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Influence of melt pouring temperature and plate inclination on solidification and microstructure of A356 aluminum alloy produced using oblique plate

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Abstract: The preparation of semisolid slurry of A356 aluminum alloy using an oblique plate was investigated. A356 alloy melt undergoes partial solidification when it flows down on an oblique plate cooled from underneath by counter flowing water. It results in continuous formation of columnar dendrites on plate wall. Due to forced convection, these dendrites are sheared off into equiaxed/fragmented grains and then washed away continuously to produce semisolid slurry at plate exit. Melt pouring temperature provides required condition of solidification whereas plate inclination enables necessary shear for producing semisolid slurry of desired quality. Slurry obtained was solidified in metal mould to produce semisolid-cast billets of desired microstructure. Furthermore, semisolid-cast billets were heat treated to improve surface quality. Microstructures of both semisolid-cast and heat-treated billets were analyzed. Effects of melt pouring temperature and plate inclination on solidification and microstructure of billets produced using oblique plate were described. The investigations involved four different melt pouring temperatures (620, 625, 630 and 635 °C) associated with four different plate inclinations (30°, 45°, 60° and 75°). Melt pouring temperature of 625 °C with plate inclination of 60° shows fine and globular microstructures and it is the optimum.
Key words: A356 aluminum alloy; semisolid; oblique plate; slurry; melt pouring temperature; plate inclination

1 Introduction

Semisolid metal processing (SSM) is an unparalleled technology where metal is cast at semisolid state unlike conventional casting where metal is directly cast from liquid state. At MIT, Cambridge, SPENCER et al [1] studied the rheological behavior of Sn−15%Pb binary alloy in the crystallization range using a Couette type viscometer. The investigations on the deformation behavior of Sn−15%Pb semisolid alloy have also been reported [2]. The effects of vibration during solidification have been studied as well [3]. FLEMINGS [4] investigated the behavior of metal alloys in the semisolid state. KIRKWOOD [5] described semisolid metal processing with lot of explanatory remarks. FAN [6] explained clearly about semisolid metal forming technology. Study on the effect of isothermal mechanical stirring on Al−Si alloy in the semisolid condition has been reported [7]. The effect of stirring on solidification pattern and alloy distribution during semi-solid metal casting has also been investigated [8]. An overview about the implication of rheology in semi-solid metal processing has been provided as well [9]. KUMAR [10] investigated experimentally the rheocasting of A356 aluminum alloy using linear electromagnetic stirring. BARMAN [11] studied numerically the transport phenomena during solidification in the presence of electromagnetic stirring. The effect of mechanical vibration of metal mould on the production of thixotropic feedstock of A356 aluminum alloy has also been investigated [12].

In addition, numerical studies on the hydrodynamic and thermo-solutal behavior of flowing down partially solidifying A356 alloy melt have been reported [13]. The scaling analysis of the stated problem has also been presented [14]. These studies are theoretical in nature and do not illuminate on the final microstructure at all. The details of solidification and microstructure can be ascertained only through the controlled experiments.

From the aforementioned investigations, to the best of our knowledge, it is apparent that there is not a single comprehensive experimental study relating to the influences of melt pouring temperature and plate inclination on quality of semisolid slurry, solidification and microstructure of cast billets produced using an

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oblique plate. With this viewpoint, the present work illustrates experimental studies with an oblique plate on A356 aluminum alloy melt involving the effects of melt pouring temperature and plate inclination on quality of semisolid slurry, solidification and microstructure. In addition, the investigations also involved isothermal holding of semisolid cast billets to produce heat treated billets with improved surface quality. Finally, to enumerate and measure the heterogeneity in microstructural morphology for realizing the desired microstructures, both semisolid cast and heat treated billets were analyzed and compared using optical microscopy and image analysis technique.

2 Experimental

Figure 1 shows a photograph of the experimental facility consisting of tundish, oblique plate, metal mould and water channel beneath the plate for conducting the experiments.

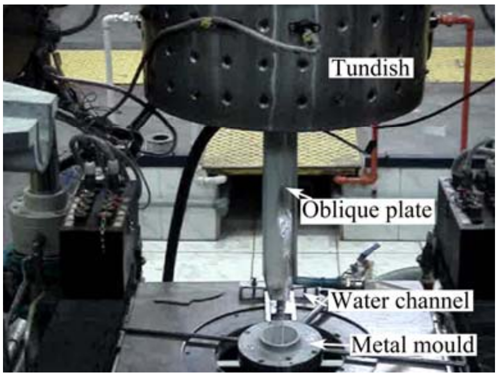

Fig.1 Photograph of experimental facility

2.1 Materials

In the present study, A356 aluminum alloy ingots with liquidus temperature of 618 °C, solidus temperature of 555 °C, and composition [10] as listed in Table 1, are used for performing experiments.

Table 1 Composition of A356 alloy (mass fraction, %)

Si	Mg	Fe	Mn	Cu	Ti	Al
7.32	0.31	0.086	≤0.010	≤0.010	0.157	Bal.

2.2 Melt preparation and treatment

Ahead of each experiment, about 20 kg of A356 aluminum alloy ingot was melted at about 720 °C in a mica glazed silicon carbide crucible kept in a tilting electric resistance furnace. Once the metal reaches molten stage, the molten alloy was held for about 45 min at 720 °C to allow for attaining temperature uniformity and complete dissolution of alloying elements. This is subsequently followed by the addition of predetermined quantities of grain modifiers (i.e. Al−Sr master alloy amounting to 0.25% of the total melt mass of the alloy) and refiners (i.e. Ti−B tablet amounting to 0.125% of the total melt mass of the alloy). This is consistent with the experiments reported by JUNG et al [15]. After that, before poured into stainless steel metal mould, the melt was allowed to soak for about 15 min to entirely feel the effects of grain modifier and refiner. Throughout the experiments, according to the melt quantity and amount of superheat, a 40−50 °C drop in temperature was normally noticed while the molten alloy was transferred from electric resistance furnace to the metal mould. This ascertained the requirement of holding such an elevated temperature in the heating furnace.

2.3 Slurry production and temperature measurements

For each experiment, about 1.5 kg of molten alloy was removed from the furnace and then transferred into a tundish. The molten alloy temperature in the tundish was frequently monitored by means of K-type mineral insulated (MI) twisted-pair thermocouples from UK based TC Ltd. Molten alloy at four different temperatures (620, 625, 630 and 635 °C) is slowly poured at flow rate of 0.025 kg/s into the metal mould via a stainless steel oblique plate of 250 mm in length, kept at four different plate inclinations (30°, 45°, 60° and 75°) with water flow rate of 7.5 L/min underneath it. The temperature of semisolid slurry collected at the plate exit was also measured regularly.

2.4 Semisolid billet casting and induction reheating

The billets of 250 mm in length and 60 mm in diameter were cast by quenching semisolid slurry in the said metal mould. For relative comparison of microstructures, some of the semisolid cast billets were also reheated up to 580 °C (i.e. slightly above solidus temperature) in an induction furnace. This induction reheating involves isothermal holding of semisolid cast billets at a temperature which is slightly above the solidus temperature of the metal alloy.

2.5 Specimen preparation

Small sections were sliced from the cast/reheated billets to form 15 mm thick disks. For metallographic analysis, all the sliced samples were polished by means of emery papers of various grades, subsequently followed by SiC powder polishing together with diamond paste polishing. Each of the polished specimens obtained by the already described procedure were etched using Keller’s reagent (1 mL HF, 1.5 mL HCl, 2.5 mL HNO_3 and 100 mL H_2O) at the ambient temperature.

2.6 Microstructure morphology and characterization

Optical microscopy and image analysis software were used to enumerate and measure the heterogeneity in microstructural morphology. The micrograph images of samples were then snapped at the centre, middle and edge for characterization using Leitz optical microscope for quantitative and metallographic analysis. Sigma Scan Pro image (version. 4.0) analysis software was deployed for quantitative metallographic analysis such as for determining the area and perimeter of primary α-phase particles. The microstructural characterizations of the snapped images were carried out based on the under-mentioned parameters:

1) Fraction of primary α-phase (%): It was determined in accordance with the area ratio of primary α-phase and eutectic Si phase.

2) Grain size: It was estimated by means of the intercept method.

3) Shape factor: It was a measure of globularity of the primary α-phase. It was evaluated with the use of the formula $S=4\pi A/P^2$, where A and P are area and perimeter of the primary α-phase, respectively. For an ideal circle the value is 1, and for a dendrite the formula yields a value tending to zero. For a rosetted structure, depending on the amount and degree of irregularity, it yields a value between 0 and 1.

4) Particle density: Otherwise termed as grain density, it is the number of primary α-phase globules per unit area; this number is bigger, the amount and degree of dendrite multiplication or breakdown is superior.

3 Results and discussion

Rigorous experiments were conducted to study the effects of melt pouring temperature and plate inclination on solidification and microstructure of both semisolid cast and heat treated billets. To begin with, molten A356 aluminum alloy at 625 °C was poured at flow rate of 0.025 kg/s on an oblique plate of 250 mm in length, inclination of 60° with water flow rate of 7.5 L/min below it.

3.1 Effect of melt pouring temperature

With the stated experimental conditions, in order to investigate the influence of melt pouring temperature on solidification and microstructure, controlled experiments were performed by pouring of A356 aluminum alloy melt at four different temperatures (620, 625, 630 and 635 °C). Since higher melt pouring temperature results in a delayed onset of solidification of the melt flowing down on the oblique plate, hence, the slurry temperature at plate exit increases with increasing the melt pouring temperature. Eventually, it results in lower solid fraction at higher melt pouring temperature. Table 2 lists the average temperatures and solid fraction data of A356 semisolid slurry collected at the plate exit and obtained from the experiments conducted at four different melt pouring temperatures.

Table 2 Temperatures and solid fraction data of A356 semisolid slurry collected at plate exit

$t_{pouring}$/°C	t_{exit}/°C	Solid fraction calculated from Scheil equation/%
620	603	30
625	607	24
630	611	17
635	615	8

3.1.1 Microstructure morphology of semisolid cast billets

Accordingly, four different semisolid cast billets were produced at the stated melt pouring temperatures. The representative samples were prepared to snap micrograph images at the centre, middle and edge using Leitz optical microscope for quantitative and metallographic analysis.

Figure 2 shows the representative microstructures of the semisolid cast billets produced at four different melt pouring temperatures. It may be observed that the primary α-phase particles are normally bigger for higher melt pouring temperature. This may be due to the fact that the semisolid slurry collected at plate exit and entering the metal mould contains fewer fractions of primary α-phase particles for higher melt pouring temperature. Delayed onset of solidification causes initiation of less nucleation sites (on the plate wall) for grain growth, dendrite fragmentation and breakage along with its transport. Ultimately, it results in fewer fractions of primary α-phase particles at plate exit. There is growth, spheroidization and microstructure refinement in the metal mould as well. Figure 2 also shows the radial variations in microstructure of the stated semisolid cast billets from globular at centre to dendritic at edge through rosette-like at middle. It can be owing to non-uniform cooling, i.e. faster cooling at the wall of metal mould and slower cooling at the centre.

This demonstrates that the evolution of microstructure certainly depends on melt pouring temperature. The results from the measurement of the grain size of α-phase particles, shape factors, eutectic fractions and the grain or particle densities along the radial direction of the billets are shown in Fig. 3.

3.1.2 Microstructure characterization of semisolid cast billets

Figure 3 shows the microstructural characteristics observed or measured along with its variations. It depicts that for higher melt pouring temperature the average grain size of α particle is more, whereas, shape factor, fraction of primary α-phase and grain density are less. Delayed onset of solidification on the plate wall causes less dendritic fragmentation, breakage along with its

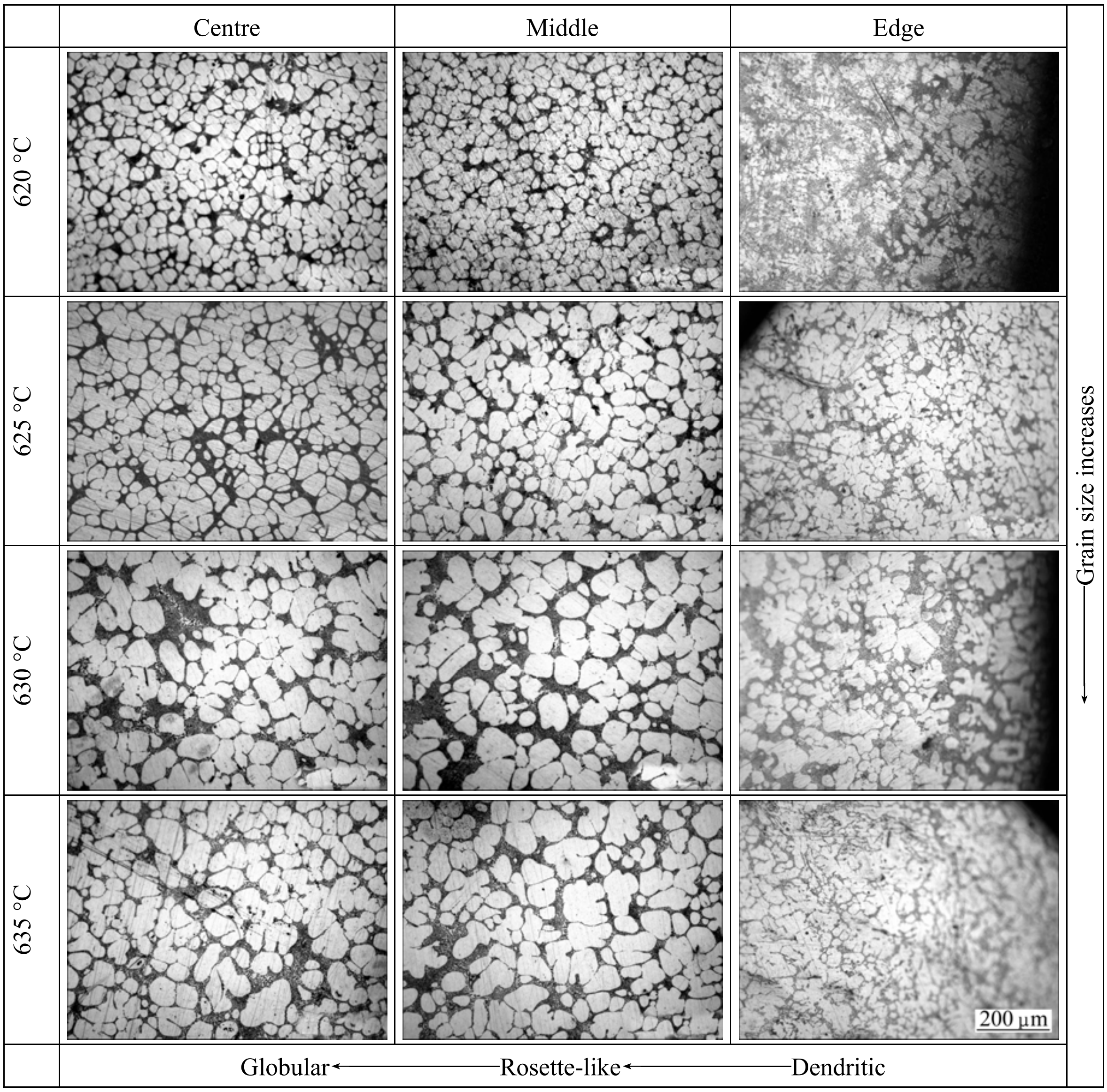

Fig. 2 SEM images of representative microstructures of semisolid cast billets at different pouring temperatures

transport, resulting in the evolution of relatively coarse microstructure. Figure 3 also shows the non-uniformity of the microstructural characteristics in the radial direction. It shows decrease in grain size, shape factor, fraction of primary α-phase and increase in grain density in radially outward direction (from centre to edge of the stated semisolid cast billets).

For the oblique plate semisolid cast billet with melt pouring temperature of 620 °C, the average grain size decreases from 50 μm at the centre to 24 μm at the edge through 47 μm at the middle (Fig. 3(a)). Correspondingly, the shape factor decreases from 0.83 at the centre to 0.38 at the edge through 0.8 at the middle (Fig. 3(b)), and the primary α-phase fraction decreases from 0.85 at the centre to 0.62 at the edge through 0.82 at the middle (Fig. 3(c)). The grain or particle density increases from 270 at the centre to 509 at edge through 290 at the middle (Fig. 3(d)). Likewise, for the billets cast with other melt pouring temperatures (625, 630 and 635 °C), the variations of average grain size, shape factor, primary α-phase fraction and grain density follow a similar trend, as shown in Fig. 3.

This demonstrates that the melt pouring temperature, i.e. the initial melt superheat of liquid aluminum alloy, definitely influences the final microstructure of the semisolid cast billets which affects average grain size, shape factor, fraction of α-phase and particle or grain density in turn.

3.1.3 Microstructure morphology of heat treated billets

To improve the surface quality, the stated semisolid cast billets were reheated up to slightly above solidus temperature of 580 °C by induction heating. The representative samples were prepared from the heat treated billets to snap micrograph images at the centre, middle and edge using Leitz optical microscope for quantitative and metallographic analysis.

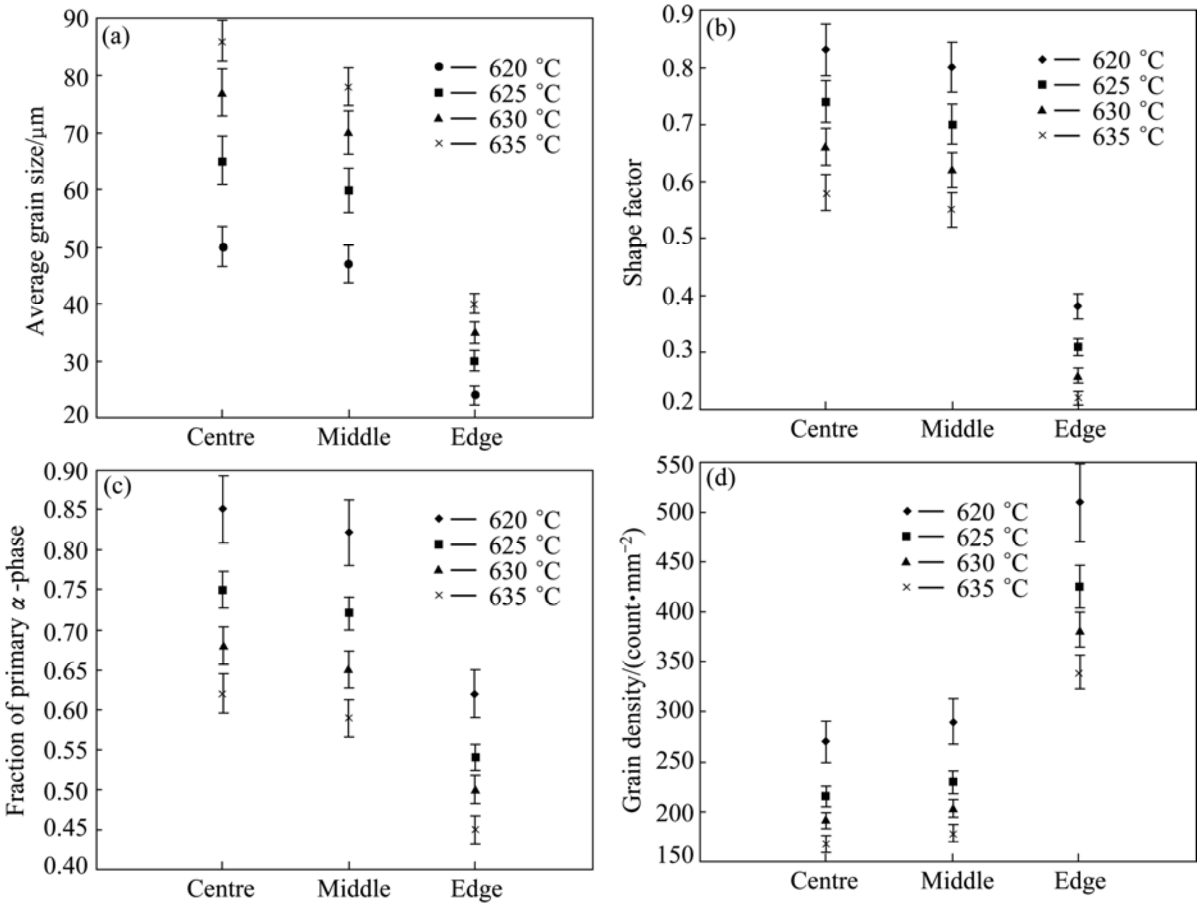

Fig. 3 Microstructure characterization of semisolid cast billets at different pouring temperatures: (a) Grain size versus location; (b) Shape factor versus location; (c) Primary α-phase fraction versus location; (d) Grain density versus location

Figure 4 shows the representative microstructures of the heat treated billets produced at different melt pouring temperatures. Here, nearly uniform and globular microstructure is observed from centre to edge of each heated treated billet. It may be due to the temperature uniformity from the centre to edge of the billets because of isothermal holding in the induction furnace for about 10 min. However, the primary α-phase particles are observed to be still coarser for higher melt pouring temperature.

This demonstrates that the microstructure morphology certainly gets improved because of induction heating. The results from the measurement of the grain size of α-phase particles, shape factors, primary α-phase fractions and the grain or particle densities along the radial direction of the heat billets are shown in Fig. 5.

3.1.4 Microstructure characterization of heat treated billets

Figure 5 shows the results obtained from the measurements of grain sizes, shape factors, eutectic fractions and the grain densities from the samples of the said semisolid cast and heat treated billets. The average grain size, shape factor, fraction of primary α-phase and grain density were found to be nearly uniform from centre to edge of each heat treated billet. However, the trends of variations in average grain size, shape factor, fraction of primary α-phase and grain density with melt pouring temperature are the same for both the said billets. Also, it may be observed that the average grain size, shape factor and fraction of primary α-phase increase with induction reheating, whereas grain density decreases with the same. It may be due to the fact that the particle coalescence occurs during isothermal holding, causing amalgamation of small particles into bigger ones. The particle coalescence also leads to liquid entrapment in primary α-phase which is also observed in some cases.

Due to isothermal holding of the semisolid cast billet produced at melt pouring temperature of 620 °C, the average grain size increases from 50 μm to 85 μm at the centre, and 24 μm to 75 μm at the edge through 47 μm to 80 μm at the middle (Fig. 5(a)). Correspondingly, the shape factor increases from 0.83 to 0.87 at the centre, and 0.38 to 0.75 at the edge through 0.8 to 0.83 at the middle (Fig. 5(b)). The primary α-phase fraction increases from 0.85 to 0.89 at the centre, and 0.62 to 0.8 at the edge through 0.82 to 0.86 at the middle (Fig. 5(c)). Also, the grain or particle density decreases from 270 to 200 at the centre, and 509 to 220 at edge through 290 to

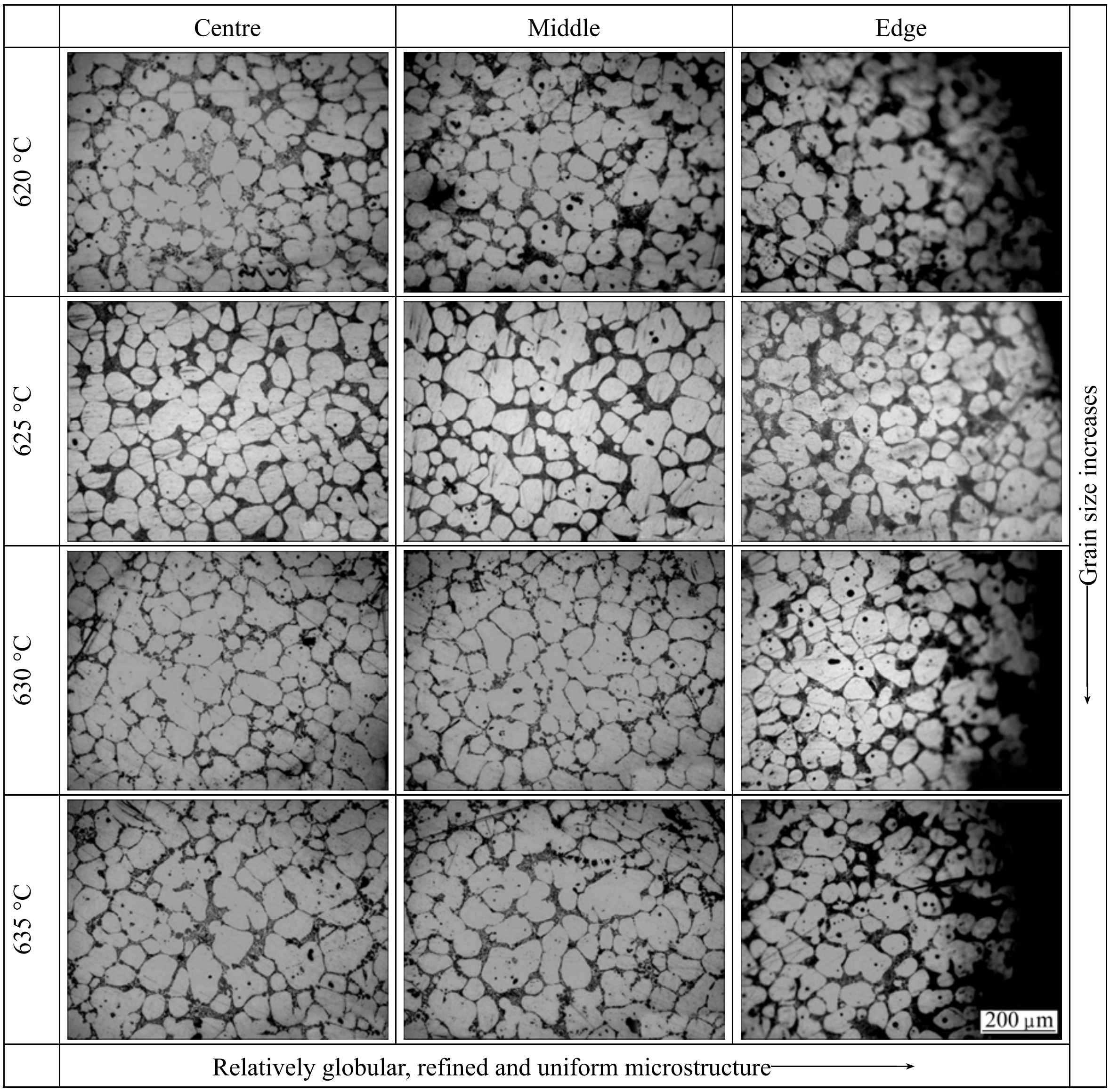

Fig. 4 SEM images of representative microstructures of heat treated billets produced at different melt pouring temperatures after isothermal holding

210 at the middle (Fig. 5(d)). Likewise, as shown in Fig. 5, the variations of average grain size, shape factor, primary α-phase fraction, and grain density follow a similar trend for the billets cast with other melt pouring temperatures (625, 630 and 635 °C).

This clearly demonstrates that the heat treatment of semisolid cast billets involving isothermal holding (slightly above solidus temperature of A356 alloy) certainly affects the final microstructure of the heat treated billets, which influences the average grain size, shape factor, fraction of α-phase, and particle or grain density, in turn.

3.2 Effect of plate inclination angle

With the stated experimental conditions, in order to investigate the influence of plate inclination angle on solidification and microstructure, controlled experiments were conducted at four different plate inclinations angle (30°, 45°, 60° and 75°). Since higher plate inclination angle involves less residence time or solidification time of the melt flowing down on the oblique plate, hence, the slurry temperature of the plate exit increases with the plate inclination angle. Eventually, it results in lower solid fraction at higher plate inclination angle. Table 3 lists the average temperatures and solid fraction data of A356 semisolid slurry collected at the plate exit and obtained from the experiments conducted at four different plate inclinations.

3.2.1 Microstructure morphology of semisolid cast billets

Accordingly, four different semisolid cast billets were produced at the stated plate inclinations. The representative samples were prepared to snap micrograph images at the centre, middle and edge using Leitz optical microscope for quantitative and metallographic analysis.

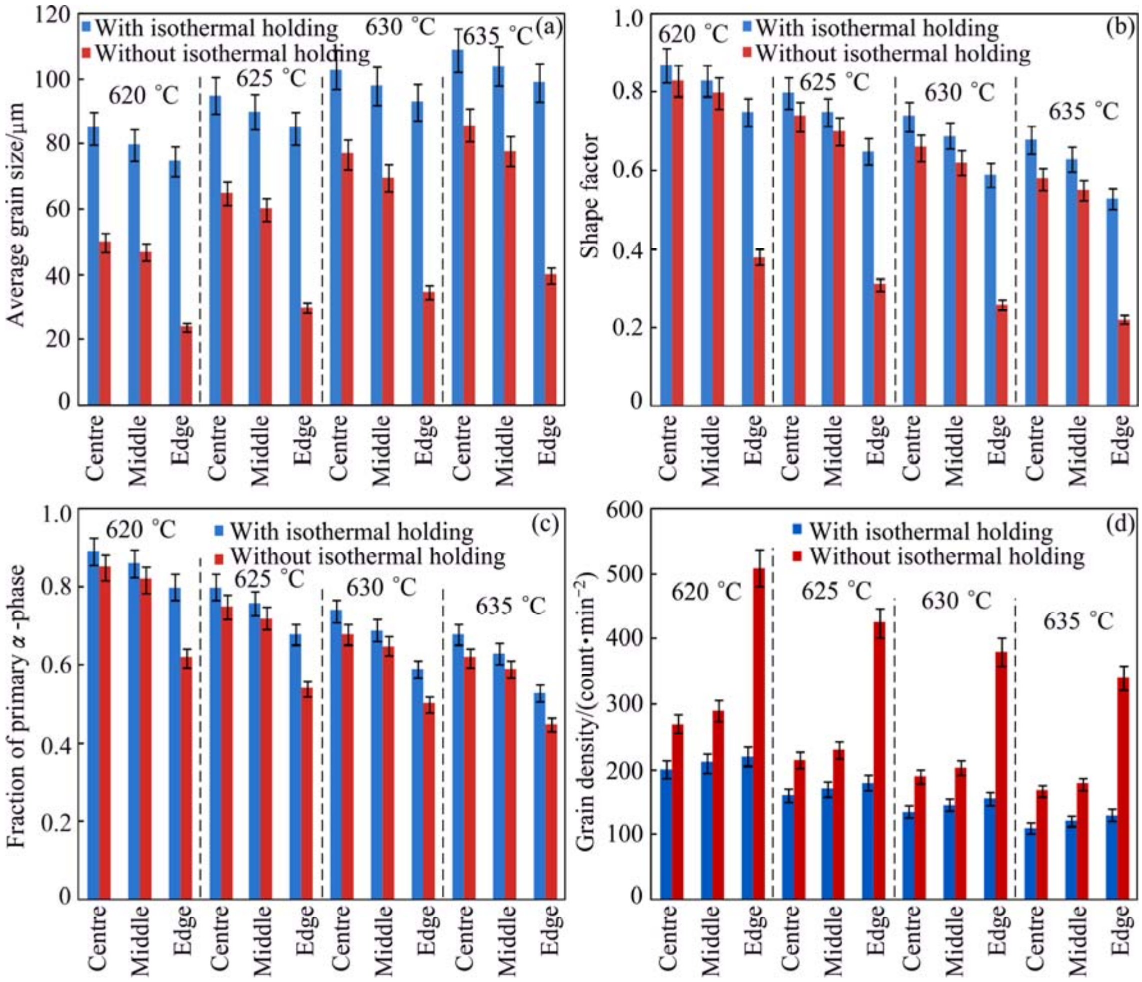

Fig. 5 Microstructure characterization of heat treated billets at different melt pouring temperatures after isothermal holding: (a) Grain size versus location; (b) Shape factor versus location; (c) Primary α-phase fraction versus location; (d) Grain density versus location

Table 3 Temperatures and solid fraction data of A356 semisolid slurry collected at plate exit

Plate inclination angle/(°)	t_{exit}/°C	Solid fraction from Scheil equation/%
30	603	30
45	605	27
60	607	24
75	611	17

Figure 6 shows the representative microstructures of the semisolid cast billets produced at four different plate inclinations angles. It may be observed that the primary α-phase particles are normally bigger for higher plate inclination angle. This may be due to the fact that the semisolid slurry collected at plate exit and entering the metal mould contains fewer fractions of primary α-phase particles for higher plate inclination angle. Lesser residence time or solidification time causes initiation of less nucleation sites on the plate wall for grain growth, dendrite fragmentation and breakage along with its transport. Ultimately, it results in fewer fractions of primary α-phase particles at the plate exit. There is growth, spheroidization and microstructure refinement in the metal mould as well. Figure 6 also shows the radial variations in microstructure of the stated semisolid cast billets from globular at centre to dendritic at edge through rosette-like at middle. It can be owing to non-uniform cooling, i.e. faster cooling at the wall of metal mould and slower cooling at the centre.

This demonstrates that the evolution of microstructure certainly depends on the plate inclination angle apart from the melt pouring temperature. The results from the measurement of the grain size of α-phase particles, shape factors, eutectic fractions and the grain or particle densities along the radial direction of the billets are shown in Fig. 7.

3.2.2 Microstructure characterization of semisolid cast billets

Figure 7 shows the microstructural characteristics observed or measured along with its variations. It depicts that for higher plate inclination angle the average grain

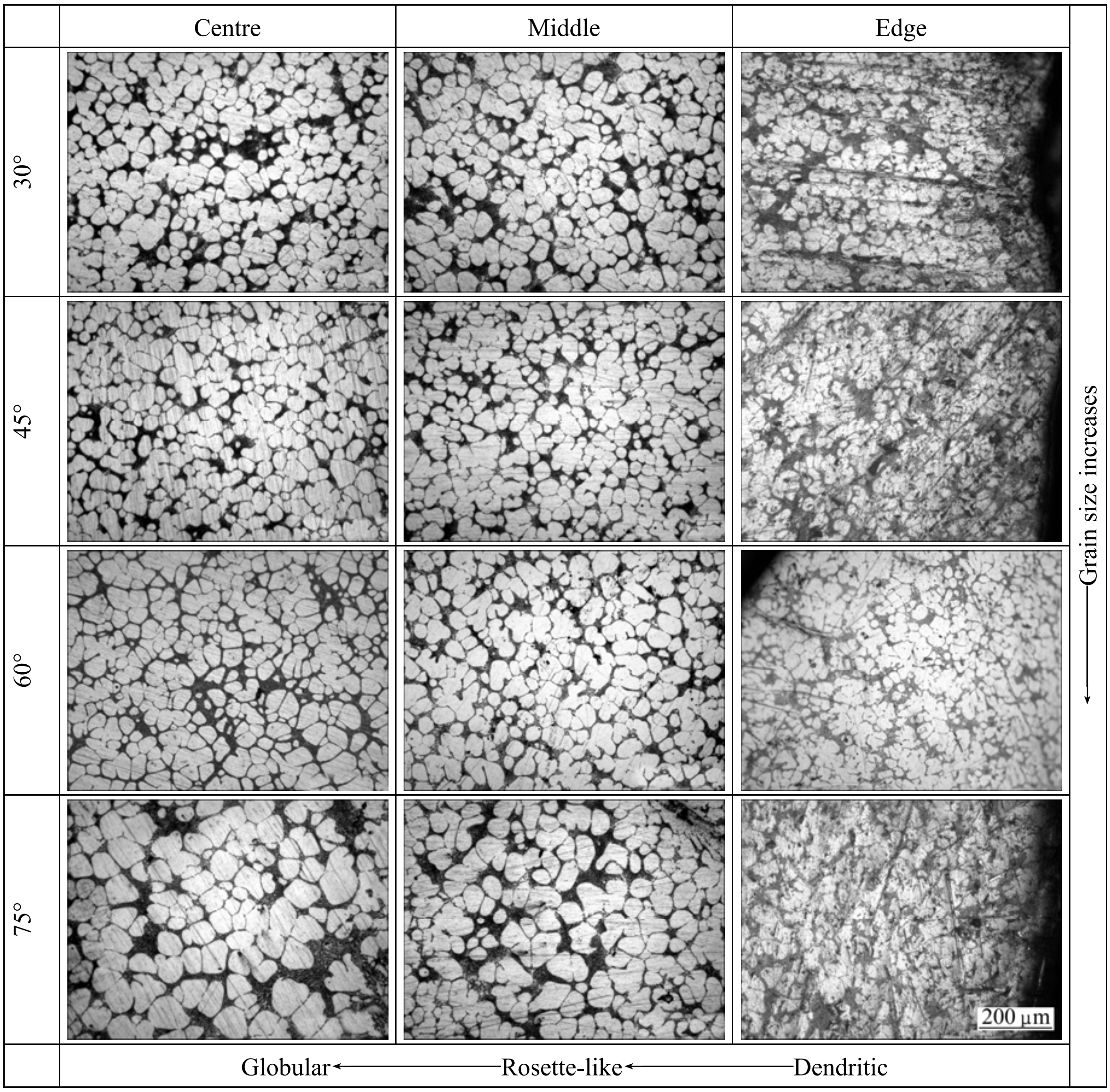

Fig. 6 SEM images of representative microstructures of semisolid cast billets produced at different plate inclination angles

size of α particle is more, whereas, the shape factor, the fraction of primary α-phase and the grain density are less. Lesser residence time or solidification time on the plate wall causes less dendritic fragmentation, breakage along with its transport, resulting in the evolution of relatively coarse microstructure. Figure 7 also shows the non-uniformity of the microstructural characteristics in the radial direction. It shows decrease in the grain size, shape factor and fraction of primary α-phase, and increase in grain density in radially outward direction (from centre to edge of the stated semisolid cast billets).

For the oblique plate semisolid cast billet with plate inclination angle of 30°, the average grain size decreases from 50 μm at the centre to 22 μm at the edge through 46 μm at the middle (Fig. 7(a)). Correspondingly, the shape factor decreases from 0.87 at the centre to 0.4 at the edge through 0.83 at middle (Fig. 7(b)), and the primary α-phase fraction decreases from 0.85 at the centre to 0.62 at the edge through 0.82 at the middle (Fig. 7(c)). The grain or particle density increases from 270 at the centre to 525 at edge through 290 at the middle (Fig. 7(d)). Likewise, for the billets cast with other plate inclinations (45°, 60° and 75°), the variations of average grain size, shape factor, primary α-phase fraction and grain density follow a similar trend, as shown in Fig. 7.

This demonstrates that the plate inclination angle definitely influences the final microstructure of the semisolid cast billets which affects the average grain size, shape factor, fraction of α-phase and particle or grain density in turn.

3.2.3 Microstructure morphology of heat treated billets

To improve the surface quality, the stated semisolid cast billets were reheated up to slightly above the solidus temperature of 580 °C by induction heating. The representative samples were prepared from the heat treated billets to snap micrograph images at the centre,

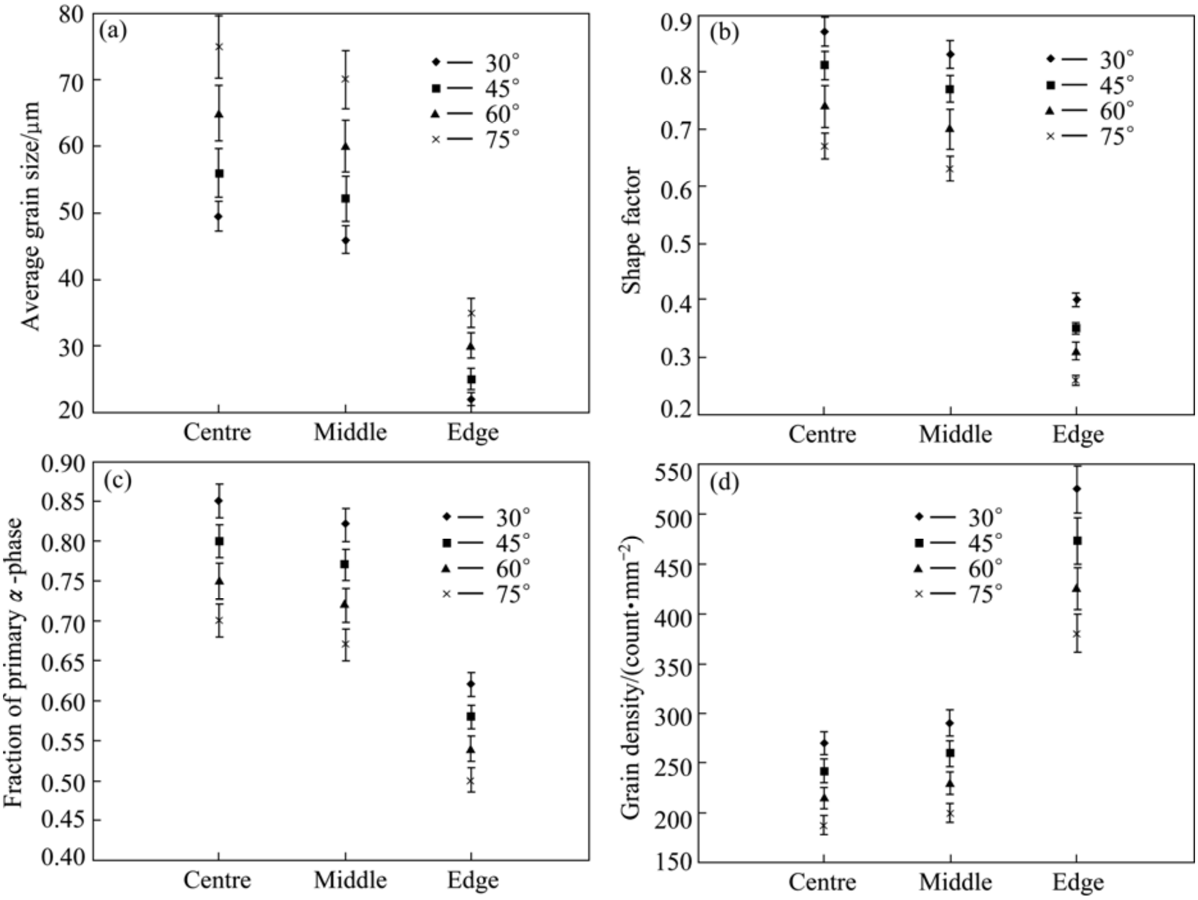

Fig. 7 Microstructure characterization of semisolid cast billets at different plate inclinations: (a) Grain size versus location; (b) Shape factor versus location; (c) Fraction of primary α-phase versus location; (d) Grain density versus location

middle and edge using Leitz optical microscope for quantitative and metallographic analysis.

Figure 8 shows the representative microstructures of the heat treated billets thus produced. Here, nearly uniform and globular microstructure is observed from centre to edge of each heated treated billet. It may be due to the temperature uniformity from the centre to edge of the billets because of isothermal holding in the induction furnace for about 10 min. However, the primary α-phase particles are observed to be still coarser for higher plate inclination.

This demonstrates that the microstructure morphology certainly gets improved because of the induction heating. The results from the measurement of the grain size of α-phase particles, shape factors, primary α-phase fractions and the grain or particle densities along the radial direction of the heat billets are shown in Fig. 9.

3.2.4 Microstructure characterization of heat treated billets

Figure 9 shows the results obtained from the measurements of grain sizes, shape factors, eutectic fractions and the grain densities from the samples of the said semisolid cast and heat treated billets. The average grain size, shape factor, fraction of primary α-phase and grain density were found to be nearly uniform from centre to edge of each heat treated billet. However, the trends of variations in average grain size, shape factor, fraction of primary α-phase and grain density with plate inclination are the same for both the said billets. Also, it may be observed that the average grain size, shape factor and fraction of primary α-phase increase with the induction reheating, whereas grain density decreases with the same. It may be due to the fact that the particle coalescence occurs during isothermal holding causing amalgamation of small particles into bigger ones. The particle coalescence also leads to liquid entrapment in primary α-phase which is also observed in some cases.

Due to isothermal holding of the semisolid cast billet produced at plate inclination of 30°, the average grain size increases from 49 μm to 85 μm at the centre, and 22 μm to 75 μm at the edge through 46 μm to 80 μm at the middle (Fig. 9(a)). Correspondingly, the shape factor increases from 0.87 to 0.91 at the centre, and 0.4 to 0.79 at the edge through 0.83 to 0.87 at the middle (Fig. 9(b)). The primary α-phase fraction increases from 0.85 to 0.89 at the centre, and 0.62 to 0.8 at the edge through 0.82 to 0.86 at the middle (Fig. 9(c)). Also, the grain or particle density decreases from 270 to 210 at the

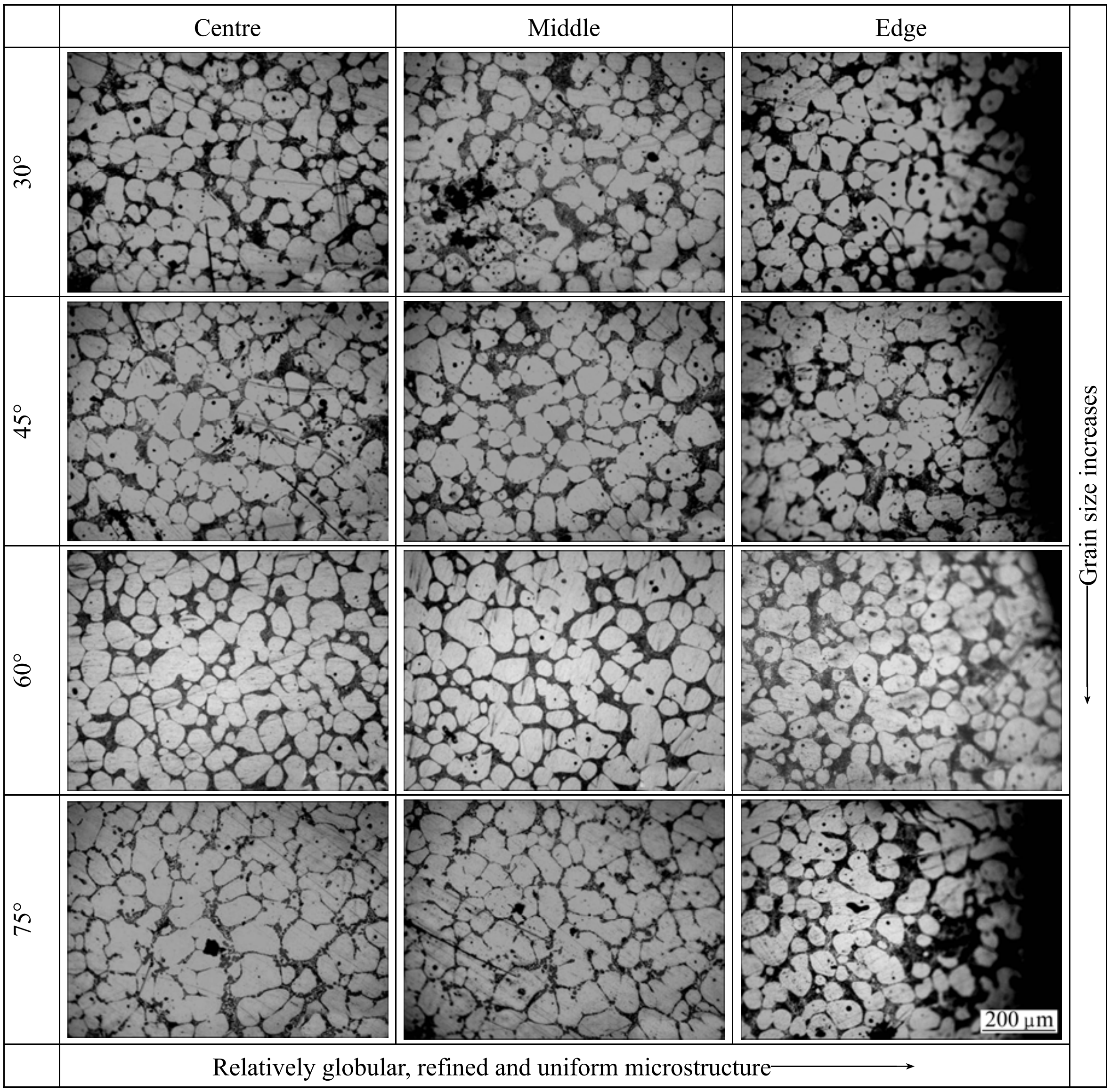

Fig. 8 SEM images of morphology of heat treated billets at different plate inclinations after isothermal holding

centre, and 525 to 230 at edge through 290 to 220 at the middle (Fig. 9(d)). Likewise, as shown in Fig. 9, the variations of average grain size, shape factor, primary α-phase fraction and grain density follow a similar trend for the billets cast with other melt pouring temperatures of 45°, 60° and 75°.

This clearly demonstrates that the heat treatment of semisolid cast billets involving isothermal holding (slightly above solidus temperature of A356 alloy) certainly affects the final microstructure of the heat treated billets, which influences the average grain size, shape factor, fraction of α-phase, and particle or grain density in turn.

4 Conclusions

1) The influences of two key process parameters namely melt pouring temperature and plate inclination angle on solidification and microstructure were comprehensively investigated. It was observed that the slurry quality and the final microstructural properties such as average grain size, shape factor, primary α-phase fraction and grain density were greatly controlled by the stated key parameters. The production of semisolid slurry in addition to the non-dendritic billets using an oblique plate sheds new light in the field of material processing.

2) Temperature of semisolid slurry at plate exit increases with increasing melt pouring temperature or plate inclination angle. The solid fraction of slurry at plate exit decreases with increasing melt pouring temperature or plate inclination angle. The grain size of primary α-phase particle increases with increasing melt pouring temperature or plate inclination angle. The shape factor, fraction of primary α-phase and particle density decrease with increasing in melt pouring temperature or

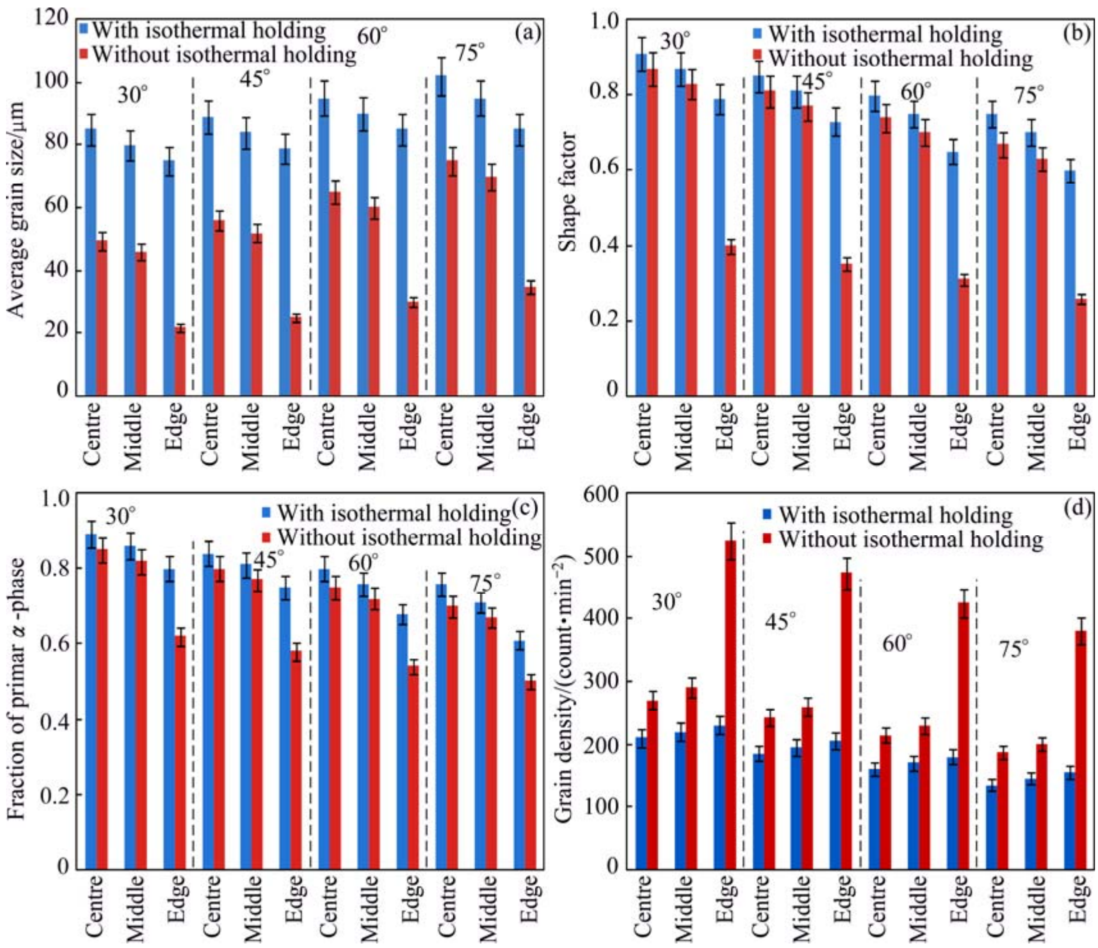

Fig. 9 Microstructure characterization of heat treated billets at different plate inclinations after isothermal holding: (a) Grain size versus location; (b) Shape factor versus location; (c) Primary α-phase fraction versus location; (d) Grain density versus location

plate inclination angle. These pronounced variations can be attributed to the delay in solidification at higher melt pouring temperature and less residence time or solidification time at higher plate inclination angle.

2) For the oblique plate semisolid cast billet produced at melt pouring temperature of 625 °C and plate inclination of 60°, the average grain size decreases from 65 μm at the centre to 30 μm at the edge through 60 μm at the middle. Correspondingly, the shape factor decreases from 0.74 at the centre to 0.31 at the edge through 0.7 at middle, and the primary α-phase fraction decreases from 0.75 at the centre to 0.54 at the edge through 0.72 at the middle. The grain density increases from 215 at the centre to 425 at edge through 230 at the middle. The trend is similar for billets cast with other melt pouring temperatures or plate inclinations. This microstructural inhomogeneity can be due to non-uniform cooling from centre to edge of the billets.

3) Due to isothermal holding of the semisolid cast billet produced at melt pouring temperature of 625 °C and plate inclination of 60°, the average grain size increases from 65 μm to 95 μm at the centre, and 30 μm to 85 μm at the edge through 60 μm to 90 μm at the middle. Correspondingly, the shape factor increases from 0.74 to 0.8 at the centre, and 0.31 to 0.65 at the edge through 0.7 to 0.75 at the middle. The primary α-phase fraction increases from 0.75 to 0.80 at the centre, and 0.54 to 0.68 at the edge through 0.72 to 0.76 at the middle. Also, the grain density decreases from 215 to 160 at the centre, and 425 to 180 at edge through 230 to 170 at the middle. Likewise, a similar trend follows for the billets cast with other melt pouring temperatures or plate inclinations. This can be due to temperature uniformity across the entire domain of the billets during induction reheating.

4) With the stated experimental conditions, it is observed that the melt pouring temperature of 625 °C with plate inclination of 60° gives fine and globular microstructures and is the optimum one as there is absolutely no possibility of sticking of slurry to the plate wall. Because little lower melt pouring temperature will accelerate onset of solidification, and little lower plate inclination will enhance residence time or solidification time, resulting in relatively higher solid fraction of slurry,

causing slurry to become more viscous. Whereas, little higher melt pouring temperature or plate inclination leads to relatively coarser microstructure owing to inadequate shearing.

Acknowledgments

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熔体浇注温度和板倾斜度对倾斜板制备 A356 铝合金的凝固和显微组织的影响

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摘　要：采用倾斜板制备 A356 铝合金半固态浆料。通过倾斜板底部的逆流水冷却使 A356 合金熔体在流下倾斜板时发生局部凝固，从而导致在板壁上形成连续柱状枝晶。由于强制对流作用，这些树枝晶被折断成等轴和破碎的晶粒，然后被连续冲洗而在斜板出口形成半固态浆料。熔体浇注温度是影响凝固组织的重要条件，而倾斜度为优质半固态浆料提供必要的剪切作用。将得到的浆料在金属模具中凝固以制备理想显微组织的半固态铸造坯料。然后，通过热处理以提高半固态铸造坯料的表面质量。对半固态铸造和热处理后坯料的显微组织进行分析。研究熔体浇注温度(620，625，630 和 635 °C)和板倾斜度(30°, 45°, 60°和 75°)对斜板制备 A356 铝合金的凝固和显微组织的影响。结果表明：在 625 °C 的熔体浇注温度和 60°斜板倾角时，A356 铝合金具有细小和球状的晶粒，是最佳的显微组织。

关键词：A356 铝合金；半固态；斜板；浆料；熔体浇铸温度；斜板倾角

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