The Effect of Orbital Shaking on the Microstructure of Lost Foam Cast A356 Aluminium Alloy

Öznur Kılıç, Serhat Acar, Kerem Altuğ Güler
Yıldız Technical University / Turkey

Abstract

As with all metallic materials, the mechanical properties of aluminium alloys are directly related to the microstructure. In both aluminium wrought and casting alloys, it was observed that mechanical properties increased due to fine and uniform microstructure during the casting process by applying grain refining process. By virtue of the fine and equiaxed microstructure, the material shows high strength and ductility. For these reasons, grain refinement is widely applied in the casting of aluminium alloys. In the literature; grain refinement processes can be realized with different methods. These techniques can be listed as; thermal, chemical and dynamic methods. In this study, orbital shaking method which lays among the dynamic methods has been investigated. Within the scope of this study, as an alternative way to the traditional mechanical vibration method; A356 aluminium casting alloy was cast by lost foam casting method (LFC) with the orbital shaking. In the experiments, the effects of the shaking rate were investigated for resulted casting parts. Expandable polystyrene (EPS) patterns (170x50x40 mm) with the density of 10 kg/m-3 were used in the moulding process. The castings were performed at 720 °C for 50, 100, 150 and 200 rpm of orbital shaking rate. The reference sample was cast at static state at the same temperature. The microstructure samples were removed from the edges and the centre parts of these samples. Metallographic examinations were carried out via image analyzer assisted optical microscope by means of calculating shape factor, grain size, and SDAS (secondary dendrite arm spacing). In addition, the densities of the samples were measured for the porosity evaluation by Archimedes' principle. The hardness values of the samples were calculated by Brinell hardness method.

1. Introduction

Aluminium casting alloys have various properties such as excellent pourability, corrosion resistance, processability, high electrical and thermal conductivity, high strength/weight ratio, weldability, conductivity and optimum surface quality. Therefore, they are widely used in the aerospace and automotive industries where complex and thin-walled applications are needed. Various casting methods such as conventional casting, permanent mold and pressure die casting are used for casting of aluminum alloys. However, defects such as misrun, porosity, oxide inclusions may occur in the aforementioned casting methods. In addition to these, mold design should be modified in the die casting and since solidification is very fast, there are difficulties in the production of thin walled parts. Also it is not always possible to obtain the dimensional precision and required surface quality with a method like sand casting process [1, 2].

The lost foam casting (LFC) was developed and patented in 1958 by Shroyer as a full mold process [3-5]. Aluminium cylinder blocks, heads for automotive and marine engines, automotive crankshafts as spherical casting materials, housing for grey cast iron electrics motors, gray cast iron ignition plugs are the best known applications of this method [6]. The lost foam casting method (LFC) is a casting method using a non-permanent, in other saying disposal patterns made of a polymer-based material. Compared to other casting methods, it is relatively new in casting method, the polymeric pattern materials are prepared first and they are assembled together to constitute the whole part with internal transitions if necessary. After the assembly process, water-based refractory slurry coating is applied. The coated pattern is molded in a flask with dry and loose sand with assistance of vibration. After whole moulding process, liquid metal is poured directly onto the pattern. Due to direct degradation of polymeric pattern material after the contact with the liquid metal, there is no extra step pattern removal. The formed degredation products are discharged to the loose sand through refractory coating [7-8].

The LFC process has many advantages compared to other casting methods. There is no need to use core to produce complex geometry, the patterns are usually inexpensive and require minimal processing thanks to their close size tolerance, lack of separation line and good surface quality. In addition, it provides low process costs due to the lack of binder and reusability of sand. This helps to make the method environmentally friendly [9-11].

On the other hand, the LFC casting method has various disadvantages such as liquid-metal penetration due to insufficient coating of the pattern, gas cavities in the casting products and shrinkage defects [12]. The process parameters must be taken into account throughout the entire process in order to avoid and disadvantages and for the sake of good quality of the final product. These process

parameters are; the type and the density of the pattern, the type and the permeability of the sand, the casting speed, the quality of the refractory coating, which provides the required surface quality and prevents the sand penetration [13].

Mechanical properties should not be considered independent of microstructure. The aim of the producers is to obtain optimum mechanical properties by having a minimum defects in the produced products. The fine and equiaxial microstructure obtain by grain refinement in general casting applications provides high strength, ductility, increases fluidity, reduces hot tear and micro porosity [14-15].

Many methods have been developed in order to obtain refined microstructure. These methods can be divided into four main groups. These groups can be classified as dynamic techniques, controlled solidification, chemical grain refinement and employment of severe deformation [16].

The mechanism of dynamic grain refinement techniques depends on the breaking of dendritic arms in the physical sense. The broken dendrites represent a base for the nucleation of new grains. During casting with orbital shaking process the entire mass rotates in a fixed orbit around the central axis of the mold as whole. In this way, dendritic fragmentation is provided by shaking without damaging the mold. For a sensitive method such as the lost foam casting technique, it is essential to employ sensitive methods for dynamic grain refinement. In this study, orbital shaking as an alternative method to mechanical vibration was applied in the LFC process of A356 alloy.

2. Experimental Procedure

In this study expandable polystyrene (EPS) pattern materials were employed for the LFC of A356 alloy. The density of the patterns was calculated as 10 kg/m-3. The dimensions of the polymeric patterns were approximately 170x50x40 mm. Prior to the casting process, the foam patterns were coated with water based refractory slurry (Metko Hüttenes Albertus Disopast 76) to prevent the sand collapsing into the liquid metal. After the coating step, the patterns were allowed to dry for 24 hours under room conditions. The patterns were placed in the dry-loose sand until a certain height and the vibration is applied to the loose sand to make the mould more compact and feeders were used as a pouring basin.

Al-Si-Mg casting alloy A356 with a chemical composition as given in Table 1 was melted in clay/graphite crucible by using electrical resistance furnace and poured at 720°C without any grain refining and modification process.

Table 1. Chemical composition of A356 alloy (mass fraction %)

Al	Si	Mg	Cu	Mn	Zn	Cr
Bal.	7.288	0.354	0.0011	0.028	0.008	0.003

The reference specimen was produced with casting under static condition. The molds prepared for the other castings were placed in an orbital shaker and the castings were performed at 50, 100, 150 and 200 rpm. Figure 1 shows a prepared mold on the orbital shaker.



Figure 1. Lost foam casting mould on orbital shaker.

The specimens were taken from the bottom of the cast product for metallographic examination. Both the edge and the center parts of the specimens were investigated for examining the effects of orbital shaking through the whole section. Specimens were grinded, polished and finally etched with Keller solution. Metallographic examinations were carried out with image analyser assisted Nikon Eclipse MA100 light microscope by means of calculating shape factor, grain size and secondary dendritic arm spacing. Afterwards, densities of the samples were measured by Archimedes principle with Precisa 205. Hardness values of the specimens were measured by Brinell hardness device with 2.5 mm ball diameter and 62,5 kgf load.

3. Results and Discussion

After castings were made, the first observation was made on the patterns and cast parts. Castings were accomplished without any failure any exact shape of the foam patterns was obtained in each casting process. Microstructures that were taken from static and cast with orbital shaking specimens are given in Figure 2. Typical microstructure of the hypoeutectic Al-Si alloys was observed in all specimens. Light gray areas represent primary aluminium phase (α-Al), dark gray and needle shaped areas represent the eutectic silicon. For all castings performed, images were taken from the edge and the center of the sample taken from the bottom of the cast parts.

Dynamic grain refining is a mechanism that breaks the growing dendrites during solidification and increases the total number of grains by creating new nuclei. Microstructure manipulation with orbital shaking can be an effective method for lost foam casting. The centrifugal force generated by the orbital shaking shows a shear force on the structure which starts to solidify. This shear force is

thought to be particularly effective on the primary (α-Al) grains of the alloy studied in this project.

In microstructure investigations, it was observed that the structure with relatively coarse grains and wide dendrite spacing undergone some changes with the effects of orbital shaking. Fine dendrites and rosette like morphology of orbital shaking cast specimens can be seen in the microstructures given in Figure 2.

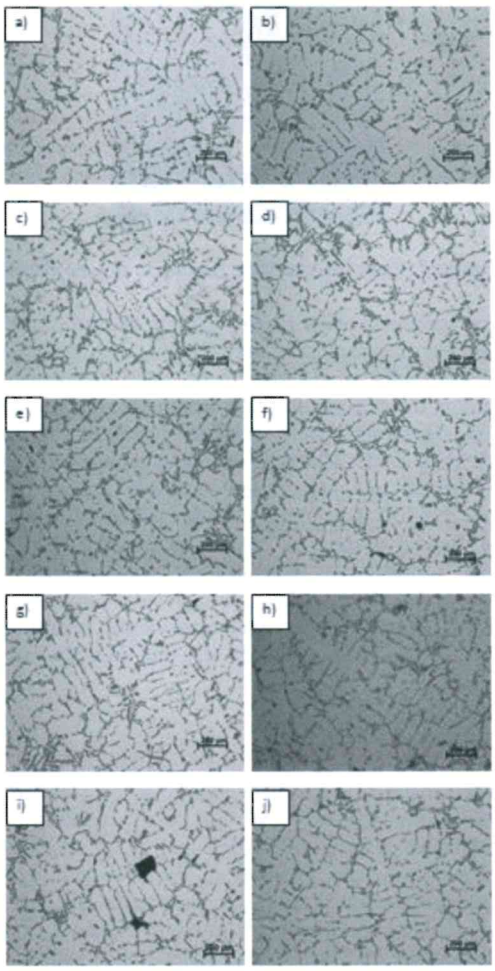


Figure 2. Microstucture of specimens by taken optical microscope,50x magnification. a)static-edge, b)static-center, c)50 rpm-edge, d)50 rpm-center, e)100 rpm-edge,f)100 rpm-center, g)150 rpm-edge, h)150 rpm-center, i)200 rpm-edge, j)200 rpm-center

SDAS values were measured from different regions of the specimens. The relation of the SDAS value with the shaking rate is shown in Figure 3.

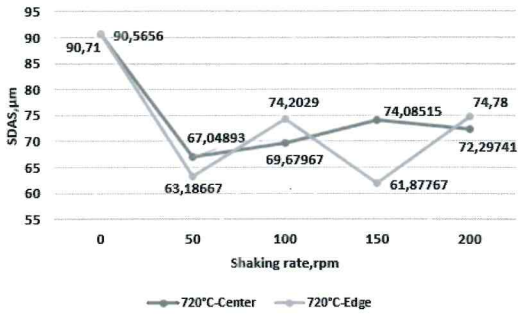


Figure 3. Effect of shaking rate on SDAS.

It was observed that the SDAS value, which is approximately 90 µm in both the edge and the center region, started to decrease with the shaking effect and stabilized for increased shaking rates. The decrease in SDAS may characterized by a slight increase in hardness. Even if the centrifugal force generated by shaking creates a G force sufficient to produce the rosette structure, it can be said that it was not enough to break up the formed rosette structure. Shape factor and grain size measurements were made in order to analyze microstructure in more details. The area (Aα) and perimeter (Pα) of the primary particles were measured for calculating the shape factor. The calculated values were substituted in the formula given below.

$$S.F.=(4\pi A\alpha/P\alpha 2) \quad (1)$$

The calculated values range from 0 to 1. As we approach 1, sphericity increases. The sphericity factors depending on the changing shaking rates were given in Figure 4.

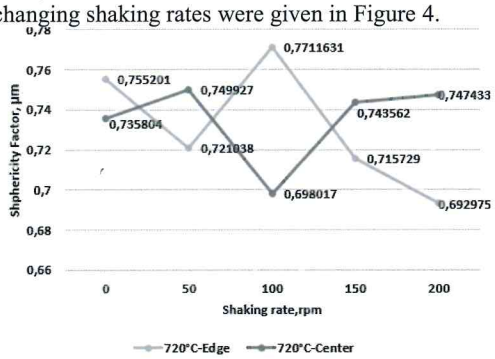


Figure 4. Effect of shaking rate on shape factor

Despite the rossete-like grain formation, some dendritic structure dominant regions were also observed within orbital shaking specimens. Therefore, no significant difference was found in terms of sphericity when compared to static casting.

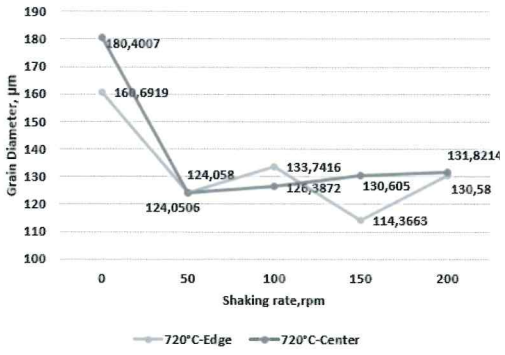


Figure 5. Effect of shaking rate on grain diameter

Figure 5 shows the variation of the measured grain diameters with shaking rate. As seen in Figure 5, the grain diameters were measured as 160 µm in the edge area and 180 µm in the center for the static casting. Orbital shaking caused a significant drop in the grain size compared to static casting product. As seen in Fig. 2, the images taken from the edges do not differ much from central images structurally. The absence of large differences display that structural uniformity is maintained in a section of 50 x 40 mm and that shaking does not form a gradient in the microstructure.

Densities of the specimens were calculated by Archimedes principle in order to evaluate the effects of shaking rate on the cast parts. Densities of all samples were given in Table 2.

Table 2. Density values of the samples

Sample	Density (g/cm^3)
Static	2,573995
50 rpm	2,635105
100 rpm	2,62849
150 rpm	2,610325
200 rpm	2,59056

According to Table 2, it can be deduced that the lowest density belongs to static cast with a value of 2.57 g/cm3. With the increase in shaking rate the density value increased slightly. However, it was observed that there was a slight decrease in the density at increased shaking rates compared to 50 rpm. The density value at the shaking rate of 200 rpm is close to the density value which is almost static cast. It can be said that low and medium shaking rates are beneficial for feeding of the casting part during solidification, and with the help of that micro porosities between dendrite arms can be filled properly. As 200 rpm shaking rate caused disruption during solidification step, unfortunately proper feeding of whole casting part could not be obtained.

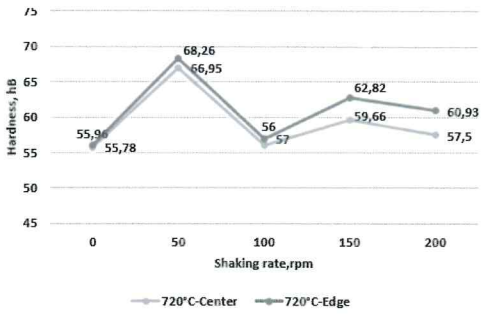


Figure 6. Effect of shaking rate on hardness

Figure 6 shows hardness values of the specimen. The SDAS value, which showed a significant decrease at the beginning, increased the hardness value. However, as the shaking at medium and high speeds resulted in an increase in the SDAS value, the hardness decreased. It is thought that a good feeding at low speeds by shaking and the lack of microporosity between dendrites is encouraged to increase the hardness.

4. Conclusion

- The orbital shaking process can be used as one of the dynamic grain refining methods.
- Compared to static castings, a significant decrease in SDAS values was observed with the shaking effect. However, too much speed can cause the solidified primary aluminum grains to come together and form a rough microstructure. Decrease in SDAS value had relatively positive effect on hardness.
- Instead of coarse grained structure, both the rosette grains and dendrites with higher length/width ratio were formed by shaking effect.
- An increase in density was observed with the effect of shaking. However, as the high shaking rate cause splashing, the reduced amount of metal affected the feed adversely.
- The grain size values of the edge and center regions are close to each other. It has been observed that the shaking did not disturb the structural homogeneity across the studied section.

References

[1] W. Jiang, Z. Fan, D. Liu, D. Liao, X. Dong, and X. Zong, Material Science and Engineering: A, 560 (2013) 396–403.

[2] L. Wang et al., Material Science Engineering: A, 673 (2016) 362–372.

[3] J.-H. Kuo, J.-C. Chen, Y.-N. Pan, and W.-S. Hwang, Material Transaction 44(10) (2003) 2169–2174.

[4] P. Kannan, J. J. Biernacki, and D. P. Visco Jr.,

Journal of Analytical and Applied Pyrolysis, 78 (2007) 162–171.
[5] H.F. Shroyer, "Cavityless casting mold and method of making same," U.S. Patent 2830343A,Apr.15, 1956.
[6] K. A. Guler,"Lost Foam Casting (Disposable Pattern)," Reference Module in Materials Science and Materials Engineering, Elsevier Ltd., 2016, Istanbul, Turkey
[7] D. A. Caulk, International Journal of Heat Mass Transfer,49 (2006) 2124–2136.
[8] M. R. Barone and D. A. Caulk, International Journal of Heat Mass Transfer,48 (2005) 4132–4149.
[9] K. A. Guler, A. Kisasoz, and A. Karaaslan, International Journal of Material Research, 102 (2011) 304–308.
[10] M. Karimian, A. Ourdjini, M. Hasbullah Idris, and H. Jafari, Transactions of Nonferrous Metals Society of China, 22 (2012) 2092–2097.
[11] H. Jafari, M. H. Idris, and A. Shayganpour, ," Transactions of Nonferrous Metals Society of China, 23 (2013) 2843–2851.
[12] H. R. Azimi, M. Rezaei, and F. Abbasi, Thermochimica Acta, 488 (2009) 43–48.
[13] T. Pacyniak and R. Kaczorowski, Archieves of Foundry Engineering, 11 (2011) 149–154.
[14] C. Limmaneevichitr, S. Pongananpanya, and J. Kajornchaiyakul, Materials & Design, 30 (2009) 3925–3930.
[15] N. Abu-Dheir, M. Khraisheh, K. Saito, and A. Male, Material Science and Engineering A,393 (2005) 109–117.
[16] R. G. Guan and D. Tie, Acta Metallurgica Sinica. (English Letters), 30 (2017) 409–432.