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SHORT COMMUNICATION

Effect of modification melt treatment and chilling on eutectic arrest temperature and time during solidification of A357 alloy

K. N. Prabhu* **and S. Hegde**

Thermal analysis technique has been recognised as an efficient non-destructive tool to assess the degree of modification in Al–Si alloys. Apart from chemical modification, chilling refines the microstructure. This is particularly significant as majority of Al–Si alloys are cast in metallic moulds. In the present study, the interaction between chilling and modification melt treatment is investigated to assess their effect on thermal analysis parameters using computer aided cooling curve analysis. For modified alloys, the depression of the eutectic arrest temperature was significant at higher cooling rates. The eutectic arrest temperature and time were correlated with the cooling rate using a power law. High cooling regime in thermal analysis plots was attributed to the combined effect of chilling and modification melt treatment on heat transfer.

Keywords: Modification, Chilling, Thermal analysis, Cooling rate

Introduction

Aluminium alloy castings are widely used in automobile, aerospace and other applications because of their high strength/weight ratio. Al–Si alloys exhibit good castability and corrosion resistance in addition to the high strength/weight ratio. However, the pursuit of high quality castings with consistent mechanical properties has lead to improvements in processing of the alloy, including grain refinement, modification and precipitation heat treatment, etc. It is a well known fact that mechanical properties of Al–Si alloys are strongly related to the size, shape and distribution of eutectic Si present in the microstructure.[1,2] The eutectic silicon morphology, dendrite arm spacing, grain size, etc. play a vital role when the alloy is put into specific use. In order to improve mechanical properties, these alloys are generally subjected to modification melt treatment, which transforms the acicular silicon morphology to a fibrous one resulting in a noticeable improvement in elongation and strength. Sodium and strontium are the common modifiers in use. Apart from chemical modification, chilling plays an important role in the refinement of the metallurgical microstructure. This is particularly significant as majority of Al–Si alloys are cast in permanent or metallic moulds rather than in sand moulds.

Conventionally, the degree of modification is assessed after pouring by microscopic examination of solidified castings. This is time consuming, and the melt quality may deteriorate after the sample has been taken. In contrast, the thermal analysis technique has been recognised as an efficient non-destructive tool to assess the degree of modification in Al–Si alloys.[3–7] The technique monitors the temperature changes in a sample as it cools through phase transformation intervals and is usually represented by a temperature–time cooling curve. Thermal analysis technique is generally carried out in standard cups and is accompanied by low cooling rates. Solidification in metallic moulds involves high cooling rates, and modification is sensitive to cooling rate. Thermal analysis parameters estimated at lower cooling rates may be significantly different at high cooling rates associated with die castings. A review of the literature suggests that the modification melt treatment is associated with the depression of the eutectic arrest temperature and significantly alters other thermal analysis parameters like the degree of undercooling, eutectic arrest time, etc.[8–10]

Hypoeutectic Al–Si alloy A357 was selected as the casting material in the present investigation. Metallic dies have higher thermal conductivity k than sand moulds and are extensively used in die casting industry. Even in sand castings, the moulds are instrumented with metallic chills to promote directional solidification. The objective of the present paper was to study the effect of chilling and modification on thermal analysis parameters. Copper having high thermal conductivity (383 W m^{-1} K^{-1}) and type 304 stainless steel having a low thermal conductivity (15 W m^{-1} K^{-1}) are used as mould materials.

Experimental

The composition of the A357 alloy used in the present investigations is Al–6·86Si–0·53Mg–0·12Fe–0·03Zn–0·14Ti (wt-%).

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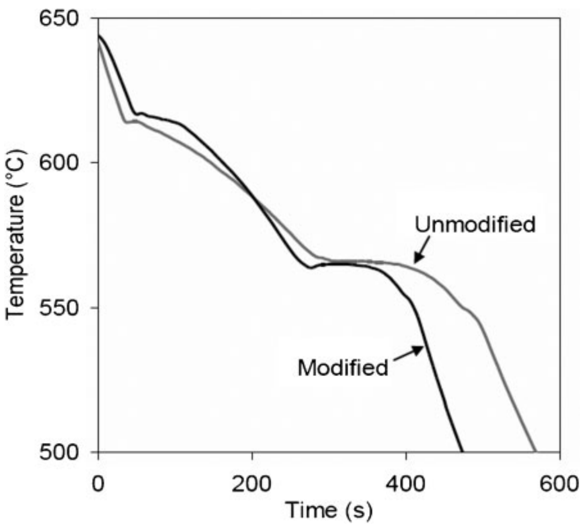
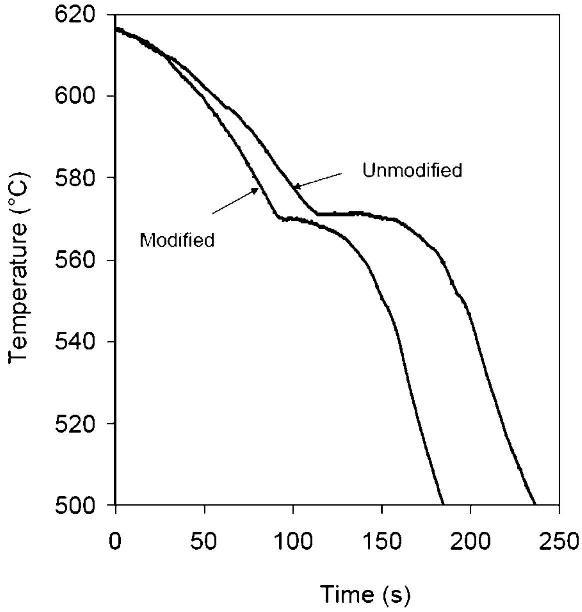


1 Cooling curves for alloy A357 solidified in clay crucible (unmodified and Na modified)



2 Cooling curve for alloy A357 solidified in clay crucible (unmodified and Sr modified)

About 750 g of the alloy was melted in a resistance heating furnace using a graphite crucible. The melt was degassed at $\sim$700°C using hexachloroethane degassing tablets. After degassing, a predetermined quantity of modifier was added to the molten alloy. Two types of modifier were used. With metallic sodium, 0·01% of modifier was added to the melt at a temperature of 720°C and held for 10 min to get complete modification. For modification with Sr, an appropriate quantity of Al10Sr master alloy was added to the melt to ensure that the concentration of Sr is at $\sim$0·05% in the melt. The master alloy was added at 780°C and held for 20 min to get effective modification. Experiments were carried out with unmodified and modified alloy subjected to air cooling in a crucible. The melt was poured into moulds. Copper and stainless steel cylindrical moulds were used to achieve different cooling rates in the solidifying alloy. The moulds used were of 5 and 30 mm internal diameters and 120 mm height. The thickness L of the mould was 30 mm in each case. The thermal resistances L/k offered by copper and stainless moulds were $7{\cdot}83\times10^{-5}$ and $0{\cdot}002$ m K W^{-1} respectively. The significant difference in thermal resistance of the two mould materials is sufficient to introduce differential cooling rates in castings.

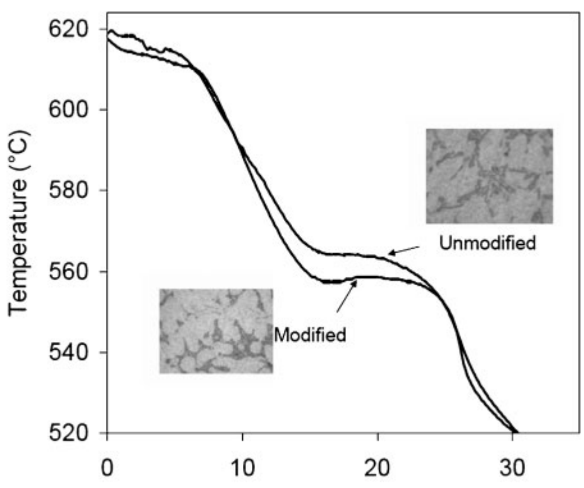
The temperature of the solidifying metal was measured using a calibrated K type thermocouple connected to an NI SCXI 1000 data logger. The thermocouple was protected by twin bore ceramic beads of 4 mm diameter. The thermocouple was located at the geometric centre of the mould and was in direct contact with the melt.

Results and discussion

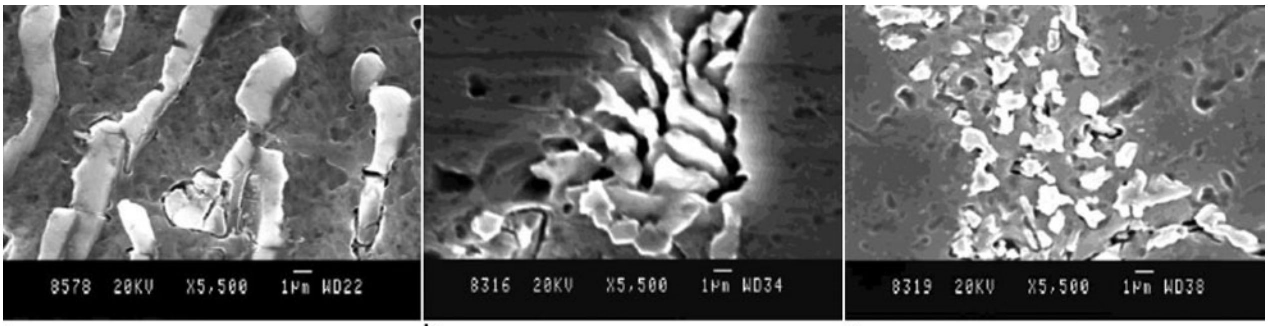
The thermal history of both unmodified and modified alloy solidifying in clay crucible was recorded. These cooling curves will be useful for comparing them with the cooling curve data obtained for chilled castings. Figure 1 shows the cooling behaviour of A357 alloy solidified in the clay crucible for both unmodified and Na modified conditions. The eutectic arrest temperature of the unmodified alloy was found to be 571°C. A eutectic depression of $\sim$2°C is observed. Figure 2 is the cooling behaviour of the alloy solidified in the clay crucible for both unmodified and Sr modified conditions.

The modified A357 alloy showed the characteristic eutectic depression and reduction in arrest time under all conditions of mould material and section thickness. For example, the thermal history of the alloy solidified in a clay graphite crucible shows that the eutectic arrest temperature of the modified alloy is lower than the corresponding temperature of the unmodified alloy by $\sim$2°C (Fig. 2).

Figure 3 shows the cooling behaviour of the A357 alloy solidified in a copper mould of 50 mm diameter in both unmodified and Na modified conditions. The modified alloy showed the characteristic eutectic depression and reduction in arrest time. From the optical microstructure shown in Fig. 3, the eutectic silicon morphology of the chilled alloy appears to be fine fibrous type. However, the SEM images (Fig. 4) clearly indicate the presence of lamellar structure in the unmodified alloy. On the other hand, the modified alloy



3 Effect of modification on solidification of A357 alloy in 50 mm copper mould



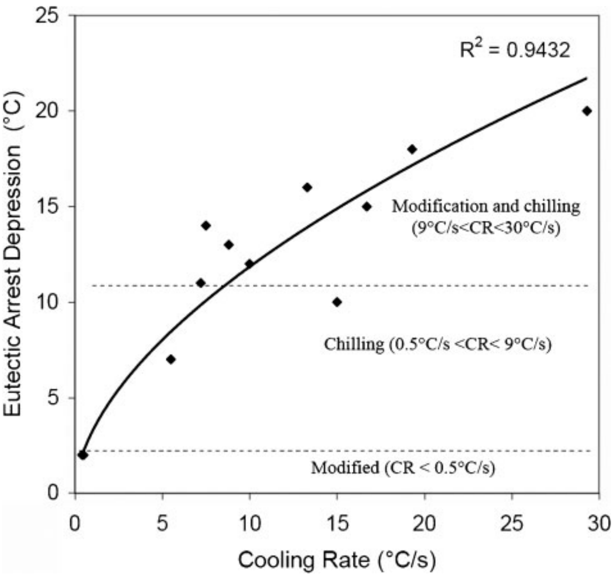
a b c

4 Images (SEM) of *a* as received unmodified alloy, *b* unmodified alloy and *c* modified alloy solidified against 50 mm copper mould

shows a fine fibrous structure. The lamellar structure of the unmodified alloy is due to the high cooling rate of the casting obtained in the copper mould. It is very clear that the chilling with copper did not modify the morphology of eutectic silicon. Similar behaviour was observed for both copper and stainless steel mould materials.

The cooling rate increased with modification irrespective of mould material/section thickness. The effect is more significant in 30 mm moulds. For example, a 30% increase in cooling rate was observed when the modified alloy was solidified in 50 mm copper mould, whereas the corresponding increase in 30 mm mould was nearly 100%. Owing to high cooling rates involved with metallic moulds, the eutectic arrest temperature and time are the only measurable thermal analysis parameters. The increase in cooling rate is accompanied by an increase in the depression of the eutectic arrest temperature and eutectic arrest time.

Figure 5 shows the effect of cooling rate on the eutectic arrest temperature for both unmodified and modified alloys. With increase in the cooling rate (CR), the eutectic arrest temperature decreases, and a lower eutectic arrest temperature was obtained with modified alloys at any given cooling rate. For modified alloys, the depression of the eutectic arrest temperature was significant at higher cooling rates.



5 Effect of cooling rate on eutectic arrest depression ΔT_E

The best fit equation is given below

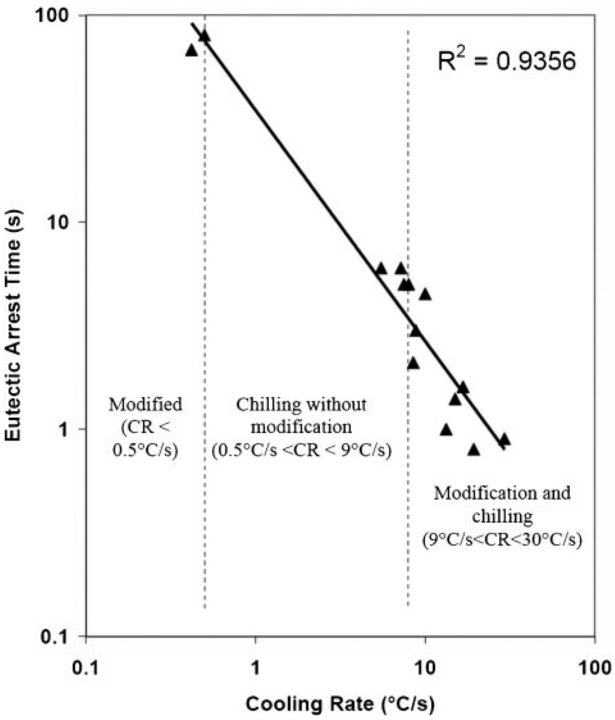
$$\Delta T_E(^{\circ}C) = 570{\cdot}84(CR)^{-0{\cdot}0081} \tag{1}$$

Figure 6 shows the effect of cooling rate on eutectic arrest time. The eutectic arrest time decreases with increase in cooling rate according to the power law

$$\theta(s) = 34{\cdot}72(CR)^{-1{\cdot}116} \tag{2}$$

The correlation coefficients for equations (1) and (2) were found to be 0·94, indicating a reasonable good fit of the data measured by computer aided cooling curve analysis. The above equations are valid for cooling rates between 0·4 and 30°C s^{-1}. The plots depicting the effect of cooling rate on thermal analysis parameters could be classified into three regimes:

(i) modified without chilling at lower cooling rate (<1°C s^{-1}) region (for sand and insulating moulds)
(ii) intermediate range (1–9°C s^{-1}) of cooling without modification



6 Effect of cooling rate on eutectic arrest time θ

(iii) higher cooling rate regime caused by the combined effect of modification and chilling (9–30°C s^{-1}).

In an unmodified alloy, there is poor thermal contact due to higher surface tension; coarse silicon morphology impedes electronic heat conduction. The addition of sodium decreases the surface tension of Al–Si alloy.[11] This results in improved wetting of the chill surface by the liquid metal and ensures prevailing of better thermal contact conditions at the metal/chill interface, leading to enhanced heat transfer rates from the casting to the mould material. Furthermore, the fine fibrous silicon morphology of the solidified shell in modified alloy facilitates electronic heat conduction.[12]

Conclusions

The effect of modification melt treatment in A357 Al–Si alloy on thermal analysis parameters was investigated. Eutectic arrest temperature and eutectic arrest time of the alloys were found to be affected significantly by the combined action of modification and chilling. With increase in the cooling rate, the eutectic arrest temperature decreases. For modified alloys, the depression of the eutectic arrest temperature was significant at higher cooling rates. This is attributed to the synergetic effect of chilling and modification. The effect of cooling rate on depression of the eutectic arrest temperature ΔT_E and eutectic arrest time θ were quantified using power law equations.

References

1. J. R. Davis: in 'Metals handbook', 9th edn, Vol. 15, 55–87, 159–168, 743–753; 1988, Metals Park, OH, ASM.
2. J. A. G. Hinojosa, C. R. González, G. M. González and Y. Houbaert: *J. Mater. Process. Technol.*, 2003, **143–144**, (20), 306–310
3. J. E. Gruzleski and B. M. Closset: 'The treatment of liquid aluminium–silicon alloys', 1–68, 95–157, 213–237; 1990, Des Plaines, IL, AFS Inc.
4. J. Morice and R. Portalier: Proc. AFS/CMI Conf., Rosemont, IL, USA, December 1984, AFS, 37–76.
5. L. Qiyang, L. Qingchun and L. Qiful: *Acta Metall.*, 1991, **39**, (11), 2497–2502.
6. A. F. Valdes, M. E. R. Agullar and J. C. E. Bocardo: *Mater. Design*, 1993, **14**, (4), 223–229.
7. X. Chen, H. Geng and Y. Li: *Mater. Sci. Eng. A*, 2006, **A419**, 283–289.
8. D. Apelian, G. K. Sigworth and K. R. Whaler: *AFS Trans.*, 1984, **92**, 297–307.
9. D. Apelian and J. J. A. Cheng: *AFS Trans.*, 1984, **92**, (27), 797–808.
10. K. N. Prabhu, S. Karanth and K. R. Udupa: *Indian Foundry J.*, 1999, **45**, (9), 177–185.
11. D. Emadi, J. E. Gruzleski and J. M. Toguri: *Metall. Trans. B*, 1993, **24B**, 1055–1063.
12. K. N. Prabhu and B. N. Ravishankar: *Mater. Sci. Eng. A*, 2003, **A360**, 293–298.