is due mainly to an increase in P and W as D increases. A decrease in AR, in spite of an increase in W, is due to the decrease in R as W increases. The decrease in T.V. is due to the fact D increases when either AP increases or the total area decreases. In this case, AP increases and T.A. decreases. Therefore, T.V. decreases.

Interaction Effects of Bead Parameters

Interaction Effect of Penetration and Reinforcement on Total Volume of the Weld Bead

Figure 10 shows the interaction effect of P and R on T.V. The figure shows the value of T.V. is the same for all values of R as P increases from 3 to 3.4 mm. The minimum value of T.V. (about 41.3 mm^3) is at the minimum value of P and R. Total value of T.V. is maximum (about 45.4 mm^3) at maximum values of P and R. Total area and the total volume of the weld bead generally increase when the areas of penetration and reinforcement increase. The areas of penetration and reinforcement increase as P and R are increased, keeping W either constant or increasing W. The total area and the total volume of the weld bead depends on the values of P, R and W. From the figure, it is noted that even though T.V. increases for all values of R when P is increased, this increasing trend of T.V. decreases gradually as R is increased from 1.6 to 2.0 mm. But T.V. is supposed to increase as R is increased. As T.V. is influenced by W, this decrease in the increasing trend of T.V. as R is increased may be due to the increase in the value of W.

Interaction Effect of Penetration and Reinforcement on Dilution of the Bead

Figure 11 shows the interaction effect of P and R on D. From the figure, it is apparent D increases as P increases from 3 to 3.4 mm for R = 1.6 and 1.8 mm, respectively. For R = 2.0 mm, D increases as P is increased from 3 to 3.6 mm. Beyond this value of P, D decreases for all values of R. Also, the value of D for any given value of R is the same as P is between 3 and 3.4 mm. This indicates P has a stronger effect on D compared to R. As P increases, AP increases, and D increases. For all values of P >3.4 mm, the value of D is more for the higher value of R. For this range of P (P = 3.4 to 4.0 mm), the effect of R is greater than P. As R increases, AR increases, T.A. increases and D decreases.

Interaction Effect of Dilution and Penetration on Total Volume of Weld Bead

Figure 12 shows the interaction effect of D and P on T.V. From the figure, it is clear the value of T.V. is minimum (41.3 mm^3) at minimum value of P and D (= 40%). This is because when P is minimum, AP is minimum for the same value of W, and T.A. and T.V. are minimum. As P increases, T.V. also increases for all values of D. For all values of P between 3.4 and 3.8 mm, the value of T.V. is more for a lesser value of D (= 45%). This is due to the fact that for this range of values of P, the increase in AP is less than that of T.A. Therefore, T.A. and T.V. are more for a lesser value of D.

Conclusions

The following were concluded from this investigation:

The *MATLAB* software package can be effectively employed for the optimization of weld bead parameters and finding the corresponding optimum process variables.

The sensitivity analysis reveals the effect of constraint limits on the value of the objective function.

The bead width has no effect on other bead parameters including total area during optimization and sensitivity analysis. The penetration has a considerable positive effect on the dilution. At a maximum penetration of 3.8 mm, the dilution is also maximum at 46.6%.

The reinforcement has very little effect on total volume of the weld bead and other bead parameters.

The percentage dilution has a negative effect on the total volume of the weld bead. At the lower dilution of 35%, the total volume is maximum and equal to 43 mm^3, and at a higher value of dilution (38% and above), the total volume is a low 41%.

The comparison of predicted and actual results shows the predicted results are accurate by about 97%.

The value for penetration and dilution as constraints for which the objective function and other parameters are sensitive is considerable, while it is narrow for other bead parameters.

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21	60	99	138	177	216	255	294	333
22	61	100	139	178	217	256	295	334
23	62	101	140	179	218	257	296	335
24	63	102	141	180	219	258	297	336
25	64	103	142	181	220	259	298	337
26	65	104	143	182	221	260	299	338
27	66	105	144	183	222	261	300	339
28	67	106	145	184	223	262	301	340
29	68	107	146	185	224	263	302	341
30	69	108	147	186	225	264	303	342
31	70	109	148	187	226	265	304	343
32	71	110	149	188	227	266	305	344
33	72	111	150	189	228	267	306	345
34	73	112	151	190	229	268	307	346
35	74	113	152	191	230	269	308	347
36	75	114	153	192	231	270	309	348
37	76	115	154	193	232	271	310	349
38	77	116	155	194	233	272	311	350
39	78	117	156	195	234	273	312	

2001-2002
AWS CONGRESSIONAL FELLOW PROGRAM

I. PREFACE

A. Technology is affecting society to an ever-increasing extent;

B. Public policy issues affecting a broad constituency are increasingly based on technological factors;

C. Informed decisions regarding public policy issues require the input of the engineering profession, among others;

D. The engineering professional constitutes one of the nation's most valuable resources, and

E. This resource should be applied in the public interest to matters having a technological content.

II. POLICY

A. AWS declares that it is the continuing policy of the American Welding Society to
   1. be sensitive to the public's interests;
   2. provide government at all levels with advice on engineering matters and policies affecting the public interest; and
   3. maintain a climate of understanding and credibility that will foster continuing dialogue with the government.

B. As one measure for furthering its policy, The Board of Directors establishes a Congressional Fellow Program to assist legislators and officials of the Congress in public policy deliberations. Each year, AWS will select a member, in a manner herein described, to serve as Congressional Fellow to assist legislators and other federal officials.

C. It is preferential that AWS and the Fellow's employer share the compensation and the expenses of the Fellow so that all parties have a financial interest in the program. However, a Fellow may serve with full employer support, provided that she or he is selected in accordance with this policy and she or he adheres to all AWS policies and guidelines of the program. AWS's share shall not exceed the amount annually budgeted. A Fellow may also participate with no employer support but recognizing the limited stipend.

D. Although the Congressional Fellow is sponsored by AWS, the Fellow's primary objective is to provide assistance to Congress while representing the welding engineering profession in objective fashion without bias or favor toward AWS or her or his employer.

In addition, AWS will help in furnishing whatever technical assistance a Congressional Fellow will request of the Society.

E. It is desirable that the Congressional Fellow be familiar with AWS operations and organizational structure in order to obtain assistance promptly and efficiently.

F. Congressional Fellows must comply with the AWS policy on Conflict of Interest and any appropriate rules of ethics of the host federal office.

III. PROCEDURE

A. Solicitation of applicants and Selection of Congressional Fellows

1. AWS will solicit applicants through appropriate means, including letters to companies, announcements in the *Welding Journal*, and appeals to the AWS leadership to identify candidates.

2. The Candidate Review Committee shall
   a. Review applications;
   b. Interview highly marked applicants;
   c. Identify the best qualified among these for possible selection as a Congressional Fellow;
   d. Forward list of recommendations for the AWS Congressional Fellows and necessary support documents to the Government Affairs Liaison Committee for final selection and approval.

3. Individuals chosen to be Congressional Fellow(s) will be assisted by the AWS Washington Government Affairs Office in his or her placement with the staff of a Representative, Senator or a congressional committee.

4. The selection of the Fellow will be announced by the President of AWS.

B. Requirements

The requirements for the Congressional Fellow Program are as follows:

1. A Congressional Fellow's term shall be twelve months, beginning in September.

2. Government Affairs Liaison Committee shall select the Fellow(s) using objective selection criteria, including a candidate's application, to determine a candidate's ability to communicate both orally and in written form, and such other attributes as the committee deems necessary for a candidate who will represent the welding profession.

3. Sex, creed, race, ethnic background and political affiliation are expressly excluded as selection criteria for Congressional Fellows.

4. Fellows shall hold at least the AWS grade of Member prior to submitting an application for Congressional Fellow.

5. Fellows shall be citizens of the United States of America.

Deadline for Receiving Applications is February 1, 2001.

For a complete application package, contact:
Richard French
Deputy Executive Director
1-800-443-WELD, ext. 218

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Miami, Florida 33126
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