Engineering Solid Mechanics (2017) 9-14

Contents lists available at GrowingScience

Engineering Solid Mechanics

homepage: www.GrowingScience.com/esm

Effect of angle, length and circulation cooling system on microstructure A360 Aluminum alloy in semi-solid metal forming by cooling slope method

Mohammad Mahdi Kaykha[a*]

[a]*Department of Mechanical Engineering, Faculty of Engineering, University of Zabol, Zabol, Iran*

A R T I C L E I N F O

Article history:
Received 6 July, 2016
Accepted 30 October 2016
Available online
31 October 2016

Keywords:
Semi-Solid forming
Cooling slope method
A360
Microstructure
Circulation cooling system

A B S T R A C T

Application of cooling slope in casting is a relatively simple process with low equipment and processing costs, which is able to produce semi-solid slurries with different parameters such as pouring temperature, length and angle of slope plate, and plate type. In this study, the effect of angle and length of copper made slope plate on the microstructure of A360-Aluminum alloy is investigated. Microstructure study of metallographic samples in different conditions revealed that for 400mm slope length and 60° slope angle the optimum sphierized and homogenized microstructure is achieved. Also, under these conditions, the most hardness (77HB) was obtained, which might be because of suitable solidification conditions namely time and rate of shear stress. After finding the suitable conditions of slope length and angle, the effect of the circulation cooling system was examined; and the method with cooling system was found to result in more homogenized microstructure compared to ordinary method.

1. Introduction

The pioneer experiment leading to the discovery of rheocasting process was introduced by Spencer in 1970 (Fan, 2002a,b; Neuyebauer & Branch, 1999). Semi-solid metal (SSM) processing has nowadays been established as an advanced technology in the manufacturing of engineering components (Giordano & Chiarmetta, 2004). In this method, shear rate is applied to a molten metal which is on its solidifying range, and dendrite microstructure is broken and change to globular microstructure (Lee et al., 2005). There are different theories about globularizing mechanism at primary phase, of which two are more popular. The first theory, presented by Vogel and Zhang (2003) states that in the presence of shear rate, dendrites bend and break to lower the surface of their energy. The second theory, presented by Sumitomo et al. (2000) suggests that breaking dendrites is result of locally re-melting of dendrites in root. There are different ways to produce globular microstructure including mechanical stirring.

* Corresponding author.
E-mail addresses: mm.kaykha@gmail.com (M. M. Kaykha)

doi: 10.5267/j.esm.2016.11.001

Using this method, Fan (1981) produced thin shield parts, impossible to produce by conventional die-casting procedures. Semi-solid metal processing is used to produce metallic components with near-net shape and improve mechanical properties (Hoffmann & Toussaint, 1999). Cooling slope (CS) method can decrease dendritic phases because of the products in the globularization structure state. It is simple technology and an easy method to accomplish as compared to other methods; not to mention it decreases energy and machine costs (Haga & Suzuki, 2001; Findon & Apelion, 2004). Among all the techniques of SSF, the CS process is a simple route. The primary phase in the SSF alloy by the CS has been reported to become spherical after being re-melted in the semi-solid state (Fan et al., 2005). In thixoforming, the alloy is partially liquid only and the shrinkage is much less than that of a fully molten alloy. One problem of thixoforming, however, is the higher feedstock material price with a limited number of suppliers (Pibworth et al., 1996). There are famous techniques of SSM, such as magneto-hydro dynamic stirring (MHD), cooling slope, and mechanical stirring. Haghayeghi et al. (2005) have improved mechanical properties of A360 aluminum alloy 10% by mechanical stirring of molten alloy. Barabazon et al. (2002) have investigated the effect of mechanical stirring on microstructure and mechanical properties of aluminum alloys. They changed the dendrite microstructure of alloy to globular by mechanical stirring. MHD stirring is the most popular method as compared to the others. These methods use shear forces by applying a rotating electromagnet. Electromagnet-related problems include structure of primary solid phases and relatively non-uniform microstructures in the radial direction of produced ingots and high equipment costs (Rice & Mendes, 2001). On the contrast, cooling slope process needs very low-cost equipment with a flexible ingot size. Furthermore, CS method restricts the dendritic microstructures' growth observed in dendrite arm fragmentation. CS provides globular or spheroidal microstructure when heated at the semi-solid temperature level, with improved mechanical properties and longer die life compared to other methods (Bae et al. 2007). In CS process, the alloy with a modest amount of superheat is casted over an inclined cooling plate (Salarfar, 2004). Solid nucleuses are formed because of the contact between the melt and the slope plate, detached from the surface as a result of applied shear due to gravity force and melting flow. In CS method, various parameters such as superheat temperature, plate length and angle, material and die temperature and reheated can affect the final microstructure (Haga & Kapranos, 2002; Haga & Suzuki, 2001). A360 aluminum alloy exhibits many profits such as wear resistance, good weld capability, and high strength to weight ratio and excellent casting capability. Therefore, these alloys are suitable for automotive parts (Birol, 2007, 2008, 2009). In present work, the effect of length and angle and circulation cooling system on microstructures has been investigated to obtain suitable conditions CS casting parameters.

2. Experimental procedure

Chemical composition of A360 Aluminum alloy used in this work is shown in Table 1.

Table 1. The analysis of the A360 alloy used in the present investigation (wt. %)

Material	Si	Cu	Mg	Zn	Fe	Al
Wt%	9	0.29	0.29	0.11	0.42	89.85

In order to perform experiments, 1 kg of A360 Alloy was melted in a Silicon carbide crucible located at a resistance furnace set at 630°C, then molten alloy was cooled down to the pouring temperature of 610°C and was poured on the surface. Temperature was monitored with a k-type thermocouple inserted in a 4mm diameter hole drilled in the center of the slugs. The CS casting is involved pouring the molten A360 alloy over a 60 mm wide and 600 mm long, inclined copper plate into a permanent mold with a diameter of 65 mm and a depth of 150 mm. The plate was cooled by water circulation underneath. In order to avoid sticking of molten alloy and to facilitate a trouble- free melt flow, the surface of the inclined plate was coated by a thin layer of zirconium oxide. Then pouring was done on cooling slope in angles of 30° , 45°, 60° and with 300 mm, 400 mm, 500 mm of lengths, respectively. In order to compare the effect of inclined plate, a conventional casting pouring was into the same mold. However, after finishing, disc sections were cut and then standard metallographic samples were prepared. The samples were etched with a %0.5 HF solution before they were examined with an optical- microscope. The hardness of samples was measured in (HB) units with a load of 50 kgf and 2 mm diameter indenter.

3. Results and Discussion

3.1. Length and angle effect

Fig. 1 shows the microstructure of the as received A360 ingot which was directly casted into the cylindrical mold without flowing on the inclined plate. (α-Al) solid solution dendrites and interdendritic network of the eutectic phase, typical of conventionally cast aluminum ingots.

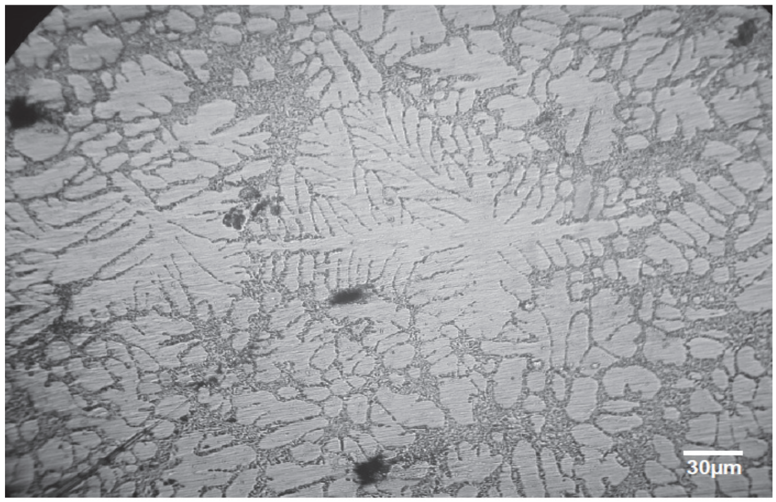

Fig. 1. Microstructure of the conventionally cast A360 alloy

It should be noted that the primary phase morphology has been completely transformed into a non-dendrite by pouring over cooling slope. Fig. 2, shows the microstructure of cast for different lengths. A comparison between Fig (2a) and (2b) shows that increase in the length of inclined plate up to 400 mm is seen due to decrease of dendrites phases. In the next step, the length increase from 400 mm to 500 mm was due to the increase in the size of (α-Al) phase. According to Fig (2a) the (α-Al) phases nucleation's detached of slope surface then moved by melt and before enough growth detached of end slope surface descend into the mold. Therefore, the majority of microstructure changed to rosette and solidification into mold. Increase in length (Fig 3b) was due to the increase of the time of shear stress and as a result more solid particles were detached in the mold. But, by increasing the length to 500 mm, shear stress is increased and causes more solidification over inclined plate resulting in more solid fraction before pour into mold. This condition may lead to increase in the size of (α-Al) phase and the structure appears to be coarser (α-Al) rosette as seen in 400 mm length.

When the melt is flowing over the surface of the inclined plate in 400mm, it creates fine and globular microstructure than other conditions. As seen in Fig (2b), Fig (3b) and Fig (4b), by increasing the angle, higher number of primary solid phases are formed into the mold and finer and globular microstructure was produced. On the other hand, increase in the angle from 30° to 60° can facilitate formation of enough solid particles and adequate fraction solid by flowing melt over the surface of the inclined plate. Fig (3b) and Fig (4b) shows that applying inclined plate in 400 mm for 45° and 60° is similar to 30° and there is a relation between the increase of angle and shear rate. Furthermore, it is necessary to obtain the optimum condition of the inclined plate in 400mm length. It is found that applying inclined plate at 400 mm for 30°, 45° and 60° may result in finer and globularity microstructures.

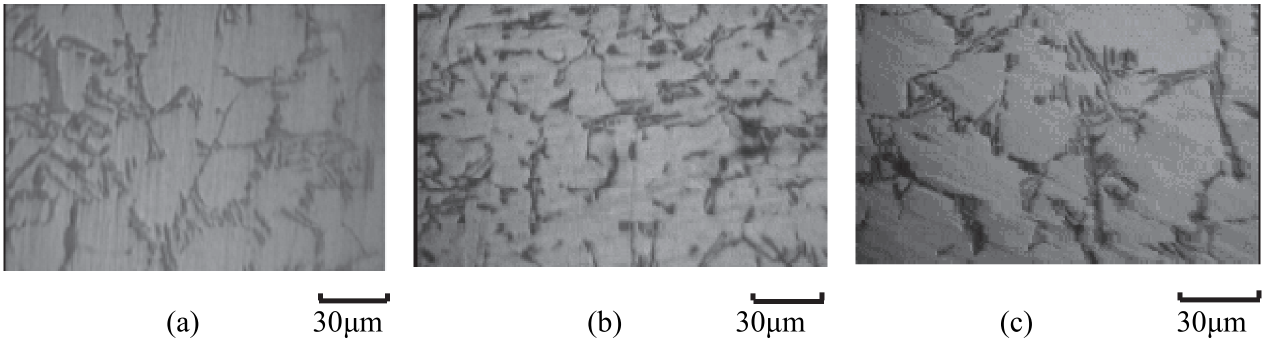

Fig. 2. Microstructure of cast over the cooling plate was performed from a pouring temperature of 630°C with the following cooling length (a) 300mm, (b) 400mm, and (c) 500mm, angle 30° permanent mold temperature 25 °C

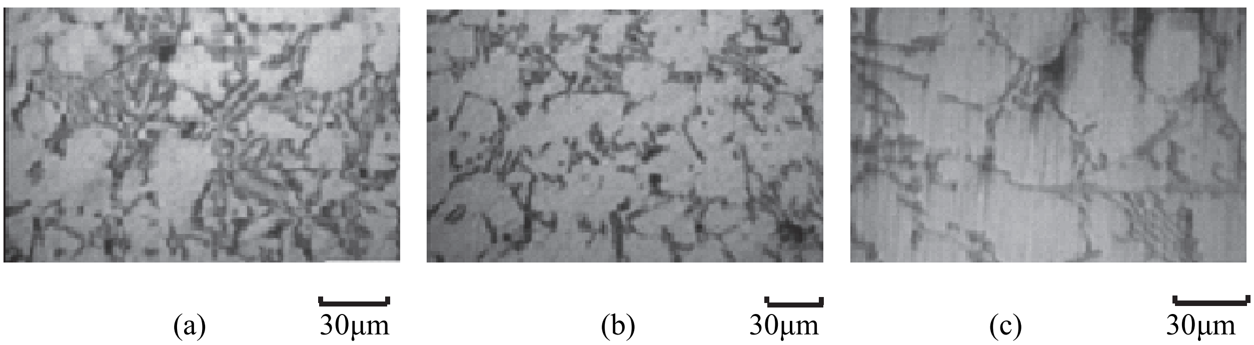

Fig. 3. Microstructure of cast over the cooling plate, performed from a pouring temperature of 630°C with the following cooling length (a)300mm, (b)400mm, and (c)500mm, angle 45° permanent mold temperature 25°C

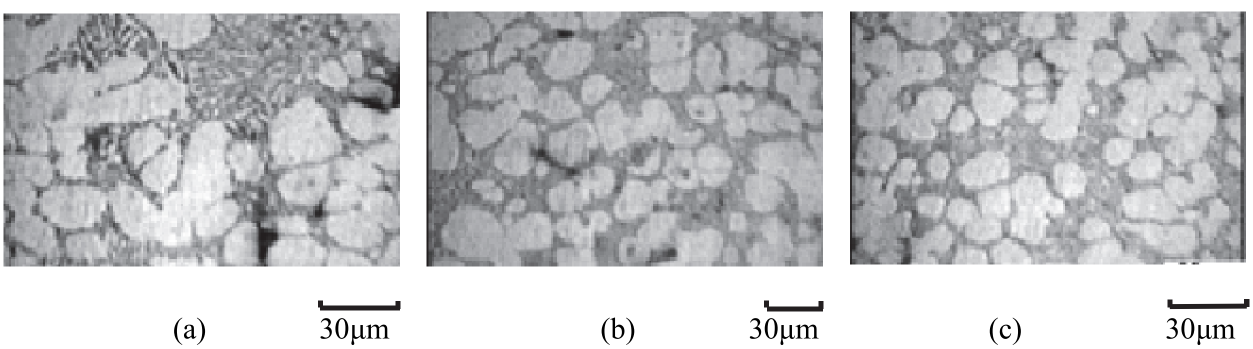

Fig. 4. Microstructure of cast over the cooling plate was performed from a pouring temperature of 630°C with the following cooling length (a)300mm, (b)400mm and (c)500 mm , angle 60° permanent mold temperature 25°C

It should be noted that the highest hardness value of about 77HB was obtained for the case 400mm length and inclined plate in 60°.

3.2. Pouring on a surface equipped with circulation cooling system

After finding the suitable temperature, the length and angle of the slope, the effect of cooling was examined. For this aim, a circulating system was installed and the melt was poured over the cooling slope with 400mm length and 60° slope under a temperature gradient. During this procedure the flow was divided into 4 regions:

(i) Slope in the boundary region,
(ii) The condensed crumby region
(iii) The scattered crumby region
(iv) The melting region

Solid particles in the crumby region will float in the melt and form a growing sphere. A layer will form on the slope due to its low temperature at the beginning of the procedure. If the cooling procedure protracts, the dendrite and solid particles will join the melt, resulting in a semi-solid stage. The crumby layer over the solid region will grow when the temperature decreases, and therefore increase the rate of particle formation. The crumby layer can increase due to reduction of temperature, and thus the cast cannot be thoroughly filled. On the other hand by increasing the temperature up to 650°C, the solid and semi-solid structures will gradually fade due to super melt stage. Therefore, the melt poured in the cast is thoroughly liquid and no solid/semi-solid particles are found, making it unsuitable. Meanwhile, when the pouring temperature increases, the cooling effect of the slope will reduce or ever eliminate, resulting in a macro grain and non-proportional structure. Furthermore, pouring temperature will increase the gas absorption and thus increased oxidation. Thus, 630°C pouring (to melt on the cooling slope) can provide more globular and fine texture of the (α-AL) phase due to effective separation of particles at the crumby stage under the flow.

4. Conclusions

1. The dendrite primary phase in the microstructure of conventionally cast alloy was replaced to obtain fine globularity morphology.

2. Changing dendrite microstructure to non-dendrite microstructure depends on the length and angle of inclined plate. Increase in the lengths lead to breaking Si eutectic. But maximum increase of length leads to decrease of nucleation of primary solid phase that lead to coarsening of (α-Al) phases. Increasing the angle of the inclined plate leads to suitable shear stress and uniform distribution of Si eutectic at matrix phase. As a result, optimum condition for producing refined and globular microstructure with uniform distribution of A360 was obtained at an angle and length of 60° and 400mm, respectively.

3. A suitable cooling system can increase the condensed crumby region and facilitate flow of solid particles into the melt, resulting in a more globular and finer (α-AL) phase.

References

Bae, J. W., Kim, T. W., & Kang, C. G. (2007). Experimental investigation for rheology forming process of Al–7% Si aluminum alloy with electromagnetic system. *Journal of Materials Processing Technology*, *191*(1), 165-169.
Birol, Y. (2008). Cooling slope casting and thixoforming of hypereutectic A390 alloy. *Journal of Materials Processing Technology*, *207*(1), 200-203.
Birol, Y. (2007). A357 thixoforming feedstock produced by cooling slope casting. *Journal of Materials Processing Technology*, *186*(1), 94-101.
Birol, Y. (2009). Forming of AlSi8Cu3Fe alloy in the semi-solid state. *Journal of Alloys and Compounds*, *470*(1), 183-187.
Brabazon, D. J. B. D., Browne, D. J., & Carr, A. J. (2002). Mechanical stir casting of aluminium alloys from the mushy state: process, microstructure and mechanical properties. *Materials Science and Engineering: A*, *326*(2), 370-381.
Hoffmann, H., & Toussaint, A. (1999, September). Strategies and future developments in the manufacturing process of light-weight car bodies. *In Proceedings of the 6th International Conference on Technology of Plasticity, Nuremberg, Germany* (pp. 1129-1140).

Fan, Z. (1981). Semi-solid Metal Processing. *Proceedings of Ninth North American Manufacturing Research Conference*, 140-144.
Fan, Z. (2002a). Semi-solid metal Forming. *International Materials Reviews, 47*(2), 1-37.
Fan, Z. (2002b). Semisolid metal processing. *International Martial Reviews. 147*(2), 6-8.
Fan, Z., Ji, S., & Liu, G. J. (2005). Development of the rheo-diecasting process for Mg-alloys. In *Materials Science Forum* (Vol. 488, pp. 405-412). Trans Tech Publications.
Findon, M., & Apelian, D. (2004). Continuous rheoconversion process for semi-solid slurry production. *Transactions of the American Foundry Society, Vol. 112*, 305-323.
Giordano, P., & Chiarmetta, G. (2004, September). New rheocasting: A valid alternative to the traditional technologies for the production of automotive suspension parts [C]. In *Proceedings of the 8th International Conference on Semi-Solid processing of Alloys and Composites. Limassol: The Worcester Polytechnic Institute and the Metals Processing Institute* (pp. 101-109).
Haga, T., & Suzuki, S. (2001). Casting of aluminum alloy ingots for thixoforming using a cooling slope. *Journal of Materials Processing Technology, 118*(1), 169-172.
Haga, T., & Kapranos, P. (2002). Billetless simple thixoforming process. *Journal of Materials Processing Technology*, *130*, 581-586.
Haghayeghi, R., Zoqui, E. J., Halvaee, A., & Emamy, M. (2005). An investigation on semi-solid Al–7Si–0.3 Mg alloy produced by mechanical stirring. *Journal of materials processing technology*, *169*(3), 382-387.
Sumitomo, T., StJohn, D. H., & Steinberg, T. (2000). The shear behaviour of partially solidified Al–Si–Cu alloys. *Materials Science and Engineering: A*, *289*(1), 18-29.
Lee, B. S., Joo, D. H., & Kim, M. H. (2005). Extrusion behavior of Al-Cu alloys in the semisolid state. *Materials Science and Engineering: A*, *402*(1), 170-176.
Neugebauer, R., & Bräunlich, H. (1999, September). Lightweight construction by innovative forming technologies. In *Proceedings of the Sixth International Conference on Technology of Plasticity, Nuremberg* (Vol. 19, No. 24, pp. 1119-1128).
Pibworth, K., Atkinson, H. V., Kirkwood, D. H., & McLelland, A. R. A. (1996, June). Thixoforming of a normally wrought aluminium alloy. In *Proc. 4th Int. Conf. on" Semi-Solid Processing of Alloys and Composites" Sheffield* (pp. 19-21).
Rice C. & Mendes P. F. (2001). Semi-solid Slurry Base Die Casting. *Journal of advanced materials and processes, 159*, 1-7.
Salarfar, S., Akhlaghi, F., & Nili-Ahmadabadi, M. (2004). Influence of pouring conditions in the inclined plate process and reheating on the microstructure of the semisolid A356 aluminum alloy. In *8th Int. Conf. on Semisolid Proc. Of Alloys and Composites, Cyprus*.
Vogel, Y., & Zhang K. (2003). The formation of rosette phase structural evolution during the reheating and semi-solid casting of AlSi7Mg Alloy. *Journal of Materials Processing Technology, 137*, 195-200.