Quantification of Delta Ferrite in Austenitic Stainless Steel Cast in Investments Shell Moulds

[1]P. Laxminarayana and A. Chennakesava Reddy[2]

[1]Professor, Department of Mechanical Engineering, Osmania University, Hyderabad, India
[2]Professor, Department of Mechanical Engineering, JNT University, Hyderabad, India
dr_acreddy@yahoo.com

Abstract: The effects of chemical composition and solidification on the delta ferrite formation in austenitic stainless steels have been investigated. The austenitic stainless steels were cast in investment shell moulds. The quantity of delta ferrite was powerfully affected by the steel chemical composition, but less affected by the cooling rate. The delta ferrite was found to be higher in the AISI 316 stainless steel than that in the AISI 3o4 stainless steel.

Keywords: Investment casting, AISI 304 stainless steel, AISI 316 stainless steel, colloidal silica binder, alumina, delta ferrite.

1. INTRODUCTION

The amount of delta ferrite formed in austenite stainless steels depends mainly on chemical composition and on the cooling rate during solidification. The important austenite stabilizer is nickel. Also, during the solidification of austenite stainless steel, a mushy zone is formed at the solidification front [1]. Based on Schaeffler diagram which divides the alloying elements into ferrite and austenite stabilizers, the amount of delta ferrite can be determined [2]. The materials used to build the investment shell mould, especially binders and refractories, play a vital role in the production of quality castings [3-9]. Using different refractory filler materials can affect the ability of the shell mould to absorb heat and maintain a critical thermal gradient.

The present work was to investigate the effects of the chemical composition and the cooling rate on the formation of delta ferrite in the austenite stainless steel cast in the investment shell moulds.

2. MATERIALS METHODS

The chemical compositions of austenite stainless steels are given in table 1. In the present work, AISI 304 and AISI 316 stainless steels were cast in the investment shell moulds. The wax pattern assembly to fabricate test coupons is shown in figure 1. The colloidal silica binder was used to fabricate the investment shell moulds from alumina as reinforced filler material. The silica content in the colloidal silica binder was 30%. Two grades (primary and backup sands) of stuccoing sand were employed in the present investigation. Finer grade silica sand having AFS grain fineness number 120 was employed for primary coats. This is synthetic sand. This sand was used for first two coats, called prime coats to get good surface finish and every detail of the wax pattern. Coarser grade sand having AFS grain fineness number 42 was employed for back up coats. This is river sand. The backup sand was employed to develop more thickness to the shell walls with minimum coats. The thickness of shell moulds were 10 mm. After all coats, the shells were air dried for 24 hours. Two shells of each treatment were made. Type R (Pt-13%Rh, Pt) thermocouples were inserted into the mold cavity in contact with the steel to measure the cooling curves at different positions during solidification. The austenite stainless steels were melted in an induction furnace under vacuum. The liquid alloy was gravity poured into the pre-heated investment shell moulds. The shell moulds were knocked off by hand hammer after solidification of the molten (figure 1). The castings were cleaned with soft brush and visually inspected for pins and projections [10-20].

Table 1: Chemical composition of Ni-base super alloy

Element	Ni	Cr	Co	Mo	C	Ti	Mn	Si	P	Cu	Nb	Al	W	V	Fe
AISI 304	9.19	18.9	0.083	0.225	0.076	0.0044	0.932	0.869	0.042	0.12	0.006	0.001	0.018	0.046	Balance
AISI 316	9.62	17.7	0.086	0.220	0.038	0.0048	0.998	1.100	0.030	0.14	0.008	0.0012	0.014	0.048	Balance

Delta ferrite content was determined with a Fischer feritscope model MP30E and the ferrite morphology was studied by optical metalography. The chemical composition (metallic elements) of the phases (ferrite and austenite) was measured by X-ray microanalysis using an energy-dispersive spectrometer (EDS) attached to a scanning electron microscope. The metallographic

preparation for both the optical and scanning electron microscopy consisted of grinding, followed by mechanical polishing with diamond paste, and finally etching with aquaregia (100 ml HCl + 3 ml HNO_3 + 100 ml methyl alcohol).

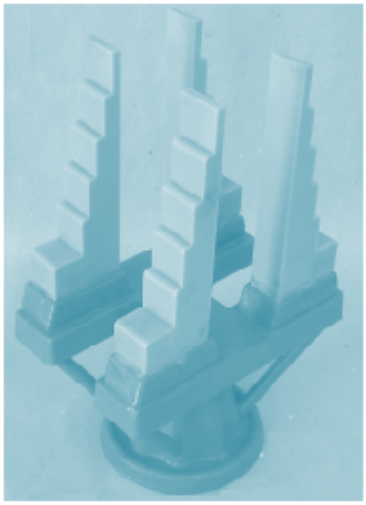

Figure 1: Assembled wax tree pattern.

3. RESULTS AND DISCUSSION

Figure 2 shows the delta ferrite distribution in different sections of the test coupon. Although the influence of the cooling rate was weak a slight decrease in delta ferrite fraction with increasing cooling rate (i.e. decreasing section thickness) is observed. The delta ferrite in AISI 316 stainless steel is higher than that in the AISI 304 stainless steel as shown in figure 2.

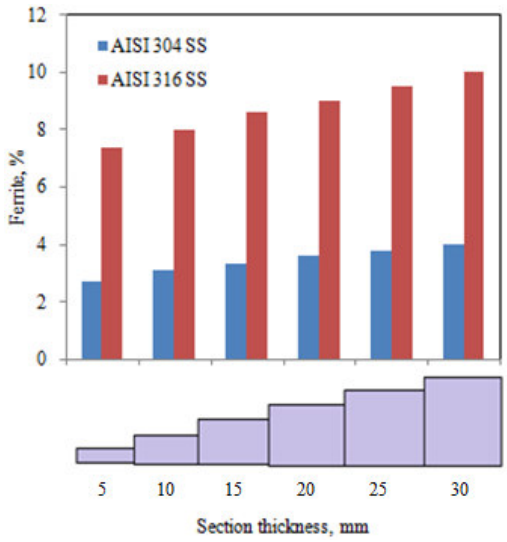

Figure 2: Ferrite content in different sections of test coupon.

The criteria for solidification modes in the austenite stainless steel are as follows:
Austenite mode: L→L + γ→ γ
Austenite + Ferrite mode: L→L + γ→L + γ + δ→γ + δ
Ferrite + Austenite mode: L→L + δ→L + δ + γ →γ + δ
where L is the liquid phase, γ is austenite, and δ is ferrite.

The solidification mode in the investment shell moulds was found to be Ferrite + Austenite mode. The EDS analysis (figure 3) and microstructure (figure 4) confirms the (Ferrite + Austenite) solidification mode with ferrite as the leading phase and formation of interdendritic austenite at the expense of ferrite dendrites during solidification. After solidification, during cooling to

room temperature, the ferrite was further consumed to form austenite. In AISI 304 stainless steel, the morphology of delta ferrite is of isolated cores; while it is of continuous network in AISI 316 stainless steel.

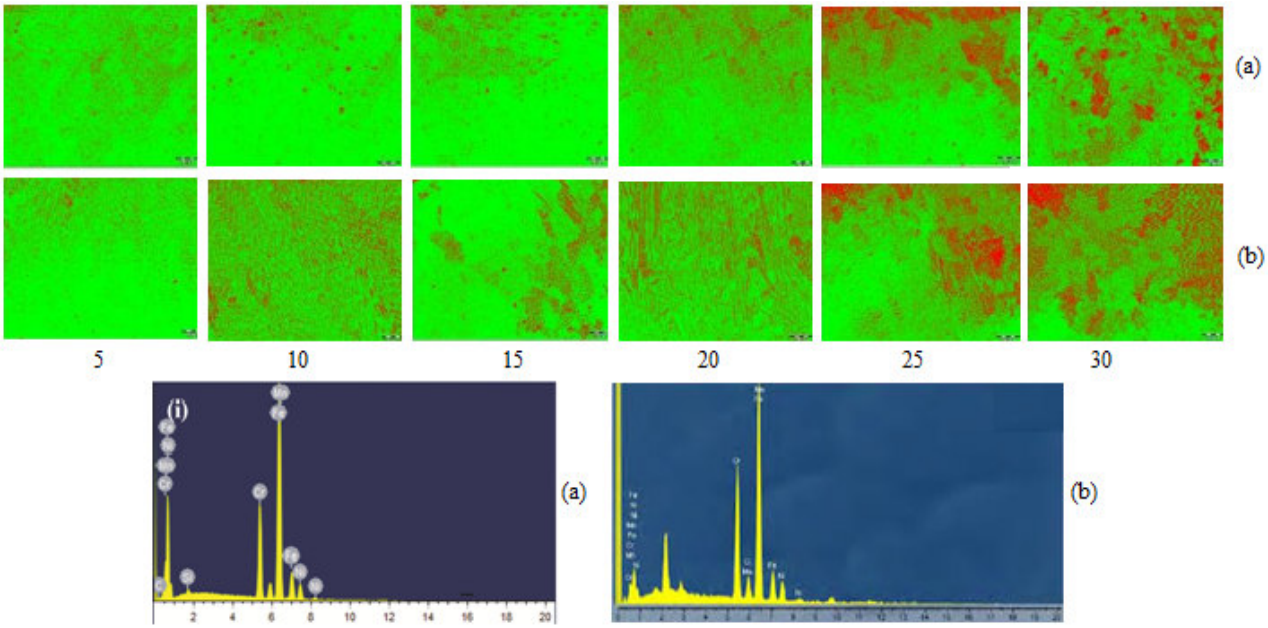

Figure 3: Formation of ferrite dendrites during solidification in austenite stainless steels: (a) AISI 304 SS and (b) AISI 316 SS.

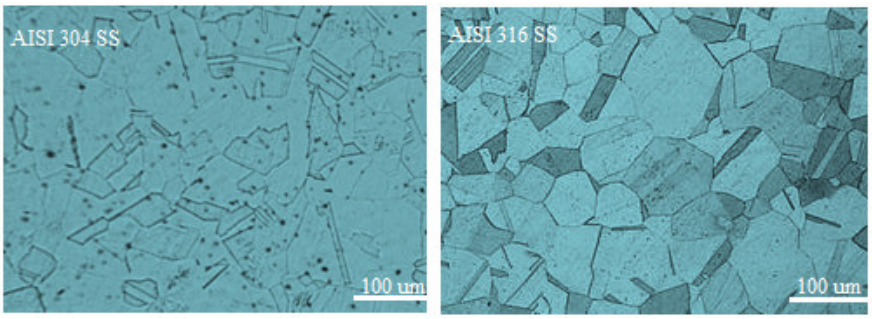

Figure 4: Microstructure of austenite stainless steels (a) AISI 304 SS and (b) AISI 316 SS.

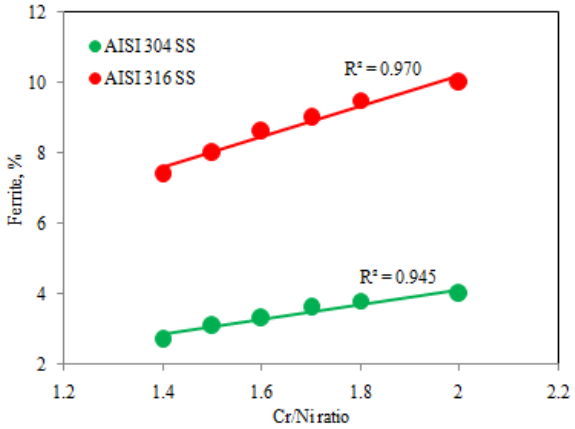

Figure 5: Delta ferrite content as a function of the ratio of chromium to nickel equivalent.

The influence of steel chemical composition on the delta ferrite content was significant. Using suggested formulas for nickel and chromium equivalents, the correlation between the ferrite content and the ratio of chromium to nickel equivalents were

examined (figure 5). For predicting delta ferrite content, correlation coefficients were computed based on Schoefer which is recommended by the ASTM A800 Standard [2].

4. CONCLUSIONS

The important conclusions drawn from the present work are as follows:

- the quantity of delta ferrite was strongly affected by the steel chemical composition, but less affected by the cooling rate
- The predicted the delta ferrite content was in good agreement with ASTM 800 standard
- The solidification mode was found to be $L \rightarrow L + \delta \rightarrow L + \delta + \gamma \rightarrow \gamma + \delta$.

REFERENCES

1. H. Fredriksson, U. Akerlind. Materials processing during casting, Wiley, 1st edition edition, 2006.
2. ASTM 800/A 800M-01, Standard practice for steel casting, austenitic alloy, estimating ferrite content thereof, American Society for Testing and Material.
3. J. Doskar, J. Gabriel, How dip-coat materials affect ceramic investment shells –Part I. Foundry, 95, 1967, p. 146.
4. A. Chennakesava Reddy, and V.S.R. Murti, Studies on Lost-Wax Process Using Silox Binder, X-ISME Conference on Mechanical Engineering, New Delhi, 09-11th December, 1996, pp.82 – 86.
5. A. Chennakesava Reddy, Characterization of ceramic shells fabricated using yttria as reinforcing filler, National Conference on Advanced Materials and Manufacturing Technologies, Hyderabad, 5-7th December 1997, pp.125-129.
6. A. Chennakesava Reddy, Characterization of ceramic shells using rutile (titania) as reinforcing filler at casting temperature, National Conference on Advanced Materials and Manufacturing Technologies, Hyderabad, 5-7th December 1997, pp. 130-134.
7. A. Chennakesava Reddy, V.S.R. Murti, and S. Sundararajan, Development of a Ceramic Moulding Process from Coal Flyash for Investment Casting, 18th AIMTDR Conference, Kharagpur, 21-23rd December 1998, pp.118-122.
8. P. Martin Jebaraj and A. Chennakesava Reddy, Prediction of thermal shock of ceramic shells using fused silica as reinforcing filler at casting conditions, National Conference on Advances in Production Technology, Bangalore, 7-9 February 1998, pp.52-56. 3
9. H.B. Niranjan and A. Chennakesava Reddy, Investment shell moulds using graphite filler to prevent dimensional instability and metal-mould reaction of Ti-alloy castings, National Conference on Advances in Production Technology, Bangalore, 7-9 February 1998, pp. 57-62.
10. A. Chennakesava Reddy, K.M. Babu, P.M. Jebaraj and M.P. Chowdaiah, Accelerator for faster investment shell making and its effect on the properties of investment moulds, Indian Foundry Journal, 41,1995, pp.03-08.
11. A. Chennakesava Reddy, H.B. Niranjan and A.R.V. Murti, Optimization of investment shell mould using colloidal silica binder, Indian Journal of Engineering & Materials, 3, 1996, pp.180-184.
12. A. Chennakesava Reddy, V.S.R.Murti and S. Sundararajan, Regression modeling approach for the analysis of investment shell moulds from coal-flyash, Foundry Journal, 9, 1997, pp.36-40.
13. A. Chennakesava Reddy, V.S.R. Murti, S. Sundararajan, Some aspects of reducing sediments rate of refractory fillers in the investment casting process, Journal of Engineering Advances, 10, 1998, pp.61-63.
14. A. Chennakesava Reddy, V.S.R. Murti and S. Sundararajan, Control factor design of investment shell mould from coal flyash by Taguchi method, Indian Foundry Journal, 45, 1999, pp. 93-98.
15. A. Chennakesava Reddy, V.S.R.Murti and P.M.Jebaraj, A new technique for measurement of the strength of ceramic shells in the precision casting process, Journal of Testing and Evaluation, 28, 2000, pp. 224-226.
16. A. Chennakesava Reddy, V.S.R. Murti and S. Sundararajan, Bonding mechanism in the coal-flyash ceramic shells, Indian Foundry Journal, 47, 2001, pp.21-25.
17. A. Chennakesava Reddy, S. Sundara Rajan and V.S.R. Murti, Dampening of Noise Parameters for Developing Ceramic Shell Process from Coal Flyash by Taguchi Method, CEMILAC Conference, Ministry of Defence, India, 20-21st August, 1999, pp.91-95.
18. Ch. Rajana and A. Chennakesava Reddy, Interfacial Reaction between Zirconium Alloy and Zirconia Ceramic Shell Mold, National Conference on Advanced Materials and Manufacturing Technologies, Hyderabad, 18-20 March 2000, pp. 212-217.
19. S. Madhav Reddy and A. Chennakesava Reddy, Interfacial Reaction between Magnesium Alloy and magnesia Ceramic Shell Mold, National Conference on Advanced Materials and Manufacturing Technologies, Hyderabad, 18-20 March 2000, pp. 218-222.
20. A. Chennakesava Reddy, Development of Alumina Investment Shell Molds to Cast 7075 Al-Alloy, National Conference on Advances in Manufacturing Technologies (AMT-2001), Pune, 9-10 March 2001, pp. 102-104.
21. A. Chennakesava Reddy, Thermo-Physical Properties of Fused Silica Investment Shell Moulds at Preheat Conditions of Steel Casting, National Conference on Advanced Materials and Manufacturing Techniques, Hyderabad, 8-9th March 2004, pp.342-346.
22. A. Chennakesava Reddy, Structure and Morphology of Recycled Iron-Rich Al-Si Alloys Cast in Thin-Walled Investment Shell Moulds, National Conference on Advanced Materials and Manufacturing Techniques, Hyderabad, 8-9th March 2004, pp. 347-349.
23. A. Chennakesava Reddy, Microstructure and Mechanical Properties of AA2219 Alloy Turbine Impeller Manufactured by Investment Casting, National Conference on Computer Applications in mechanical Engineering, Anantapur, 21st December, 2005, pp. 321-323.
24. A. Chennakesava Reddy, Impact of Boron Coated Investment Shell Moulds on Surface Modification of Hypoeutectic Al-Si Alloys, National Conference on Computer Applications in mechanical Engineering, Anantapur, 21st December 2005, pp. 324-326.