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Grain refinement of LM6 Al–Si alloy sand castings to enhance mechanical properties

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Abstract

Al–Ti–B master alloys are well accepted in Al–Si alloys casting industry as grain-refiners to enhance the castings quality. Grain refinement is achieved in aluminium alloys by inoculating the melt in the furnace with specific amount of selected grain-refiner. The grain-refiners come in different chemical compositions and there is no guideline to add the optimal level of them into the melt for sound castings. This research work investigates the effect of Al5Ti1B on the mechanical properties of LM6 Al–Si alloy sand casting. The typical LM6 aluminium alloy contains 10–13 wt.% of silicon and thus inherently solidifies with coarse grain sizes. The mechanical properties ascertained are hardness and ultimate tensile strength (UTS). The grain macrostructures of the castings are studied by optical and scanning electron microscopes. The experimental work is performed on a sand casting of different modulus, which inherently induces different cooling rates to enable a simple correlation between cooling rate and grain refinement level. The addition level of Al5Ti1B into the melt ranges from 0 wt.% to 1 wt.% with the increment of 0.25 wt.%. The experimental results show that the mechanical properties of LM6 sand casting can be optimally improved by grain refinement of 0.5 wt.% AL5Ti1B. Further increase of grain-refiner quantity does not provide any more significant improvement. The data shows that solidification rate is directly proportional to the addition level of grain-refiners but inversely proportional to the casting modulus. In the original sand casting of LM6, section of lower modulus with higher solidification rate has better mechanical properties. When the optimal level of grain-refiner is added, more uniform mechanical properties are achieved throughout the casting irrespective of section modulus.

Keywords: Grain refinement; Sand casting; Hardness; Ultimate tensile strength; Solidification rate

1. Introduction

Grain refinement is considered to be one of the most important and popular melt treatment processes for aluminum–silicon alloys castings. The use of grain-refiners to improve castings mechanical properties is widespread in aluminium industry, and its associated benefits on final products are well documented [1]. Grain refinement of aluminium alloys provides a number of technical and economic advantages, including reduced ingot cracking, better ingot homogeneity [2], susceptibility to hot cracking is reduced [3] and mechanical properties are improved significantly [4]. Grain refinement improve the quality of castings by reducing the size of primary α-Al grains in the casting, which otherwise will solidify with coarse columnar grain structure. Fine equiaxed grain structure leads to several benefits, such as uniform distribution of second phases and microporosity, improved feeding ability [5], high yield strength, high toughness, improved machinability and excellent deep drawability of the products [6].

Several mechanisms take place in the formation of grains in a casting during solidification. In general, there are two factors that contribute to the formation of grains. First, there must be the presence of suitable substrates in sufficient amount to act as heterogeneous nucleation sites. Secondly, there has to be sufficient undercooling to facilitate the survival and growth of the nuclei [7]. The undercooling can be achieved by either rapid cooling to generate bulk undercooling and/or by partition of solute during solidification to generate constitutional undercooling. Both of these criteria have to be fulfilled to obtain a small grain size in a casting [8].

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As is well known, grain refinement by inoculation of melts is based on the mechanism of heterogeneous nucleation [9]. The inoculation of aluminium alloys is usually achieved by the addition of Al–Ti or Al–Ti–B master alloy into the melt of base metal. Grain-refiners are produced commercially with a wide range of Ti/B ratios. The Al–(3 or 5)%Ti–1%B and Al–(3 or 5)%Ti–0.2%B grain-refiners of the Al–Ti–B system have long dominated the grain refining market for several decades. Several new types of grain-refiners had entered the market in recent years, such as TiBAlloy and Strobloy [10]. TiBAlloy contains 1.6%Ti, 1.4%B, 0%Sr and the boride phase is majority in $(Al,Ti)B_2$. While Strobloy contains the similar contents of titanium and boron, and additional 10%Sr. The boride phases of Strobloy are TiB_2 and SrB_6, and its aluminide phase is $SrAl_4$. The use of TiBAlloy for the hypoeutectic alloys used in the foundry sector has been shown to provide benefits in terms of minimizing porosity and lack of fade [11]. Strobloy has been described as combining the benefits of grain refinement of TiBAlloy with the modification effects of Sr [12]. Another new member of the grain-refiner family is Al–3%Ti–0.15%C. It has been used in a wide range of alloy systems and solidification process methods [13]. Compared to the traditional Al–Ti–B grain-refiners, a number of advantages are achieved by Al–3%Ti–0.15%C include melt cleanliness, interactions with degassing and filtration systems, finer grain structure and better surface appearance. The earliest systems in which Al–3%Ti–0.15%C has found approval and acceptance to replace other grain-refiners have been in aerospace applications (7XXX series alloys) [14].

In the present study, the grain-refiner employed is Al5Ti1B master alloy supplied by KBM AFFILIPS and the base metal is LM6. Previous casting with LM6 without grain-refiner is used to benchmark the effect of Al5Ti1B grain refinement on the interested mechanical properties of harness and ultimate tensile strength (UTS). The addition levels of grain-refiner in terms of weight percentage are 0.25%, 0.5%, 0.75% and 1.0%, respectively. The casting process is CO_2 sand casting process.

2. Experimental procedures

The experimental procedures for making of molds, pouring, testing and analysis of castings are explained in the following consecutive sections.

2.1. Mold design and construction

The casting was designed to have varying modulus (2.25, 4.08, 6.90 and 8.96) to incur different cooling rates during solidification process. The thicknesses opted are 5 mm, 10 mm, 20 mm and 30 mm, respectively. The width and length of each section are 80 mm and 100 mm. The sprue was designed in conical shape with top diameter 28 mm, bottom diameter 18 mm and height 126 mm. The sprue well is a hemisphere shaped one with 20 mm diameter. The four ingates leads into the cavity have similar cross-section of 19 mm × 7 mm, and the runner has a cross-section of 15 mm × 20 mm. The feeder was also designed in conical shape of top diameter 40 mm, bottom diameter 20 mm and height 50 mm. Initially the dimensions were determined according to AFS standard guidelines and specifications found in the literature but later it has been found that the calculation results were not practical to construct a mold without blockage of feeding [15]. Therefore, the dimensions of the gating system as per the calculations are modified and replaced by the above-mentioned dimensions. The overall design of the mold is shown in Fig. 1.

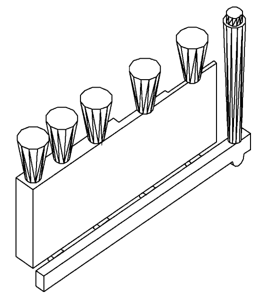

Fig. 1. Mold system.

The pattern of the feeder, cavity and gating system are made of wood [16]. The mold box or flask used to assemble the cope and drag is also made of wood. Fig. 2 shows the pattern and sand mold for the experimental analysis.

The tensile test samples were molded by another mold as shown in Fig. 3. Each mold will produce four pieces of test samples for similar chemical compositions of casting materials. The dimensions of the test samples are decided according to ASTM E8-00.

Fig. 2. Pattern and sand mold.

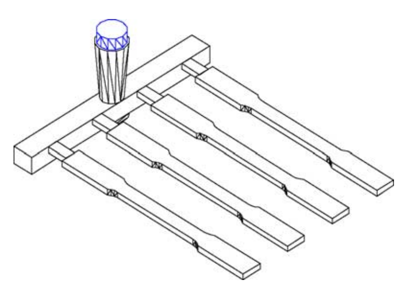

Fig. 3. Tensile test sample mold.