Properties and Applications
of
Ni-Resist and Ductile Ni-Resist Alloys

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Properties and Applications of Ni-Resist and Ductile Ni-Resist Alloys

General Characteristics of the Ni-Resist Austenitic Cast Iron Alloys

There are two families of Ni-Resist austenitic cast irons. These are the standard or flake graphite alloys and the ductile or spheroidal graphite alloys. As time passes, the spheroidal grades, because of higher strength, ductility and elevated temperature properties, are becoming more prominent. However, the flake materials with lower cost, fewer foundry problems and better machinability and thermal conductivity are still produced by many foundries. General characteristics of both groups are described below.

Corrosion Resistance: The Ni-Resists are specified for handling salt solutions, sea water, mild acids, alkalies and oil field liquids, both sweet and sour. Their corrosion resistance is far superior to that of normal and low alloy cast irons. They are not stainless steels and do not behave as such. They are characterized by uniform corrosion rather than by localized deterioration.

Wear Resistance: Cylinder liners, pistons, wear rings and sleeves, bearings, glands and other metal-to-metal rubbing parts are cast in Ni-Resist alloys. Their galling resistance is excellent.

Erosion Resistance: Slurries, wet steam and other fluids with entrained solids are substances which are extremely erosive to most metals. Ni-Resist alloys offer a combination of corrosion-erosion resistance which is superior in these environments. They are outstanding when compared to gray cast iron, ductile irons and steel.

Toughness and Low Temperature Stability: Ni-Resist alloys are much superior to gray cast iron, particularly at low temperatures.

Controlled Expansion: Expansivities from as low as 5.0 X 10^{-6} to as high as 18.7 X 10^{-6} cm/cm per °C (2.8 X 10^{-6} to 10.4 X 10^{-6} in/in per °F) are possible with the different Ni-Resist alloys. The lower value makes possible a cast metal with low expansivity for precision parts. Also, the range permits matching Ni-Resists with many different metals and alloys.

Magnetic and Electrical Properties: Some Ni-Resist alloys are non-magnetic. These and others have high electrical resistance. Thus, they are used for resistance grids, electric furnace parts, in clutches and other applications requiring these properties combined with machinability and heat resistance.

Heat Resistance: Originally, because of good heat and oxidation resistance, the flake graphite Ni-Resist alloys were used at temperatures up to 700°C(1300°F). However, because of the superior elevated temperature properties of the spheroidal graphite Ni-Resists, the flake alloys are now seldom used above 315°C(600°F). Spheroidal graphite Ni-Resist alloys can be and are used at temperatures up to 1050°C(1930°F). Although the ductile alloys are better, all Ni-Resists have relatively low rates of oxidation in air. The resulting oxides adhere tenaciously, further reducing oxidation with time.

Machinability: The machining techniques possible for Ni-Resist castings are similar to those for the higher strength grades of gray cast iron and austenitic stainless steels.

Castability: Complicated and intricate designs that are often difficult to cast in other materials are possible with Ni-Resist alloys. This leads to products that are economically produced.

Part I
The Alloys

The Ni-Resist cast irons are a family of alloys with sufficient nickel to produce an austenitic structure which has unique and superior properties. The family is divided into two groups. These are the standard or flake graphite alloys and the ductile or spheroidal graphite alloys. Except for the copper containing ones, the groups have materials similar in composition but for a magnesium addition which converts the graphite to the spheroidal form in the ductile Ni-Resists. Copper interferes with the magnesium treatment and alloys high in copper cannot be produced with spheroidal graphite. Typical micro-structures of flake and spheroidal graphite alloys are shown in *Figures 1* and *2*, respectively.

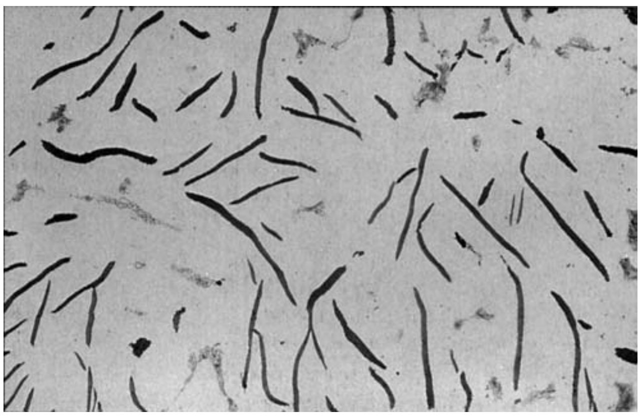


Figure 1 Typical Microstructure of Flake Graphite Ni-Resist Alloys - Ni-Resist 1- Graphite Flakes and Carbide Areas within Austenite Matrix

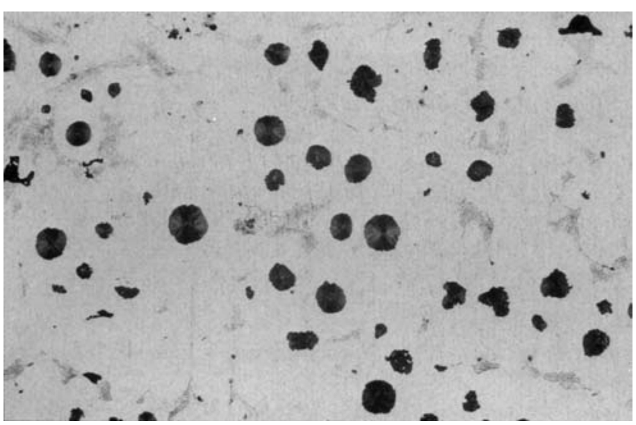


Figure 2 Typical Microstructure of Spheroidal Graphite Ni-Resist Alloys - Ni-Resist D-2W - Graphite Spheres and Carbide Areas within Austenite Matrix

The composition and properties of the Ni-Resists are covered by a number of national and international specifications. Unfortunately, the nomenclature describing these alloys varies from country to country. *Tables I* and *II* give the common name for the various alloys and their designations in four different specifications. The specifying bodies in these tables are the American Society for Testing and Materials(ASTM), the International Standards Institute (ISO), The Deutsches Institut fur Normung (DIN) and the British Standards Institute (BSI). Some other national designations are given in **Part II**. Nominal chemical compositions are in *Tables III* and *IV*. Refer to the national or international specifications for precise chemical requirements.

Table I Typical Nomenclatures for Flake Graphite Ni-Resist Alloys

Common Name	ASTM A 436-84	ISO 2892-1973	DIN 1694	BS 3468:1986
NiMn 13 7	-	L-NiMn 13 7	GGL-NiMn 13 7	-
NiResist 1	Type 1	L-NiCuCr 15 6 2	GGL-NiCuCr 15 6 2	Grade F1
Ni-Resist 1b	Type 1 b	L-NiCuCr 15 6 3	GGL-NiCuCr 15 6 3	-
Ni-Resist 2	Type 2	L-NiCr 20 2	GGL-NiCr 20 2	Grade F2
Ni-Resist 2b	Type 2b	L-NiCr 20 3	GGL-NiCr 20 3	-
Nicrosilal	-	L-NiSiCr 20 5 3	GGL-NiSiCr 20 5 3	-
Ni-Resist 3	Type 3	L-NiCr 30 3	GGL-NiCr 30 3	Grade F3
Ni-Resist 4	Type 4	L-NiSiCr 30 5 5	GGL-NiSiOr 30 5 5	-
Ni-Resist 5	Type 5	L-Ni 35	-	-
Ni-Resist 6	Type 6	-	-	-

Table II Typical Nomenclatures for Spheroidal Graphite Ni-Resist Alloys

Common Name	ASTM A439-83 A571-84	ISO 2892-1973	DIN 1694	BS 3468:1986
NiResist D-2	Type D-2	SAO 20 2	GGG-NiCr 20 2	Grade S2
NiResist D-2W	-	-	GGG-NiCrNb 20 2	Grade S2W
NiResist D-2B	Type D-2B	SAO 20 3	GGG-NiCr 20 3	Grade S2B
Nicrosilal Spheronic	-	SASCr 20 5 2	GGG-NiSiCr 20 5 2	-
NiResist D-2C	Type D-2C	S-Ni 22	GGG-Ni 22	Grade S2C
NiResist D-2M	Type D-2M	SAW 23 4	GGG-NiMn 23 4	Grade S2M
NiResist D-3A	Type D-3A	S-NO 301	GGG-NiCr 301	-
NiResist D-3	Type D-3	SAO 30 3	GGG-NiCr 30 3	Grade S3
NiResist D-4A	-	-	GGG-NiCr 30 5 2	-
NiResist D-4	Type D-4	S-NiSiCr 30 5 5	GGG-NiSiCr 30 5 5	-
NiResist D-5	Type D-5	S-Ni 35	GGG-Ni 35	-
NiResist D-5B	Type D-5B	SAO 35 3	GGG-NiCr 35 3	-
NiResist D-5S	Type D-5S	S-NiSiCr 35 5 2	GGG-NiSiCr 35 5 2	Grade S5S
NiResist D-6	-	SAW 13 7	GGG-NiMn 13 7	Grade S6

FLAKE GRAPHITE ALLOYS

NI-Resist NiMn 13 7 – Relatively low cost, non-magnetic alloy is not used where corrosion and/or high temperature resistance are required.

Ni-Resist 1 – Good resistance to corrosion in alkalis, dilute acids, sea water and other salt solutions has good moderate temperature and wear resistance. Used for pumps, valves and products where wear resistance is required. Used for piston ring inserts because of matching expansion characteristics of aluminum piston alloys.

Ni-Resist 1b – Similar applications as Ni-Resist 1, but

Table III Chemical Compositions of Flake Graphite Ni-Resist Alloys, %

Common Name	Ni	Cr	Si	Cu	Mn	C max	Other
NiMn 13 7	12.0-14.0	.2max	1.5-3.C	-	6.0-7.0	3.0	-
NiResist 1	13.5-17.5	1.5-2.5	1.0-2.8	5.5-7.5	0.5-1.5	3.0	-
NiResist1b	13.5-17.5	2.5-3.5	1.0-2.8	5.5-7.5	0.5-1.5	3.0	-
NiResist 2	18.0-22.0	1.5-2.5	1.0-2.8	.5max	0.5-1.5	3.0	-
NiResist 2b	18.0-22.0	3.0-6.0	1.0-2.8	5max	0.5-1.5	3.0	-
Nicrosil-al	18.0-22.0	1.5-4.5	3.5-5.5	-	0.5-1.5	2.5	-
NiResist 3	28.0-32.0	2.5-3.5	1.0-2.C	.5max	0.5-1.5	2.6	-
NiResist 4	29.0-32.0	4.5-5.5	5.0-6.C	.5max	0.5-1.5	2.6	-
NiResist 5	34.0-36.0	.1max	1.0-2.C	.5max	0.5-1.5	2.4	-
NiResist 6	18.0-22.0	1.0-2.0	1.5-2.5	3.5-5.5	0.5-1.5	3.0	1.0Mo

Table IV Chemical Compositions of Spheroidal Graphite Ni-Resist Alloys, %

Common Name	Ni	Cr	Si	Cu	Mn	C max	Other
NiResist D-2	18.0-22.0	1.75-2.75	1.0-3.0	0.5max	0.70-1.25	3.0	-
NiResist D-2W	18.0-22.0	1.50-2.20	1.5-2.2	0.5max	0.5-1.5	3.0	.12-20Nb
NiResist D-2B	18.0-22.0	2.75-4.00	1.5-3.0	0.5max	0,70-1.25	3.0	-
Nicrosilal Spheronic	18.0-22.0	10-2,5	4.5-5.5	0.5max	0.5-1.5	3.0	-
NiResist D-2C	21.0-24.0	0.5max	1.0-3.0	0.5max	1.8-2.4	2.9	-
NiResist D-2M	22.0-24.0	0.2max	1.5-2.5	0.5max	3.75-4.50	2.6	-
NiResist D-3A	28.0-32.0	1.0-1.5	1.0-2.8	0.5max	1.0max	2.6	-
NiResist D-3	28.0-32.0	2.5-3.5	1.0-2.8	0.5max	1.0max	2.6	-
NiResist D-4A	29.0-32.0	1.5-2.5	4.0-6.0	0.5max	0.5-1.5	2.6	-
NiResist D-428	.0-32.0	4.5-5.5	5.C-6.0	0.5max	1.0max	2.6	-
NiResist D-534	0-36.0	0.1 max	1.0-2.8	0.5max	1.0max	2.4	-
NiResist D-5B	34.0-36.0	2.0-3.0	1.0-2.8	0.5max	1.0max	2.4	-
NiResist D-5S	34.0-37.0	1.15-2.25	4.9-5.5	0.5max	1.0max	2.3	-
NiResist D-6	12.0-14.0	0.2max	2.0-3.0	0.5max	6.0-7.0	3.0	-

has superior corrosion-erosion resistance. Higher chromium content produces an alloy that is harder and stronger.

Ni-Resist 2 – Higher nickel content makes this alloy more corrosion resistant in alkaline environments. Has found applications for handling soap, food products, rayon and plastics. Used where freedom from copper contamination is required.

Ni-Resist 2b – Greater hardness improves corrosion-erosion resistance. This alloy performs well in metal-to-metal wear situations.

Nicrosilal – Has improved corrosion resistance in dilute sulfuric acid. Used for pumps, valves and other castings requiring higher mechanical properties.

Ni-Resist 3 – Has resistant to corrosion in wet steam and corrosive slurries. Can be used where it is necessary to match the coefficient of expansion of gray cast iron or steel at temperatures around 260°C(500°F). Applications include pumps, valves and machinery castings.

Ni-Resist 4 – Has excellent stain resistance. Is superior to other Ni-Resist alloys with regard to corrosion-erosion resistance.

Ni-Resist 5 – Has lowest coefficient of thermal expansion of Ni-Resist alloys. Provides dimensional stability for machine tool parts, forming dies, instruments and expansion joints.

Ni-Resist 6 – Is an uncommon alloy. When produced, it is used for pumps and valves handling corrosive solutions. Is not related to Ni-Resist D-6.

SPHEROIDAL GRAPHITE ALLOYS

Ni-Resist D-2 – Has good resistance to corrosion, corrosion-erosion and frictional wear. Can be used at temperatures up to 760°C(1400°F). Applications are pumps, valves, compressors, turbocharger housings and exhaust gas manifolds used with Ni-Resist D-2W, a primary ductile grade.

Ni-Resist D-2W – Has similar properties and applications as Ni-Resist D-2, but with better weldability when proper procedures are followed.

Ni-Resist D-2B – Has higher chromium content which results in better corrosion and corrosion-erosion resistance than Ni-Resist D-2. Has similar applications to Ni-Resist D-2.

Nicrosilal Spheronic – Has improved corrosion resistance in dilute sulfuric acid and good high temperature stability. Used for pumps, valves and other castings requiring higher mechanical properties.

Ni-Resist D-2C – Used for pumps, valves, compressors and turbocharger parts where high ductility is desired. Because of good resistance to wet steam erosion, another important application is in steam turbines. Sometimes used for non-magnetic components. Is also used for some low temperature applications.

Ni-Resist D-2M – Maintains ambient temperature mechanical properties down to -170°C(-275°F). Major uses are for refrigeration and cryogenic equipment.

Ni-Resist D-3A – Suggested where a high degree of wear and galling resistance are required along with moderate amounts of thermal expansion.

Ni-Resist D-3 – Has good corrosion resistance at elevated temperatures. Excellent corrosion-erosion resistance in wet steam and salt slurries. Uses include pumps, valves, filter parts, exhaust gas manifolds and turbocharger housings.

Ni-Resist D-4A – Has excellent corrosion and corrosion-erosion resistance with superior high temperature properties. Finds uses in pumps, armatures, exhaust gas piping and turbocharger parts.

Ni-Resist D-4 – Corrosion, corrosion-erosion and heat resistant properties are superior to those of Ni-Resists D-2 and D-3. Applications are similar to Ni-Resist D-4A.

Ni-Resist D-5 – Is used where low thermal expansion is required. Applications include machine tool parts, scientific instruments and glass molds.

Ni-Resist D-5B – Has low thermal expansion with high levels of heat and corrosion resistance. Has good mechanical properties at elevated temperatures. Used for low pressure gas turbine housings, glass molds and other elevated temperature applications.

Ni-Resist D-5S – Has excellent resistance to growth and oxidation at temperatures up to 1050°C(1930°F). Low coefficient of thermal expansion with good thermal shock resistance. Used in gas turbines, turbocharger housings, exhaust manifolds and hot pressing dies.

Ni-Resist D-6 – Is non-magnetic with good mechanical properties. Used for switch insulator flanges, terminals, ducts and turbine generator parts.

EFFECT OF COMPOSITION ON STRUCTURE AND PROPERTIES

Each of the alloying elements in the iron base of the Ni-Resists affects the structure and/or properties in different ways. The intentional additions make important and necessary contributions. The following is a brief synopsis of the unique effects of these substances.

Nickel

Nickel is the element which gives the Ni-Resist alloys their defining characteristics. It is primarily responsible for the stable austenitic structure and makes substantial contributions to corrosion and oxidation resistance and to mechanical properties throughout the usable temperature range. The coefficient of thermal expansion is also largely dependent on the nickel content, reaching a minimum at 35% nickel.

Chromium

The most important effects of chromium are improvements in strength and corrosion resistance at elevated temperatures. It also causes increased hardness which improves wear and corrosion/erosion resistance. Chromium decreases ductility by forming a higher percentage of hard carbides. Higher chromium can lead to a greater propensity for microporosity in castings.

Copper

Copper improves corrosion resistance in mildly acidic solutions. It interferes with the magnesium treatment used to produce spheroidal graphite and cannot be added to ductile Ni-Resists.

Carbon

Carbon is a characteristic element in all cast irons. High carbon reduces the solidification temperature and improves the melting and pouring behaviour. Lower carbon contents usually lead to fewer carbides and higher strength and toughness.

Silicon

Silicon is another essential element in cast irons. It improves fluidity of the melt which leads to better casting properties, especially for thin-walled sections. Silicon also contributes to greater high temperature corrosion resistance. This element lessens chromium carbide formation.

Manganese

Manganese provides no improvements in corrosion resistance, high-temperature or mechanical properties. However, it is an austenite stabilizer which makes important contributions to the low temperature properties of Ni-Resist D-2M and to the non-magnetic alloys such as Ni-Resist NiMn 13 7.

Niobium (Columbium)

Niobium is an important addition agent which leads to the improved weldability of Ni-Resist D-2W. Control of silicon, sulfur and phosphorous are also necessary for maximum effect. It will probably have similar effects in other compositions.

Molybdenum

Molybdenum is not specified in the various grades of Ni-Resist alloys, but about 2% is sometimes added for improved high temperature strength.

Magnesium

A necessary ladle addition which leads to the formation of spheroidal graphite in the ductile Ni-Resists. Only a very small quantity is present in castings.

MECHANICAL PROPERTIES

Tables V and *VI* list the nominal mechanical properties for flake and spheroidal graphite Ni-Resist alloys, respectively. These are average values given for guidance only. Mechanical properties can be varied by heat treatment and by altering the levels of carbon, silicon, chromium and, if desired, molybdenum. For unique service requirements, special agreements on composition and properties can often be reached between buyer and producer. There are some variations in required or typical mechanical properties in the various national and international specifications. Actual specification values for many of these are given in **Part II**. In general, these are for as-cast material. Heat treatment may change them considerably.

Tensile Strength

The tensile strength of the flake graphite alloys is similar for all types. This is because the austenite matrix common to all of the alloys controls the strength level; although some variation in strength can be attained by controlling the size, amount and distribution of graphite flakes through heat treatment. It is also possible to raise strength levels by lowering carbon and silicon and/or raising chromium.

Table V Mechanical Properties of Flake Graphite Ni-Resist Alloys

Alloy	Tensile Strength MPa(ksi)	Compressive Strength MPa(ksi)	Elongation %	Modulus of Elasticity MPa(ksi)x10^3	Brinell Hardness
NiMn 13 7	140-220	630-840	-	70-90	120-150
	(20-31)	(90-120)		(10-13)	
Ni-Resist 1	170-210	700-840	2	85-105	120-215
	(24-30)	(100-120)		(12-15)	
Ni-Resist	190-240	860-1100	1-2	98-113	150-250
	(27-34)	(123-157)		(14-16)	
Ni-Resist 2	170-210	700-840	2-3	85-105	120-215
	(24-30)	(100-120)		(12-15)	
Ni-Reslst	190-240	860-1100	1-2	98-113	160-250
	(27-34)	(123-157)		(14-16)	
Nicrosibl	190-280	-	2-3	-	140-250
	(27-40)				
Ni-Resist 3	190-240	700-910	1-3	98-113	120-215
	(27-34)	(100-130)		(14-16)	
Ni-Resist 4	170-240	560	-	105	150-210
	(24-34)	(80)		(15)	
Ni-Resist 5	120-180	560-700	1-3	74	120-140
	(17-26)	(80-100)		(11)	
Ni-Resist 6	170-210	700-840	-	-	130-180
	(24-30)	(100-120)			

The tensile strengths of the spheroidal graphite alloys, with the exception of Ni-Resist D-2M, are about the same, although at significantly higher values than for the flake graphite materials. This similarity is again caused by the common austenite matrix. Strength values can also be varied by similar compositional changes as mentioned above for the flake graphite alloys. The 0.2% offset yield strengths are also about the same for the spheroidal graphite alloys, except for Ni-Resist D-2C and D-4 where it is lower and higher, respectively.

Elongation (Ductility)

As seen in *Tables V* and *Vl*, elongation values for the spheroidal graphite varieties are significantly higher than for the flake graphite alloys. This is also true when comparing the spheroidal types to normal and alloyed gray cast irons. Higher chromium content will lower ductility in the spheroidal graphite alloys because of an increased amount of carbides in the austenitic matrix. Changing the carbide content through heat treatment can also affect elongation values.

Modulus of Elasticity

The moduli of elasticity of the flake graphite alloys are similar to those for gray cast iron. For alloys of similar chemical composition, the values are slightly, but not significantly, higher for ductile Ni-Resists. Typical values are given in some of the mechanical property tables in the specifications in **Part II**.

Impact Strength

The impact strength of flake graphite Ni-Resist alloys are higher than those of gray cast iron, but are still quite low. They are usually not included in specifications. Charpy V-notch values for spheroidal graphite Ni-Resists are much higher. Typical values are given in some of the mechanical property tables in the specifications in **Part II**. Chromium content has a marked effect on impact strength with low or chromium-free

Table VI Mechanical Properties of Spheroidal Graphite Ni-Resist Alloys

Alloy	Tensile Strength MPa(ksi)	Yield Strength 0.2% Offset MPa(ksi)	Elongation %	Modulus of Elasticity MPa(ksi)x10^3	Charpy Impact Kg-m(ft-Ib)	Brinell Hardness
Ni-Resist	370-480	210-250	7-20	112-130	14-27	140-200
D-2	(53-69)	(30-36)		(16-19)	(101-197)	
Ni-Resist	370-480	210-250	8-20	112-130	14-27	140-200
D-2W	(53-69)	(30-36)		(16-19)	(101-197)	
Ni-Resist	390-500	210-260	7-15	112-133	12	150-255
D-2B	(56-71)	(30-37)		(16-19)	(87)	
Nicrosilal	370-440	210-260	10-18	-	-	180-230
Spheronic	(53-63)	(30-37)				
Ni-Resist	370-450	170-250	20-40	85-112	21-33	130-170
D-2C	(53-64)	(24-36)		(12-16)	(153-240)	
Ni-Resist	440-480	210-240	25-45	120-140	24-34	150-180
D-2M	(63-69)	(30-34)		(17-20)	(175-248)	
NI-Resist	370-450	210-270	13-18	112-130	16	130-190
D-3A	(53-64)	(30-39)		(16-19)	(117)	
Ni-Resisl	370-480	210-260	7-18	92-105	8	140-200
D-3	(53-69)	(30-37)		(13-15)	(59)	
Ni-Resist	380-500	210-270	10-20	130-150	10-16	130-170
D-4A	(54-71)	(30-39)		(19-21)	(73-117)	
Ni-Resist	390-500	240-310	1-4	91	-	170-250
D-4	(56-71)	(34-44)		(13)		
Ni-Resist	370-420	210-240	20-40	112-140	20	130-180
D-5	(53-60)	(30-34)		(16-20)	(145)	
Ni-Resist	370-450	210-290	7-10	112-123	7	140-190
D-5B	(53-64)	(30-41)		(16-18)	(56)	
Ni-Resist	370-500	200-290	10-20	110-145	12-19	130-170
D-5S	(53-71)	(29-41)		(16-21)	(87-138)	
Ni-Resist	390-470	210-260	15-18	140-150	-	120-150
D-6	(56-67)	(30-37)		(20-21)		

alloys having higher values. The impact resistance decreases as temperature drops to sub-zero levels, but, because of the austenitic structure, there is no sharp embrittlement or transition point. In the case of Ni-Resist D-2M, the impact strength is maintained to -196°C(-321°F).

PHYSICAL PROPERTIES

Tables VII and *VIII* list the average physical properties for flake and spheroidal graphite alloys. These also are average values given for guidance only. Refer to **Part II** for physical properties required or expected in some of the national and international specifications.

Density

As can be seen from the tables, the density of the various Ni-Resist alloys is about the same, except for Ni-Resists D-5 and D-5B. Generally, the density of Ni-Resists is about 5% higher than for gray cast iron and 15% lower than cast bronze alloys.

Thermal Expansion

For the various Ni-Resist alloys, the coefficients of thermal expansion range from 5.0 x 10^{-6}/°C(2.8 x 10^{-6}/°F) to 18.7 x 10^{-6}/°C(10.4 x 10^{-6}/°F). These values for a given alloy can vary with the nickel content within the specified composition. Thus, by selecting the Ni-Resist alloy and the nickel content a matching thermal expansivity with many other materials can be found.

Table VII Typical Physical Properties of Flake Graphite Ni-Resist Alloys

Alloy	Denisty gm/cc (lb/in³)	Thermal Expansion m/m°C (in/in°F)	Thermal Conductivity W/m°C	Electrical Resistivity ohm mm²/m	Magnetic Permeability
NiMn 13 7	7.4 (.268)	17.7 (9.8)	38-42	1.2	1.02
Ni-Resist 1	7.3 (264)	18.7 (10.4)	38-42	1.6	1.03
Ni-Resist lb	7.3 (.264)	18.7 (10.4)	38-42	1.1	1.05
Ni-Resist 2	7.3 (.264)	18.7 (10.4)	38-42	1.4	1.04
Ni-Resist	7.4 (.268)	18.7 (10.4)	38-42	1.2	1.04
Nicrosilial	7.4 (.268)	18.0 (10.0)	38-42	1.6	1.10
Ni-Resist 3	7.4 (.268)	12.4 (6.9)	38-42	-	-
Ni-Resist 4	7.4 (.268)	14.6 (8.1)	38-42	1.6	2.00
Ni-Resist 5	7.6 (.275)	5.0 (2.8)	38-42	-	-
Ni-Resist 6	7.3 (.264)	18.7 (10.4)	38.42	-	-

Table VIII Typical Physical Properties of Spherodial Graphite Ni-Resist Alloys.

Alloy	Denisty gmlcc (lb/in³)	Thermal Expansion M/m°C (in/in°F)	Thermal Conductivity W/m°C	Electrical Resistivity ohm mm²/m	Magnetic Permeability
Ni-Resist D-2	7.4 (268)	18.7 (10.4)	12.6	1.0	1.02
Ni-Resist D-2W	7.4 (.268)	18.7 (10.4)	12.6	-	1.04
Ni-Resist D-213	7.45 (.270)	18.7 (10.4)	12.6	1.0	1.05
Nicrosilal Spheronic	7.35 (.266)	18.0 (10.0)	12.6	-	-
Ni-Resist D-2C	7.4 (268)	18.4 (10.2)	12.6	1.0	1.02
Ni-Resist D-210	7.45 (.270)	14.7 (82)	12.6	-	1.02
Ni-Resist D-3A	7.45 (.270)	12.6 (7.0)	12.6	-	-
Ni-Resist 3	7.45 (270)	12.6 (7.0)	12,6	-	-
Ni-Resist D-4A	7.45 (270)	15.1 (8.4)	12.6	-	-
Ni-Resist D-4	7.45 (270)	14.4 (8.0)	12.6	-	-
Ni-Resist D-5	7.6 (275)	5.0 (2.8)	12.6	-	-
Ni-Resist D-513	7.7 (279)	5.0 (2.8)	12.6	-	-
Ni-Resist D-5S	7.45 (270)	12.9 (7.2)	12.6	-	-
Ni-Resist 6	7.3 (264)	18.2 (10.1)	12.6	1.0	1.02

Thermal Conductivity

The thermal conductivities of the Ni-Resist ailoys are very consistent within a class, either flake or spheroidal graphite. This is easily seen in *Tables Vll* and *VIll*. It is also obvious that the thermal conductivity of the flake graphite alloys is considerably higher than that of the spheroidal graphite ones; that is, about 40W/m°C versus 12.6W/m°C, respectively.

Electrical Resistivity

The electrical resistivity of some of the alloys is given in *Tables Vll* and *VIll*. In general, the spheroidal graphite alloys have lower values. If electrical conductivity is an important property, they are usually preferred.

Magnetic Properties

The magnetic permeability of the Ni-Resists is strongly influenced by the presence of carbides. Since their number and size can depend on heat treatment and other factors, measurements of magnetic properties are often variable. While Ni-Resists NiMn 13 7 and D-6 are usually considered the only truly non-magnetic alloys, D-2 and, especially, D-2C have been used in many non-magnetic applications. The data in *Tables Vll* and *Vlll* are compiled from the specifications in **Part II**.

PROPERTIES AFFECTING DESIGN AND MANUFACTURE

Design of Castings

Pattern design and shrinkage allowance is similar for flake and spheroidal graphite Ni-Resist alloys of similar nickel content. The shrinkage allowance decreases with increasing nickel content. For the lower nickel grades (Ni-Resists 1,1b, 2, 2b and the various D-2s) it is .02mm/mm(.25in/ft). At intermediate levels of nickel (Ni-Resists 3, 4, D-3 and D-4) it is .015mm/mm (.19in/ft) and at the highest nickel contents (Ni-Resists 5 and the D-5s) it is .01 mm/mm(.125in/ft). The same precautions taken for the design of high strength gray iron castings apply to all Ni-Resist alloys. The principle of "controlled directional solidification" should be followed. This means that a casting should be designed to freeze without interruption from light to heavy sections. Abrupt changes in section thickness should be avoided. Provision should be made for the proper placement of feeders. It is always helpful if foundry engineers are consulted during casting design.

Machining

The machinability of Ni-Resist alloys is inferior to that of pearlitic gray cast iron but usually better than cast steels. The chromium content is the most important factor in determining the machinability of the various grades of Ni-Resist alloys. As chromium content increases machinability is reduced because of increasing amounts of hard carbides. Of course, good machining practices should always be followed. Proper selection of cutting tools, cutting lubricants and speed and feed rates are necessary for optimum results.

HEAT TREATMENT

Stress Relief

It is advantageous to use heat treatment to stress-relieve Ni-Resist castings to remove residual stresses formed during cooling after casting and subsequent machining. This is done by heating to 600-650°C(1110-1200°F) at a rate of 50-100°C/hour (90-180°F/hour). The castings should be held in this temperature range for 2 hours plus

1 hour per 25mm(1 inch) of section thickness. They should then be furnace-cooled to or near ambient temperature. With castings made from Ni-Resist alloys with the higher coefficients of expansion and with thin sections, it is most important to have controlled, uniform heating and slow cooling. A small reduction in yield strength may occur after stress relieving.

High Temperature Stability

Ni-Resist castings intended for static or cyclic service at 480°C(900°F) and above can be given a dimensional stabilization heat treatment. If not done, carbon is slowly removed from the austenite matrix while at service temperatures. This results in a small growth in volume and distortion can occur. When the heat treatment is used this problem is eliminated. The proper cycle is to heat to 850-900°C(1560-1650°F) at 50-100°C(90-180°F) per hour. The castings should be held in this temperature range for not less than 2 hours plus 1 hour for each 25mm (1 inch) of section thickness followed by air cooling.

Normalizing

The same heat treatment that is used for high-temperature stabilization can be used for normalizing. It will result in an increase in yield strength and elongation.

Annealing

If Ni-Resist castings of the correct composition are higher in hardness than expected, excessive carbide formation has probably occurred. Some softening and improved machinability can be achieved through high-temperature annealing. This heat treatment will breakdown and/or spheroidize some of the carbides. To anneal, castings should be heated to 950-1025°C(1740-1875°F) at 50-100°C(90-180°F) per hour. They should be held in this temperature range for 2 hours per 25mm (1 inch) of section thickness followed by cooling in the furnace or in still air.

Ambient Temperature Stability

For assured dimensional stability for service at ambient temperatures, slow, uniform heating to 815-840°C(1500-1560°F) is suggested. Castings should be held in this temperature range for one hour per 25mm (1 inch) of section thickness and uniformly cooled to at least 315°C(600°F) . For stringent requirements, the uniform cooling can be continued to ambient temperature.

WELDING

Ni-Resist alloys are all capable of being welded, provided that correct welding parameters are followed and that sulfur and phosphorous contents are controlled to proper limits. The degree of welding that is possible varies from alloy to alloy as described in the following.

In general, the flake graphite Ni-Resists are slightly tougher and more ductile than gray cast irons and, despite their higher coefficients of expansion, have proved to be tolerant to welding stresses. Where welding will be required and in order to prevent hot cracking in the weld heat affected zone, sulfur and phosphorous must be controlled to 0.04% or less.

The superior mechanical properties, toughness and ductility of spheroidal graphite Ni-Resists suggest enhanced weldability over ordinary gray cast iron and flake graphite Ni-Resist alloys. In practice, this is not necessarily correct. The presence of the magnesium required for the spheroidization process decreases ductility at the welding temperature and small cracks can occur in the weld heat affected zone. Because of this problem, alloy D-2W was developed. In this material, the addition of niobium (columbium), combined with the control of silicon, phosphorous and the residual magnesium contents, has led to an alloy with very adequate weldability. Practical experience has demonstrated excellent welding repairability of major casting defects.

Welding Practice

Most welding will be concerned with the repair or reclamation of castings, but in any case, preparations prior to welding are always very important. It is recommended that all unsound metal be removed before starting by machining, chipping or grinding. If the former two methods are used, only carbide tipped tools should be employed. To ensure that only sound metal remains, a dye penetrant should be employed. The actual area to be welded should be wider and more open than for steel. This is shown in *Figure 3*. Since positional welding is difficult with certain electrodes, the work piece should be placed for downhand welding. A thin weld coating or "buttering" of the surface, prior to welding greatly assists in preventing heat affected zone cracking.

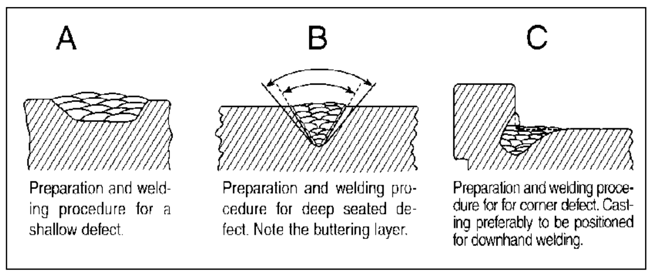


Figure 3 Examples of Preparation and Welding Procedures for Repairs to Defects in Castings

The usual welding process is manual metal arc with flux coated electrodes. The choice of electrodes is critical with the widely available 55% nickel/iron types strongly suggested. This composition is used for welding ordinary gray cast iron and is suitable for flake graphite Ni-Resist alloys. Most 55% nickel/iron electrodes deposit metal with a tensile strength equal to that of Ni-Resist alloys D-2, D-2B and D-2W. However, they are often lacking in impact toughness. To avoid this problem, the electrode selected to weld spheroidal graphite alloys should be carefully evaluated to provide a deposit with acceptable soundness, toughness and machinability Ease of operation and freedom from slag inclusions in the weld metal are also important properties. It is very important to follow the electrode manufacturer's instructions for storage, drying, baking and using the electrodes.

Following welding, all slag and weld spatter should be thoroughly removed by brushing or grinding. Peening should not be done. Undercuts should be removed by grinding and carefully refilled.

Welding Heat Treatments

When welding flake graphite Ni-Resist alloys, preheating to 300-350°C (570-660°F) is recommended. The interpass temperature should also be maintained at that level. On completion of welding, care should be taken to allow slow cooling in still air. For complex welds, transfer to a preheated oven or furnace and slow cooling under controlled conditions may be advantageous.

Preheating is normally unnecessary when welding spheroidal graphite alloys. However, in practice, it is sometimes beneficial to use a low preheat to about 100°C (210°F) when welding conditions are not ideal and cold air drafts are present. A low interpass temperature of 150°C(300°F) is essential for the ductile Ni-Resists.

Post weld heat treatments are usually not necessary for structure or properties in any Ni-Resist alloy. But stress relief is often required, especially if castings are to be exposed to an environment where stress corrosion cracking is a possibility. The heat treatment procedures for stress relief given previously should be followed.

Effect of Chemical Composition on Welding

It was mentioned above that the addition of niobium (columbium) to the alloy D-2 composition led to the development of the more weldable grade, D-2W. In utilizing this alloy, attention must be paid not only to the niobium content (.12% min.), but also to silicon (2.25% max.), phosphorous (0.04% max.) and magnesium (0.05% max.). There also appears to be an inter-relationship between these elements which assists in obtaining excellent toughness and ductility, without any significant changes in other mechanical properties. In addition to type D-2W, a niobium addition seems to have a beneficial effect on other Ni-Resist alloys, although the research in this area has been limited.

Research has also indicated that a higher level of chromium content can improve welding response. Thus, alloys such as D-2B have satisfactory weldability. This is in spite of the lower ductility and higher propensity to microporosity caused by increased chromium. A niobium addition and control of the other elements as in alloy D-2W is also advantageous with this type of composition.

PROPERTIES AFFECTING SERVICE PERFORMANCE

Wear and Galling Resistance

The presence of dispersed graphite, as well as the work hardening characteristics of Ni-Resist alloys, bring about a high level of resistance to frictional wear and galling. Ni-Resists 2, D-2, D-2C, D-3A, 4 and D-4 offer good wear properties with a wide variety of other metals from sub-zero to elevated temperatures. In the case of the ductile alloys, temperatures can go as high as 800°C(1500°F). Ni-Resists D-2B, 3 and D-3 are not recommended for frictional wear applications because their microstructures contain massive, hard carbides that can abrade the mating metal.

When comparing Ni-Resist alloys to other metals, Ni-Resists D-2 and D-2C have been shown to have the lowest frictional wear rates when compared to bronze, regular ductile iron and nickel/chromium alloy N0600. Between the two Ni-Resist alloys, D-2 had the least wear.

With mating parts, it is often useful to "wear-in" the two surfaces. During this operation prior to actual service, a solid lubricant such as molybdenum disulfide is effective. A work-hardened, glazed surface develops which resists wear and extends life.

Corrosion Resistance

It is usually said that Ni-Resist alloys have a corrosion resistance intermediate between gray and low alloy cast irons and stainless steel. This statement is an over-simplification of their usual form of corrosion. They corrode in a manner similar to the gray cast irons, but because of their chemical composition, form denser, more adherent corrosion product films which suppress further corrosion. They are not stainless steels and do not behave as they do. In neutral and mildly acidic halide-containing solutions, stainless steels often corrode in destructive localized ways. That is, they suffer pitting, crevice corrosion and, sometimes, stress corrosion cracking. Ni-Resist alloys seldom have these forms of attack. Their corrosion is usually uniform at fairly low rates. Of course, Ni-Resists do not have the typically good corrosion resistance of stainless steel in mild and/or strongly oxidizing acids and should not be used in such environments.

In additional to the comments, tables and figures in this section of this brochure, the corrosion behaviour of Ni-Resist alloys in many different environments is given in **Part III**. Please refer there for specific media and service conditions.

Special Forms of Attack

Galvanic Corrosion: Galvanic corrosion occurs when two substances with different electrochemical potentials (activities) are in contact in a conducting solution or electrolyte. In *Figure 4*, the relative potential of Ni-Resist alloys to other metals and alloys is given in moderate velocity, ambient temperature sea water. The Ni-Resists are less active (cathodic) than zinc, aluminum alloys, low alloy steels and cast iron. This means that the corrosion

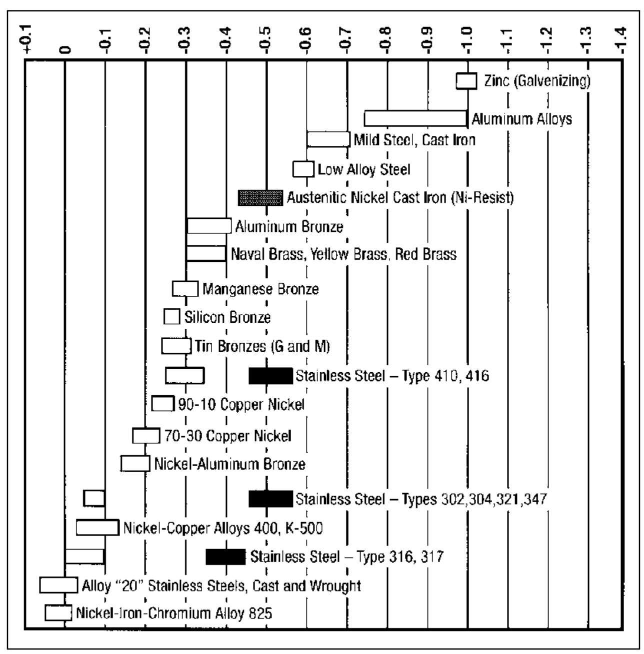


Figure 4 Galvanic Series of Various Metals in Flowing Sea Water at Ambient Temperatures. Velocity Range: 2.4-4.0 meter/sec(8-13 feet/sec), Temperature Range: 10-27°C(50-80°F)

rate of these alloys will be accelerated when they are in contact with Ni-Resists. *Figure 3* also shows that Ni-Resist alloys are active (anodic) with regard to copper base alloys, stainless steels and nickel base alloys. Thus, they will corrode preferentially to these materials. In order to distribute the corrosion over a large area, designers and engineers should always provide for a larger relative area of Ni-Resist when it is in contact with these types of alloys. When this is done serious problems in the galvanic corrosion of Ni-Resists will usually not occur. Typical examples that are particularly successful are stainless steel trim in Ni-Resist valves and stainless steel impellers and shrouds in Ni-Resist pumps.

Graphitization: In cast irons, graphite occurs as flakes or spheroids in a metal matrix. Certain environments, such as sea water, other salt solutions and soil, cause the metal matrix to corrode preferentially, leaving a structure of hydrated iron oxide and graphite particles. This form of attack is called graphitization or graphitic corrosion. The graphite/oxide surface layer is often porous and, because of the potential difference between graphite and iron, accelerated corrosion of the underlying cast iron can occur. Other iron, steel or bronze parts are also active with respect to graphitized cast iron and corrode at high rates. Because of their inherent superior corrosion resistance, Ni-Resist alloys are less apt to form a graphitized surface layer. Thus, the above problems are largely avoided. When Ni-Resists do form a graphitized layer, the acceleration of their corrosion is much less because the potential difference between Ni-Resist alloys and graphite is smaller than with cast iron.

Corrosion/Erosion: Although not as good as austenitic stainless steels, the Ni-Resist alloys, when compared to most cast irons and steel, have excellent ability to resist the combined effects of corrosion and erosion in high velocity solutions. When ordinary and low-alloy cast irons corrode in aqueous environments, a loosely adherent corrosion product layer of hydrated iron oxides and graphite is formed. If velocities exceed 3.0-3.7 metres/second (10-12 feet/second), this film is washed away, continuously exposing fresh metal surfaces for ongoing corrosion. The Ni-Resists, particularly those that contain chromium, form denser, more adherent corrosion product surfaces. Because of this, they can resist high fluid flow velocities. For example, see *Tables IX* and *X* When solids are present it is desirable to select the harder types of Ni-Resist, such as 2b, D-2B, 4 and D-4.

Table IX Corrosion of Cast Materials in Low Velocity Sea Water

Temperature	**Ambient**
Duration of Test:	**3 Years**
Agitation:	**Tidal flow with continous immersion**
Marine Fouling:	**All specimens completely covered with fouling organisms at time of removal from test**
Material	**Corrosion Rate cm/yr(in/yr)**
Ni-Resist 1	.0053(.0021)
Ni-Resist 2	.0043(.0017)
Ni-Resist D-2	.0041(.0016)
Ni-Resist 3	.0038(.0015)
Ductile Gray Cast Iron	.0246(.0097)
Gray Cast Iron	.0254(.0100)

Cavitation Damage: Cavitation damage is the mechanical fracturing of a metal surface in fluids under conditions which cause large cyclic hydraulic pressure changes. For example, as a pump impeller rotates at high velocity, it produces alternating areas of high and low pressure on the casing wall. During the low pressure cycle, bubbles can form in the liquid. They subsequently collapse under high pressure and the fluid "hammers" the metal surface. The alternating character of the stresses induce a condition which leads to metal fatigue. Metals that are stronger, harder and have higher corrosion fatigue strength resist cavitation damage best. Thus, the Ni-Resists are superior to most other cast irons with alloys 1 b, 2b, D-2B, 4 and D-4 being preferred.

Stress Corrosion Cracking: Stress corrosion cracking is the brittle failure of metals when exposed to specific media. The stresses involved can be well below the elastic limit and are almost always residual rather than applied. Common examples are austenitic stainless steels in hot chloride-containing solutions, carbon and low alloy steels in strong caustics and copper alloys in ammoniacal environments. Ni-Resist alloys are highly resistant to this form of corrosion, but there have been some probable stress corrosion cracking failures in warm sea water. The problem is greatly alleviated and probably eliminated by proper stress relief heat treatment after casting, welding and machining. The procedures for this are given on page 6. Other work has suggested that the ductile grades of Ni-Resist are more resistant to stress corrosion cracking than the flake graphite alloys or that some ductile grades are better than others in this regard. These are not absolute solutions to the problem, because the assigning of degrees of susceptibility is of questionable merit. It is best to consider all Ni-Resists to be equal in this regard. Additionally when examining Ni-Resist alloys after cracking failures, the possibility of poor quality castings, corrosion fatigue and other failure modes should be considered before deciding on an inherent susceptibility to stress corrosion cracking.

Corrosion Fatigue: Metallic fatigue failures can occur when a metal is subject to a large number of cyclic stresses below the elastic limit. In air, most metals have a fatigue limit or stress below which fatigue failures do not occur. However, in a corrosive media this fatigue limit is lowered and does not exist for continuously corroding metals. Because of their better corrosion resistance in aqueous solutions than ordinary cast irons, Ni-Resist alloys might be expected to have better corrosion fatigue resistance than ordinary cast irons. However, this has

Table X Corrosion of Pump Materials in High Velocity Sea Water

Alloy	Temperature °C(°F)	Velocity m/sec(ft/sec)	Corrosion Rate* mm/yr(in/yr)
Type 316 Stainless Steel	10(50)	43(141)	.005(.0002)
Ni/Cu alloy 400	11(52)	43(141)	.010(.0004)
Ni-Resist 1	27(81)	41(134)	.990(.040)
88Cu/10Sn/2Zn	2(36)	42(138)	1.10(.044)
85Cu/5Sn15Zn/5Pb	25(77)	41(134)	1.35(.054)
Gray Cast Iron	20(68)	38(125)	13.5(.540)

*All tests were 30 days duration except for Gray Cast Iron. Because of excessive attack on specimens of this material its tests were stopped after 10 days.

not been observed, possibly because the corrosion product film is continually being fractured by the cyclic stresses and its protectiveness is not permitted to develop.

Atmospheric Corrosion: The Ni-Resist alloys are similar in performance to the "weathering" steels in that they form dense, self protecting corrosion product surfaces during exposure to air. There are substantial advantages over unalloyed cast iron and steel. Painting and other protective coatings are usually not required.

Corrosion Performance in Specific Environments

Marine Environments: Ni-Resist alloys are very well suited for a number of important applications near and in seawater. *Figure 5* illustrates this superiority from long term tests in a marine atmosphere 240 metres from the sea. When immersed in sea water the Ni-Resists provide advantages over other metals at velocities ranging from no flow to turbulent conditions. This is shown in *Tables IX, X* and *XI*. *Figures 6* and *7* demonstrate the good performance of Ni-Resist D-2 in aerated and deaerated sea water with increasing temperature. The high velocity performance, including resistance to corrosion/erosion and cavitation damage, is the primary reason Ni-Resist alloys are so frequently selected for use in sea water pumps and valves. Ni-Resists D-2 and D-2W are commonly preferred.

Petroleum Production: Ni-Resist alloys find major applications in oil and gas production. In crude or "sour" oil and gas containing hydrogen sulfide, carbon dioxide and organic acids, self protective corrosion deposits result in low corrosion rates. This is shown in *Tables XII* and *XIII*. The hard, carbides in the chromium containing grades of Ni-Resist impart erosion resistance and are useful when sand and other solids are present. The combination of sea water and petroleum fluids corrosion resistance makes Ni-Resist alloys well suited for applications in offshore oil and gas production.

Table XI Corrosion/Erosion of Various Alloys in High Velocity Sea Water

Turbulent Flow Conditions 60 Day Test - 825 cm/sec (27ft/sec) Temperature 23-28T (73-82°F)	
Material	**Corrosion Rate** cm/yr(inlyr)
Gray Cast Iron	0.686(0.270)
2% Nickel Cast Iron	0.610(0.240)
88/10/2 Cu/Sn/Zn Bronze	0.117(0.046)
65/35 Cu/Zn Brass	0.107(0.042)
Aluminum Bronze	0.092(0.036)
Ni-Resist 2	0.079(0.031)
90/10 CuNi	0.051(0.020)
5°% Nickel Aluminum Bronze	0.030(0.012)
Ni-Resist 1	0.020(0.008)
Ni-Resist 3	0.018(0.007)
NiCu Alloy K500	0.008(0.003)
25/20 CrNi Stainless Steel	0.005(0.002)

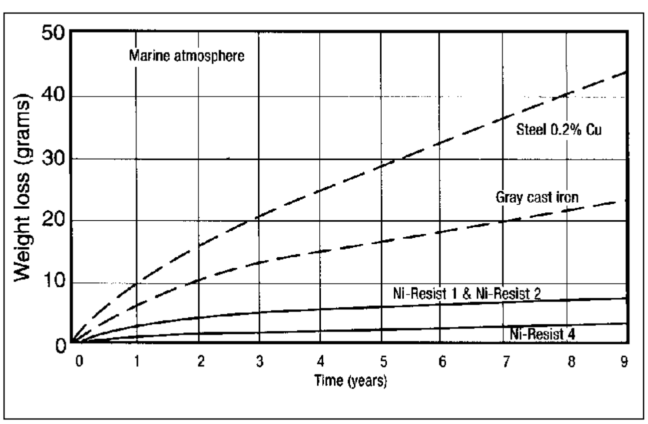


Figure 5 Corrosion Behavior of Cast Irons and Copper Containing Steel in a Marine Atmosphere 240 Meters (800 Feet) from the Sea - North Carolina, USA

Table XII Weight Loss in Still Natural Gas with Hydrogen Sulfide at 80°C(180°F)

Alloy	100	200 Hours	300 Hours	400 Hours
	gms/lm²(lbs/ft²)			
Ni-Resist 1	60(.007)	83(.C10)	83(.010)	83(.010)
Gray Cast Iron	79(.010)	189(.023)	222(.027)	248(.030)
Piston Ring Gray Cast Iron	157(.019)	215(.026)	253(.031)	295(.036)
Plain Carbon Steel 0.4% Carbon	85(.010)	218(.027)	310(.038)	363(.044)

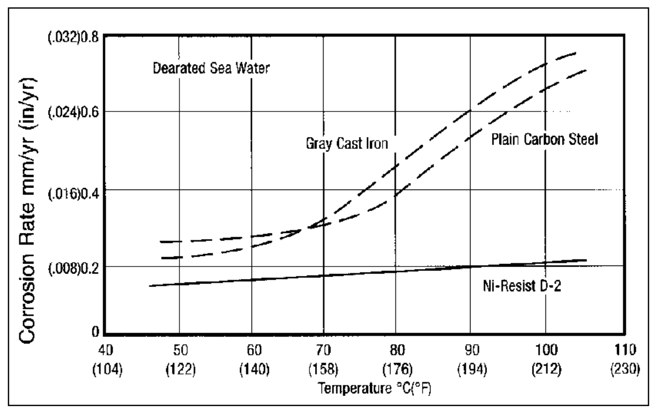


Figure 6 Corrosion in Ueaerated Sea Water as a Function of Temperature

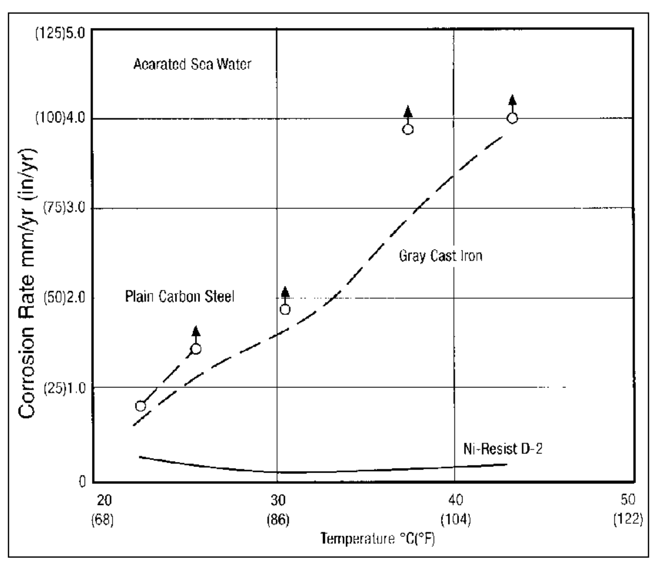


Figure 7 Corrosion in Aerated Sea Water as a Function of Temperature

Table XIII Corrosion Tests in Sour Crude Oils

Corrosion Rate cm/yr(in/yr) Material	Test 1	Test 2	Test 3
Ni-Resist 1	.0017(.0007)	.025(.010)	.0023(.0009)
Ni-Resist 3	-	.017(.007)	-
Gray Cast Iron	.0053(.0021)	.113(.045)	.040(016)
Mild Steel	.0043(.0017)	.130(.052)	Consumed
Type 304 Stainless Steel	<.0003(<0001)'	.020(.008)"	<.0003(<.0001)

*.010cm(.004in) pitting
**.030cm(.012in) pitting

Test 1 - Exposed in 200,000 liter (55,000 gallon) sour crude oil storage tank at ambient temperature, Immersed in liquid for 23 days and suspended vapour above liquid for 52 days

Test 2 - Exposed In top of crude flash tower at 105-115°C(220-240°F) for 43 days. Crude contained 0.34% sulfur 0.021% sodium chloride.

Test 3 - Exposed in crude oil preheater (average temperature 145°C(295°F) with flow rate of 210cm/sec(701sec) for 463 days. Crude contained 0.4% sulfur and .031% sodium chloride

Table XIV Effect of Nickel Content on the Corrosion Rate of Cast Iron in 50% to 65% Sodium Hydroxide

Temperature: Boiling with vacuum of 66cm(26in) of mercury
Duration of Test: 81 Days
Agitation: Boiling action only

Per Cent Nickel	Corrosion Rate cmlyr(inlyr)
0	212(.083)
3.5	.119(.047)
5	.124(.049)
15	.076(.030)
20	.0084(.0033)
20(2% Cr)	.0152(.0060)
30	.0010(.0004)

Table XV Plant Corrosion Tests of Various Alloys in 74% Sodium Hydroxide

Temperature: 125°C(260°F)
Duration: Specimens exposed far 20 days in liquid and 12 days in vapor over liquid. Corrosion rates based on 21 days exposure.
Agitation: Stagnant(in strorage tank)

Material	Corrosion Rate cmlyr(inlyr)
NiCu alloy 400	0023(.0009)
Ni-Resist 3	.0064(.0025)
Ni-Resist D-2	.0127(.0050)
Ni-Resist 2	.0152(.0060)
Type 304 Stainless Steel	.0381(.0150)
Mild Steel	.190(.075)
Gray Cast Iron	.193(076)

Alkaline Environments: Ni-Resist austenitic cast irons are widely used in handling sodium hydroxide and other strong caustics. The addition of nickel to iron results in a marked improvement in corrosion resistance in such environments. This is clearly shown in *Tables XIV* and *XV*. Because of their high (30%) nickel content, Ni-Resists 3, D-3 and D-3A are preferred. Iron base alloys often suffer stress corrosion cracking failures in hot, strong caustics. This has not been a problem with the Ni-Resists, but a reasonable precaution is to stress relieve all castings prior to being placed in service.

Acid Environments: Ni-Resist alloys can be used in dilute and concentrated sulfuric acid at ambient temperature. Intermediate concentrations and higher temperatures are to be avoided. The copper containing alloys, Ni-Resist 1 and 1 b, are preferred. They are much better than gray cast iron. In hydrochloric acid, the higher nickel Ni-Resists such as 3, D-3 and D-3A are marginally useful in dilute solutions at low temperatures. Increases in solution velocity, agitation and aeration adversely affect the corrosion performance of Ni-Resist alloys in most acids throughout temperature and concentration ranges. Data for a number of acid environments is given in **Part III**.

Elevated Temperature Performance

Ni-Resist alloys, when compared to gray and low alloy cast irons, have superior properties at elevated temperatures. This applies to both flake and spheroidal graphite alloys. However, because of much higher mechanical properties and resistance to internal oxidation, the ductile Ni-Resists are preferred at elevated temperatures up to 1050°C(1930°F).

Mechanical Properties

The high temperature mechanical properties of the spheroidal graphite Ni-Resist alloys are given in *Table XVI*. Room temperature properties after long-time exposure to elevated temperatures are shown in *Table XVII*. *Figure 8* illustrates the short term, high temperature tensile properties of Ni-Resist D-2. Creep data for some ductile Ni-Resists are shown graphically in *Figure 3*, along with a comparison to CF-4 cast stainless steel (18Cr, 8Ni). The stress rupture curves for Ni-Resists D-2, D-3 and D-5B, with and without molybdenum, are given in *Figures 10, 11* and *12* along with the data for HF cast stainless steel (19Cr, 9Ni).The hot hardness values of Ni-Resists D-2, D-3, D-4 and D-5B, also with and without molybdenum, are shown in *Figure 13*. Although a variation from the specifications, it is important to note that the addition of 0.5-1.0% molybdenum to ductile Ni-Resists usually raises the elevated temperature mechanical properties with only a slight reduction in elongation. The stress rupture and creep performance benefit from molybdenum (see *Tables XVI* and *XVII* and *Figures 10, 11* and *12*) such that the resultant alloys are equal to or superior to the HF and CF-4. The addition of molybdenum also raises the as-cast hardness, except for Ni-Resist D-4, and maintains it at elevated temperatures (see *Figure 13*).

Resistance to Cracking and Distortion

During cyclic heating and cooling to temperatures of 675°C(1250°F) and above, cast iron and steels pass through a critical range which frequently results in cracking and/or distortion of castings. Volume changes which lead to this problem occur because of matrix phase changes between ferrite and austenite at this temperature. The Ni-Resists, being austenitic at all temperatures do not have a transformation and have no sharp volume changes. However, there can be the slight high temperature stability problem described in the heat treatment section. Using the heat treatment suggested there will alleviate any troubles.

Steam Service

Ni-Resist alloys D-2 and D-3 have been excellent for applications requiring resistance to wet steam erosion.

Table XVI Elevated Temperature Mechanical Properties of Some Spheroidal Graphite Ni-Resist Alloys.

Property and Temperature	D-2	D-2C	D-3	D-4	D-5B
TENSILE STRENGTH			**MPa(ksi)**		
Ambient	407(59)	428(62)	400(58)	442(64)	421(61)
426°C(800°F)	373(54)	359(52)	-	-	-
538°C(1000°F)	331(48)	290(42)	331(48)	421(61)	324(47)
649°C(1200°F)	248(36)	193(28)	290(42)	331(48)	283(41)
760°C(1400°F)	152(22)	117(17)	186(27)	152(22)	173(25)
0.2% YIELD STRENGTH			**MPa(ksi)**		
Ambient	242(35)	235(34)	269(39)	304(44)	283(41)
426°C(800°F)	193(28)	179(26)	-	-	-
538°C(1000°F)	193(28)	159(23)	193(28)	283(41)	179(26)
649°C(1200°F)	173(25)	166(24)	186(27)	235(34)	166(24)
760°C(1400°F)	117(17)	117(17)	104(15)	131(19)	131(19)
ELONGATION FROM SHORT TIME TENSILE TESTS				**Per Cent**	
Ambient	10.5	25	7.5	3.5	70
426°C(800°F)	12	23	-	-	-
538°C(1000°F)	10.5	19	7.5	4.0	90
649°C(1200°F)	10.5	10	7.0	11	65
760°C(1400°F)	15	13	18	30	24.5

Table XVII Room Temperature Mechanical Properties After 10,000 Hours Exposure at Indicated Temperature

Alloy	Temperature °C(°F)	Tensile Strength MPa(ksi)	Yield Strength 0.2% MPa(ksi)	Elongation Per Cent	Charpy Impact ft-lb
Ni-Resist D-2	550(1022)	455(66,0)	278(40.3)	6.0	5.5
	660(1202)	497(72.0)	254(36.8)	7.5	7.2
Ni-Resist D-2	550(1022)	459(66,5)	302(43.7)	3.0	3.6
with 1% Mo	660(1202)	490(71.0)	300(43.5)	4.0	3.6
Ni-Resist D-213	550(1022)	452(65.5)	312(45.2)	4.0	4.0
	660(1202)	483(70.0)	274(39.7)	5.0	4.7
Ni-Resist D-3	600(1202)	495(71.7)	268(38.8)	8.0	7.2
NI-Resist D-5S*	870(1600)	513(74.4)	222(32.2)	23.0	-

*2500 Hours Exposure

At higher steam temperatures, where resistance to growth and scaling is important, these same materials are also superior. Steam turbine components such as diaphragms, shaft and labyrinth seals and control valves are examples of applications. *Table XVI* and *Figure 8* give useful strength and creep data for steam service. *Table XVIII* favourably compares the growth of some Ni-Resist alloys to gray cast iron in steam.

Resistance to Elevated Temperature Oxidation

Both flake and spheroidal graphite Ni-Resists have high temperature oxidation performance up to ten times better than that for gray cast iron. The high chromium and high silicon grades, especially, form dense, adherent self protecting oxide scales. However, because of the preference for the higher strength ductile alloys for elevated temperature service, only they will be considered here. For example, ductile Ni-Resists D-2, D-2B, D-3, D-4, D5B and D-5S provide good resistance to oxidation and maintain useful mechanical properties up to 760°C(1400°F). At higher temperatures, alloys D-2B, D-3, D-4 and D-5S can be considered with D-5S having good oxidation resistance up to 925°C(1700°F).

Table XIX provides oxidation data for some ductile Ni-Resists and other alloys, under both static and cyclic conditions. Thermal cycling causes the metal to expand and contract regardless of whether any phase changes occur. This leads to cracking and flaking of the protective scale. To minimize this, low expansion grades of Ni-Resist, such as D-4, should be considered. If high toughness is not required, it can be used at least to 815°C(1500°F).

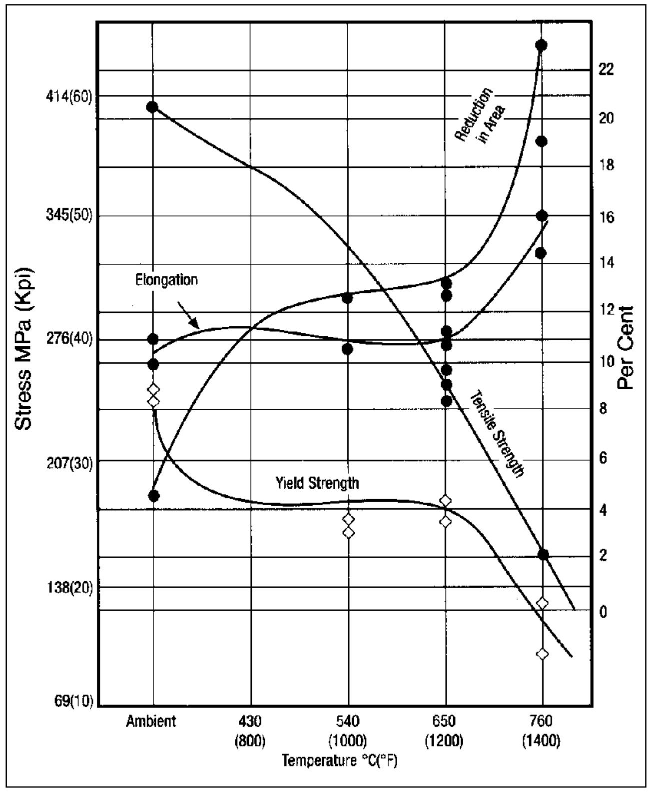


Figure 8 Short Time Tensile Properties of Ni-Resist D2 at Elevated Temperatures

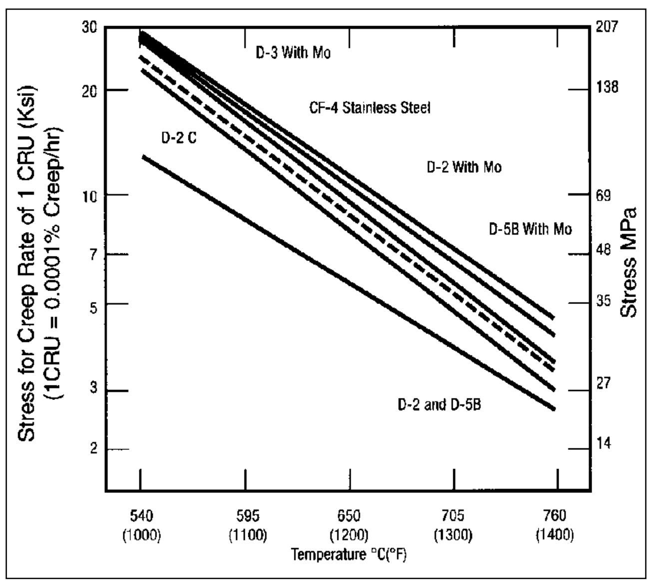


Figure 9 Creep Behavior of Several Spheroidal Graphite Ni-Resist Alloys and CF-4 Stainless

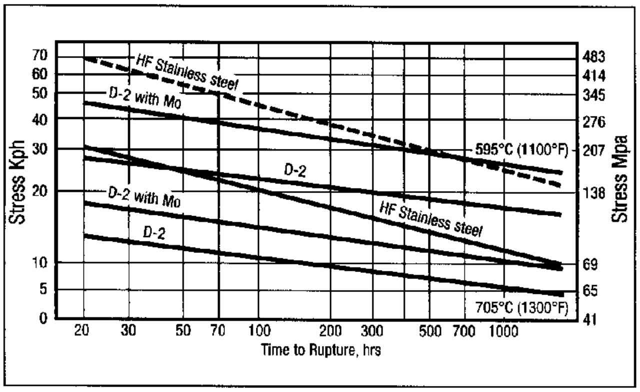


Figure 10 Stress Rupture Data for Ni-Resist D-2

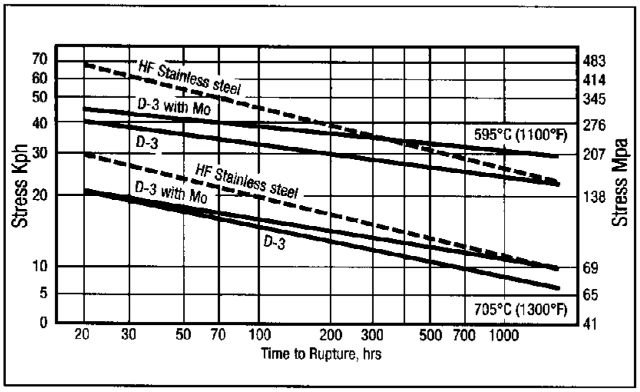


Figure 11 Stress Rupture Data for Ni-Resist D-3

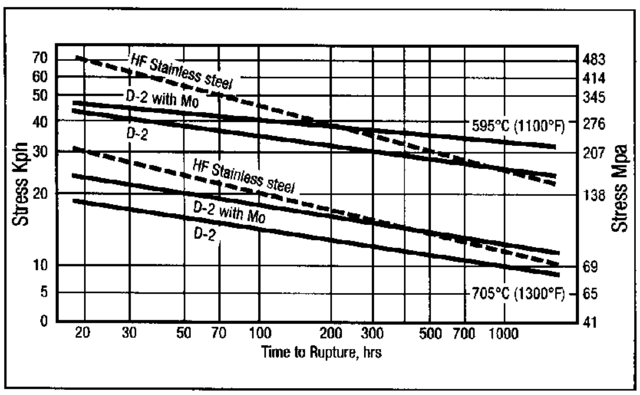


Figure 12 Stress Rupture Data for Ni-Resist D-513

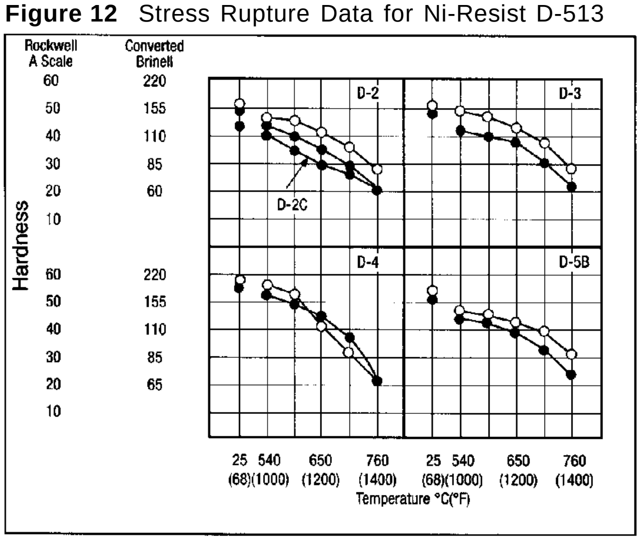


Figure 13 Hot Hardness of Some Spheroidal Graphite Ni-Resist Alloys. Solids Symbols are Standard Compositions. Open Symbols are Alloys with 0.7%-1.0% Mo Added

Table XVIII Growth of Gray Cast Iron and Some Ni-Resist Alloys in Steam at 482°C(900°F)

Alloy	Growth in cm/cm (in/in) at 482°C(900°F)		
	After 500 Hours	After 1000 Hours	After 2500 Hours
Gray Cast Iron	.0023	.0052	.014
Ni-Resist 2	.0005	.0010	.0015
Ni-Resist 3	.0003	.00045	.00048
Ni-Resist D-2	.0003	.0005	.0005
Ni-Resist D-3	.0003	.0000	.0000

Table XIX Oxidation of Various Alloys for Different Times and Temperatures

Material
Ductile Iron (2.5 Si)
Ductile Iron (5.5 Si)
Ni-Resist D-2
Ni-Resist D-2C
Ni-Resist D-4
Ni-Resist 2
Type 309 Stainless Steel

Test 1 - Furnace Atmosphere - air, 4000 hours at 704°C(1300°F)
Test 2 - Furnace Atmosphere - air, 600 hours at 870-925°C(1600-1700°F), 600 hours at 315-925°C(600-1700°F), 600 hours at 425-480°C (800-900°F)

Table XX Low temperature Impact Properties of Some Spheroidal Graphite Ni-Resist Alloys

Alloy	Charpy V-Notch – ft/lbs				
	20°C 68°F	0°C 32°F	-50°C -58°F	-100°C -148°F	-196°C -321°F
M-Resist D-2	9	9	9	8	7
NI-Resist D-2C	24	24	28	26	10
Ni-Resist D-2M	28	28	29	29	28
Ni-Resist D-3	7	7	6	5	3
Ni-Resist D-3A	-	14	-	13	7.5
Ni-Resist D-5	-	17	-	15	11

The presence of appreciable sulfur containing gases in a high temperature environment can greatly reduce the useful service life of Ni-Resist and other alloys. Usually the maximum temperature must be lowered by 200-300'C (360-540° F)

Low Temperature Performance

Ductile Ni-Resist alloys generally retain their usual good impact properties to quite low temperatures. The austenitic structure is stable and they do not have a ductile/ brittle transition temperature. *Table XX* gives Charpy V-notch values for six of the alloys from ambient temperature to -196°C(-321°F). Most of the alloys show only slight decreases until temperatures drop below –100°C(-148°F). At -196°C(-321°F), impact values are noticeably lower for Ni-Resists D-2C, D-3 and D-3A. However, there is no reduction for Ni-Resist D-2M which was especially developed for cryogenic service. Obviously, it is the alloy of choice at these low temperatures. However, it is not an economic or practical substitute for D-2 or D-2W in corrosive enviroments at ambient and elevated temperatures, regardless of its attractive mechanical properties.

ADVANTAGES AND APPLICATIONS OFTHE PHYSICAL PROPERTIES OF NI-RESIST ALLOYS

Thermal Expansion

The Ni-Resist alloys have a wide range of coefficients of thermal expansion. These differences have been exploited in a number of ways. Average values for the various alloys are given in *Tables Vll* and *Vlll*. Reference should be made to **Part II** for the national and international specifications.

High Expansion

The 15% and 20% nickel alloys (Ni-Resists 1, 2, D-2 and their derivatives) are those with relatively high expansivities. These are the alloys that are often used in conjunction with other metals such as aluminum, copper and austenitic stainless steel which also have high thermal coefficients of expansion. By matching the thermal expansion properties of dissimilar metals, engineers can work to closer tolerances without being concerned about joint warpage. Examples of this practice are Ni-Resist piston rings inserts cast in aluminum pistons, austenitic stainless steel vanes in Ni-Resist pump casings and Ni-Resist heating units in copper heads of soldering irons. Because Ni-Resist D-4 has a similar expansion coefficient to S30400 austenitic stainless steel, stainless steel vanes are used in Ni-Resist turbocharger diaphragms.

Intermediate Expansion

Ni-Resists 3 and D-3 are the alloys used to match the coefficients of expansion of carbon and low alloy steels, gray and low alloy cast iron, ferritic stainless steels and some nickel base alloys. The data in *Figure 14* indicate that by varying the nickel content of Ni-Resist D-3 that a range of coefficients of expansion will exist. Similar data have been produced for Ni-Resist 3. Thus, many of these dissimilar alloys can become closely compatible.

Low Expansion

Where low thermal expansion is required for dimensional stability in machine tools, scientific instruments, glass molds and forming dies, Ni-Resist alloys 5, D-5, D-5B and D-5S are used. A high level of galling resistance and good machinability are added advantages. Ni-Resists D-5B and D-5S also have excellent oxidation resistance and mechanical properties combined with low distortion at elevated temperatures. As a further aid in diminishing distortion, the heat treatment given on page 7 should be used.

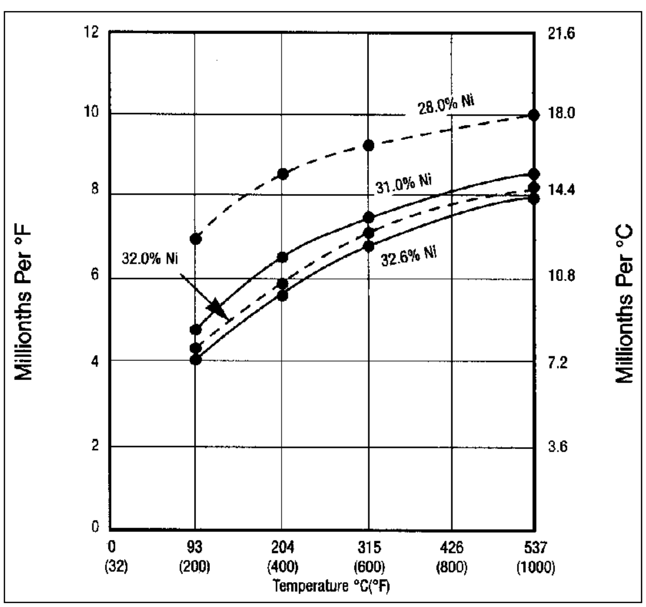


Figure 14 Effect of Nickel Content on the Thermal Expansion of Ni-Resist D-3

Thermal Shock Resistance

Because the strength and toughness of the spheroidal graphite Ni-Resists are superior to similar properties of the flake graphite alloys, the thermal shock resistance is also superior. In most cases involving temperature changes of up to 225°C(400°F), Ni-Resist D-3 can be used. However, where the thermal shock is known to be unusually severe, such as cycling between 500 and 1050°C(930 and 1930°F) Ni-Resist D-5S is the desired selection. This is particularly true because of its combination of oxidation resistance, ductility, hot strength and low expansion coefficient.

Electrical Resistivity

As can be seen from *Tables Vll* and Vlll and the specifications in **Part II**, the electrical resistivities of the flake graphite alloys are higher than for the corresponding ductile ones. *Table XXI* shows they are also higher than the values for gray cast iron and carbon and stainless steels. This properly is advantageous in certain electrical applications, especially in switches.

Magnetic Properties

The magnetic permeabilities of some ductile Ni-resists compared to other alloys are given in *Table XXII.* Ni-Resist alloys D-2 and D-2C have been used in many non-magnetic applications. However, the only truly non-magnetic grades are Ni-Resists NiMn 13-7 and D-6. This property combined with their relatively good castability make them useful materials.

Table XXI Electrical Resistivity of Various Alloys

Alloy	Electrical Resitivity Microhms/cm^2
Gray Cast Iron	75-100
Ni-Resists 1, 1b, 2, 2b	130-170
Medium Carbon Steel	18
12%Cr Stainless Steel	57
18%Cr-8% NI Stainless Steel	70

Table XXII Magnetic Permeability of Some Spheroidal Graphite Ni-Resists and Other Alloys

Alloy
NI-Resist D-2
Ni-Resist D-28
NI-Resist D-2C
Ni-Resist D-2M
Ni-Resist D-6
Gray Cast Iron
Plain Carbon Steel
12% Cr Stainless Steel
18% Cr 8% Ni Stainless Steel
Aluminum Bronze
Copper

FIELDS OF APPLICATION

Throughout the text, numerous examples of applications of Ni-Resist alloys have been mentioned. In this section, we have grouped them by industry area and have included some additional uses. There are also a number of pictures of finished and unfinished castings intended for various applications.

Chemical Processing

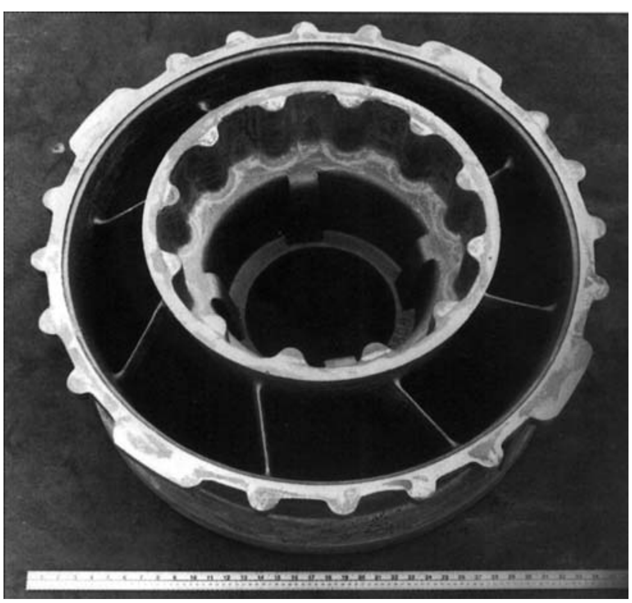
Chemical equipment requires the ability to withstand long periods of service under a wide variety of corrosive conditions. For those applications in chemical plants where cast components are suitable and economical, the Ni-Resist alloys are widely and successfully used.

Some of the more frequent applications are:

- Blowers
- Compressors
- Condenser parts
- Cryogenic equipment
- Furnace parts
- Piping
- Pots and kettles
- Pump casings and impellers
- Roils and conveyors
- Salt solution and slurry handling equipment
- Valves and valve fittings

Electrical Power Industry

Increases in the demand for electricity and the need to replace old and obsolete generating facilities have meant that engineers and designers must devise means for increasing the efficiency of power production. Thus, higher pressures, higher operating temperatures and other requirements mean demands for better materials of construction. In many cases, the Ni-Resist family of alloys provide economical and efficient answers. For example, application opportunities include equipment for generation, transmission and utilization of electricity



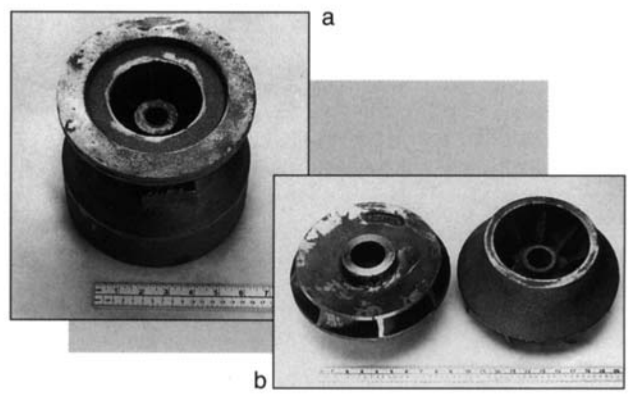
Exhaust gas diffuser for stationary gas turbine used for generation of electricity. Weight - 235 kgs (520 Ibs). Ni-Resist D-2B. (Macaulay Foundry, Berkeley, California, U.S.A.)

Pump impellers and vertical parts. Pumps made from these parts were for marine service but they could have been used in many different environments and industries. Ni-Resist D-2C. (The Taylor Group, Larbert, U.K.)

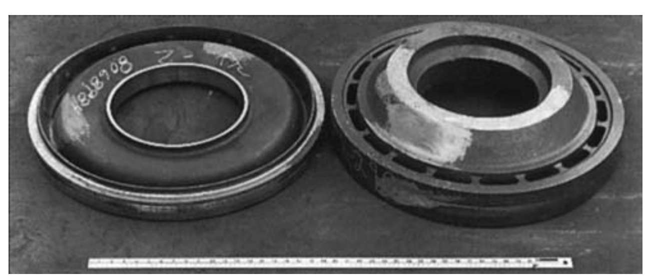
derived from gasoline and diesel engines as well as well as from steam, water and gas powered turbines.

Some of the more frequent applications are:

- Mechanical seals
- Meter parts
- Non-magnetic housings
- Pole line hardware
- Pump casings, diffusers and impellers
- Resistance grids
- Steam handling equipment
- Switch parts
- Turbine parts
- Valves and related attachments



Pump diffuser (a) and impellers (b) used in municipal sewage treatment plants. These are rough castings prior to final machining. Ni-Resist 1b. (Harris Industries, Longview, Texas, U.S.A.)

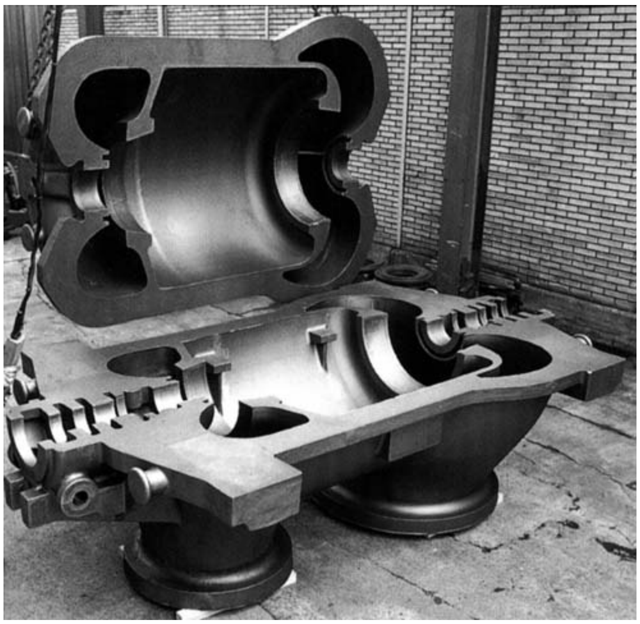


Third and fourth stage diaphragms for stationary gas turbine for generation of electricity. Weight - left 85 kgs (190 Ibs) right 130 kgs (290 Ibs). Ni-Resist D-5B. (Macaulay Foundry, Berkeley, California, U.S.A.)

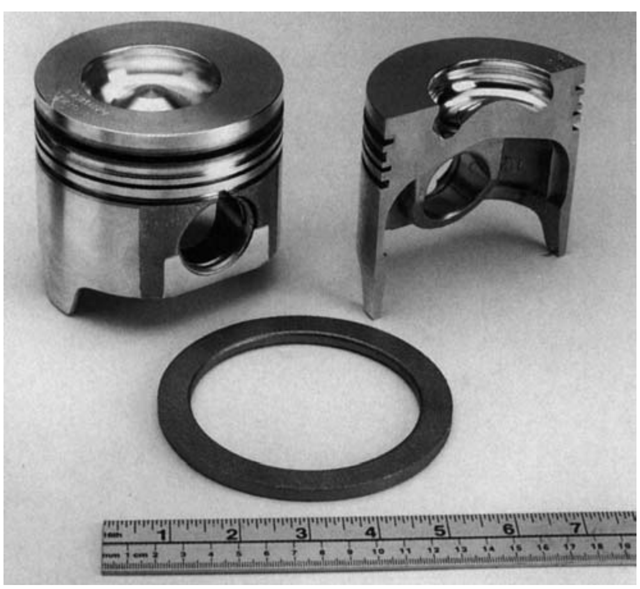
Food Handling and Processing

Sanitation is necessary in all food processing equipment that comes in contact with the product. Corrosion must be minimized and cleaning must be quick and thorough. For equipment that lends itself to castings, Ni-Resist alloys have given very satisfactory service.

Prevention of contamination or discoloration of food is often achieved by the use of Ni-Resists 2, 2b, 3 or 4 and their ductile counterparts in pumps, kettles, filters and valves. Ni-Resist 4 provides advantages in quality cooking, with little warping or pitting. Food does not stick to utensils, pots or grills. Cooking equipment made with this alloy are easy to keep clean and remain smooth, bright and attractive.



Compressor housing for use with steam containing solid particles. Ni-Resist D-2C. (Sulzer-Escher Wyss, Zurich, Switzerland)



Aluminum alloy piston for a truck diesel engine with Ni-Resist 1 ring insert, cut-away view and Ni-Resist 1 ring prior to being cast in-place. (Zollner Pistons, Ft. Wayne, Indiana, U.S.A.)

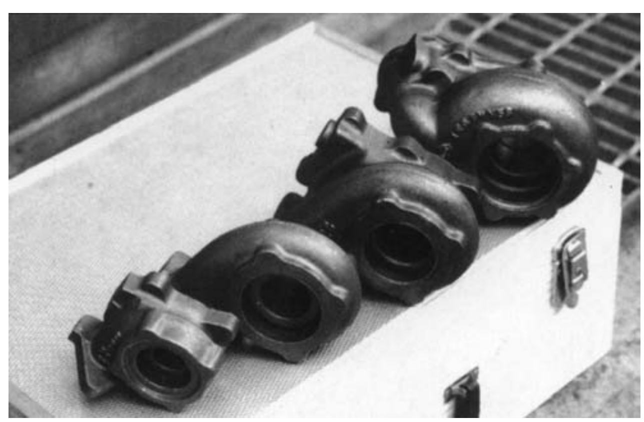
Some of the more frequent applications are:

- Baking, bottling and brewing equipment
- Canning machinery
- Distillery equipment
- Feed screws
- Fish processing equipment
- Heavy duty range tops and grills
- Meat grinders, chopper and packing equipment
- Pots and kettles
- Pumps and pump parts
- Salt solution filters

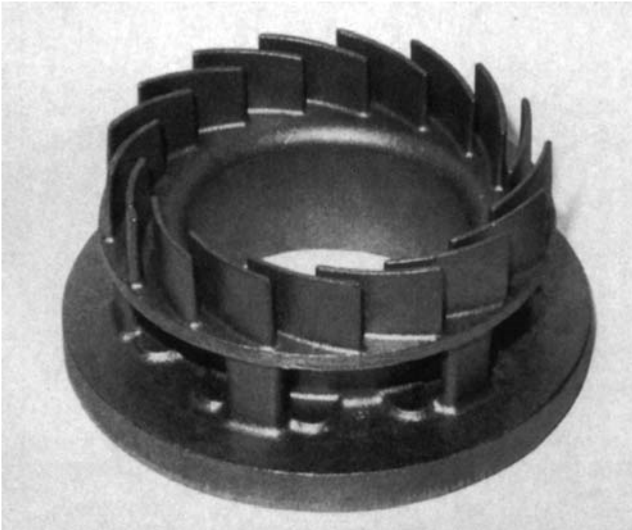
Internal Combustion Engines

The Ni-Resist alloys have certain outstanding advantages in this field. They are used in gasoline, diesel and LPG powered engines in trucks, busses, railway locomotives, stationary power plants and marine and aircraft propulsion units.

Turbine manifolds and housings for automotive gasoline powered engines. Ni-Resist D-5S. (Duport Harper Foundries Ltd., Tipton, U.K.)



Turbocharger casings for passenger automobiies. Engine sizes range from 0.6 liter to about 2.0 liters. Weights 1.5 kgs (3.3 Ibs) to 5.0 kgs (11 Ibs). Ni-Resist D-2 for smallest casting on left, Ni-Resist D-5S for others. (Enomoto Foundry Ltd., Kawaguchishi, Saitama, Japan)

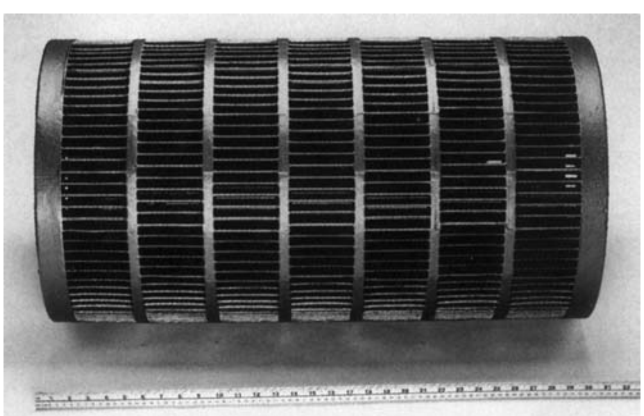


Turbocharger guide wheel for automotive engine Ni-Resist D-5S. (Hasenclever, Battenberg, Germany)

For exhaust parts such as manifolds and valve guides, Ni-Resist castings have proved resistant to the effects of temperatures up to 1050°C(1930°F) and the severe wear that can be caused by valve stem motion. They are also resistant to attack by most usual combustion products. Thermal expansion coefficients of Ni-Resist alloys which closely match those of stainless steels and UNS N06600 are another factor in exhaust applications.

Cylinder heads of Ni-Resist alloys resist corrosion from water and combustion products and have good metal-to-metal wear behavior. Ni-Resist finds wide spread use as insert rings in aluminum alloy pistons.

Water pump impellers and bodies offer another appropriate use for Ni-Resist alloys in engines. With increases in power, modern water pumps must operate at higher velocities than in the past. Higher water temperatures and pressures may increase the corrosion hazard and higher speeds can cause increased erosion damage.



Rotating filter drum for a fresh water treatment plant. Weight 106 kgs (234 Ibs). Ni-Resist 2. (Taylor & Fenn Company, Windsor, Connecticut U.S.A.)

Some of the more frequent applications are:

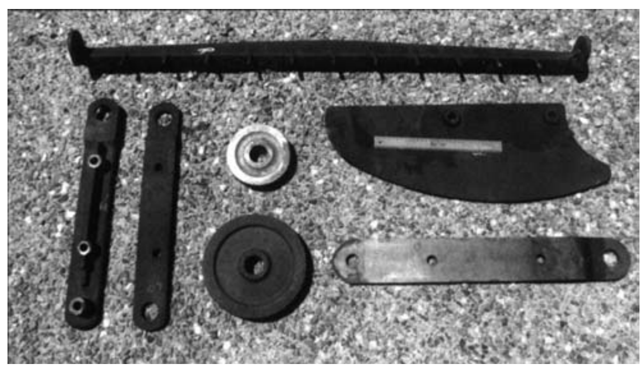
- Cylinder liners
- Diesel engine exhaust manifolds
- Exhaust valve guides
- Gas turbine housings, stators and other parts
- Insert rings and hot spot buttons for aluminum Alloy pistons
- Turbocharger housings, nozzle rings, heat shields and other parts
- Water pump bodies and impellers

Liquid Handling

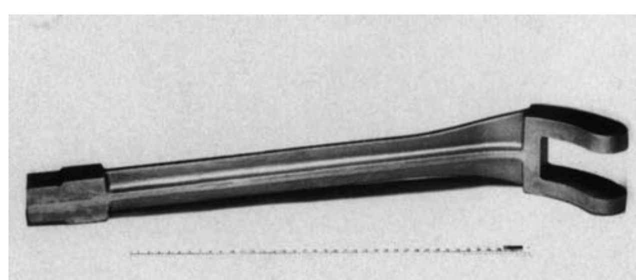
The same characteristics that have made the Ni-Resist alloys so valuable in the chemical and process industries apply to many other areas where corrosive liquids and erosive conditions exist.

Some of the more frequent applications are:

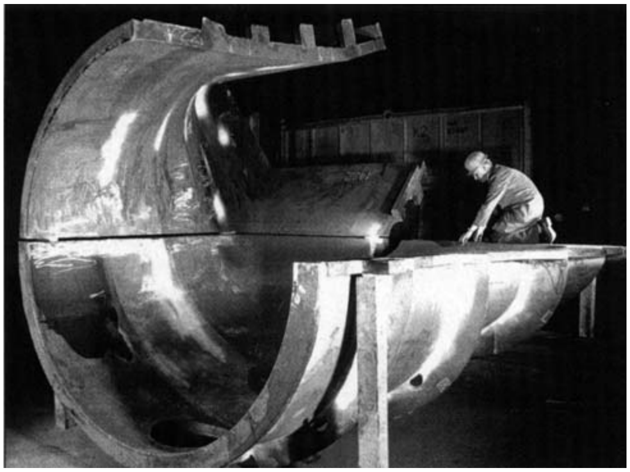
- Diffuser housings
- Mechanical seals
- Pipe and pipe fittings
- Pumps and pump parts
- Steam ejectors
- Strainers
- Valves of all kinds



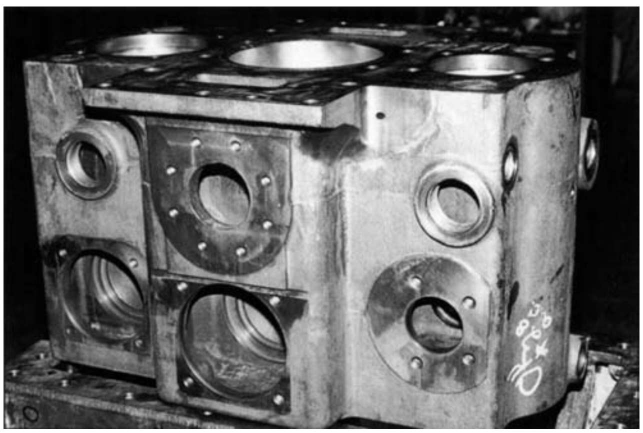
Miscellaneous cast parts for a moving sea water trash screen. Ni-Resist 3. (Castech Casting Technology, Wingfield, South Australia, Australia)



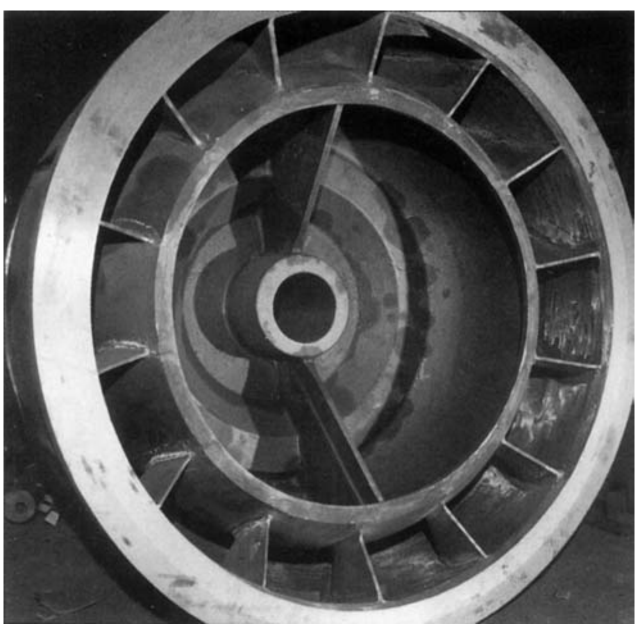
Hinge arm for a fresh water sluice gate. Weight 77 kgs (170 Ibs). Ni-Resist D-2. (Taylor and Fenn Company, Windsor, CT, U.S.A.)



Housing sections for a large fresh water pump. Ni-Resist D-2W (Deutsche Babcock, Oberhausen, Germany)



Three stage piston air compressor for marine service, Casting weight 293 kgs (644 lbs). Ni-Resist D-2 (Taylor and Fenn Company, Windsor, Connecticut, U.S.A.)



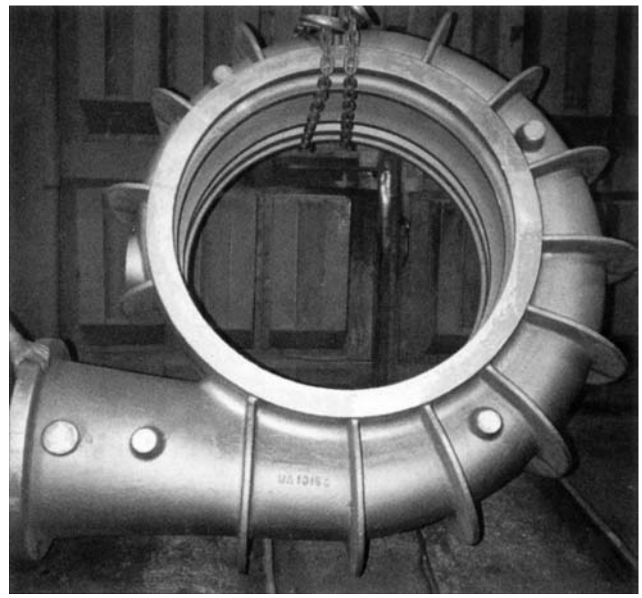
Bowl section for a large sea water pump. Weight 2000 kgs (4400 lbs). Ni-Resist D-2W. (The Taylor Group, Larbert, U.K.)

Marine Industry

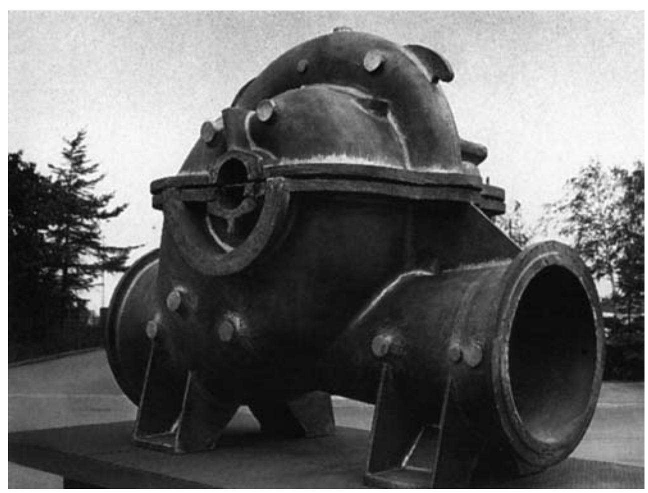
The corrosion and erosion resistance of Ni-Resist alloys in sea water have made these materials exceptionally useful for a broad range of applications where sea water is encountered.

Some of the more frequent applications are:

- Diesel engine manifolds
- Miscellaneous hardware
- Pipe and pipe fittings
- Pumps and pump parts
- Strainers
- Valves and valve parts



Pump volute or spiral outlet casting. Weight 2090 kgs (4600 lbs). Ni-Resist 1. (St. Mary's Foundry, St. Mary's, Ohio, U.S.A.)



Two-part water pump for a desalination plant. Ni-Resist D-2W. (Klein, Schanzlin and Becker, Bremen, Germany)

Petroleum Industry

When petroleum fluids enter feed lines, refineries and other processing plants, they must be distributed to the processing equipment. In addition, large quantities of water are often required in the various operations. In all of this, corrosion resistant materials are needed. For cast parts, Ni-Resist alloys have proved to be very successful. They have good corrosion resistance to salt water, corrosive petroleum fractions and some of the milder acids and caustics often encountered.

Some of the more frequent applications are:

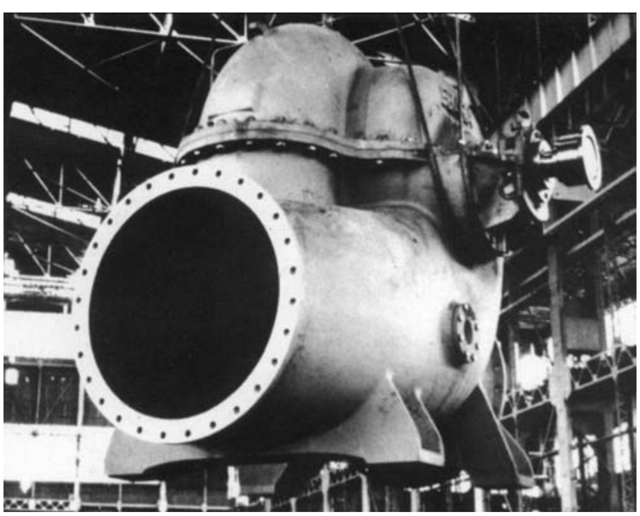
- Deep well, acid water and water flood pumps
- Gas compressors
- Motor parts
- Pipe and pipe fittings
- Petroleum fluids pumps and pump parts
- All kinds of valves and valve parts

Precision Machinery

Because of their low coefficients of thermal expansion, Ni-Resists 5 and D-5 are the primary cast alloys used where dimensional stability is a requirement. The accuracy of many machine tools, gauges and instruments may be increased by using them in vital parts. The coefficient of thermal expansion of these Ni-Resist alloys is one-third of that for gray cast iron. Ni-Resist D-5 is considerably tougher. Both alloys are more corrosion resistant and they are comparable with regard to vibration damping capacity and machinability.

Some of the more frequent applications are:

- Bases, bridges and work supports
- Forming dies
- Gauges
- Glass molds
- Instrument parts
- Machine tool ways
- Measuring tools
- Optical parts
- Spindle housings



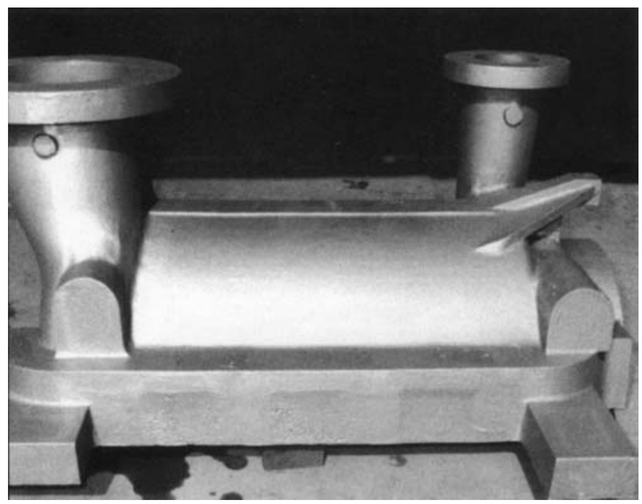
Double suction pump for a sea water desalination plant. Upper section weight 2000 kgs (4400 lbs), lower section weight 4800 kgs (10560 lbs). Ni-Resist D-2. (Ebara Corporation, Tokyo, Japan)

Pulp and Paper Industry

Corrosion is a problem at practically all stages in the manufacture of pulp and paper. The sulfite process has acid conditions. Kraft mills have alkaline environments. A combination of corrosion and erosion exist in both types of plants. Ni-Resist alloys offer useful solutions in many areas.

Some of the more frequent applications are:

- Dryer rolls
- Fourdrinier castings
- Grids
- Pipe and pipe fittings
- Press rolls
- Pumps and pump parts
- Screen runners
- Spiders
- Valves and valve parts
- Wood steamers



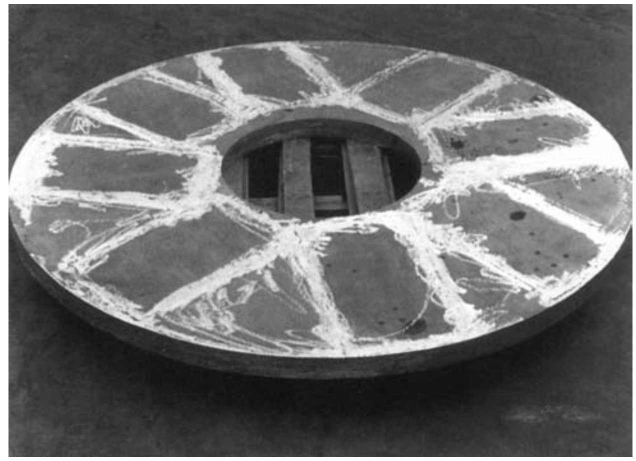
Part for a boil-off gas compressor for a liquid natural gas plant. Weight 2500 kgs (5500 lbs). Ni-Resist D-2M. (Ebara Corporation, Tokyo, Japan)

Parts for an optical instrument before and after assembly. Ni-Resist D-5. (Wolfensberger, Bauma, Switzerland)

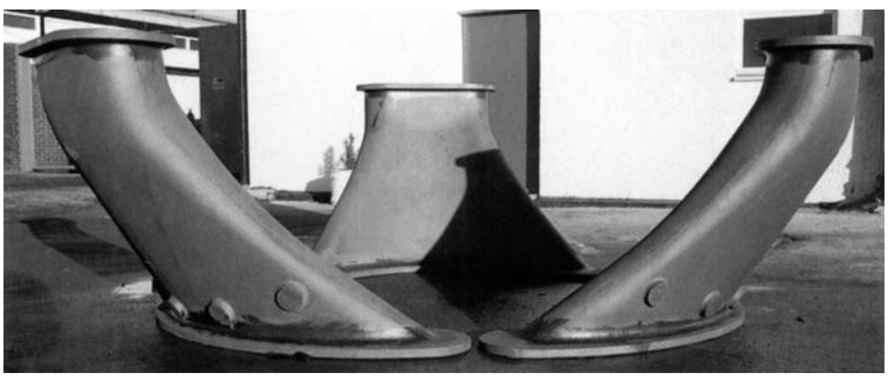
Miscellaneous Applications

The above listings of applications within particular industries are only a beginning where NI-Resist alloys are concerned. As a class, the Ni-Resists area very versatile group and can be found in almost any field. In order to emphasize this, we have included pictures of Ni-Resist products which are not easily categorized, but have both widespread or unique uses.

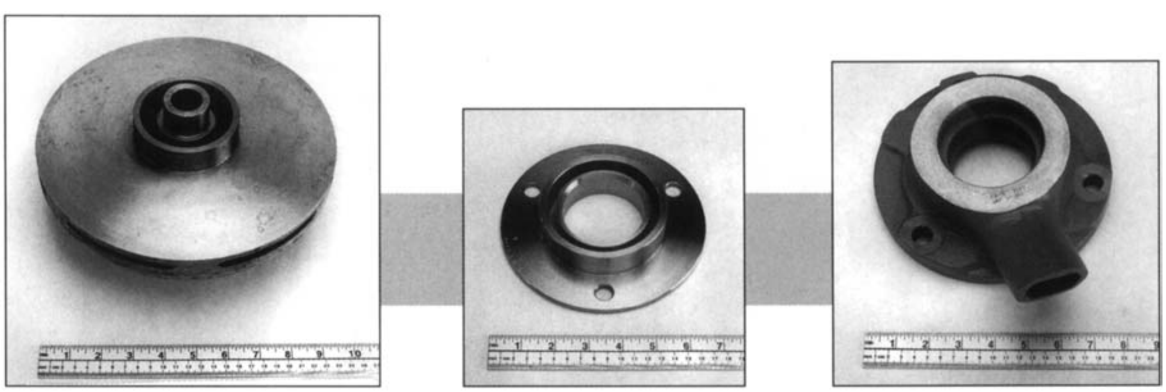
Plug valve intended for pulp and paper plant service. Valves of this type are used in many liquid handling systems in various industries. Ni-Resist 2. (DeZurik Division of General Signal, Sartell, Minnesota, U.S.A.)



Unpolished lapping wheel. Weight 1070 kgs (2350 Ibs). Ni-Resist D-2. (Macaulay Foundry, Berkeley, California, U.S.A.)



Hot air ducts for a variable temperature wind tunnel where operating temperatures can reach 580°C(1075°F). Ni-Resist D-2W. (The Taylor Group, Larbert, U. K.)



Miscellaneous small parts for liquid handling service. From the left a pump impeller in Ni-Resist 2, a stationary seal ring housing in Ni-Resist 1 and a flange in Ni-Resist 2. (Western Foundry, Longmont, Colorado, U.S.A.)

Part II
National and International Standards

The following tables indicate the designations for ASTM ISO, and draft European (CEN) NiResist standards and for the national Ni Resist standards in Australia, France, Germany, Japan and the United Kingdom.

Comparison of International and National Standards Covering Austenitic Cast Iron.

Flake Graphite Austenitic Cast Iron Grades.

Equivalent Ni-Resist Grades	United States ASTM A439-1994	International ISO 2892-1973	European Standard (Draft)*	Australia AS-1833-1986	France NF A32-301-1992	Germany DIN 1694-1981	Japan JIS G 5510-1987	United Kingdom BS 3468-1986
–	–	L-NiMn 13 7	EN-GJL-AX NiMn 13 7	LAW 13 7	FGL-Nil 3 Mn7	GGLANn 13 7	FCA-NiMn 13 7	–
1	Type 1	L-NiCuCr 15 6 2	EN-GJL-AX NiCuCr 15 6 2	L-NiCuCr 15 6 2	FGL-Nil 5 Cub Cr2	GGL-NiCuCr 15 6 2	FCA-NiCuCr 15 6 2	F1
1 b	Type 1 b	L-NiCuCr 15 6 3	–	L-NiCuCr 15 6 3	FGL-Ni15 Cub Cr3	GGL-NiCuCr 15 6 3	FCA-NiCuCr 15 6 3	–
2	Type 2	L-NiCr 20 2	–	L-NiCr 20 2	FGL-Ni20 Cr2	GGL-NiCr 20 2	FCA-NiCr 20 2	F2
2b	Type 2b	L-NiCr 20 3	–	L-NiCr 20 3	FGL-Ni20 Cr3	GGL-NiCr 20 3	FCA-NiCr 20 3	–
–	–	L-NiSiCr 20 5 3	–	L-NiSiCr 20 5 3	FGL-NI20 Si5 Cr3	GGL-NiSiCr 20 5 3	FCA-NSCr 20 5 3	–
3	Type 3	L-NiCr 30 3	–	L-NiCr 30 3	FGL-Ni30 Cr3	GGL-NiCr 30 3	FCA-NiCr 30 3	F3
4	Type 4	L-NiSiCr 30 5 5	–	L-NiSiCr 30 5 5	FGL-Ni30 Si5 Cr5	GGL-NiSiCr 30 5 5	FGA-NiSiCr 30 5 5	–
5	Type 5	L-N135	–	L-NI35	FGL-Ni35	–	FCA-NI35	–
–	Type 6	–	–	–	–	–	–	–

*This European Standard is being developed under "Founding -Austenitic cast irons, CEN Work Item 00190007, and when issued will replace the French, German and UK standards shown.

Spheroidal Graphite (Ductile) Austenitic Cast Iron Grades.

Equivalent Ductile Ni-Resist Grades	United States ASTM A439-1994 ASTM A571 M-1992	International ISO 2892-1973	European Standard (Draft)*	Australia AS-1833-1986	France NF A32-301-1992	Germany DIN 1694-1981	Japan AS G 5510-1987	United Kingdom BS 3468-1986
D-2	Type D-2	S-NiCr 20 2	EN-GJS-AX NiCr 20 2	S-NiCr 20 2	FGS-Ni20 Cr2	GGG-NiCr 20 2	FCDA-NiCr 20 2	S2
D-2W	–	–	EN-GJS-AX NiCrNb 20 2	–	FGS-Ni20 Cr2	GGG-NiCrNb 20 2	FCDA-NiCrNb 20 2	S2W
	–	–	–	–	Nb0.15	–	–	–
D-2B	Type D-2B	S-NiCr 20 3	–	S-NiCr 20 3	FGS-Ni20 Cr3	GGG-NiCr 20 3	FCDA-NiCr 20 3	S2B
	–	S-NiSiCr 20 5 2	–	S-NiSiCr 20 5 2	FGS-Ni20 Si5 Cr2	GGG-NiSiCr 20 5 2	FCDA-NiSiCr 20 5 2	–
D-2C	Type D-2C	SAO	EN-GJS-AX Ni 22	S-Ni 22	FGS-Ni22	GGG-Ni 22	FCDA-Ni 22	S2C
D-2M	Type D-2M	S-NiMn 23 4	EN=GJS-AX NiMn 23 4	SAW 23 4	FGS-Ni 23 Mn4	GGG-NiMn 23 4	FCDA-NiMn 23 4	S2M
D-3A	Type D-3A	S-NiCr 301	–	S-NiCr 301	FGS-N130 Crl	GGG-NiCr 301	FCDA-NiCr 301	–
D-3	Type D-3	S-NiCr 30 3	EN-GJS-AX NiCr 30 3	S-NiCr 30 3	FGS-Ni30 Cr3	GGG-NiCr 30 3	FCDA-NiCr 30 3	S3
D-4A	Type D-4A	–	–	–	FGS-Ni30 Si5 Cr2	GGG-NiSiCr 30 5 2	FCDA-NiSiCr 30 5 2	–
D-4	Type D-4	S-NiSiCr 30 5 5	EN-GJS-AX NOD 30 5 5	S-NiSiCr 30 5 5	FGS-Ni30 Si5 Cr5	GGG-NiSiCr 30 5 5	FCDA-NiSiCr 30 5 5	–
D-5	Type D-5	S-Ni 35	EN-GJS-AX Ni 35	S-Ni 35	FGS-Ni35	GGG-Ni 35	FCDA-Ni 35	–
D-5B	Type D-5B	S-NiCr 35 3	EN-GJS-AX NO 35 3	S-NiCr 35 3	FGS-Ni35 Cr3	GGG-NiCr 35 3	FCDA-NiCr 35 3	–
D-5S	Type HS	–	EN-GJS-AX NiSiCr 35 5 2	–	FGS-N135 Si5 Cr2	GGG-NiSiCr 35 5 2	FCDA-NiSiCr 35 5 2	S5S
D-6	–	S-NiMn 13 7	EN-GJS-AX NiMn 13 7	S-NiMn 13 7	FGS-Ni13 Mn7	GGG-NiMn 13 7	FCDA-NiMn 13 7	S6

*This European Standard is being developed under 'Founding -Austenitic cast irons, CEN Work Item 00190007, and when issued will replace the French, German and UK standards shown.

Typical chemical compositions and mechanical and physical properties of flake graphite and spheroidal graphite austenitic cast irons follow.
Note: In most specifications there are differences in composition, mechanical and physical property ranges and mandatory clauses. Before using any standard it is advisable to check an original text for details.

A. United States
A-1 Flake Graphite Grades, Chemical Composition
A-2 Flake Graphite, Mechanical Properties
A-3 Spheroidal Graphite Grades, Chemical Composition
A-4 Spheroidal Graphite, Mechanical Properties

B. International Organization for Standardization, ISO
B-1 Flake Graphite Grades, Chemical Composition and Mechanical Properties
B-2 Spheroidal Graphite (Ductile) Grades, Chemical Composition
B-3 Spheroidal Graphite (Ductile) Grades, Mechanical Properties

C. European Standard (Draft)
Engineering Grades
C-1 Flake Graphite and Spheroidal Graphite, Chemical Composition
C-2 Flake Graphite and Spheroidal Graphite, Mechanical Properties
Special Purpose Grades
C-3 Flake Graphite and Spheroidal Graphite, Chemical Composition
C-4 Flake Graphite and Spheroidal Graphite, Mechanical Properties

D. Typical Properties
D-1 Typical Physical Properties of Flake Graphite Ni-Resist
D-2 Typical Physical Properties of Spheroidal Graphite Ni-Resist
D-3 Typical Low Temperature Properties of Ductile Ni-Resist

United States

A-1 Flake Graphite Grades ASTM A 436-84 (Reapp. 1992).
Composition, wt%

	C max	Si	Mn	Ni	Cu	Cr	S	S Mo
Type 1	3.00	1.00-2.80	0.5-1.5	13.50-17.50	5.50-7.50	1.50-2.50	0.12	–
Type 1 b	3.00	1.00-2.80	0.5-1.5	13.50-17.50	5.50-7.50	2.50-3.50	0.12	–
Type 2	3.00	1.00-2.80	0.5-1.5	18.00-22.00	0.50 max	1.50-2.50	0.12	–
Type 2b	3.00	1.00-2.80	0.5-1.5	18.00-22.00	0.50 max	3.00-6.OO[A]	0.12	–
Type 3	2.60	1.00-2.00	0.5-1.5	28.00-32.00	0.50 max	2.50-3.50	0.12	–
Type 4	2.60	5.00-6.00	0.5-1.5	29.00-32.00	0.50 max	4.50-5.50	0.12	–
Type 5	2.40	1.00-2.00	0.5-1.5	34.00-36.00	0.50 max	0.10 max	0.12	–
Type 6	3.00	1.50-2.50	0.5-1.5	18.00-22.00	3.50-5.50	1.00-2.00	0.12	1.00 max

[A]where same machining is required, the 3.00-4.00°/ Cr range is recommended.

A-2 Mechanical Properties

	Tensile Strength min.ksi (MPa)	Brinell Hardeness (3000kg)
Type 1	25(172)	131-183
Type 1 b	30(207)	149-212
Type 2	25(172)	118-174
Type 2b	30(207)	171-248
Type 3	25(172)	118-159
Type 4	25(172)	149-212
Type 5	20(138)	99-124
Type 6	25(172)	124-174

A-3 Spheroidal Graphite Grades ASTM A 439-83 (Reapp. 1994), D-2M-ASTM A571-84 (Reapp. 1992).
Composition, wt%

	C max	Si	Mn	Ni	Cr	P max
Type D-2[A]	3.00	1.50-3.00	0.70-1.25	18.00-22.00	1.75-2.75	0.08
Type D-2B	3.00	1.50-3.00	0.70-1.25	18.00-22.00	2.75-4.00	0.08
Type D-2C	2.90	1.00-3.00	1.80-2.40	21.00-24.00	0.50 max[B]	0.08
Type D-2M	2.2-2.7[C]	1.50-2.50	3.75-4.50	21.00-24.00	0.20 max[B]	0.08
Type D-3A	2.60	1.00-2.80	1.00 max[B]	28.00-32.00	1.00-1.50	0.08
Type D-3 [A]	2.60	1.00-2.80	1.00 max[B]	26.00-32.00	2.50-3.50	0.08
Type D-4	2.60	5.00-6.00	1.00 max[B]	26.00-32.00	4.50-5.50	0.08
Type D-5	2.40	1.00-2.80	1.00 max[B]	34.00-36.00	0.1 max	0.08
Type D-513	2.40	1.00-2.80	1.00 max[B]	34.00-36.00	2.00-3.00	0.08
Type D-5S	2.30	4.90-5.50	1.00 max[B]	34.00-37.00	1.75-2.25	0.08

A - Additions of 0.7-1.0% Mo will increase the mechanical properties above 800°F (425°C)
B - Not intentionally added
C - For casting with sections under ¼ in., it may be desirable to adjust the carbon upwards to a max. of 2,90%

A-4 Mechanical Properties

	Tensile Strength min.ksi (MPa)	Yield Strength, 0.2% offset, mil (MPa)	Elongation, in 2" or 50mm, min%	Brinell Hardness, 3000kg	Charpy V-notch D	
					min. av 3 tests	min. ind. test
Type D-2	58 (400)	30 (207)	8.0	139-202	-	-
Type D-2B	58 (400)	30 (207)	7.0	148-211	-	-
Type D-2C	58 (400)	28 (193)	20.0	121-171	-	-
Type D-2M CI 1	65 (450)	30[B](205)	30	121-171	20 [C]	16 [C]
Type D-21V CI 2	60 (415)	25[B](170)	25	111-171	27	20
Type D-3A	55 (379)	30 (207)	10.0	131-193	-	-
Type D-3	55 (379)	30 (207)	6.0	139-202	-	-
Type D-4	60 (414)	–	–	202-273	-	-
Type D-5	55 (379)	30 (207)	20.0	131-185	-	-
Type D-5B	55 (379)	30 (207)	6.0	139-193	-	-
Type D-5S	65 (449)	30 (207)	10.0	131-193	-	-

A - Heat-treated condition
B - Yield strength shall be determined at 0.2% offset method, see Test Methods E8. Other methods may be agreed upon by mutual consent of the manufacturer and purchaser.
C - Not more that one test in a set of three may be below the min. average required for the set of three.
D - The energy absorption values shown are applicable at temperatures down to and including-195°C.

International Organization for Standardization, ISO

B-1 Flake Graphite Grades – ISO 2892-1973 (E)
Composition, wt

Alloy Grade	C max	Si	Mn	Ni	Cu	Cr	Mechanical Property UTS, (R,)min. N/mm^2
L-Ni Mn 13 7	3.0	1.5-3.0	6.0-7.0	12.0-14.0	0.5 max	0.2 max	140
L-Ni Cu Cr 15 6 2	3.0	1.0-2.8	0.5-1.5	13.5-17.5	5.5-7.5	1.0-2.5	170
L-Ni Cu Cr 15 6 3	3.0	1.0-2.8	0.5-1.5	13.5-17.5	5.5-7.5	2.5-3.5	190
L-Ni Cr 20 2	3.0	1.0-2.8	0.5-1.5	18.0-22.0	0.5 max	1.0-2.0	170
L-Ni Cr 20 3	3.0	1.0-2.8	0.5-1.5	18.0-22.0	0.5 max	2.5-3.5	190
L-Ni Si Cr 20 5 3	2.5	4.5-5.5	0.5-1.5	18.0-22.0	0.5 max	1.5-4.5	190
L-Ni Cr 30 3	2.5	1.0-2.0	0.5-1.5	28.0-32.0	0.5 max	2.5-3.5	190
L-Ni Si Cr 30 5 5	2.5	5.0-6.0	0.5-1.5	29.0-32.0	0.5 max	4.5-5.5	170
L-Ni 35	2.4	1.0-2.0	0.5-1.5	34.0-36.0	0.5 max	0.2 max	120

B-2 Spheroidal Graphite (Ductile) Grades – ISO 2892-19973 (E)
Composition, wt

Alloy Grade	C max	Si	Mn	Ni	Cu max	Cr
S-Ni Mn 13 7	3.0	2.0-3.0	6.0-7.0	12.0-14.0	0.5	0.2 max
S-Ni Cr 20 2	3.0	1.5-3.0	0.5-1.5	18.0-22.0	0.5	1.0-2.5
S-Ni Cr 20 3	3.0	1.5-3.0	0.5-1.5	18.0-22.0	0.5	2.5-3.5
S-Ni Si Cr 20 5 2	3.0	4.5-5.5	0.5-1.5	18.0-22.0	0.5	1.0-2.5
S-Ni 22	3.0	1.0-3.0	1.5-2.5	21.0-24.0	0.5	0.5 max
S-Ni Mn 23 4	2.6	1.5-2.5	4.0-4.5	22.0-24.0	0.5	0.2 max
S-Ni Cr 301	2.6	1.5-3.0	0.5-1.5	28.0-32.0	0.5	1.0-1.5
S-Ni Cr 30 3	2.6	1.5-3.0	0.5-1.5	28.0-32.0	0.5	2.5-3.5
S-Ni Si Cr 30 5 5	2.6	5.0-6.0	0.5-1.5	28.0-32.0	0.5	4.5-5.5
S-Ni 35	2.4	1.5-3.0	0.5-1.5	34.0-36.0	0.5	0.2 max
S-Ni Cr 35 3	2.4	1.5-3.0	0.5-1.5	34.0-36.0	0.5	2.0-3.0

B-3 Spheroidal Graphite (Ductile) Grades – ISO 2892-1973 (E)
Mechanical properties

Grade	Tensile Strength (R_M) min. N/mm^2	0.2% Proof stress ($R_{p0.2}$) min. N/mm^2	Elongation (A) min. %	Minimum mean impact value on 3 tests V-notch (Charpy) J[1]	U-notch (Mesnager) J[1]
S - Ni Mn 13 7	390	210	15	16	-
S - NiCr202	370	210	7	13	16
S - NiCr203	390	210	7	-	-
S - NiSiCr2052	370	210	10	-	-
S - Ni 22	370	170	20	20	24
S - Ni Mn 23 4	440	210	25	24	28
S - Ni Cr 301	370	210	13	-	-
S - NiCr303	370	210	7	-	-
S - Ni Si Cr 30 5 5	390	240	-	-	-
S - Ni 35	370	210	20	-	-
S - Ni Cr 35 3	370	210	7	-	-

1-1J=1N–m.

European Standard (Draft)

C-1 Engineering Grades - Chemical Composition

Graphite Form	Designation Grade	C max %	Si %	Chemical Mn %	composition Ni %	Cr %	P max %	Cu max
Flake	EN-GJL-AX NiCuCr 15 6 2	3.0	1.0-2.8	0.5-1.5	13.5-17.5	1.0-3.5	0.25	5.5-7.5
	EN-GJS-AX NO 20 2	3.c	1.5-3.0	0.5-1.5	18.0-22.0	1.0-3.5	0.08	0.50
	EN-GJS-AX NiMn 23 4	2.6	1.5-2.5	4.0-4.5	22.0-24.0	0.2 max	0.08	0.50
Spheroidal	EN-GJS-AX NiCrNb 20 2 2[(1)]	3.0	1.5-2.4	0.5-1.5	18.0-22.0	1.0-3.5	0.08	0.50
	EN-GJS-AX Ni 22	3.0	1.0-3.0	1.5-2.5	21.0-24.0	0.5 max	0.08	0.50
	EN-GJS-AX Ni 35	2.4	1.5-3.0	0.5-1.5	34.0-36.0	0.2 max	0.08	0.50
	EN-GJS-AX NiSiCr 35 5 2	2.0	4.0-6.0	0.5-1.5	34.0-36.0	1.5-2.5	0.08	0.50

(1) For good weldability of this material Nb%¾0.353 - 0.032 (Si% + 64. Mg%)
(Typical niobium addition 0.12 - 0.18 °%)

C-2 Engineering Grades - Mechanical Properties

Graphite Form	Designation Grade	Tensile Strength (R_M) min NImm²	Mechanical Properties 0.2% Proof Stress (R_{po2}) min N/mm²	Elongation (A) min %	Minimum mean impact value on 3 tests V notch Charpy (J)
Flake	EN-GJL-AX NiCuCr 15 6 2	170	not specified	not specified	not specified
	EN-GJS-AX NO 20 2	37C	210	7	13*
	EN-GJS-AX NiMn 23 4	440	210	25	24
Spheroidal	EN-GJS-AX NiCrNb 20 2	370	210	7	13*
	EN-GJS-AX Ni 22	370	170	20	20
	EN-GJS-AX Ni 35	370	210	20	23
	EN-GJS-AX NiSiCr 35 5 2	370	200	10	not specified

Optional requirement by agreement with the customer.

C-3 Special Purpose Grades - Chemical Composition

Graphite Form	Designation Grade	C max %	Si %	Chemical Mn %	composition Ni %	Cr %	P max %	Cu max %
Flake	EN-GJL-AX NiMn 13 7	3.0	1.5-3.0	6.0-7.0	12.0-14.0	0.2 max	0.25	0.50
Spheroidal	EN-GJS-AX NiMn 13 7	3.0	2.0-3.0	6,0-7.0	12.0-14.0	0.2 max	0.08	0.50
	EN-GJS-AX NO 30 3	2.6	1.5-3.0	0.5-1.5	28.0-32.0	2.5-3.5	0.08	0.50
	EN-GJS-AX NiSCr 30 5 5	2.6	5.0-6.0	0.5-1.5	28.0-32.0	4.5-5.5	0.08	0.50
	EN-GJS-AX NO 35 3	2.4	1.5-3.0	0.5-1.5	34.0-36.0	2.0-3.0	0.08	0.50

C-4 Special Purpose Grades - Mechanical Properties

Graphite Form	Designation Grade	Tensile Strength (R_M) min N/mm²	Chemical composition 0.2% Proof Stress (R_{po2}) min N/mm²	Elongation (A) min %	Minimum mean impact value on 3 tests V notch Charpy (J)
Flake	EN-GJL-AX NiMn 13 7	140	not specified	not specified	not specified
Spheroidal	EN-GJS-AX NiMn 13 7	390	210	15	16
	EN-GJS-AX NO 30 3	370	210	7	not specified
	EN-GJS-AX SO 30 5 5	390	240	not specified	not specified
	EN-GJS-AX NO 35 3	370	210	7	not specified

Typical Properties

D-1 Typical Physical Properties of Flake Graphite Ni-Resist.

These grades corrolate to those in the ASTM standard.

Flake Graphite Ni-Resist Grades	Nominal Denisty Mg/m^3	Thermal Coeff. of Expansion 20-200°C $m/(m°C)\ x10^{-6}$	Thermal Conductivity W (m°C)	Specific Heat J/(g°C)	Specific Electrical Resistance $\Omega mm^2/m$	Relative Permeability μ (where H=8) (kA/m)	Modulus of Elasticity E KN/mm^2
1	7,3	18.7	37.7-41.9	0.46-0.50	1.6	A.05	85-105
1b	7.3	18.7	37.7-41.9	0.46-0.50	1.1	A.05	98-113
2	7.3	18.7	37.7-41.9	0.46-0.50	1.4	>1.05	85-105
2b	7.3	18.7	37.7-41.9	0.46-0,50	1.2	>1.05	98-113
3	7.3	12.4	37.7-41.9	0.46-050		magnetic	98-113
4	7.3	14.6	37.7-41.9	0.46-0.50	1.6	magnetic	
5	7.3	5.0	37.7-41.9	0.46-0.50		magnetic	

D-2 Typical Physical Properties of Spheroidal Graphite Ni-Resist

These grades corrolate to those in the ASTM standard.

Ductile Ni-Resist Grades	Nominal Denisty Mg/m^3	Thermal Coeff. of Expansion 20-200°C $m/(m°C)\ x10^{-6}$	Thermal Conductivity W (m°C)	Specific Electrical Resistance $\Omega mm^2/m$	Relative Permeability μ (where H=8) (kA/m)	Modulus of Elasticity E KN/mm^2
D-21D-2W	7.4	18.7	12.6	1.00	>1.05	112-133
D-2B	7.4	18.7	12.6	1.00	>1.05	112-133
D-2C	7.4	18.4	12.6	1.00	1.02-1.05	85-112
D-2M	7.4	14.7	12.6		1.02-1.05	120-140
D-3A	7.4	12.6	12.6		magnetic	112-130
D-3	7.4	12.6	12.6		magnetic	92-105
D-4A	7.4	15.1	12.6		magnetic	
D-4	7.4	14.4	12.6	1.02	magnetic	
D-5	7.6	5.0	12,6		magnetic	112-140
D-513	7.6	5.0	12.6		magnetic	112-123
D-5S	7.6	12.9	12.6		magnetic	110-145

D-3 Typical Low Temperature Properties of Ductile Ni-Resist

Grade D-2M*

Temp °C	Tensile Strength (R_M) N/mm^2	0.2% Proof stress ($R_{p0.2}$) N/mm^2	Elongation (A) %	Reduction in area after fracture %	Charpy V-notch strengths impact J
+20	450	220	35	32	29
0	450	240	35	32	31
-50	460	260	38	35	32
-100	490	300	40	37	34
-150	530	350	38	35	33
-183	580	430	33	27	29
-196	620	450	27	25	27

[1]-1J=1N-m.
*Ductile Ni-Resist Grade D-2M corrolates to ASTM A571-1984 (1992).

Part III

Corrosion

Selected results from service and laboratory tests comparing Ni-Resist with cast iron for a variety of conditions. Additional data on comparative service of Ni-Resist irons in other corrosive environments may be obtaineo on request.

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
Acetic Acid, 10%	Laboratory		60	Some		880	20	1-2
Acetic Acid, 25%	Laboratory		60	Some		790	20	1-2
Acetic Acid, 25% (by vol.)	Laboratory	168 hours	68		None	*	1	1-2
Acetic Acid, 25% (by vol.)	Laboratory	600 hours	68		None	*	2	1-2
Acetic Acid, concentrated	Laboratory		60	Some		80	20	1-2
Acetic Acid, 47%; 24% NaCl; some Oleic Acid and Oxidizing salts	Recirculating tank	23 days	too			20	4	1-2
Acetone, 10 parts, and one part Oleic Acid-Linoleic Acid mixture	Solvent recovery still	150 hours	145	None	Natural ebulition	20	Gained weight	1-2
Acetone, 5 parts, and one part Oleic Acid-Linoleic Acid Mixture	Separator tank	131 days	35.6-102 dys 68.0-150 hrs	None	None	0.4	06	1-2
Acetylene Tetrachloride, trichlorethylene vapor, lime	In Still	30 days	210	None	Boiling	70	4	1-2
Aluminum Sulfate, 57%(at end);.02% Ferric, and .8% Ferrous Sulfate	Alum evaporator	44 days	140-240			*	300	
Aluminum Sulfate, 2#/gal.	Alum storage tank	62 days	90-98			*	4	1
Aluminum Sulfate, 5%	Laboratory		60	Some		40	16	1
Aluminum Sulfate, 0.1%	Laboratory		60	Same		5	2	1
Ammonium Hydroxide, 5%	Laboratory		60			No loss	01	1-2-3
Ammonium Hydroxide, 10%	Laboratory		60			No loss	0.2	1-2-3
Ammonium Hydroxide, 25%	Laboratory		60			No loss	0.18	1-2-3
Ammonia solution, 50%	Laboratory		60			No loss	No loss	1-2
Ammonia solution, 75%	Laboratory		60			No loss	No loss	1-2
Ammonia solution, concentrated	Laboratory		60			2	No loss	1-2
Ammonia, 5-6% by vol.; 150 p.p.m.; Phenol carried by water vapor	Top of phenol tower	309 days	215.6	None	750,00.0 cu. ft./hr	2	0.9	1-2
Ammonia liquors of 10 g/l Ammonia	Inside ammonia coils	318 days	77		By flaw		0.2	1-2
Ammonia liquors of 10 g/l Ammonia	Inside ammonia coils	318 days	158		By flow		6	1-2
Ammonia liquor	Ammonia liquor separator tank	225 days				.09	.05	1-2
Ammonia liquors of 6.5 g/l Ammonia	Liquor balance tank	307 days	215.6	None	1500 gal./hr	3	0.6	1-2
Ammonia liquors carrying Sulfates, Sulfides, etc.	Feed tank	449 days	100	Slight	By flow	0.1	C1	1-2
Ammonium Chloride, 5%	Laboratory		60	Some		50	3	1-2
Ammonium Chloride, 5%	Laboratory		200	Some		190	6	1-2
Ammonium Chloride, 10%	Laboratory		60	Some		40	7	1-2
Ammonium Chloride, 10%	Laboratory		200	Some		210	6	1-2
Ammonium Chloride, 20%	Laboratory		60	Some		50	10	1-2
Ammonium Chloride, 20%	Laboratory		200	Some		230	3	1-2
Ammonium chloride 35%, zinc chloride 35%. Slightly alkaline	Dissolving tank	59 days	Room to 225°	Air agitated	Agitated	150	10	1
Ammonium Chloride, 25% by wt. slightly alkaline, less than 15% Ammonia	Process tank	68 days	221-230				5	1-2
Ammonium Chloride, 28-40%	Evaporating tank	762 hours	77-216			360	10	1-2
Ammonium perchlorate 265-300 gpl-sodium chloride 214-250 gpl, sodium perchlorate 36 gpl, pH 5.2	Crystalizer	192 days	122	Air free	Low		3.3	1

* Ordinarily not satisfactory.

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
Ammonium nitrate 66.8% + ammonia 16.6% and ammonium nitrate 55.5% + ammonia 26%	Pump suction from mixing tank	36 days	120	Low	4.1 fps	2.2	0.4	2
Ammonium and Sodium Nitrate solution settled after shaking in the presence of the sample with NH3 gas until free NH_3 was 80 g/l	Laboratory	0.33 hour	149	$NaHC0_3$ reacted with HN,NO2 to produce free NH_3 and $C0_2$ gas		120	10	1-2
Ammonium Sulfate with 8% Sulfuric Acid and Ammonia liquors	In a saturator drain table	99 days	150	Aerated	Some	70	5	1
Ammonium Sulfate, 5%	Laboratory		60	Some		30	6	1
Ammonium Sulfate, 10%	Laboratory		60	Some		30	4	1
Ammonium Sulfate, 25,%	Eaboratory		60	Some		10	0.7	1
Saturated Ammonium Sulfate in 3-10% H2SO4, plus coke oven gas	Saturator on “Cracker Pipe”	77 days	131	None	Violent	80	2	1
Arsenic Acid, 65%	Collection tank	21 days	80-120	Exposed to air	Stagnant except when tank filled & emptied	650	370	
Benzine	Laboratory			Some	None	0	0	1-2
Benzol vapors and liquid	At bottom plateof fractionating column of benzol still	186 days					8	1-2
Benzol vapors and liquid	At 24th plate from bottom of fractionating column of benzol still	186 days					6	1-2
Benzol liquid	Still body	146 days				4	1	1-2
Boron trichloride 95%, chlorine 5%, traces of ferric chloride and aluminum chloride	Stripping column condenser	60 days	54	Air free	Agitated liquid and gas		4.9	4
Boron trichloride 99%, traces of chlorine	Refining column condenser	67 days	55	Air free	Agitated liquid and gas		1	3
Calcium Chloride, 5%	Laboratory		60	Some	None	9	5	1-2
Calcium Chloride, 5%, plus Magnesium Chloride, 5%	Laboratory		60	Some	None	5	4	1-2
Calcium Chloride, 8%; Calcium Bromide, 38%; Lithium, 11%; Bromide brine.	Dehumidifying of air	38 days	120	Yes	Considerable		2	1-2
Calcium Chloride cooling brine with Potassium Dichromate inhibitor	Brine tank	372 days		None	Slow circulotion	0.4	09	1-2
Calcium Chloride cooling brine	Brine tank	355 days		None	Slow circulation	7	3	1-2
Calcium-Sodium-Magnesium Chloride brines in 28% concentration	Evaporator at liquor level	752.5 hours	160	Goad	By boiling	20	3	1-2
Calcium-Magnesium Chloride brine; 50% total chlorides	Evaporator at liquor level	26 days	Boiling	Good	By boiling	30	4	1-2
Calcium Hydrosulfide containing 45-50 g/l CaO	Turbo gas absorber above impeller hood	46 days	139	Sat'd with H_2S gas	1-21/sec.	8	1	1-2
Calcium Hydroxide, saturated solution	Laboratory	20 hours	86	With $C0_2$ free air	15.31/sec.		Slight gain in weight	1-2
Calcium Hydroxide (Lime water)	Laboratory		60	Some	None	3	0.2	1-2
Calcium Hypochlorite, concentrated	Laboratory		60	Some	None	6	0.8	1-2
Calcium Hypochlorite, 0.07%	Laboratory		60	Some	None	8	2	1-2
Calcium Sulfite liquors	Gas absorbing chamber	68 days	200	Good	Liquid as a fine spray or mist	5	2	1-2
Carbon Dioxide, saturated aqueous solution	Laboratory		60	Some		30	1	1-2
Carbon disulfide and water	Inside railroad tankcar	240 days	Atmosphere			6.3	2	13

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
Carbon Bisulfide, plus Carbon Tetrachloride, plus Sulfur Monochloride. plus free Sulfur	Suspended from agitator arm in still	339 days			Some	Completely Destroyed	1	1-2
Carbon Tetrachloride	Sump tank, dry cleaning machine	66 days	70-90				1	1-2
Carbon Tetrachloride	Main still-vapor, dry cleaning machine	66 days	160-170				0-3	1-2
Carbon Tetrachloride	Main still-liquid, dry cleaning machine	66 days	160-170				1	1-2
Carbon Tetrachloride	Main storage tank, dry cleaning machine	98 days	Room				2	1-2
Carbon Tetrachloride vapor containing S2C12 and CS2	Vapor stream above top plate of bubble cap rectification column	133 days	171	None	Considerable flow	7	0.5	1-2
Carbon Tetrachloride, crude	Plate 19 of bubble cap rectification column, 3 plates above feed plate	133 days	176	None	Violent	5	0.4	1-2
Carbon Tetrachloride, 90%; Benzol, 10%-Kolene Solvent	Storage tank	40 days	Room	None	None	20	0.6	1-2
Carbon Tetrachloride, 90%; Benzol, 10%-Kolene Solvent	Bottom of still	38 days	287	None	By boiling	4	2	1.2
Cellulose acetate 10-15%, magnesium sulfate 2-5%, acetic acid 75-80%		133 days	140	Moderate	Moderate		1.5	2
Chlorinated Benzene	Top of still	137 days	280	None	Some	2	1	1
Chlorinated solvents, condensate and steam	Condenser	99 days	140-200			90	10	1-2
Chromic Acid, 3.4%, plus Sodium Sulfate	Cleaning tank	50 days	Room			90	8	1
Coal Tar (High Chloride Content)	Fractionating Column Top Middle Bottom	 154 days 154 days 154 days	 390 515 550	 None None None	 Some Some Some	 200 13 6	 6 1 3	 3 3 3
Coke Oven Gas, Raw	In gas stream ahead of final cooler	133 days	150	None	Some	28	2	1
Corn gluten and Sulfurous Acid	Gluten settler	840 hours	90			40	5	1-2
Corn syrup, pH 5.0	Syrup tank	528 hours	140			1	0.7	1-2
Corn syrup	Above liquid level in syrup mixing tank	114 days	170	In the air	Securely fastened to shell	2	0.4	1-2
Corn syrup	Below liquid level in syrup mixing tank	114 days	170	Open to air	Constant	1	0.2	1-2
Corn: glucose liquor 22° Be, pH 4-4 .5	Between plates and side of filter press	100 days	168-180	Moderate	4 gal./sq. ft./min.	10	3	1-2
Corn, gluten, plus 0.05% Sulfur Diox-Ide	Near middle of gluten settler	77 days	70-90	Slight	None	20	5	1-2
Corn sugar-dextrose; first sugar Massecuite, 40 Be, pH 4 due to HCl	On agitator arm of dextrose crystalizer	70 days	84-120	None	7'/min.	2	06	1-2
Diethanolamine water solution 11-15% containing 10-15 grams H_2S per gal.	Laboratory	483 days	228	None	50'/sec.	17	1.1	1
Ethyl Alcohol, 68% by vol.; Acetone, 30%; Methanol, 21%; balance air	In vapor space above carbon bed in activated carbon absorber	278 hours	69	Good	Practically none	50	3	1-2
Fatty acids; crude split Oleic and Stearicacids	In vapor in fatty acid still	3 weeks	440			730	10	2
	In liquid in fatty acid still	3 weeks	440			790	20	2
	Vacuum bubble tower between top tray & scum	2002 hours	425 to 600	Some		370	20	2
Fatty acids, crude	Vacuum bubble tower between top tray & feed tray	2002 hours	425 to 600	Some		390	30	2
	Vacuum bubble tower between trays 4 and 5	2002 hours	425 to 600	Some		180	10	2

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Carr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
Fatty acids, animal	Twitchell saponifer tank	38 days	Boiling			70	20	2
Fatty acids; concentrated mix from fish oils	Storage tank	130 days	200	None	None	60	8	2
Fatty acid vapors from fish oils	Vapor stream of fatty acid still	210 days	475		By vapor flow	140	10	2
Fertilizer: Ammonium nitrate and phosphate, potassium chloride, aqua ammonia, 45% salt concentration	Downstream from meter	29 days	107	Moderate	200'/min	170	7	4
Fertilizer, Commercial "5-10-15" chemical fertilizer	In contact with damp granules in storage	290 days	ATM	Some	None	10	3	1-2
Fish solubles condensed at a pH of 4.6	Near bottom of worse tank	170 days	90	Air free	60'/min.	4.9	1	1
Fish solubles condensed at a pH of 4.2	Bottom of work tank	105 days	90	Air free	40'/min.	2.7	0.2	1
Furfural, 25% and traces of acetic and formic acids and other organic compounds	Condenser head inlet	317 days	210	Air free	75-100'/sec		1.5	1
Gasoline, vapor of straight run (63° A.P.I.)	Lower section above y16 tray of stabilizer	6252 hours	375		95 P.S.I. press.	6	2	1-2
Gasoline, straight run (63° A.P.I.)	5' above bottom of re-flux accumulator	6252 hours	110		60 p.s.i. press.	3	2	1-2
Gasoline, straight run, with some HCI and H_2S	Top tray of bubble tow-er in topping unit	116 days	250-260	None	Rapid due to bubbling	50	10	1-2
Gasoline, cracked, with some HCI and H2S	Top tray of bubble tower in Donnelly cracking unit	116 days	400-415	None	Rapid due to bub bling	2	1	1-2
Gasoline, aviation	Base of column below packing in Stedman fractionating column	13 days	225	Slight	Vaporstream 25'/sec.	2	0.6	1-2 Dry during major portion of distilla-tion cycle, but steam present from 180-212 F. Specimens in col umn during 3 steamout periods totaling 30 hrs.; max. temp. 350 F. Balance of time samples exposed to air at 100 F. av-erage temperature
Glue, 5˙/0; water, 95J	Cooling tank	10 months	140-190	Unknown	None	4	.04	Immersed 1/3 of time, in air the balance. 1-2
Glutamic Acid, crude, pH 5.6	In vapors of evaporator	36 days	158	None	Considerable	17	8	1-2
Glutamic Acid and saturated solution of NaCl, pH 3.2	In liquid in crystallizer	28 days	77	Yes	Considerable	6	4	1-2
Glycerine, fed to evaporator	Feed tank	182 days	130				2	Cu-free 2 Ni-Resist
Glycerine soap lye with 10-12% Glyc-erme, 13-16% NaCl and Na_2SO_4, mud and water	Alkali treating tank	105 days	185	Some	Some	40	10	2
Glycerine salt (evaporated spent soap lye); concentrated Glycerine satu-rated with salt in suspension	in still	648 hours	320		Violent	80	10	2
Glycerine, concentrated, saturated with salt plus salt crystals	In vapor phase at-tached to head of still	2125 hours	300	None	Violent boiling un-der vacuum of 10 mm. Hg absolute pressure	80	10	2
Grapefruit juice	Laboratory	18 hours	Boiling	None	None	2340	20	3 hours only for C.I. 1-2
Hydrochloric Acid, 5% by vol.	Laboratory		60	Some	None	70	10	1
Hydrochloric Acid, 10% by vol.	Laboratory		60	Some	None	1220	9	1
Hydrochloric Acid, 25o by vol. I	Laboratory		60	Some	None	1220	20	3

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
Hydrochloric Acid, 1%	Laboratory		Room			200	6	1
Hydrochloric Acid, 2%	Laboratory		68			880	5	1
Hydrochloric Acid, 3.7%	Laboratory		68			5180	15	1
Hydrochloric Acid, 5%	Laboratory		Room			672	10	1
Hydrochloric Acid, 20%	Laboratory		Room			2240	12	1
Hydrochloric Acid gas made by volatilizing 31.5% Hydrochloric Acid	Hollow shaft leading to carbonizer	37 days	220	Some air enters with HCI		20	10	Flow of gas is intermittent-60, of 303 passed thru in 1 hour every 3}/4 his. 1 1 passed thru for short time after HCI passed thru
Hydrofluoric Acid, 10%	Laboratory	30 days	50-70			220	1	1
Hydrofluosilicic Acid, 6-9%, and Sodium Fluosilicate crystals containing 10-12%, water.	Storage tank and fluosilicate hopper	163 days	100 in hydrofluosilicic acid, atmospheric in sodium Fluosilicate hopper	Agitated with air	With air	160	6	135 days in hydro fluosilicic acid, 28 days in sodium Fluosilicate 1
Hydrofluosilicic Acid, 22%	In Wier box	94 days	145	None	Considerable	5520	4.8	Speed in acid 24 hrs. a day, altho high temp. and agitation exist- 1 ed only 8 hours a day. C.I. had to be removed end of 6 days
Hydrogen Sulfide, moist	Laboratory	7 days	200			70	10	1
Hydrogen Sulfide, 98%; balance air and N_2	Gas path of extraction unit	188 days	90	Good	By gas flow	3	2	1
Insecticide: Pesticide solutions used for spraying tomatoes consisting of Marsate wettable powder, Farzate wettable powder, tribasic copper sulfate, Zerlate wettable powder	Spray tank	420 days	60-100	None	Mechanical	3	0 8	1
Margarine	At waterline in margarine tank	38 days	Boiling and atmospheric			190	4	2
Meat juice extract; acidified extract of animal tissue, pH 4-5, organic solids conc'd from 0.5% to 40%, inorganis salts of Na and K as chlorides and phosphates 0.1% to 5% max. HCI for acidification	Laboratory	129.5 hours	120-180		Due to evaporation	50	5	1-2
Methyl Alcohol, crude	still	1927 hours	160	Away from air	Mild	12	4	1-2
Mining: Flue gas from combustion of Ohio strip mine coal-sulfur 2.5-4.5%	Unit air heater	197 days	300	20%	2000' min.	2.8	0.9	1
Monoethanolamine, in scrubbing of $C0_2$ from H_2	Stripping tower	100 days	180-220	Open to gas		8	4	1-2
Monoethanolamine Plus $C0_2$ and H_2S	Girbitol Stripper	270 days	230	None	Considerable	2	0.2	1-2
Naphtha, plus 15-30% of a mixture of Oleic, Lincleic and Abietic acids	At bottom of scrubber	196 days	Room to 570	None	None	2	0.2	2
Naphthalene, crude, plus Sulphuric Acid	Bottom of washer	10 days	185-203	Negligible	Mechanical Agitation	2140	450	Initial conc'n of acid : 93%, final: 60-75I
Naphthenic acids in distillate from South American petroleum (low velocity liquid phase)	Bottom primary fractionating column	174 days	500	None	Low liquid velocity	8	5	1-2
Naphthenic acids in heavy distillate from South American petroleum	Between trays 6 and 7 of second fractionating column	59 days	554	None	By flow	8	10	1-2
Nickel Plating solution	Wood tank	820 hours	75		None	8	4	1

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature ˚F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
oil, sour lube (2% Sulfuric Acid, 58% Hydrocarbons, 40% water)	Agitator	365 hours	100	None	None	160	20	1
Oil, condensate of light gas, non-condensible gases and steam	Condensate line	1176 hours	90-120			30	7	1-2
Oleic Acid	Red oil wash tank at water line	38 days	Boiling and atmospheric			30	1	2
Oleum, 15%	Immersed–Laboratory	30 days	70	None	None	0.1	1.4 Type 1 0.3 Type 3	Type 3 Preferred
Oleum, 15%	Immersed–Laboratory	7 days	500	None	None	5	15 Type 1 4 Type 3	Type 3 Preferred
Paper pulp with small amounts of $S0_2$, Cl_2, H2SO4, pH 4-4.5	Decker effluent	198 days				6	2	1-2
Paper stock with 0.15 g/l HCl and 0.02 g/l free Chlorine	Cylinder mold	91 days				180	20	1-2
Paper stock solution, 0.1 g/l free Chlorine, pH 2.3-2.5	Thickener vat	449 days					9	1-2
Paper: deckered Kraft stock screened and washed, pH 7.9	On agitator shaft of storage chest	98 days	46	Sligh	501/min.	6	3	1-2
Paper: Kraft digester fumes	Digester gas-off line	75 days	200	Vapors and air mix	Occasionally high	5	0.9	1-2
Paper: spent neutral sulphite. Tomahawk Liquor	In evaporator liquor	145 hours	134-233	Slight-Moderate	3'/sec.	67	6.4	1
Paper sulfite pulp, pH 6.5 previously treated with Calcium Bisulfite cooking liquor and containing Ligno sulfonic Acid	Head box	79 days	68	Negligible	75'/min.	4	2	1-2
Paper sulfite pulp, pH 5.5, previously treated with Calcium Bisulfite cooking liquor and containing Ligno sulfonic Acid	Head box of blow pit Oliver washer	82 days	68	Negligible	25'/min.	20	10	1-2
Paper sulfite pulp, pH 7.0, with residual Calcium Hypochlorite bleach liquor and Sodium Hydroxide	Head box	97 days	68	Negligible	75'/min.	10	3	1-2
Paper: “soft” sulfite stock from the drainer, pH 5.6; consistency 2%	On agitator shaft of stock chest	83 days	47	Moderate	50'/min.	20	7	Specimens out of the stock 50 of time. 1-2
Paper: Turpentine from Kraft Pulping (Pacific Northwest). Small amount of hydrogen sulfide, methyl mercaptan, dimethyl sulfide	Turpentine phase of decanter	97 days	150-200	Moderate	Flow rate 10-20 gal hour	2.3	0.8	1
Paper: groundwood and white water, treated with Cu Sulfate, Alum and Chloramine	Under bull screen	101 days	100	None	None	20	10	1-2
Paper: groundwood stock, consistency ½%	Groundwood screen stock spout, in solution	68 days	102	Practically None	4-51/sec.	30	10	1-2
Perch lorethylene vapors	Solvent recovery still	64 days	260	None	None	10	4	1-2
Petroleum: crude oil and H_2SO_4	Crude oil agitator	92 months	Atmospheric		Some	40	3	1
Petroleum: Coal tar base of Quinoline type, pH 8-9. Impurities-carbon and iacradine	Tank	185 days	100-200				0.1	3
Petroleum: Hydrocarbons containing traces of HCl and H_2S	Top head of primary distillation unit	453 days	250	Nil	Rapid	1.5	0.4	2
Petroleum: Hydrocarbons containing traces of HCl and H_2S	Above 20th tray in primary distillation unit	453 days	275	Nil	Rapid	2.5	0.1	2
Petroleum: Hydrocarbon stream containing 45 ppm phenols, 130 ppm chlorides and slight trace of sulfides	Primary column	430 days	250-320		1.2'/sec.	1.6	1	1
Petroleum: Ranger low S crude	Above highest baffle below lowest of 10 bubble trays	1701 hours	640		170 p.s.i. pressure	20	10	1-2
Petroleum: Overhead from crude oil fractionation, hydrogen sulfide and hydrochloric acid present	Crude distillation unit	128 days	200-300	None	1.3'/sec.	3	1.4	1

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iran	Ni-Resist Iron	
Petroleum: Overhead from crude oil fractionation, hydrogen sulfide and hydrochloric acid present	Crude distillation unit	128 days	80-100	None	High agi-Tation	2.6	0.3	1
Petroleum: Reduced Redwater crude oil and superheated steam; sulfur compounds and some naphthenic acids present	Vacuum unit	175 days	700		Continuous Agitation	0.9	0.4	1
Petroleum: Sour water containing some light flashed distillate and hydrogen sulfide	Vacuum flasher	309 days	130	None	Medium	3	0.2	2
Petroleum: Sodium sulfide and sulfonic acid derivatives	Vapor side of evapora-for in vapor and gas gas zone	84 days	140	Moderate	High at Start	0.4	0.1	1
Petroleum: Sour water, hydrogen sulfide and light hydrocarbons	Bottom of debutanizer overhead accumulator	568 days	120	Nil	Nil		0.5	1
Phenol, 5%	Laboratory		60	Some	None	8	9	2-3
Phenol, Amyl	Bottom of storage tank in vapors	106 days 106 days	200 200	Moderate Moderate	Slight Slight	14 5	10 4	1 1
Phosphoric Acid (tetra), concentrated	Laboratory		Varying	None		*	20	1
Phosphoric Acid, 80-90%, and oxidizing substance	In launder acid from precipitator	7-80 days	200			1690	20	1
Phosphoric Acid (tetra), concentrated, 83.5-84.5y, P_2O_o	Laboratory	48 hours	140	None	None	*	1.9	1
	Laboratory	48 hours	356	None	None	*	20	1
Phosphorus Molten	Molten storage	185 days	140	None	None	0.6	0.6	1
Pineapple juice	Laboratory	48 hours	188	Alternate Immersion	None	790	70	
Pineapple juice	Laboratory	48 hours	75	Alternate immersion	None	60	10	1-2
Potassium Aluminum Sulfate, 5%	Laboratory		60	Some	None	6	2	1
Potassium Aluminum Sulfate, 10%	Laboratory		60	Some	None	30	10	1
Potassium Aluminum Sulfate, .1%	Laboratory		60	Some	None	4	1	1-2
Potassium hydroxide 81%	Laboratory	68 hours	428				10	3
Potassium hydroxide 92%	Laboratory	36 hours	515				10	2
Protein hydrolyzate mixture containing hydrochloric acid to a pH of 1.5 + low concentration of $S0_2$	Laboratory	84 days	110	Some	Mild	34	9.5	1
Rosin: wood rosin and its derivatives	Vapor section of still	173 days	700	Good	By steam injection	580	10	52 runs of 8 hours each 1-2
Sewage sludge, activated	In aeration tank	481 days		Some		2	2	1-2
Sewage fumes, raw and untreated, 100% humidity, some H_2S, no Cl_2	In gas chamber	260 days	Atmospheric			20	6	1-2
Sewage	Sewage regulation chamber	190 days	Atmospheric	None	Some	18	5	1
Smelting: Flue gases from sulphate recovery furnace	Cottrell precipitation	170 days	295	Moderate	Consider-able	1.2	0.8	4
Smelting: Flue gases from sulphate recovery furnace	C. E. recovery boiler	189 days	310	Moderate	Consider-able	2.6	0.3	4
Soap: Reaction of fatty acid and sodium hydroxide to produce 50% free fatty acid and 50% sodium and aluminum soaps	Neutralization kettle	75 days	370	None	Agitator	56	4	
Soap: saponification of fats with Caustic Soda and graining with salt and brine	At top of settling cone	106 days	160-212	Some air in steam	By live Steam	10	0.1	2-3
Soap: Tallow, acidulated cottonseed and soybean oil soapstocks	Mixing tank	10.5 days	138	Air free	50'/min.	3.9	0.9	1
Sodium Bromide, concentrated from 22-47° Be	In boiling tank	265.5 days	Boiling			30	3	Tank was alternately full and empty 1-2
Sodium Carbonate, 5%	Laboratory		60	Some	None	No loss	No loss	1-2

* Ordinarily not satisfactory.

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Casl Iron	Ni-Resist Iron	
Sodium Carbonate, 10%	Laboratory		60	Some	None	No loss	No loss	1-2
Sodium Chloride, saturated, with steam and air	In graining pan	30 days	200			70	5	Alternately ex posed 1-2
Sodium Chloride, saturated	In salt grainer	60 days	ISO			2	0 4	1-2
Sodium Chloride, saturated brine and salt cake	In Oliver filter	145 days	200			20	2	1-2
Sodium Chloride	Salt brine tank	180 days	50	Consider-able	Some	10	3	1
Sodium Chloride, natural brine feed	Storage tank	221 days	80	Moderate	Some	2	1	1
Sodium Chloride, 14% NaCl, 16.7% $CaCl_2$,3.4% $MgCl_2$	Salt settler	215 days	157	None	Some	21	3	1
Sodium Chloride, 14% NaCl, 16.7% $CaCl_2$, 3.4% MgC12	Hot end of brine heater	215days	160	None	4'/sec.	26	3	1
Sodium Chloride, 45% NaCl. 18% $CaCl_2$, 3.2J 18/$MgCl_2$	Filter feed tank	215 days	130	Moderate	Some	13	3	1
Sodium Chloride Bittern, 9%, NaCl, 22% $CaCl_2$, 5% $MgCl_2$	Settler	221 days	128	Moderate	Some	33	4	1
Sodium Chloride Bittern, 6% NaCl, 18% $CaC1_2$, 10% $MgCl_2$	Heater	365 days	175	None	1500 gpm		2.5	1
Sodium and Potassium chlorides, saturated solution	In heating agitator– half immersed	31 days	120	Good	500" min. (theoretical)	20	3	1-2
Sodium Chloride, 18%, plus residual soap and .03% total Na_20, .003% free Na_20	In trough of filter press	65 days	140	Good	Good	70	1	1-2
Sodium Chloride brine plus sl. impuri-ties of $CaC0_3$, $CaS0_4$, & Na_2SO_4 pH 9.5	In vacuum evaporator A. Above liquid B. Below liquid	55 days 55 days	215 215	None None	Consider-able Consider-able	72 13	0.2 1	1-2 1-2
Sodium Chloride brine up to 50%, plus oxidizing materials from products of combustion of gas flame	In salt evaporator	329 hours	200	Some due to excess air entrain-ed with gases	Consider-able due to combustion gases pass-ing thru	240	20	1-2
Sodium Chlorite, 0.5%, Calcium Hy-pochlorite, direct chlorination with added Sulfuric Acid to adjust pH to 4.5	In Bellmer bleach heater	31 days	97	For ¼ of time	60'/min.	10	7	34.3 hrs. to .5% Sodium chlorite. 138 firs. to sera lion-571.7 hrs. to combined chlori nation and hypo pochlorite treat ments 1
Sodium Chlorite: 1% Caustic Soda and 0.02% Textore	Under grating of bleaching keir	23 days	215	None	Some	7	0.1	Actual boiling time about 12 hrs. day, remainder of time consumed in cool ing and reloading 1-2
Sodium Cyanide solution for heavy metals recovery	In overflow tank	60 days	136.4	Slight	By flow	2	0.3	1-2
Sodium Cyanide solution with Sodium Chloride	In solution discharge from Traylor coolers	30 days	154	Good	180 gal. min.	0.9	0.2	1-2
Sodium Cyanide 10 oz./gal. plus So-dium Hydroxide 10 oz./gal.	In plating tank	49 days	100-110		Caused by work sus-pended in bath	2	3	1-2
Sodium Hydroxide 30% plus heavy concentration of suspended salt	Salt tank	82 days	180	Moderate	Moderate	6.3	0.1	4
Sodium Hydroxide, 50%	In caustic evaporator	92 days			None		0.7	2-3
Sodium Hydroxide, 50%	In distributor box to settler	32 days	Hot			20	4	2-3
Sodium Hydroxide, 50%,	In evaporator	38 days	Hot			30	6	2-3
Sodium Hydroxide, 70%	In high concentration evaporator	94 days	Hot			40	20	125 firs. in 70% caustic, remain der time in 50% 2-3

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
Sodium Hydroxide (Anhydrous)	In flaker pan	96 days	700	None	Some	510	13	3
Sodium and Potassium Hydroxide each 90%	In flaker pan	170 hours 118 NaOH 52 KOH	700	Some	Continuous overflow & return	500	13	3
Sodium Hydroxide, 75%	Storage tank between vacuum evaporator and finishing pots	35 days	275			70	4	2-3
Sodium Hydroxide and dissolved silicates in production of metal cleaner	In Dopp kettle	32 days	120	None	None	30	5	2-3
Sodium Metasilicate	In evaporator in intermittent contact with liquor	6 weeks	230			20	0.4	1-2
Sodium Phenolate, with 20% (by vol.) tar acids. Total alkalinity of 20% by wt. NaOH	In phenol tower	329 days	248	None		2	0.7	2
Sodium Phosphate, 5%	Laboratory		60	Some	None	0.4	0.6	1-2
Sodium Sulfite and Sodium Bicarbonate, pH 7.5	In storage tank	28 days	75.2	None	None	1	09	1-2
Sodium Tetraborate 2.5 g/l; 22 g/l Sodium Carbonate; 25 g/l Sodium Chloride	In crystallizer	108 days	86-212	Slight		20	1	1-2
Soybean meal; air, steam, and vapors from hot, moist expeller	In cooling conveyor	800 hours	168	Good	By steam flow	10	5	1-2
Soybean meal; air, steam and vapors from hot, moist raw extracted	In vent stack of elevator leg	675 hours	156	Good	By gas flow	40	20	1-2
Stannic Chloride: crude liquid with some free Chlorine	In still	432 hours	220-240	Some	Some	40	20	1-2
Starch liquor with Chlorine	In starch tub	184 days				5	1	1-2
Steam and hot water with other reagents picked up during vat aging of printed goods	In steam space of vat ager	268 days	212	in the steam		4	1	1-2
Steam	In a nipple expanded from high pressure steam line	31 days	350	Good	120 lb. pressure	2	0.7	2
Steam condensate with dissolved 0 and CO_2	In condensate return line	30 days	180	Good	By flow	2	04	1-2
Steam condensate and cooling water	In nipples expanded from steam lines	30 days	60-200	Good	By flow	40	20	1-2
Sugar liquors	In sugar tank	280 days				2	0.8	1-2
Sugar syrup	In syrup tank	280 days		Some	Some	1	0.8	1-2
Sugar liquors	In glucose pan	652 hours				0.9	1	1-2
Sugar liquors	In liquor trough	652 hours				8	3	1-2
Sugar juice: hot cane before clarification	In Corr thickener	92 days	180	Good	Good	1	0.4	1-2
Sugar cane juice, raw	In discharge line	92 days	Atmospheric	Good	high	6	1	1-2
Sugar cane juice, clarified: also subject to cleaning methods with 5% Caustic and 5% Hydrochloric Acid	In evaporator	55 days	150-180	None	Good	240	10	1-2
Sugar waste water	In Char filter waste trough	217 days	176	None	17,000-25,-000 gal./hr	20	10	1-2
Sugar sweet water before 10% solids evaporation;	In storage tank	320 hours	170	None	By flow	2	0.9	1-2
Sugar juice, thin: 14.1 Brix and 8.4; 13.1% pH sugar and 1.0% non-sugar	In thin juice tank	60 days	197	Slight	By flow	9	3	1-2
Sugar juice, thin beet, after sulfitation; 10.4 Brix and pH 7.9; purity 89.9	In box shunted from main pipeline	49 days	177	None	Slow but continuous flow	30	20	1-2
Sugar (beet); second carbonation juice; Brix 11.0; alkalinity 0.015; pH 8.8; purity 89.8	In carbonation tank	74 days	195	None	Continuous gentle flow	10	2	1-2

* Consult with Inca for specific corrosion rates for the various Types of Ni-Resist irons.

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iran	Ni-Resist Iron	
Sugar (beet) diffusion juice in processing; pH 6.8; purity 86.1; Brix 12.5	In measuring tank	87 days	103	Alternately	Intermittent gentle flow	9	10	1-2
Sulfate black liquor	Under screen plates in diffuser	349 days		None	None	10	1	1-2
Sulfate black liquor	In receiving tank	90 days	156	None	5-10'/min.	20		1-2
Sulfate black liquor	In storage tank	92 days	195	Practically none	None	10	8	1-2
Sulfate black liquor	In storage tank	39 days	200	In air part of time	Practically none	20	10	1-2
Sulfate black liquor	In secondary washer	32 days	137	Practically none	Practically none	20	1	1-2
Sulfate green liquor	In distribution box	60 days	200	Slight	Fairly rapid flow	30	6	1-2
Sulfonated animal and vegetable oils made alternately acid with 93% H_2S0_4, and alkaline with 10%, caustic	In neutralization and wash tank	60 days	104	None	Commercial practice is to stir	190	5	1
Sulfonated oil; mixture of animal and vegetable oils with 93% H_2SO_4	In sulfonator tank	70 days	77-104	None	Commercial practice is to stir	180	5	1
Sulfonated oils with 66° Be H_2S0_4, followed by washing with Glauber's Salt and neutralization with Caustic Soda	In sulfonator	40 batches (1 year)	212	Good	Good	*	5	37 sulfonations of castor oil, 2 sulfo nations tea seed oil, 1 sulfonation of olive oil. Figures = in./100 batches. 1
Sulfonated oils with dilute H_2SO_4	In wash tank	40 days	104		Medium	40	20	1
Sulfur, molten	Laboratory	20 hours	260	Partial admission of air	None	20	20	1
Sulfur, molten	Laboratory	20 hours	260	Partial admission of air	None	8	7	Partial immer sion 1
Sulfur, molten	Laboratory	4 days	260	None	None	0.8	5	1
	Laboratory	4 days	500	None	None	30	30	1
Sulfur, molten	Laboratory	2 days	835	None	None	400	590	
Sulfur, molten, plus air and moisture	In pipeline of a sulfur mine	11 days	305	Yes	Violent	55	13	1
Sulfur Chloride vapors, 98% S_2Cl_2	Below bottom prate of bubble cap column	133 days	257	None, 3-5u pressure	0.5'/sec. vapor velocity	160	1	2-3
Sulfur Chloride, 98.3%; Carbon Tetrachloride, 013%; Iron as $FeCl_2$ 0.1%	In reboilerforrectification column	133 days	280	None	By boiling	130	2	2-3
Sulfuric Acid, 5%	Laboratory	20 hours	86	None	None	*	20	1
Sulfuric Acid, 10%	Laboratory	20 hours	86	None	None	*	20	1
Sulfuric Acid, 80%	Laboratory	20 hours	86	None	None		20	1
	Laboratory	20 hours	86	None	15.5'/min.		20	1
Sulfuric Acid, 96%.	Laboratory	25 days	Room	None	None	4	5	1
Sulfuric Acid and oils	In oil sulfonator	8 batches			Stirred	230	3	Ins./100 batches 1
Sulfuric Acid, 25% and acid sludge	In discharge line	1326 hours	140		Forced flow	Completely destroyed	8	1
Sulfuric Acid 66° Be, plus various amounts of Nitrous Acid generated by continuous addition of Sodium Nitrate	In dye developing tank	9 days	175	Slight	Slight	1720		1
Sulfuric Acid, 72%, Polymer Gasoline, Butane and Butylenes	In gasoline tower	237 days	175		Due to hubble caps	70	20	1
Syrup, soft; the mother liquor separated from crystallized soft sugar	In "soft syrup" tank	217 days	140	Good	1550 gals./hour	5	0.1	1-2

* Ordinarily not satisfactory.

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Corr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
Tanning solutions: Tannin extract from chestnut wood	In evaporator	24 days	212		Continual ebullition	220	20	1-2
Tar (coal)	At top of still	5 months	700			10	9	1-2
	At center of still	5 months	700			10	9	1-2
	At bottom of still	5 months	700			8	6	1-2
Tar Acid (coal)	In vapors in still In liquid in still	1248 hours 1248 hours	260 260	In vapors None	None None	0.8 40	004 5	1-2 1-2
Tar (coal)	In vapors in still In liquid in still	1052 hours 1052 hours	550 600	In vapors None	None None	2 3	0.4 0.8	1-2 1-2
Tar (coal), complex organic constituents of	In still	10 days		430	Good	80	9	1-2
Tomato juice	Laboratory		125		Some	110	20	2
Vinegar syrup, sweet, with 2% Acetic Acid, 3% Sodium Chloride, 35% sugar	In kettle	1 hour, 55 minutes	Boiling			340	015	2
Vinegar, sweet	Storage tank	40 days	63-212				0006	2
Water: Acid, mine, containing iron and copper salts leached from sulfide ore	Mine shaft	187 days	Atmos-phere			6	1	2
Water, brackish East River, N.Y.C.	Water box of Steam Power Plant	334 days	54	Yes	High	10	2	1
Water, brackish Harlem River, N.Y.C.	Water box of Steam Power Plant	197 days	55	Yes	0.8 1/sec.	10	4	1
Water, cooling tower at pH 8.0-8.5 as obtained from Syracuse water sup ply treated with algicide, oakite sani- tizer #1 and aerated	Cooling tower basin	232 days	45-88	Extensive	1'/sec.	42	1 3	1
Water, distilled	Laboratory		60	Some	None	10	0.6	1-2
Water, fresh, pH 8.5 (185 p.p.m. CaC02)	In discharge from cooling tower	23 days	85	80% sat-urated	Some	30	20	1-2
Water, salt, from oil wells	In salt water pit	217 days	60	Slight	By flow	20	1	1-2
Water, sea	On screens in rotating screen house	394 days	Atmos-pheric	Screens moving in and out of water	Good	10	2	1-2
Water, sea	Velocity testing apparatus	60 days	86°F.	Consider-able	27 ft./sec.	176	8	1
Water, sea	Intake flume	740 days	ATM	Consider-able	5 ft./sec.	50	2	2
Water, sea	In condenser	58 days	158-176		By flow	40	10	1-2
Water, steep (0.070% H2SO3)	In germ separator	184 days				30	5	1-2
Water, steep, with 0.05°% $C0_2$ and 0.5-1.0% Lactic Acid, pH 3.5-4.5	In steep water evap-orator	40 days	150	Moderate	By boiling	70	20	1-2
Water, steep, vapors with 0.05°7 S02 and 0.5-1.0% Lactic Acid, pH 3.5-4.5	In steep water evap-orator	24 days	160	Liquor go-ing to pan sat'd with air	20-50'/sec.	40	10	1-2
Water, steep	In circulating tank	107 days	125-135	None	None	10	5	1-2
Wheat starch, water, S02 and Dowi cide, pH varied from 2.2 to 3.8	Drum dryer	68 days	320-340	Slight	Slight	45	14	1
Whiskey slop, thick	In tank	104 days, 6 days,'wk,	Near boil-ing	None	None	50	10	89 days actual operation 1-2
Whiskey slop, thin	In tank	104 days, 6 days/ wk	Near boil-ing	None	None	10	7	89 days actual operation 1-2
Whiskey mash	In beer still	103 days		Exposed in still	Due to movement of liquid and vapors	110	20	88 days actua operation 1-2
Whiskey mash	In open fermenter	103 days	65-75	None	None	1 40	3	1-2

Corrosive Medium	Location of Test Specimens	Duration of Test	Temperature °F	Aeration	Velocity	Average Carr. Rates Mils per year		Type Ni-Resist Iron Preferred
						Cast Iron	Ni-Resist Iron	
Whiskey slap, thin	In tank	3 months	150-220	Aerated as passed over screen but not in tank		20	4	1-2
Whiskey slop, thin	At outlet from still in screening unit	3 months	210-225	Complete	130'/min.	10	7	1-2
Whiskey slop, thin; concentrated 25% solids, 5% Lactic Acid	In reserve tank	90 days	220			20	2	1-2
Whiskey slap, thin	In settling tank	3 months	Varying	None	None	20	4	1-2
Whiskey slop	In slop outlet	3 months	Hot	None	None	20	2	I-2
Whiskey slop, thin	In settling tank	1 month		None	None	30	4	1-2
Whiskey slap, thin	In tank	5 weeks		None	None	40	2	1-2
Wine, sherry	In cooker	7-15 days	110		Wine circulated	*	2	2
Wine, sherry	In cooker	7-15 days	135			*	8	2
Zinc, molten	Laboratory; half immersed	36 hours	925-950			42700	23900	
Zinc; return electrolyte from electrolytic cells	In acid heating cell	7 days	140	None	50 gal./min	Completely dissolved	380	
Zinc Chloride, 66%, and 20% Ammonium Chloride	Laboratory	2 hours	182-204	None	None	680	20	1-2
Zinc Chloride, 85y,, and Gasoline vapors	In Lachman tower		380			6	1	1-2
Zinc Chloride, 80%, and Sodium Dichromate, 20%	In salt cylinder	144 days	140	None	None	4	0.3	1-2

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