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IMPROVED DEFECT CONTROL AND MECHANICAL PROPERTY VARIATION IN HIGH PRESSURE DIE CASTING (HPDC) OF A380 ALLOY BY HIGH SHEAR MELT CONDITIONING

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ABSTRACT

A380 alloy has been widely employed to produce thin-wall components via high pressure die casting (HPDC). During HPDC processing, there is a significant problem of property variation even with the very stable and precision automated casting procedure. The enlarged variation lowers the component performance and affects the steady and uniform property distribution along the whole component. In this study, high shear melt conditioning technology was developed and applied to the melt prior to pouring into the shot sleeve. Experimental results show that with application of intensive melt shearing, the variation of elongation was decreased from 21.8 to 13.9%, and yield strength variation was reduced from 5.5 to 3.6%. The improved property variation is attributed to enhanced nucleation both in shot sleeve and the die-cavity, and to the improved distribution of porosity and secondary phases as a benefit of high shear induced grain refinement. With application of high shear, large number of the Spinel phase ($MgAl_2O_4$) particles with double size distribution in average diameter of 80 and 300 nm were formed. Due to the good orientation relationship and small misfit between alpha Al and $MgAl_2O_4$, the particles act as the effective nuclei in shot sleeve and die cavity, respectively.

KEYWORDS

High shear, High pressure die casting, Grain refinement, Mechanical property variation, $MgAl_2O_4$

INTRODUCTION

A380 alloy had been widely used for produce automotive components by cold chamber high pressure die casting (HPDC) processing, due to its relative good mechanical properties and castability performance, and more important most of A380 ingots were produced by recycled Al alloys. Therefore, to promote utility of A380 will contribute to reducing emission of CO_2 and to the lightweight of automotive industry as well. When cold chamber HPDC was employed to produce the components, the mechanical properties of A380 alloy always have a distribution range (named variation herein), or in other words the properties were not stable. The reason was ascribed to the typical solidification characteristics occurred in HPDC processing. During HPDC processing, there are three steps of melt movement. The first step is that the melt was poured into shot sleeve at temperature of about 680°C, in which shot sleeve was preheated by few shots of melt filling, or by heater. During step one, the first solidification of melt was happened in shot sleeve and about 20% solid made of coarse α-Al grains was formed (Li, Xiong, & Guo, 2016). Such kind of grains will retain in the final products and deteriorate the properties variation. The second step is that the melt was forced moving forward slowly by plunger at about 0.2–0.3 m/s until the liquid melt front to the inner gate of mold. The third step is that the melt moved very fast to complete the filling of die cavity and refilling the solidification shrinkage by fast movement of plunger about 2–3 m/s. The second solidification was occurred in die cavity and fine α-Al grains will be formed by high cooling rate at about 500–1000°C/s. From the solidification point of view, the grain size was dominated by nucleation and growth. When HPDC was employed to produce components, the melt quality becomes the priority factor to control the solidification process as the other casting parameters were kept at the same.

Coarse α-Al grains formed in shot sleeve was considered that they are the main factor affect the mechanical properties stability. To minimize the existence of the coarse grains and then reduce mechanical properties variation, many efforts were taken such as optimizing the filling process, increasing shot sleeve temperature and pouring temperature. Indeed, these methods can reduce the variation of HPDC alloys. But this improvement is achieved at the expense of shortening the shot sleeve and die lifetime caused by the erosion of molten melt.

Grain refinement is proven that it is the best approach to obtain the fine uniform microstructure and improve the yield strength and elongation simultaneously, and Al5Ti1B is the best grain refiner for Al alloys currently (Quested, Dinsdale, & Greer, 2005). During producing A380 alloy components, Al5Ti1B refiner was always added into melt as a necessary casting procedure. In view of the specific solidification of HPDC and the characteristics of A380 alloy, the addition of Al5Ti1B refiner contributes limited improvement of mechanical properties variation.

Recently, physical refinement method by high shearing melt treatment technique patented by BCAST had been proved that it can refine most Mg and Al alloys (Fan, Wang, Xia, & Arumuganathar, 2009; Li, Xia, Jarry, Scamans, & Fan, 2011; Men, Jiang, & Fan, 2010; Xia, Mitra, Brij, Liu, & Fan, 2010). The refinement mechanism is that high shear can disperse the existing oxide films into fine particles as potential nuclei for Mg and accelerate the formation of $MgAl_2O_4$ as effective nuclei for Al alloys.

In the present study, the mechanical properties variation of A380 components produced via HPDC with traditional melt processing, and with high shear melt conditioning prior to HPDC (MC-HPDC) was investigated. The mechanisms of the influence of high shear both on shot sleeve solidification and die cavity solidification are discussed.

EXPERIMENTAL

A380 alloy supplied by Norton was used as raw material for conducting HPDC processing, its composition was listed in Table 1. In present study, clay-graphite crucible and electrical resistance furnace were used to melt alloys, and two crucibles of 50 Kg A380 ingots each were prepared for comparison of melt with and without high shear melt conditioning. When the melt temperature reaches 750°C, 30 minutes of holding time was needed to uniform the composition distribution. Then rotary degassing and high shearing were employed for A380 melt, respectively. The parameter of rotary degassing was of 350 rpm stirring speed for 8 minutes with Ar flow rate of 4 L/min. High shear melt conditioning included two steps, the first step was degassing with Ar flow rate of 0.2 L/min and shearing 5 minutes at rotor speed of 1500 rpm, and the second step was only shearing at 1500 rpm for 10 minutes to complete the melt conditioning treatment without introducing Ar. After finishing melt treatment, the melt was poured into shot sleeve manually with transfer ladle, and then melt was pushed into die cavity by plunge to obtain 8 tensile test samples with 6.35 mm in diameter in extensometer part for each shot, in which the temperature of melt, shot sleeve and die mold was 680, 180 and 150°C, respectively.

Table 1. Chemical compositions of A380 alloy used in present study (in wt.% percent)

	Si	Cu	Zn	Fe	Mn	Mg	Ti	Ni	Pb	Sn	Al
A380	9.35	4.51	1.51	0.84	0.32	0.07	0.065	0.03	0.03	0.02	Bal.

After 24 hours nature aging, the samples were tested at as-cast state by Instron 5500 Universal Electromechanical Testing System at an ambient temperature. The gauge length of the extensometer was 25 mm and the ramp rate for extension was 1 mm/min. Specimen for microstructure analysis were cut from the centre of tensile sample bar with cross section perpendicular to tensile direction.

To collect the particles in A380 melt with and without high shear melt conditioning, prefil method was employ to filtrate the melt with SiC filter. Then, the samples were cut perpendicular to the filtration direction to obtain the sample for microstructure observation at filter and melt interface. Samples for metallographic examination were prepared by a standard technique, Field-emission scanning electron microscopy (FE-SEM, SUPRA 35VP, Carl-Zeiss Company) equipped with an energy dispersive X-ray spectroscopy (EDS) was used for microstructure analysis.

RESULTS AND DISCUSSION

Figure 1 showed the yield strength and elongation of A380 alloys with rotary degassing and high shear melt conditioning. The distribution range of yield strength and elongation of A380 alloy with rotary degassing was from 129.1 to 152.9 MPa, and from 2.91 to 6.88%, respectively. With application of high shearing, the distribution range of yield strength and elongation was from 130.7 to 149.9 MPa, and from 3.73 to 6.62%, respectively. It can be seen from the comparison that high shear can reduce the distribution range of both yield strength and elongation of A380 alloy. To obtain the coefficient of variation (CV), the equation of $CV=SD/\mu\times100\%$ is used to calculate its value, in which SD is standard deviation, and μ is the average value of yield strength or elongation. The small value of CV means the narrow distribution range of properties and the good property stability. The influence of high shearing melt conditioning on the coefficient of variation of A380 alloy was shown in Table 2. The data in Table 2 revealed that with high shearing treatment, yield strength variation was decreased from 5.48 to 3.62%, and elongation variation was decreased from 21.83 to 13.96%. The variation comparison indicated that high shear melt conditioning can improve the mechanical properties variation.

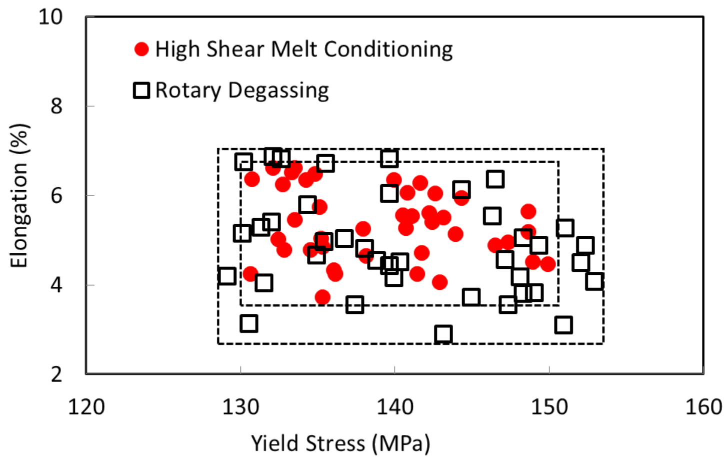

Figure 1. The comparison of mechanical properties of A380 alloys between rotary degassing and high shear melt conditioning showed that melt treatment with high shear can improve the variation both on yield strength and elongation

Table 2. Coefficient of variation of yield strength and elongation of A380 alloys with melt treatment of rotary degassing and high shear, respectively

Melt treatment	Average value (μ)		Standard Deviation (SD)		Coefficient of Variation(CV)	
	Yield strength (MPa)	Elongation (%)	Yield strength (MPa)	Elongation (%)	Yield strength (%)	Elongation (%)
Rotary degassing	141.10	4.90	7.74	1.06	5.48	21.83
High Shear	139.30	5.40	5.04	0.75	3.62	13.96

To investigate the mechanism of variation improvement, observation of microstructure evolution was necessary to reveal the grain refinement performance, secondary phase distribution and porosity distribution and so on. Figure 2 showed the grain morphology of α-Al formed in shot sleeve (α-Al_1) and in die cavity (α-Al_2) of A380 alloy with rotary degassing (Figure 2a) and with high shear melt conditioning (Figure 2b). α-Al grains formed in shot sleeve were normally in the form of coarse morphology due to the relative slow cooling rate and more growth time after nucleation. α-Al grains formed in die cavity was very fine and its size was below 10 μm because of the high cooling rate of HPDC. It can be seen from Figure 2a that there were coarse α-Al grains existed in the alloy with rotary degassing, the size was about 50 μm. And the size of another kind of α-Al grains formed in shot sleeve was about 10 μm. After application of high shear melt conditioning, both the size of coarse α-Al_1 grains and fine α-Al_2 grains was reduced, and the size was about 30 μm for α-Al_1 grains and 5 μm for α-Al_2 grains. More importantly, the size distribution of α-Al grains was more uniform than that of microstructure without high shear application.

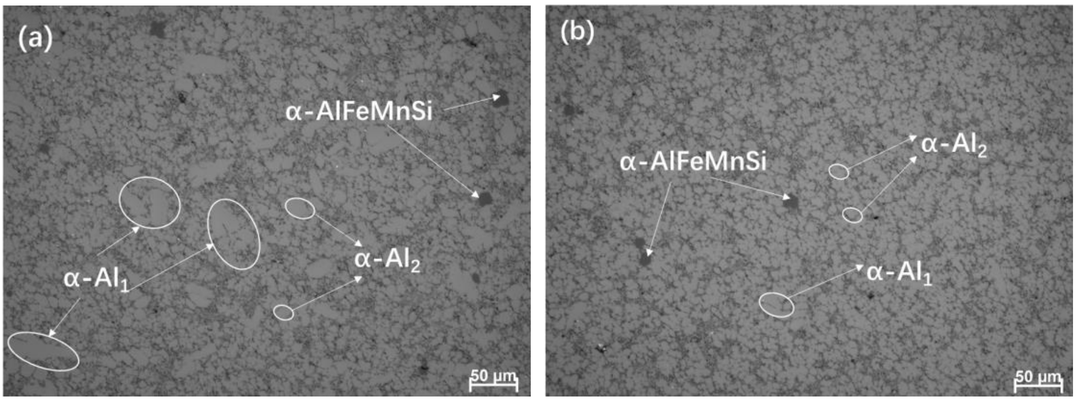

Figure 2. Grain morphology of A380 alloys showed that the better grain refinement and uniform grain distribution were achieved with high shear melt conditioning (b) compared to the microstructure without high shearing (a), and the size of α-Al formed in shot sleeve (α-Al_1) was decreased significantly with high shearing

The refinement of α-Al both formed in shot sleeve and die cavity illustrated that high shear can promote the nucleation performance of A380 alloy. Spinel ($MgAl_2O_4$) was revealed that it can be the effective nucleation site for α-Al in Al-Mg alloy (Li, Wang, & Fan, 2012) and in Al alloy (Zhang, Wang, Xia, Hari Babu, & Li, 2016) due to the small misfit of about 1.4% between spinel and Al. Basing on the relationship between undercooling and nuclei size, to activate the spinel as effective nuclei, the size distribution of particles became the important factor to dominant the spinel performance on grain refinement of Al alloy produced by HPDC processing.

The particles in A380 alloys were analyzed using SEM after collecting via the prefil method, the results were shown in Figure 3. It can be seen from figure 3a that TiB_2 was the main particle type in A380 alloy with rotary degassing, and its size was about or more than 1 μm. These TiB_2 particles were from the new added grain refiner and from the retained TiB_2 particles added as refiner in recycled Al. Figure 3b showed that besides TiB_2 particles, $MgAl_2O_4$ with two kinds of size distribution were found in A380 alloy with high shear melt conditioning. The size of relative big $MgAl_2O_4$ particles was about 300 nm, and the size of small particles was about 80 nm. The existence of $MgAl_2O_4$ indicated that high shear can promote the formation of such phases. The formation mechanism of $MgAl_2O_4$ can attributed to the disperse effect of high shear on existing Al_2O_3 film in Al melt. There always have many Al_2O_3 film in melt due to the disturbance of melt surface and the active reaction between Al and O_2. During high shear unit running, the melt was forced into the shearing area with a shear rate of about 10^5–10^6/s, any oxide films into these area would be breakup into fine particles. If the melt containing Mg, the reaction between dispersed Al_2O_3 particles and Mg will occur and then form $MgAl_2O_4$.

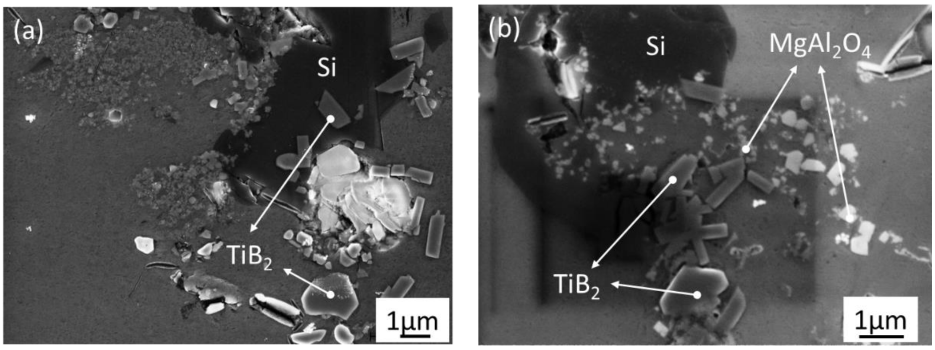

Figure 3. Microstructure of prefil samples showed that TiB_2 was the main type of particles in A380 alloy with rotary degassing (Figure 3a), and $MgAl_2O_4$ and TiB_2 were the main kinds of particles in A380 alloy with high shear melt conditioning (Figure 3b)

From the nucleation point of view, if such kind of particles employed as effective nuclei in HPDC process, it would enhance the grain refinement and then subsequently benefit the mechanical properties improvement. The enhanced grain refinement of A380 alloy with high shear melt conditioning revealed that in present study, $MgAl_2O_4$ with the double size distribution of about 300 and 80 nm can nucleate α-Al effectively both formed in shot sleeve and die cavity.

CONCLUSIONS

High shear melt conditioning can reduce the scatter of yield strength and elongation of HPDC A380 alloy. With MC-HPDC, the coefficient of variation of elongation was decreased from 21.8 to 13.9%, and yield strength variation was reduced from 5.5 to 3.6%. The improved property variation is attributed to enhanced nucleation both in shot sleeve and the die cavity caused by formation of $MgAl_2O_4$ particles, in which double size distribution of about 80 and 300 nm were synthesized. The grain refinement principle was ascribed to the good orientation relationship and small misfit between α-Al and $MgAl_2O_4$.

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