Chapter 9
Evaluation of the Effect of Melt Thermal Treatment on Microstructure and Mechanical Properties of Al–7Si Alloy

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Abstract The objective of this research was to investigate the effect of melt thermal treatment on microstructure and mechanical properties of Al–7Si alloy. Various characterization techniques and testings such as optical microscopy, scanning electron microscopy, tensile test and hardness test were carried out to evaluate the samples. The results showed that the melt thermal treated alloys have a more refined structure than that of the unrefined and chemically refined alloys. This led to a considerable improvement in tensile strength, hardness and ductility in the melt thermal treated alloys. The ultimate tensile strength, hardness and elongation of the only melt thermal treated alloys are observed to 153 MPa, 82 HRB and 14.8%, respectively, compared to 143 MPa, 72 HRB and 13.1% in the case of unrefined alloy. In the final microstructure of the melt thermal treated Al–7Si alloy most of the primary dendritic arms were found to be broken, which is an evidence of grain refinement. Besides, melt thermal treated alloy was observed to show refined Si to a certain extent. The average length of eutectic Si was lesser in case of the sample that had undergone both melt thermal treatment and Sr-modification than the only Sr-modified alloy.

Keywords Melt thermal treatment · Microstructure · Al–7Si alloy · Grain refiner · Grain modifier · Eutectic Si · α-Al dendritic

Introduction

With the advancement of automobile and aerospace industries, the requirement for metal parts with high specific mechanical properties is continuously increasing as they provide high performance, along with less fuel consumption. Al–Si alloys are a group of lightweight cast metals, which are normally used to lighten a structure in comparison to that of steel. This is because of its high strength to weight ratio, better corrosion resistance, excellent thermal and electrical conductivities. Hence, the cast Al–Si alloys have widely been used for the production of engine components in

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automobile and aerospace industries [1, 2]. However, microconstituents of the cast Al–Si alloys consist of coarse α-Al dendritic structure and needle-like Si particles in unmodified condition, which reduces toughness and ductility significantly. This structure could be refined and modified by various methods leading to a finer equiaxed α-Al dendrite and short needle or fibrous Si, which exhibit better mechanical properties. In the conventional casting process, the refinement and modification can be achieved by following methods [3–6]: thermal method such as superheating and rapid cooling; chemical method such as introducing inoculants; mechanical vibration and electromagnetic induction.

Various elements were used in the past as the grain refiners and modifiers such as Na, Sr, Sb, Ti, Ba, Ca and several rare earth elements. Sr-based alloys are most widely used as modifiers, and Al–5Ti–B and rare element-based alloys are used as grain refiners for Al–Si alloys [7–11]. Commercially Al–Ti–B master alloys have TiB_2 particles, which form a layer of Al_3Ti on these particles. These particles act as heterogeneous nucleation sites for solidification of primary aluminium dendrites [12–14]. However, these grain refiners are not effective when the silicon content is greater than 5 wt%. This is because Ti reacts with Si to form Al–Ti–Si ternary phases and therefore effective refinement does not take place [15, 16]. The grain modifiers are also associated with different problems like Na has poor retention in the melt due to low boiling point, Sb has toxic effect and Sr-based modifier cause the absorption of hydrogen [16–19].

With the development of casting practices, some melt processes such as melt thermal treatment (MTT) have been developed which can refine and modify Al–Si alloys structure to a certain extent without the addition of foreign substances. Melt thermal treatment is a melt process in which one part of melt is superheated by 200 °C above actual temperature and is then quenched up to pouring temperature by the addition of the other low temperature melt part. Mixing of the superheated part with the low temperature melt part increases the nucleating sites for the α-Al and hence results in grain refinement along with modification to a certain extent [20]. Various researches have been conducted [21–23] on the effects of MTT on hypereutectic Al–Si alloys, but very limited work is carried out to find the effects of MTT on hypoeutectic Al–Si alloys. The objective of this research work is to investigate the effect of MTT on microstructure and mechanical properties of Al–7Si alloy.

Materials and Methods

Al–7Si alloys were prepared by melting commercially pure Al (99.8%) and Al–15Si master alloy in desired proportion at 720 °C in an electrical resistance muffle furnace. The prepared alloy was degasified by the addition of C_2Cl_6 tablets into the melt. In chemical refining process, the prepared melt was added with 0.5% grain refiner (Al–5Ti–1B) and a holding time of 15 min was then provided. The modification was carried out by the addition of Al–5Sr (Sr ~ 250 ppm) in selected samples. Finally, refined and/or modified melt was poured into preheated graphite mould of dimensions 20 mm diameter and 150 mm height for casting.

In case of MTT, prepared melt was divided into two parts. In one part, the melt temperature was raised by 150 °C and was known as the superheated melt. The other half melt temperature was decreased by 150 °C and was known as the low temperature melt. Each melt was placed in different furnaces and was hold at respective temperatures for 15 Min. Then the superheated melt was poured into the low temperature melt followed by stirring and pouring into a preheated graphite mould. Chemical compositions of commercial pure Al, Al–15Si master alloy, Al–5Ti–1B and Al–5Sr as investigated by optical emission spectrometer (OES) (Spectrolab) are given in Table 9.1. The sample codes, and the percentage weight of refiner and modifier that have been added in various alloys are given in Table 9.2. The prepared alloys were then went through sectioning, wet grinding (SiC emery paper) and polishing by Al_2O_3 suspension on velvet cloth. The polished samples were finally etched with Keller's regent (95% H_2O, 2.5% HNO_3, 1.5% HCl, 1% HF) for dendritic structure examination and with Poulton's etchant (60%HNO_3, 30% HCl, 5% HF, 5%H_2O) for grain size measurement. The microstructure of the alloys were captured with the help of an optical microscope (Zeiss Axio vert. A1) and grain size analysis was carried out on the obtained images using ImageJ software by line intercept method. Investigation of changes in morphology of eutectic Si with different treatments was carried out using field emission scanning electron microscope (FE-SEM, Nova Nano SEM 450) [24, 25].

The ultimate tensile strength (UTS) was measured on a tensile testing machine (Model: H25KL, Tinius Olsen) at a strain rate of 1 mm/min. The testing was carried out on at least two different samples having dimenions (gauge diameter = 6 mm and

Table 9.1 Chemical composition of different raw materials as obtained by OES analysis

Element	Al	Si	Mg	Fe	Ti	Cu	Zn	V	B
Pure Al	Bal	0.25	0.40	0.05	0.03	0.05	0.01	0.01	–
Al–15Si	Bal	14.8	0.01	0.24	0.01	0.01	0.001	0.012	–
Al–5Ti–1B	Bal	0.05	–	0.15	4.98	–	0.01	0.01	0.96
Al–5Sr	Bal	0.05	–	0.15	0.01	–	0.01	0.01	4.97

Table 9.2 Chemical composition of prepared alloys

Sample code	Sample	Al–5Ti–1B (wt%)	Al–5Sr (wt%)
A	Al–7Si	0	0
AG	Al–7Si–0.5GR	0.5	0
AMT	Al–7Si–MTT	0	0
AGM	Al–7Si–0.5GR–1GM	0.5	1
AMTM	Al–7Si–MTT–1GM	0	1

Fig. 9.1 Experimental set-up for cooling curve analysis

gauge length = 24 mm) prepared under similar conditions to ensure reproducibility of the results. Hardness was measured on a Rockwell hardness testing machine using *B* scale. The reported results are the average of 5 different reading each taken on two different specimens prepared under similar conditions.

Cooling curve analysis was done to co-relate the results of thermal analysis with that of the microstructural analysis. Figure 9.1 shows experimental set-up of cooling curve analyzer in which prepared melt was poured into a clay crucible with a centrally located K-type thermocouple, and thermal parameters such as undercooling and eutectic temperature was recorded by a data logger.

Results and Discussion

Microstructural Analysis

Figure 9.2 comparatively shows the changes in microstructure of Al–7Si alloys after the addition of 0.5 wt% grain refiner (Fig. 9.2c, d) and melt thermal treatment (Fig. 9.2e, f). First column microstructures are captured after etching with Keller's reagent at 100× magnification (Fig. 9.2a, c, e). The results indicate that the sample which is treated by MTT has broken dendritic structure. This also implies

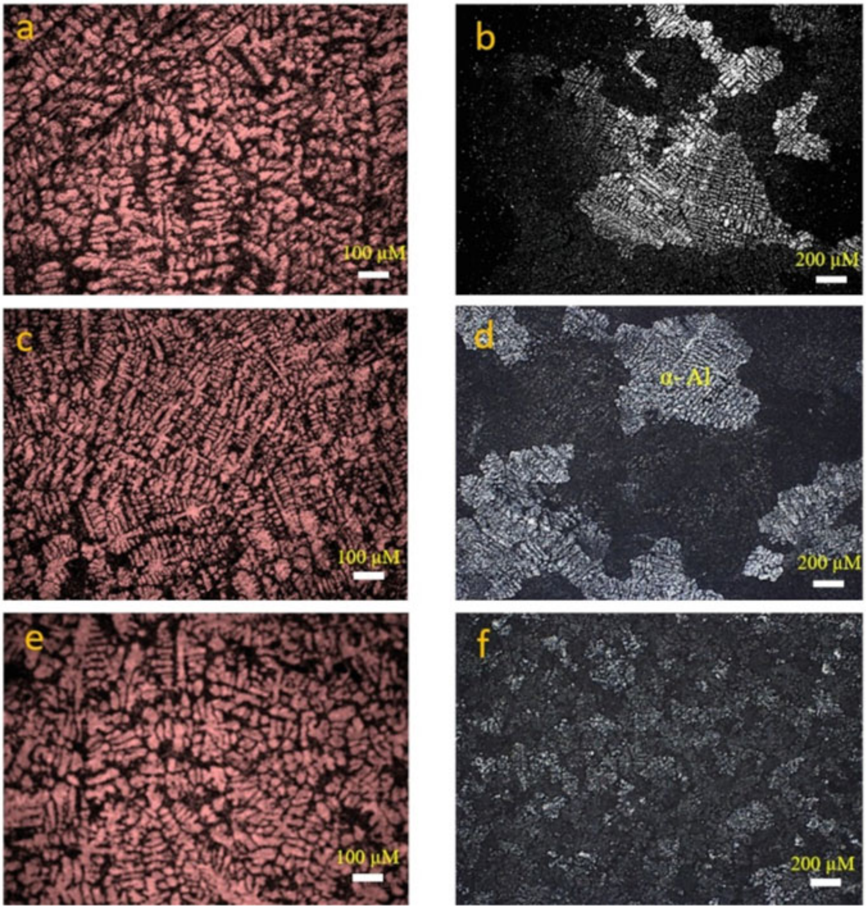

Fig. 9.2 Optical microstructure **a**, **b** Al–7Si, **c**, **d** Al–7Si–0.5GR and **e**, **f** Al–7Si–MTT

lower average length of primary dendritic arms (λ) in case of MTT alloys than in case of unrefined and refined alloys.

Second column microstructures are captured after etching with Poulton's regent at 50× magnification (Fig. 9.2b, d, f). It has been observed that the grain size of α-Al reduced by ~12% after the addition of grain refiner and reduced by ~45% after the MTT method. In the case of grain refiner addition, Ti might be reacting with the Si in the melt to form intermetallic phases [16]. This leads to a reduction in effectiveness of grain refinement result. In the case of the MTT method, mixing of melts create a lot of small sized uniformly distributed atomic clusters and broken arms which in turn act as nucleation sites for α-Al [22]. This leads to a significant reduction in grain size.

Scanning electron microscope (SEM) images of unrefined alloys (Fig. 9.3a, b) and MTT alloys (Fig. 9.3c, d) indicate that the morphology of the eutectic Si remains

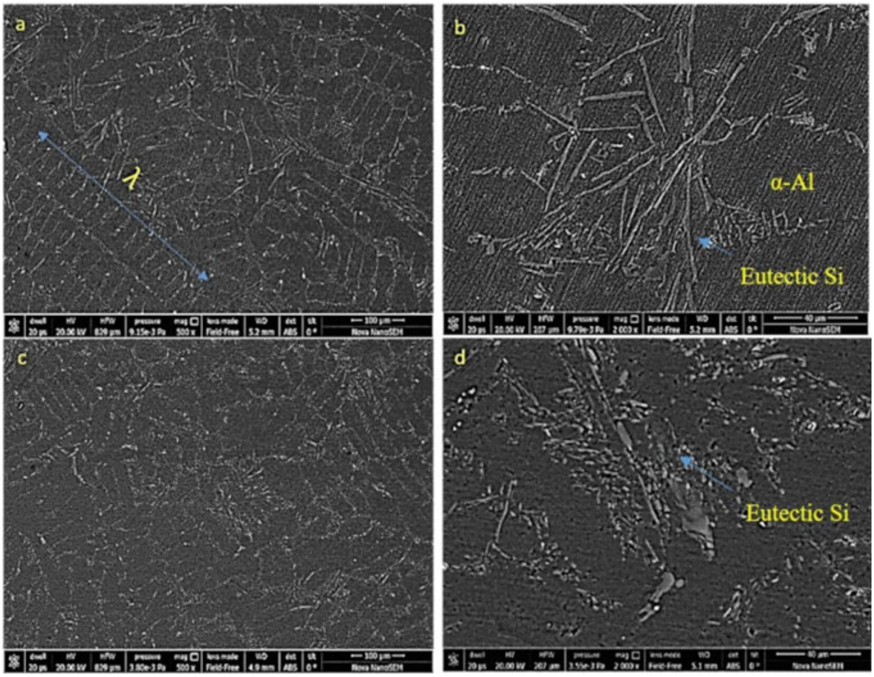

Fig. 9.3 SEM images **a** Al–7Si, **b** Al–7Si, **c** Al–7Si–MTT and **d** Al–7Si–MTT

similar in both the cases. However, the average length of eutectic Si is found to be lesser in the case of MTT alloys, which is expected to improve ductility of the alloy. The structure (Fig. 9.3a, b) also confirms that the value of λ is lesser in the case of MTT samples.

Figure 9.4 shows the SEM images of samples treated both with MTT and Sr-modifier (Fig. 9.4a, b), and only with Sr-modifier (Fig. 9.3c, d). The images (b and d) indicate that the morphology of eutectic Si has changed from needle to fibrous in both cases. However, average length of eutectic Si is found to be lesser in case of the samples treated both with MTT and Sr-modifier than those treated only with Sr-modifier. The MTT alloys have also shown better roundness of eutectic Si.

Cooling Curve Analysis

Table 9.3 shows the results obtained from the cooling curve analysis. It can be observed that the amount of undercooling has lowest value (0.47) in the case of the MTT alloys.

Higher undercooling indicates poor nucleation rate and hence leads to poor grain refinement [26]. The level of modification is indicated by ΔT (difference in eutectic

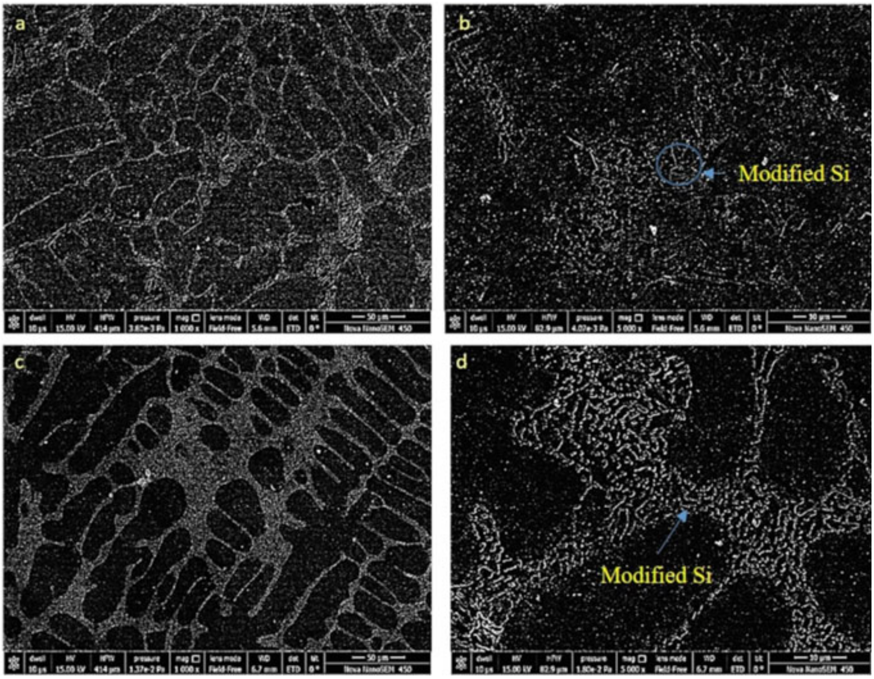

Fig. 9.4 SEM images **a** Al–7Si–MTT-1GM, **b** Al–7Si–MTT–1GM, **c** Al–7Si–0.5GR–1GM and **d** Al–7Si–0.5GR–1 GM

Table 9.3 Results of cooling curve analysis

Sample	Undercooling (°C)	Eutectic temperature (°C)
Al–7Si	1.65	572.14
Al–7Si–0.5GR	0.94	573.32
Al–7Si–MTT	0.47	576.37

temperature of unmodified alloy vs. modified alloy). The higher value of ΔT indicates a higher level of modification. The ΔT is observed to be higher (4.24) in the case of MTT alloys indicating a higher level of modification of the microstructure than that of the chemically refined alloys.

Mechanical Properties

Figure 9.5 shows variation in mechanical properties of the Al–7Si alloy after different treatments. It can be observed that chemical refined alloy (AG) have not shown any significant improvement in ultimate tensile strength, hardness over the unrefined alloys. However, the ductility is observed to improve by 21%. In the case of the

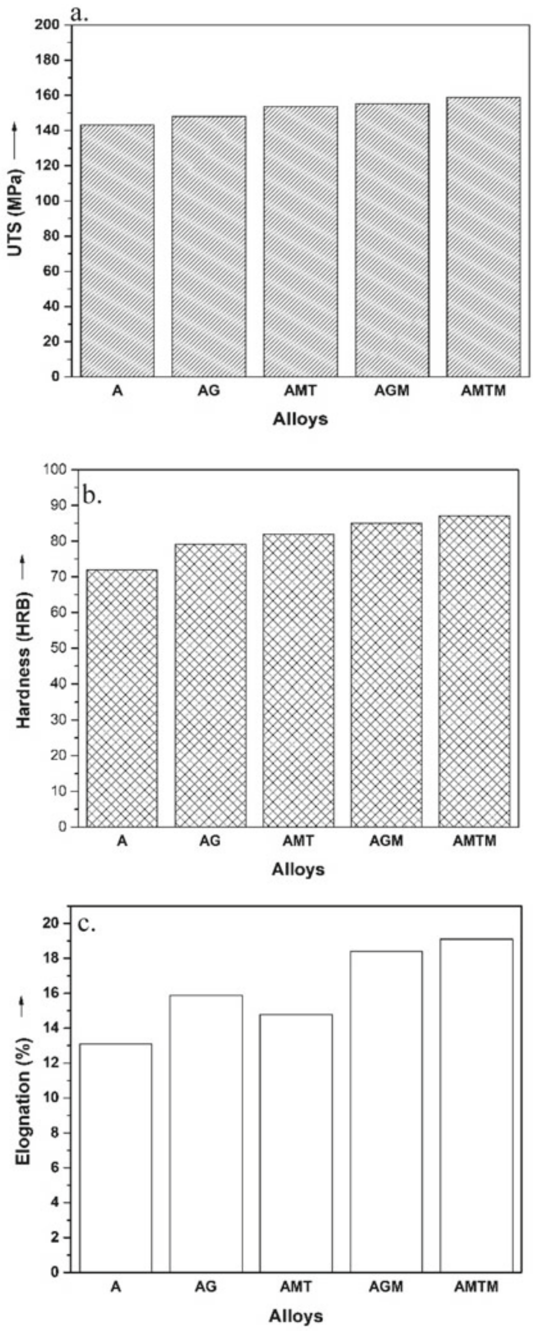

Fig. 9.5 Variation in mechanical properties with different treatment **a** UTS, **b** hardness and **c** elognation

alloy that has gone through grain refinement along with modification (AGM), the ductility has shown significant improvement (~39%) over the only refined alloy. This is attributed to the drastic change in morphology of eutectic Si from needle to short rod or fibrous. It can also be observed that MTT alloys (AMT and AMTM) show better ultimate tensile strength, hardness and ductility than the chemical refined and modified alloys. The UTS, hardness and elongation of the only MTT treated alloys (AMT) are observed to 153 MPa, 82 HRB and 14.8%, respectively, and that of the MTT treated along with modified (AMTM) are observed to be 159 MPa, 88 HRB and 19.1%, respectively. This improvement is attributed to lesser value of the average diameter of eutectic Si particles and its better roundness in the case of AMTM alloys.

Conclusions

The following conclusions may be made from the present study.

- MTT method reduces length of primary dendrites arms (λ) and refines eutectic Si to a certain extent.
- Modification along with MTT results in a smaller average length of eutectic Si than the only modified alloy.
- Cooling curve results indicate that the MTT alloy requires lesser amount of undercooling for solidification of primary Al dendrites.
- MTT alloys show better mechanical properties than only chemically refined alloy.

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