International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:5, No:1, 2011

Semisolid Structure and Parameters for A360 Aluminum Alloy Prepared by Mechanical Stirring

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Abstract**—**Semisolid metal processing uses solid–liquid slurries containing fine and globular solid particles uniformly distributed in a liquid matrix, which can be handled as a solid and flow like a liquid. In the recent years, many methods have been introduced for the production of semisolid slurries since it is scientifically sound and industrially viable with such preferred microstructures called thixotropic microstructures as feedstock materials. One such process that needs very low equipment investment and running costs is the cooling slope. In this research by using a mechanical stirrer slurry maker constructed by the authors, the effects of mechanical stirring parameters such as: stirring time, stirring temperature and stirring Speed on micro-structure and mechanical properties of A360 aluminum alloy in semi-solid forming, are investigated. It is determined that mold temperature and holding time of part in temperature of 580ºC have a great effect on micro-structure and mechanical properties(stirring temperature of 585ºC, stirring time of 20 minutes and stirring speed of 425 RPM). By optimizing the forming parameters, dendrite microstructure changes to globular and mechanical properties improves. This is because of breaking and globularzing dendrites of primary α-AL.

Keywords**—**Semi-Solid Forming, Mechanical properties, Shear Rate.

I. INTRODUCTION

MICRO-structural control of cast parts is one of the important parameters which are concerned in casting industry. Micro-structural control is obtained by controlling size and shape of primary phase and second phase morphology on micro-structure [1]. Optimizing mentioned parameters by using outer factors which are engaged with them, time of production and other economical parameters, leads to production of part with superior quality. In conventional casting, dendrite micro-structure which form naturally, leads to presence of different defects such as shrinkage and gaseous porosity which weaken mechanical properties [1]. In semi-solid processes, shear rate is applied to a molten metal which is on its solidifying range, and dendrite micro-structure is broken and change to globular micro-structure[2].There are different theories about globularzing mechanism of primary phase. Two of these theories are accepted more. First theory is presented by Vogel [3]. He believed that in presence of shear rate, dendrites bend and break to lower the surface of their energy. Second theory is presented by Hellawel [4]. He believed that breaking dendrites is result of locally re-melting of dendrites in root. There are different ways to produce globular micro-structure. One of them is mechanical stirring. Numbers of researchers have been studied on semi-solid forming of metals by mechanical stirring. Fan and Rice [5] with using this method could produce thin shield parts which cannot produce with conventional die-casting processes. Haghayeghi and co-workers [6] have improved mechanical properties of A360 Aluminum alloy 10 percent by mechanical stirring of molten alloy. Barabazon and co-workers [7] have investigated the effect of mechanical stirring on micro-structure and mechanical properties of Aluminum Alloys. They could change the dendrite micro-structure of alloy to globular by mechanical stirring. In present work by mechanical stirring of A360 Aluminum alloy, dendrite micro-structure is changed to globular and mechanical properties are improved. Also effect of forming parameters such as mold temperature and reheating time of specimen at 580ºC, on micro-structure and mechanical properties are investigated**.**

II. MATERIALS AND EXPERIMENTS

If you are using *Word,* use either the Microsoft Equation In this work, A360 Aluminum alloy has been used to produce a semi-solid formed part. Chemical composition of A360 alloy is presented in table 1. Liquids and solids temperature of this alloy are 600ºC and 557ºC respectively. To comparison of mechanical properties of semi-solid formed parts with gravity casting part, a part is produced with pouring temperature of 670ºC by gravity casting. Yield stress and hardness of gravity cast part are 119 MPa and 59.8 HB respectively.

TABLE I
CHEMICAL COMPOSITION OF A360 ALUMINUM ALLOY

Si	Fe	Cu	Mg	Al
9.00	0.42	0.29	0.29	Base

Procedure of producing semi-solid formed parts is as follows:

After melting of alloy, it's temperature was 610ºC. Then temperature of alloy is decreased slowly until reach to stirring temperature. After that stirring process by steel blade in constant temperature began. Before stirring begins, surfaces of stirrer blades and mold are coated by zirconium oxide. This coat prevent molten metal to attach to stirrer blades and prevent attaching part to mold. Also zirconium oxide protects molt against impurities. In accordance to later researches and previously done works, variable parameters of semi-solid process were chosen as presented in table II.

TABLE II
STUDIES PARAMETERS AND THEIR VALUES

Mold Temperature during pouring the slurry (ºC)	25, 300, 600
Reheating Time of Specimen at 580ºC (Min)	5, 10, 15

slurry making machine which is used in present work consists a multi speed stirring system and an electric furnace. Placing of thermocouple in molten metal leads to exact measurement of melt temperature. After each experiment, produced slurry is poured to a cylindrical mold. Result of pouring is producing of a cylindrical specimen whose height and diameter are 150mm and 70mm respectively. From this part some samples produced for tensile and hardness test. To have exact results 3 samples of tensile test in accordance with Standard ASTM B557M were tested. Also 5 points of part were tested for hardness measurement. The average values of tests were reported as results. Also to observe micro-structure of produced specimen, some samples were prepared and be metalographied.

III. RESULTS AND DISCUSSION

Figure 1 shows micro-structure of A360 aluminum alloy which is produced by gravity casting. In micro-structure 1-a there are dendrites of primary α-AL phase which spread in micro-structure. Also in micro-structure 1-b there are dendrites of eutectic silicon phase. Effect of silicon on aluminum alloys depends on shape of silicones on micro-structure and the way alloy is solidify. There for in different processes, silicon provides different properties. Silicon improves casting properties of alloy with increasing fluidity and decreasing percentage of gas absorption.

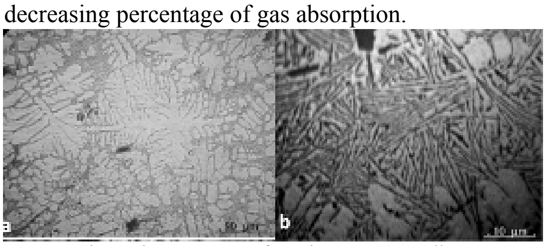

Fig 1 Micro-structure of gravity cast A360 Alloy.
a: dendrites of primary α-AL phase b: dendrites of eutectic silicon phase

Figure 2 shows micro-structures of A360 alloy which is formed in stirring temperature of 585ºC, stirring time of 20 minutes and stirring speed of 425 RPM. In figure 2 a to c, mold temperatures during pouring the slurry were 25ºC, 300ºC and 600ºC, respectively. In Fig2-a, α-AL particles are in form of semi globular and semi rosette. These particles are at same size and spread uniformly on the micro-structure. Also there are eutectic silicon particles which are in form of fine needles on the micro-structure. These particles did not spread uniformly. In Fig 2-a the slurry is poured in a mold which was in ambient temperature (25ºC). The temperature of mold was low; there for solidification rate is too high. High solidification rate causes molten phase of slurry to solidify very fast. Fast solidification of molten phase causes that α-AL globes and broken eutectic silicon particles did not have enough time to reconfiguration and spread in molten phase. In Fig 2-b slurry is poured in a mold which its temperature was 300ºC, and then the part is slowly cooled to room temperature. Because the mold temperature was high enough, after pouring the slurry it took time that molten phase solidify. During solidification, there was enough time for α-AL globes and eutectic silicon particles to reconfiguration and spread uniformly in molten phase. There for α-AL globes and particles of eutectic silicones are spread more uniformly on micro-structure. Caparisoning micro-structures presented in Fig 2-a and Fig 2-b show that α-AL globes are more globular as well as uniformly spread and globes are finer. Also there are fine needles of eutectic silicon particles which are spread uniformly on micro-structure. But shape of these particles did not change. A reason which leads to globularize particles of eutectic silicones is heating time. These particles have enough time to re-melt and change the shape of them to globular structure. Also α-AL particles have enough time to re-melt and trim the shape of themselves to globular structure. Fig 2-c shows the micro-structure of slurry which is poured in a mold whose temperature was 600ºC. The globes of α-AL phase are very big in comparison with micro-structures shown in Fig 2-a and Fig 2-b. Also these particles are not globular. The shape of silicon particles is not changed.

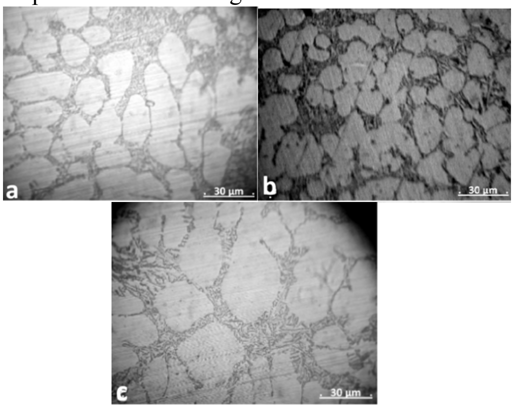

Fig. 2. Micro-structure of semi-solid formed A360 Alloy.
Stirring Speed: 300 RPM, Stirring Temperature: 585ºC Stirring Time: 10 minutes Mold Temperature (ºC) a: 25, b: 300, c: 600

But these eutectic silicones surround bigger α-AL globes. In Fig 2-c because temperature of mold was high, the solidification rate is too slow and solidification time is too long. Long solidification time permits α-AL particles joint to each other and make bigger α-AL particles. Also by increasing solidification time α-AL globes absorb more molten alloy and become non globular. As expected, when slurry is poured in a mold which are in suitable temperature, because of good shape and configuration of α-Al and eutectic silicon particles, mechanical properties are improved.

After producing slurry with suitable amount for stirring time, stirring speed and stirring temperature and pouring the

International Journal of Chemical, Materials and Biomolecular Sciences
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slurry in a mold with temperature of 300ºC, specimens are reheated at 580ºC for different times. Specimens then quenched in 40ºC water. Figure 3 shows micro-structures of A360 alloy which reheated at 580ºC. In Fig 3-a, alloy is reheated at 580ºC for 5 minutes. In Fig 3-b and Fig 3-c alloy is reheated at 580ºC for 10 and 15 minutes, respectively. In Fig 3-a, α-AL globes are more globular and spread more uniformly in comparison with pervious micro-structures. Eutectic silicones are spread more uniformly and shape of them has changed from needle form to globular form. Because reheating time at 580ºC in Fig 3-a is low (5 minutes), alloy did not enter melting range. But because temperature of specimen became high, eutectic silicones are diffused and decreased their surface of energy. This is the reason of changing the shape of these particles. In fig 3-b which is micro-structure of specimen reheated for 10 minutes, α-AL globes are more globular and spread more uniformly. Reheating time of 10 minutes at 580ºC causes temperature of specimen became very closed to melting range and even some parts of specimen locally melt. High temperature of specimen and reaching near to temperature of eutectic process causes dendrites of eutectic silicones decrease their surface of energy and bent. Also with locally re-melting of specimen, these bent silicon diffused in micro-structure of reheated specimen. Suitable reheating time of 10 minutes at 580ºC which leads to locally re-melting of specimen, causes α-AL globes by contacting with melt phase, lower its surface of energy and trim itself and became more globular. Fig 3-c is micro-structure of specimen which is reheated at 580ºC for 15 minutes. α-AL globes are very big in micro-structure of Fig 3-c. Also eutectic silicones are in form of dendrites. High reheating time of specimen at 580ºC, causes temperature became high and specimen melted. This means that temperature of specimen became more than eutectic process (577ºC). In temperatures more than 577ºC there is not sign of eutectic silicones. In this condition α-AL globes attach to each other and form big α-AL globes. A eutectic silicon particle which is formed by quenching, are presented in micro-structure in form of dendrites. In table 3 results of yield stress and hardness tests are presented.

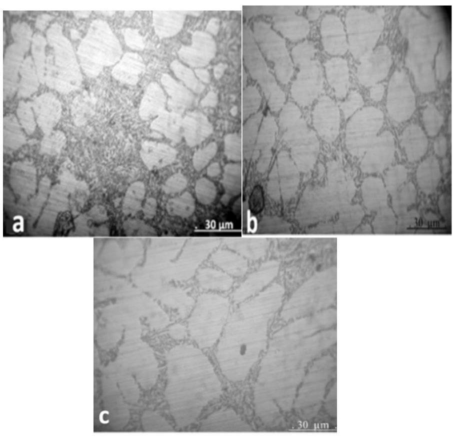

Fig 3 Micro-structure of semi-solid formed A360 Alloy.
Stirring Speed: 300 RPM, Stirring Temperature: 585ºC, Stirring Time: 10

TABLE III
MECHANICAL PROPERTIES OF SEMI-SOLID FORMED A360 ALLOY STIRRING TIME: 20 MINUTES, STIRRING TEMPERATURE: 585ºC STIRRING SPEED 425 RPM, MOLD TEMPERATURE: 300ºC

Holding Time at 585ºC (Min)	5	10	15
Yield Stress (MPa)	164	171	158
Hardness (HB)	87.1	89.7	85.8

As expected, when part is held at 580ºC for suitable time, because of globularizing α-AL phase and eutectic silicones and better spread of these phase on micro-structure, mechanical properties are improved.

IV. CONCLUSION

Investigations which have done in this work, leads to following results:

Mold temperature and holding time of produced alloy at 580ºC, have great effect on micro-structure and mechanical properties. Suitable mold temperature and holding time of produced alloy at 580ºC, causes particle of α-AL phase and eutectic silicones have enough time to trim themselves and spread uniformly on micro-structure. Best result for yield stress and harness tests for semi-solid form A360 aluminum alloy in present work was 171 MPa and 89.7 HB, respectively. Values of forming parameters which leads to above results were as follows: Stirring Temperature: 585ºC, Stirring Time: 20 minutes, Stirring Speed: 425 RPM, Mold Temperature during pouring slurry: 300ºC, Holding Time of produced alloy at 580ºC: 10 minutes.

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