Light Metals 2013 *Edited by: Barry Sadler*
TMS (The Minerals, Metals & Materials Society), 2013

GRAIN REFINER FOR Al-Si ALLOYS

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Keywords: Grain refinement, Al-Si alloys, Casting

Abstract

Over the last few decades the grain refinement practice using Ti based chemical additions (Al-Ti-B) is well established for wrought Al alloys, however in the case of Al-Si casting alloys, the practice of adding grain refiners and the impact on castability is not well established in industries, due primarily to chemical instability of conventionally known Ti based grain refiner with Si element in the melt. Research at Brunel University has identified a novel chemical composition that can effectively refine grain structure of Al-Si castings alloys. First, the effect of addition of grain refiner, in the form of powder addition, on microstructural and mechanical properties of LM6 (A423) and LM25 (A356) alloys was investigated. Afterwards, a suitable method to produce the novel grain refiner in the form of master alloy was developed and the effect of addition of master alloy on grain refinement of the previously mentioned Al-Si alloys was studied.

Introduction

Among light metals, aluminum is well-known for its high corrosion resistance, high thermal conductivity and low electrical resistivity. Aluminum alloys are commonly subdivided between wrought and cast alloys depending on the fabrication method employed to obtain the material. Concerning cast aluminum alloys, they present special advantages such as relatively low melting temperature, negligible solubility for all gases except hydrogen and sufficiently good surface finish which make them much more versatile in comparison to other foundry metals. Al-Si alloys, where silicon constitutes the mayor alloying elements, are the most important aluminum casting alloys due to their very good fluidity which allows to production of complicated shapes. When slow cooled Al-Si casting alloys are characterized by a very coarse microstructure in which the Al-Si eutectic comprises large plates or needles of silicon in a continuous aluminum matrix. Rapid cooling can help in refining the microconstituents changing the shape of the eutectic to a fibrous form [1]. Another industrial common practice for the refinement of the microstructure of Al-Si casting alloy is done by adding specific master alloys and it is known as modification. Grain refinement of casting aluminum alloys has significant influence for the improvement of mechanical performances [2-3]. Along the years, different elements or combination of elements have been tried keeping in mind that crystals with small lattice mismatch are expected to leads to a refinement of the microstructure because they favor heterogeneous nucleation [4]. Many studies are available about the modification of Al-Si casting alloys performed by means of Al-xTi-yB master alloys with different ratio of titanium to boron [5], where the Al-5Ti-1B master alloy seems to be the most studied [6] and also the most industrially employed. The fundamental of using master alloys based on the Al-Ti-B ternary system is the possibility to have TiB_2 and Al_3Ti particles which act as heterogeneous nucleation sites and dissolved in the melt, respectively [7-10]. Nonetheless, different study demonstrated that the effectiveness of these master alloys is quite poor when the Si weight percentage is greater than 2% [11-15]. Particularly, it seems that there is a poisoning effect [16] from the addition of Al-xTi-yB master alloys, due to the reaction between Ti and Si, which limits the refinement of α-Al grains [17], by forming titanium silicides like $TiSi_2$ [18].

From the analogy between Al-Ti and Al-X equilibrium phase diagrams [19], novel grain refiner can be developed [20, 21]. It should be possible to use these novel grain refiners in the casting of automotive parts, like engine blocks, brackets or wheels and rims, obtaining more complicated shaped parts with thinner walls. The aim of this work is to study the influence of the novel grain refiner, developed at Brunel University, addition to Al-Si alloys. In particular, a comparison of the results as a function of the production method of the novel grain refiner, powder addition and master alloy, is considered. The influence of the addition of the novel grain refiner as a function of a great range of cooling rates, which are generally applied during the processing of aluminum in industry is also studied.

Experimental Procedure

The alloys used to perform the study of the influence of the novel grain refiner are the LM6 and LM25, as specified in the British Standard 1940, equivalent to the A413 and A356 alloys, respectively. Table 1 reports the composition of these two aluminum casting alloys where it can be seen that LM6 is an eutectic alloy, having a silicon content in between 10 wt.% and 13 wt.%, whilst LM25 is a hypo-eutectic alloy with approximately 7 wt.% of silicon as primary alloying element.

Table 1. Chemical composition of the materials studied.

Element [wt.%]	Alloy	
	LM6	*LM25*
Al	Balance	Balance
Si	10.0-13.0	6.5-7.5
Fe	0.6	0.2
Cu	0.1	0.2
Mn	0.5	0.1
Mg	0.1	0.2-0.4
Zn	0.1	0.1
Ti	0.2	0.2

The starting material was placed inside a clay graphite crucible, melted and, prior to casting, kept at a processing temperature of 790ºC at least for 1 hour in order to guarantee the complete melt of the ingot. At this point, the reference alloy was left to cool down to approximately 740 (±3) ºC and casted into two different permanent molds pre-heated at 120ºC (wedge mold) and 250ºC (cylindrical mold). Figure 1 shows a sketch of the processing temperature profile employed during this study.

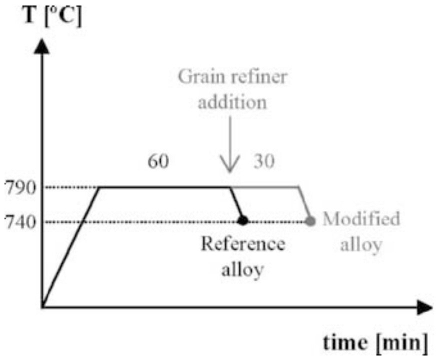

Figure 1. Sketch of the processing cycle employed.

In the case of novel grain refiner in the form of master alloy addition, after holding for 60 minutes at 790ºC, a minimum time of 30 minutes was left for the novel grain refinement to dissolve inside the melt to guarantee a homogeneous distribution of the grain refining phases. In the case of powder addition, the holding time was for at least 60 minutes. The molds for the casting of the alloys are a 30 mm diameter steel mold and a copper wedge shaped mold. In the wedge mold, the cooling rate studied by means of this configuration ranges between 2ºC/s to 150ºC/s as it can be seen in the sketch presented in Figure 2.

The samples were cut and the cross-section prepared by following the classical metallographic route (grinding with 120-1200 SiC paper and polishing with OPS solution). The etching for revealing the microconstituents was done by means of Tucker's solution (25 ml H_2O + 15 ml HF + 15 ml HNO_3 + 45 ml HCl). Microstructural analysis was carried out with a Carl Zeiss Axioskop 2 MAT optical microscope. In particular, macroetching of the cross-section of the samples was done to analyze the effect of the cooling rate combined with the addition of the novel grain refiner and microetching to study the Al-Si eutectic and primary Si particles features.

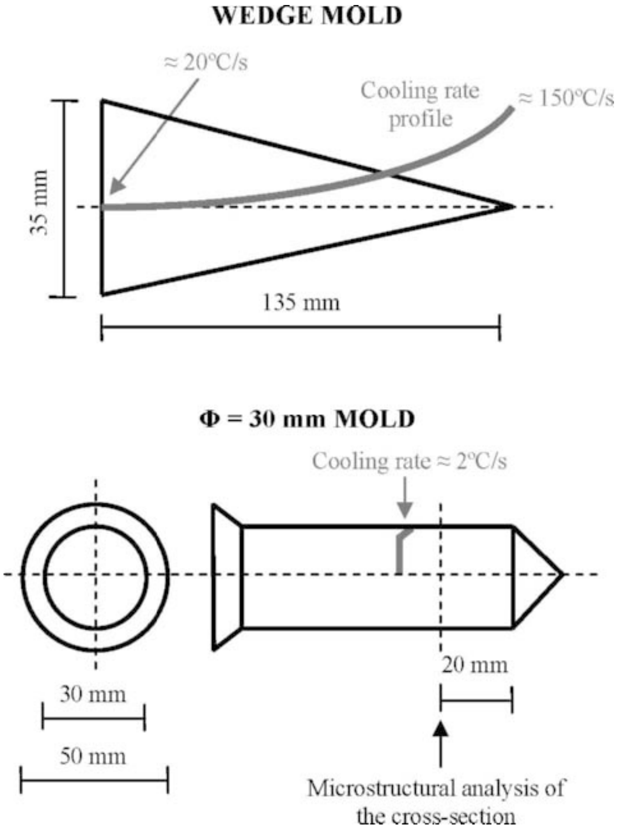

Figure 2. Sketch of the mold employed with the relative cooling rate and cooling rate profile.

Tensile samples were obtained by a permanent steel mold and, afterwards, machined to the specified dimensions (ASTM E8). Tensile test were performed on a Instron ® 5569 universal testing machine using a crosshead speed of 2 mm/min, equivalent to a strain rate of 1.33×10^{-3} s^{-1}. A 25 mm gauge length external extensometer was used to record the elongation of the samples. The yield strength, ultimate tensile strength and strain at fracture were obtained directly from the dedicated program of the universal testing machine.

Results and Discussion

Microstructures of LM6 and LM25 obtained by the addition of grain refiner powders can found elsewhere [20, 21]. In these proceedings, microstructural investigations on master alloy added samples are presented. As already stated in the experimental procedure, a reference sample without the addition of any grain refiner and a specimen where the novel grain refiner was added where considered for each alloy, each mold and each production method. Since no big differences could be highlighted between the samples where the novel grain refiner was added in the form of powder and those where the novel grain refiner in the form of master alloy was used, representative examples of microstructure are considered hereafter. In particular, the macroetched surfaces of the cross-section of the reference and master alloy addition wedge sample for LM6 and LM25 are presented in Figure 3 and Figure 4, respectively.

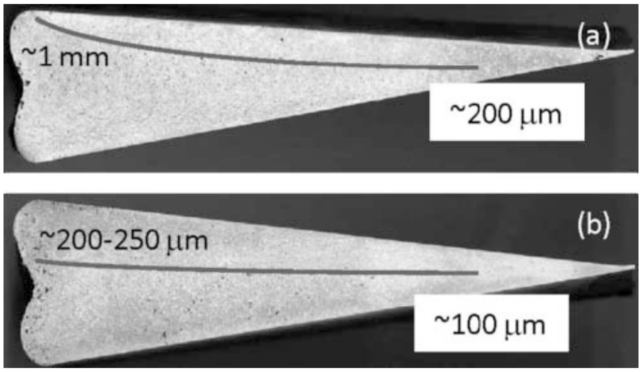

Figure 3. Macroetched cross-sections of LM6 wedge shape specimens: a) without and b) with novel grain refiner addition.

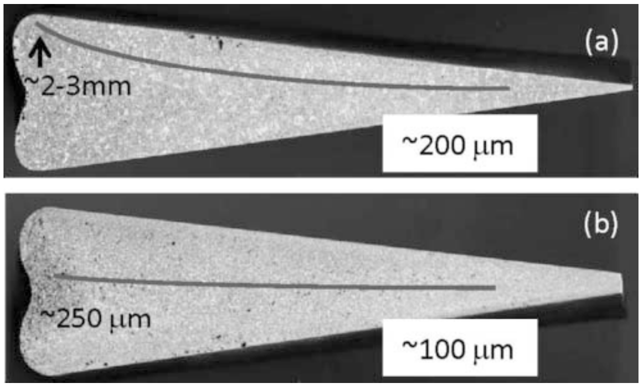

Figure 4. Macroetched cross-sections of LM25 wedge shape specimens: a) without and b) with novel grain refiner addition.

From the analysis of the macroetched samples shown in Figure 3 and Figure 4, it can be clearly seen that both LM6 and LM25 reference samples are characterized by very coarse microstructure where the primary α-Al grains have a size that ranges from 1 mm to 3 mm. On the other hand, the grain refined LM6 and LM25 specimens present a much finer microstructure with primary α-Al grains in the order of approximately 200-300 µm.

From Figure 3 and Figure 4, it can also be seen that, as expected, the microconstituents of the alloy get coarser with the decrease of the cooling rate, being finer at the tip of the wedge shape sample. Nonetheless, this behaviour is much more pronounced for the reference samples and far less noticeable when using the novel grain refiner.

Figure 5 and Figure 6 show the macroetched surfaces of the cross-section of the reference and master alloy addition 30 mm sample cylindrical for LM6 and LM25, respectively.

From Figure 5 and Figure 6, once again the addition of the novel grain refiner leads to a much finer microstructure which can be clearly seen on macro-etched surfaces. It is also remarkable that in the reference samples of both LM6 and LM25 the difference in grain size between the outer diameter of the samples, which was in directly in contact with the mold, is more significant than in the case of the addition of the grain refiner. When the grain refiner is added, the grain size across the sample thickness is small (100 µm) and uniform. In the reference sample (i.e alloy cast without grain refiner addition), the grain size is inhomogeneous and also there elitists large area of eutectic regions in the middle of the sample.

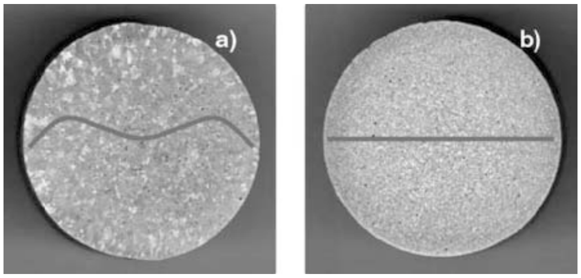

Figure 5. Macroetched cross-sections of LM6 cylindrical specimens: a) without and b) with novel grain refiner addition. Spatial variation of grain size along the sample thickness is shown schematically.

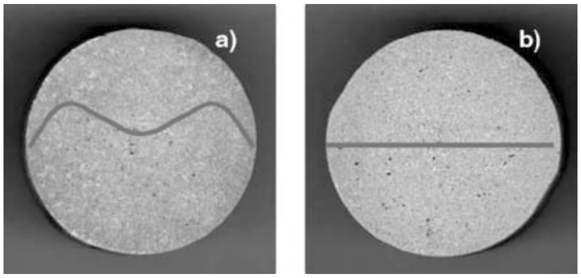

Figure 6. Macroetched cross-sections of LM25 cylindrical specimens: a) without and b) with novel grain refiner addition. Spatial variation of grain size along the sample thickness is shown schematically.

Representative results of the microstructural analysis carried out on cylindrical samples of LM6 are shown in Figure 7. From these microstructures, it can be seen that large α-Al dendrites in reference sample in comparison with finer grains for master alloy added samples. Both LM6 and LM25 reference materials are characterized by a quite large amount of eutectic phase concentrated in small area whilst in the case of the addition of the novel grain refiner the eutectic phase is more uniformly distributed throughout the whole microstructure.

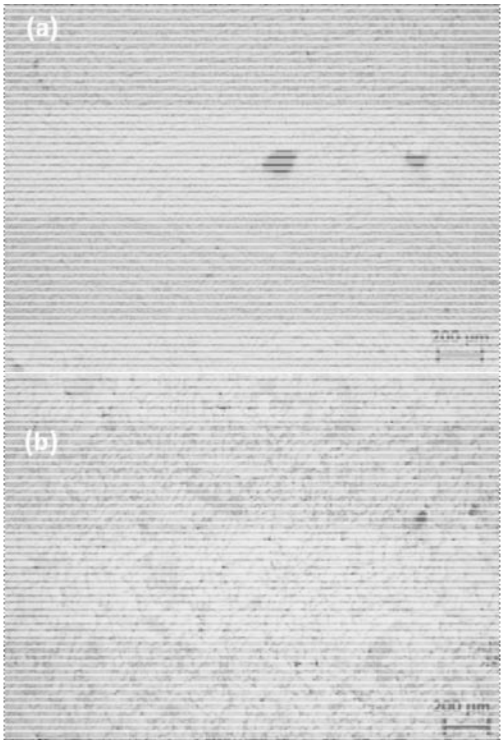

Figure 7. Microstructural analysis results for LM6 alloy: a) without and b) with novel grain refiner addition.

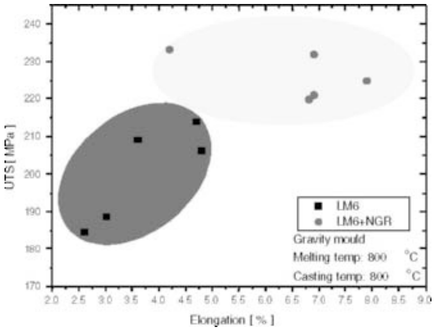

Figure 8. Comparison of ultimate tensile strength (UTS) and elongation for LM6 alloys.

Tensile properties for grain refined alloy (powder addition) are compared with reference sample in Figure 8. The observed increase in ultimate tensile strength could be due to finer grain structure and the increased elongation could be due to finer eutectic grain structure observed in this grain refined samples.

Conclusions

A suitable method to produce the novel grain refiner in the form of master alloy was developed for refining Al-Si microstructure. The effect of addition of master alloy on grain refinement of the LM6 (A423) and LM25 (A356) Al-Si alloys is presented. Grain refiner addition resulted in finer α-Al grain structure. As a result of finer grain structure, uniformly distributed eutectic regions and finer eutectic Si needles are observed. Wedge shaped molds reveal that when the master alloy is added to the Al-Si melt, the grain size is observed to be less sensitive to the cooling rates.

Acknowledgments

The authors are thankful for the financial support from the Engineering and Physical Sciences Research Council (EPSRC) through the EP/J013749/1 Project.

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