Effect of cooling rate and eutectic modification on texture and grain structure of Al-Si-Cu-Mg die cast alloy

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The effect of cooling rate and eutectic modification on texture evolution and grain structure of an Al-Si-Cu-Mg die cast alloy were investigated using optical microscopy (OM) and electron backscatter diffraction (EBSD) techniques. Directional solidification technique was utilized to produce as-cast specimens having low level of casting defects with controlled microstructural scale: specimens with average SDAS of 10 and 25 μm. Mode of solidification, cooling rate and eutectic modification did not induce any significant texture in the microstructure. An increase in cooling rate resulted in reduction grain size. High degree of grains orientation randomness was found in high cooling rate regardless of modification treatment.

KEYWORDS: AL-SI ALLOY- ANISOTROPY - MICROSTRUCTURE - DIRECTIONAL SOLIDIFICATION - EBSD

INTRODUCTION

The most widely used light metals are Al-Si based casting alloys thanks to their superior specific strength, encouraging mechanical properties and having low-cost manufacturing method [1]. On the other hand, such alloys suffer lack of ductility due to presence of casting defects (particularly porosity), which leads to premature failure [2]. Hence the tensile test data corresponding the specimens produced via conventional die casting are quite scattered. Several researchers [3, 4] used directional solidification technique (DST) in order to produce cast specimens containing low level of defects and controlled microstructural scale. This technique, however, could raise the risk of texture evolution in the cast specimens. This as a result may disqualify comparing specimens produced via DST with conventionally cast sample.

In a complex die casting, the thickness varies from region to another which leads to variation in cooling rates (CR), microstructural scale and grain size [2, 3] . A high CR results in a smaller secondary dendrite arm spacing (SDAS), finer eutectic Si and other secondary phases, while the opposite is true for the case of low CR [4]. It has been realized that the grain size has also inverse relations with CR. Different solidification processes may also change the shape and size of the grains even if the CR is rather the same [5]. However, the effect of different CRs on possible texture evolution in cast aluminum alloys has not thoroughly been addressed.

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Eutectic modification is a common treatments on Al-Si cast alloys being done through addition of modifier agents (commonly Sr) which results in refinement of eutectic Si from coarse plate-like to fine fibers morphology and also causes an increase in the size of eutectic grains [6]. This transformation was associated with changes in nucleation and growth fashion of eutectic phase [7]. Knowledge regarding the grain structure help to expand understanding the deformation behavior and mechanical properties of such alloys. Unlike the role of grain refiners, studies on the effects of Sr modification on the crystal orientations and grain size of Al-Si cast alloys is still limited in literatures.

This work attempts to address the following questions regarding texture evolution and grain structure of an Al-Si-Cu-Mg cast alloy (EN AC-46000) which is cast by DST, in unmodified and modified condition: (i) Is DST associated with any texture evolution or preferred crystal orientation in the cast specimens? (ii) What is the effect of CR on texture and grain structure of cast samples? (iii) What is the influence of Sr-modification on size and misorientation of the grains? In this study, optical microscopy (OM) and electron back scattering diffraction (EBSD) were used for material characterizations.

EXPERIMENTAL PROCEDURE

Ingots of alloy EN AC-46000 was melted at 730 °C in graphite crucible. In order to investigate the effect of eutectic Si modification, a second melt was prepared with a Sr level of 486 ppm, using Al-10 %Sr master alloy. The chemical compositions of the alloys was shown in Tab. 1.

Tab. 1 - Chemical compositions of EN AC-46000 in modified and unmodified conditions (wt. % except for Sr ppm).

	Si	Cu	Mg	Fe	Zn	Mn	Sr	Al
Unmodified	10.0	2.6	0.24	0.8	0.8	0.26	0	Bal.
Modified	9.9	2.5	0.24	0.8	0.8	0.28	486	Bal.

The melt was poured in a Cu die preheated at 250 °C in order to produce rod shaped specimens, so called die cast specimen (length 20 cm, diameter 1 cm). The die cast specimens were subsequently heated to 710 °C in a Bridgman furnace and were held for 20 minutes under Ar-atmosphere to ensure complete melting and homogenization before solidification. The gradient solidification is achieved by cooling the samples with water jets right below the rising furnace. The microstructural length-scale, i.e. SDAS, was controlled by varying the rising speed of the furnace. To obtain microstructures with similar length scales to those obtained by high pressure die casting (HPDC) and gravity die casting, raising speed was set to 3 and 0.3 mm $^{s-1}$, which lead to average SDAS of 10 and 25 µm respectively.

The as-cast cylindrical bar were mounted longitudinal and cross-sectional, grinded and polished landing to the center of rods. The microstructures were studied using OM (OLYMPUS GX71) and an image analysis software (Stream Motion Image Analyzer) was employed for quantitative analysis of the microstructure. A longitudinal area of 10×30 mm^2 and cross-sectional area of 78.5 mm^2 were characterized through EBSD (EDAX, Digiview 3 camera) using JEOL 7001F scanning electron microscope at an accelerating voltage of 25 kV with 5 µm step size. A multi-field EBSD data collection was done to cover a relatively large area for grain size measurement and texture analysis. Collected data were further analyzed using TSL-OIM software. All the acquired EBSD maps had confidence index (CI) standardization followed by exclusion of points with CI less than 0.1. The grain size was measured according to the ASTM E112 intercept method. Some 500 grain boundaries over five fields of view were counted on the screen of the image analyzer at three locations along the specimen.

RESULTS AND DISCUSSION

The typical EBSD orientation maps of the specimens in different as-cast conditions were presented in Fig. 1. The boundary criterion was set for maximum angular deviation of 15 deg. The average grain size as well as SDAS of each condition was measured and summarized in Tab. 2. All as-cast specimens comprised quite large grains having an average size larger than 1 mm. No significant preferential grain orientation was observed looking at EBSD maps of the specimens. However, in the case of the low cooling rate (SDAS 25µm), a number of grains were found to have tendency to elongate toward the solidification direction. The grains in the specimen of SDAS 10 µm (unmodified and modified) and die cast were randomly-oriented. The average grain size was reduced by increasing the cooling rate, which has been well-accepted in scholars [8]. Non-index regions (black spots in the EBSD map) are primarily due to porosity in the specimens. The porosity formation is facilitated by decreasing the cooling rate. This can be readily observed in EBSD maps of SDAS 25 µm as well as conventionally cast specimen (die cast). Although Sr addition evolved a significant refinement in eutectic Si-particles, the average grain size remained rather similar comparing SDAS 10 in unmodified and modified conditions. The grain size of die cast material was found to be quite similar with directionally solidified specimens with SDAS10 µm. Fig. 2e shows a series of pole figures where the ideal positions of the important texture components that are encountered in aluminum material (FCC) are presented. The texture components in aluminum are well-known as Cube {100} ⟨001⟩, Brass {110} ⟨112⟩ and Copper ⟨111⟩ {112} (from top to bottom in Fig. 2e) [8]. The comparison between the standard and experimental pole figures indicates a preferential directions of ⟨001⟩ in (100) plane for the case of SDAS 25 µm.

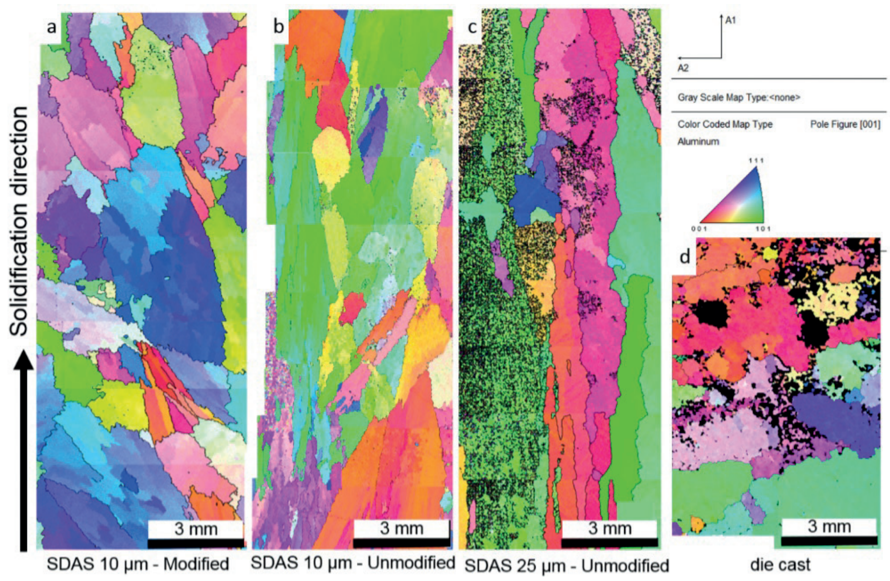

Fig. 1 - Composite EBSD map taken from the center of cast specimens.

Tab. 2 - Quantitative measurements of the microstructural features for different as-cast microstructure.

Furnace raising speed (mm/s)	Mode of Solidification	Sr level (ppm)	SDAS (µm)	Grain size (mm)
0.3	Directional	-	25.9 ± 3.5	2.10 ± 0.36
3	Directional	-	10.1 ± 2.3	1.19 ± 0.24
3	Directional	486	10.4 ± 2.1	1.32 ± 0.30
-	Conventional (die cast)	-	19.4 ± 4.4	1.22 ± 0.18

Directions of [100] are usually parallel to the axis of the columnar grains or perpendicular to the mold wall. Therefore, the frequency of such poles is conceivable in cross-sectional planes normal to the mold wall. The normal [100]-type preferred orientation in aluminum cast alloys has been pointed out in other works, termed Al-casting texture [9]. The study reveals that high cooling rate (SDAS 10 unmodified and modified) lead to an increase in degree of grain orientation randomness. The support for this observation is the reduced number of crystallites that occupied preferential orientations from 12.8 in low cooling rate to 7.3 and 5.7 in high cooling rate, see Fig. 2a, b and c. However Galindo et al. [10] showed that there is no correlation between preferred grain orientation and solidification speed in Al-Cu cast alloy. The authors believe that more investigation is required on this matter. Regarding the Sr-modification, no substantial changes in both grain structure and crystallographic texture were observed.

CONCLUSION

The grain structure and texture evolutions during directional solidification of aluminum EN AC-46000 alloy were investigated using EBSD and OM techniques. The grains were found to be rather large (> 1 mm) in all as-cast conditions. High degree of grains orientation randomness was found in high cooling rate regardless of modification treatment. There was no correlation between grain size/orientation and Sr-modification. Low cooling rate directionally solidified specimens as well as conventionally cast specimens showed slight [100]-type preferred orientation. The directional solidification technique was not associated with any texture generation in Al-Si cast specimens.

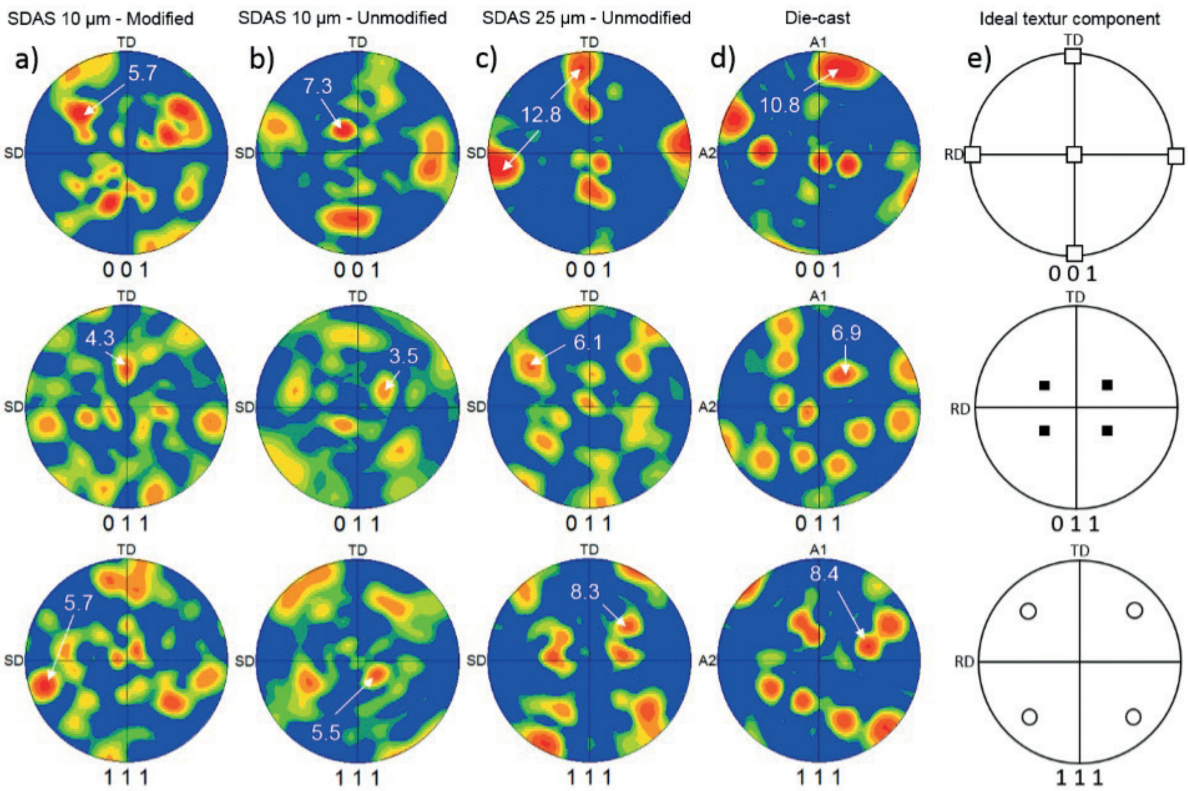

Fig. 2 - a-d) Experimental pole figures of each case. e) Standard pole figures showing ideal texture components. SD is solidification direction, TD is transversal direction.

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