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Study Conditions of Aluminum Billets for Relationship between Precipitated Phases and Homogenizing Temperature with Different Cooling Methods

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Abstract

In producing cast aluminum billets for using in extruded profile production, homogenization is one of the significant steps of the process. This project examined a suitable homogenizing temperature for usage in manufacturing besides common condition. Computerized fluid dynamics and image analysis solution were techniques to identify the relationship between the area fraction of precipitated phases and homogenizing temperature with different cooling methods. Temperature gradient pattern revealed that soaking temperatures at 575˚C and 565˚C are suitable conditions to be used in manufacturing. Furthermore, area fraction calculation showed that the area fractions of precipitated phases of each cooling method were not significantly different.

Key words: Aluminum billet, Homogenization, Precipitated phase, Cooling

Introduction

One of the energy goals of aluminum billet manufacturers is to save energy; as a result, they developed an internal database where a large number of energy saving ideas is made accessible to their plant energy teams. One viable idea is to reduce the consumption of large amounts of energy in heat treatment of aluminum billet via homogenization which means to improve the properties of as-cast billets. According to the as-cast microstructure, Mg_2Si (precipitated Mg-Si phase) are mostly found as particles in the interdendritic areas of AA6063 billet along with other precipitated phases (β-AlFeSi, Al-Mn-Fe-Si, and Cu-Al) in microstructures. These phases cause reduction of forming ability of billet during extrusion, hence suitable heat treatment is needed to dissolve these precipitates in order to control billet properties before extrusion [(1, 2)].

Homogenization involves heating the billet to a temperature between 510°C to 600°C, the temperature being closely controlled to prevent any incipient melting in the interdendritic regions. An appropriate soaking time and subsequent cooling rate must also be selected to provide optimum workability and final properties in wrought sections. Furthermore, a high solution heat treatment temperature increases solubility of the as-cast intermetallics, while increased cooling rate reduces particle sizes of any Mg-Si phase that may form via precipitation during cooling.

Large precipitated particles form owing to slow cooling from homogenizing temperature, whereas faster cooling retains a substantial amount of Mg and Si in solid solution. Mg_2Si particles which are large enough have lower tensile properties. Homogenization and subsequent water cooling can decrease the precipitated constituents around the grain boundary. Decreased precipitation around the grains reasons to become hard of the alloys because substantial amount of Mg and Si were dissolved in solid solution. [(3)]. In other words**,** very fast cooling yields a solid solution that is supersaturated with Mg_2Si. Consequently, resistance to deformation will be higher, and extrusion velocity will be lower. On the contrary, a slow rate of cooling yields a solid solution containing very little magnesium and silicon, all the Mg_2Si being thrown out of solution as coarse precipitates. Resistance to deformation will be low, so that extrusion velocity will be high [(3)].

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Computer simulation has become popular in manufacturing recently, such as determining the conditions of the extrusion process at varying ram speeds to prevent the extrude temperature from rising excessively [(4)] and determining an optimal homogenization temperature of aluminum alloy extrusion billet in order to improve manufacturing [(1)].

The aim of the study was to investigate the summary of area fraction of precipitated phases of different cooling methods with the different homogenizing temperatures. Using COSMOSFlowWorks™ to determine the optimal soaking temperature in simulation results would be simultaneous with quantification techniques for determining the content of precipitated phases so that assuring computer simulation results, for example, determining the average volume fraction of the second phase by point-counting method [(5)]. According to the quantification technique, image analysis technique would result in the average area fraction of these phases in this project.

Table 1. Chemical composition of examined aluminum billet (% by weight).

Al	Mg	Si	Fe	Cu	Mn	Zn	Cr	Ti
98.85	0.45	0.42	0.177	0.02	0.03	0.02	0.01	0.01

Materials and Experimental Procedures

Preparation of Samples

Samples, 125 mm diameter AA6063 billets, were provided by an aluminum billet manufacturer. Table 1 reveals the chemical composition of the billets that is the same as common alloy grade.

Heating and Cooling

Experiments were carried out in homogenizing furnace and cooling furnace. During both heating and cooling, aluminum billets were stacked in the horizontal furnace; the diagram of stacking of billets is displayed in Figure 1. The conditions of homogenizing temperature were 585˚C, 575˚C and 565˚C; subsequently, billets were cooled via different methods, i.e. quenching in water, forced air cooling, and sucked air cooling. Figure 2 shows producing conditions of aluminum specimens.

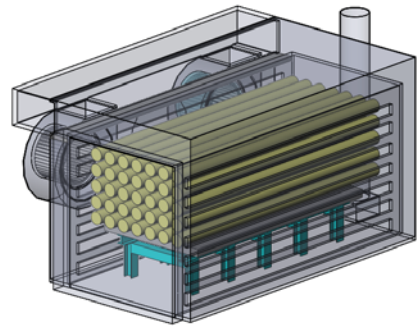


Figure 1. Model of stacking of billets in heating furnace.

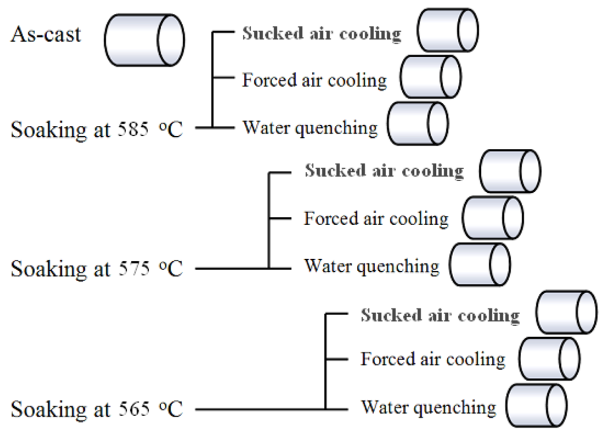


Figure 2. Conditions of specimens, i.e. as-cast and homogenizing at 585˚C, 575˚C and 565˚C cooled by different methods.

Results and Discussion

According to homogenization, values of heating rate (duration of heating up and soaking) and cooling rate were recorded as shown in Figures 3(a) and 3(b), respectively. Before the soaking temperature was reached, heating up duration from 200˚C to 585˚C was two hours and soaking was then approximately two hours. The cooling rate of homogenized billets at 585˚C, 575˚C and 565˚C with sucked air cooling, forced air cooling, and water quenching are summarized in Figures 4(a)-4(c), respectively. Cooling rate of each soaking temperature condition shows a similar trend, sucked air cooling specimen shows the lowest cooling rate, whereas water quenching specimen shows the highest cooling rate. Furthermore, all values are lower than 150˚C/hr; the highest cooling rate for producing AA6XXX. Computerized fluid dynamics (COSMOSFloWorks™ 2007) simulated temperature gradient pattern of billets while they were heating (Figure 5). The relative temperature was found to be between 560˚C to 600˚C with higher temperature at closer distance from burner of heating furnace. This leads to further experiments at 575˚C and 565˚C of soaking temperature (the same soaking duration) in order to compare their billet structures with the structure of 585˚C homogenized billets.

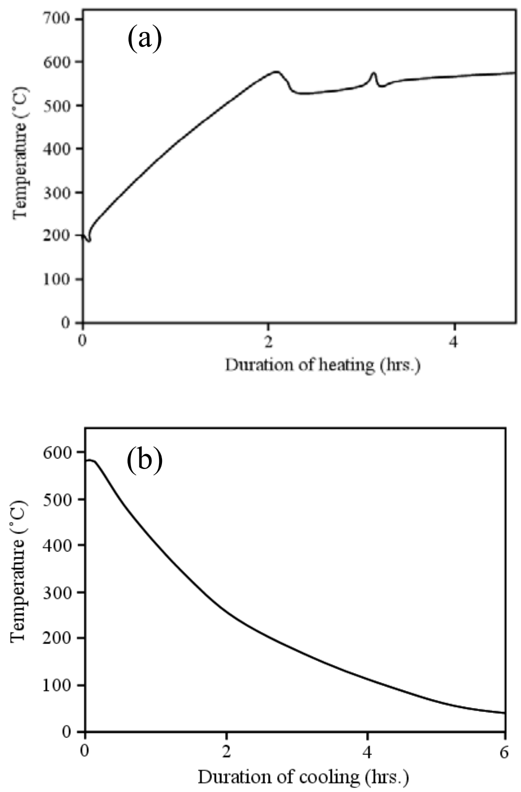
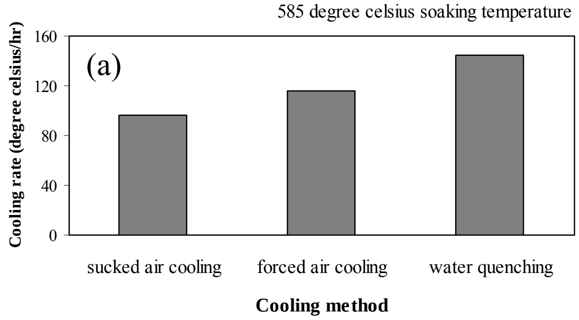


Figure 3. The relationship between temperature of aluminum billets and time during (a) homogenizing at 585˚C and (b) cooling.



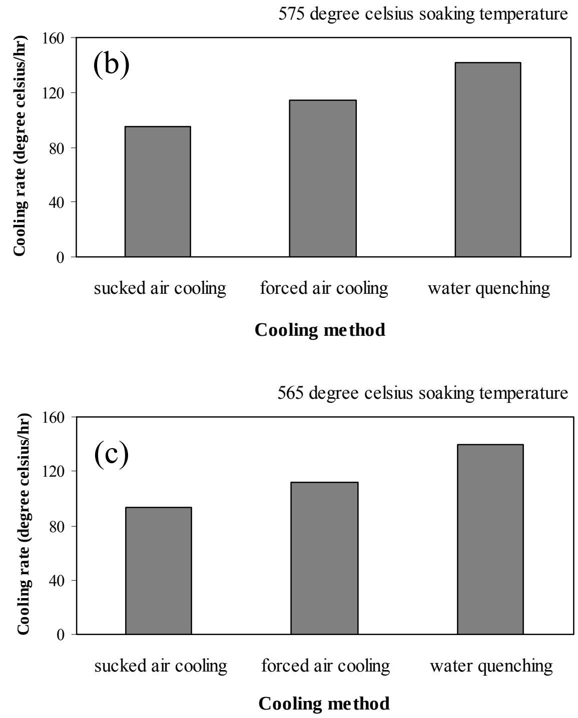


Figure 4. A summary of cooling rates of soaked billet at (a) 585˚C, (b) 575˚C and (c) 565˚C with sucked air cooling, forced air cooling, and water quenching.

Microstructures of the specimens were quantified by optical microscope (OLYMPUS BX41M). Specimens of each condition were sampled, and then each of them was cut to size (30 mm. cubes while examining position was 3 cm. from surface of billet), ground, polished and etched prior to studying the structure. Regarding as-cast structure, β-AlFeSi intermetallics and Mg_2Si (block habit) were distributed in the matrix as illustrated in Figure 6(a), whereas homogenized billet contained α-AlFeSi because the β-AlFeSi phase broke up into beads of rounded α-AlFeSi. In addition, Mg_2Si particles were dissolved during solution treating. The transformation can be clearly seen in Figure 6(b). Image-Pro® Plus was used to quantify area fraction of the precipitated phases by the color contrast technique. Comparison of area fractions of specimens is represented in Figure 7. It can be observed that for each of cooling method, the relationship was nonlinear and the range of area fraction of phases was from 1% to 2.5% (the value of as-cast billet was about 5%). Regarding each soaking temperature, area fraction of precipitated phases of water quenching billets had the lowest value compared to that of the other cooling methods.

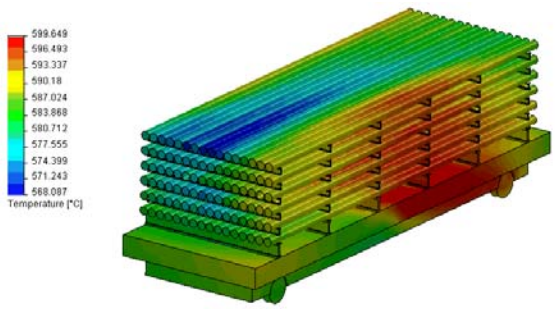


Figure 5. Temperature gradient of the stacking of billets during Homogenization analyzed by COSMOSFloWorks™.

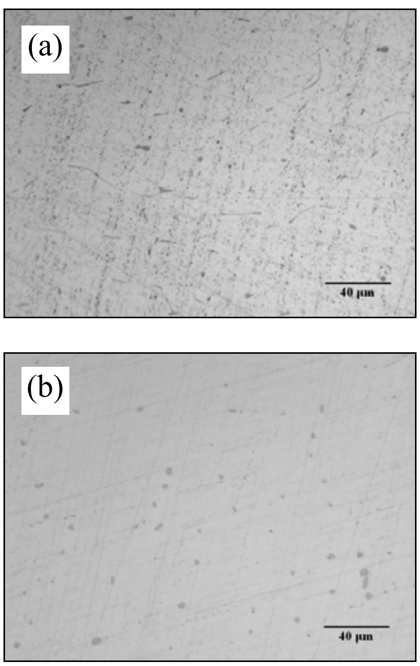


Figure 6. Microstructure of (a) as-cast billet contained β-AlFeSi and Mg2Si and (b) homogenized billet contained α-Al(FeMn)Si. Mg2Si precipitates were dissolved.

Owing to fast cooling of water quenching retained a substantial amount of precipitated phases in solid solution and reduced particle sizes of precipitated phases. On the contrary, the highest value of area fraction of sucked air cooling billets indicated that this was due to Mg_2Si being thrown out of solution as coarse precipitates, large particles of Mg_2Si, and a solid solution containing very little magnesium and silicon. As a result, resistance of deformation of the billets which had large precipitated phases would be low, but extrusion velocity would be high [(3)]. In this study, the area fractions of precipitated phases of each soaking temperature are similar. Therefore, some properties, i.e. hardness, tensile strength and extrusion velocity of billets may not be significantly different.

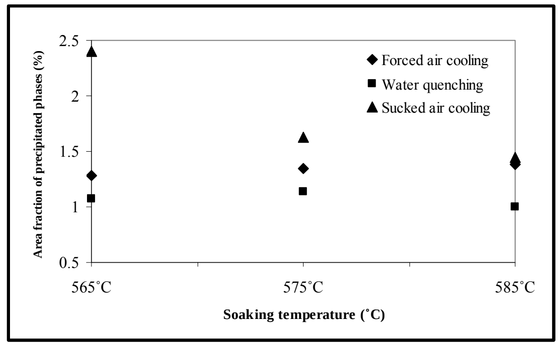


Figure 7. A summary of area fraction of precipitated phases of sucked air cooling, forced air cooling and water quenching with the soaking temperatures of 565˚C, 575˚C, and 585˚C. The as-cast structure contained 5% area fraction (not shown in the plot).

Conclusions

Besides common homogenizing temperature, the temperature gradient pattern gave a hint that soaking temperatures at 575˚C and 565˚C are suitable conditions to be used in manufacturing. This investigation confirmed by area fraction calculation shows that the area fractions of precipitated phases of each cooling method were not significantly different. To decrease heating-up time and consumed energy of homogenization of aluminum billet manufacturing by soaking at 575˚C or 565˚C is an interesting energy saving idea. However, mechanical properties testing should be used for further assurance that the comparing structure method is accurate.

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