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Microstructure and mechanical properties of rheo-diecasted A390 alloy

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Abstract: The microstructure and mechanical properties of the rheo-diecasting (RDC) A390 alloy under as-cast and T6 heat treatment conditions were investigated. The results indicate that the RDC sample has fine and uniform microstructure throughout the sample under the as-cast condition, and the average size of primary Si spheroids is 20−30 μm. Meanwhile, the intermetallic compounds in RDC sample are reduced. Compared with the alloy produced by conventional liquid die-casting(LDC), RDC samples have improved tensile strength, ductility, hardness and wear resistance. It is also found that heat-treatment of the RDC A390 alloy under T6 condition, can substantially improve mechanical properties, with the tensile elongation more than 100% improvement.

Key words: A390 alloy; rheo-diecasting; ultrasonic vibration; microstructures; mechanical properties

1 Introduction

Hypereutectic Al-Si alloys such as A390 are widely applied to manufacturing automotive engine pistons, cylinder blocks and compressors parts due to their low coefficient of thermal expansion, high hardness and wear resistance. However, these alloys are difficult to be cast because of their large freezing range, which leads to coarse silicon particles aggregated severely in the microstructure, thus the mechanical properties are adversely affected[1].

Semi-solid processing of hypereutectic Al-Si alloys is mainly limited to the thixocasting route[2–3]. It is well known that rheocasting is of cost advantage over thixocasting and successfully used in hypoeutectic Al-Si alloys[4–5]. However, the rheocasting of hypereutectic Al-Si alloy has seldom attained success with acceptable microstructure in an economic and efficient way[6].

As ultrasonic vibration(USV) requires less expensive equipments for production and is easy to be introduced into the melt, it has been widely applied to treating liquid metals for improving the microstructures of ingots[7–10], and also employed to prepare billets or slurry[11–13]. However, few studies were conducted for rheo-diecasting (RDC) of slurry prepared by USV, and the process as well as slurry solidification after action of USV needs to be investigated. Therefore, in this work, the process of rheo-diecasting of slurry created by USV was investigated.

2 Experimental

The A390 alloy used was prepared using Al-22%Si master alloy, commercial aluminum (99.7 %), 99.6% Cu and 99.5% Mg. The materials were melted in a resistance furnace at 750–780 °C, and the melt was degassed for 15 min with argon gas through a graphite lance. The melt was cooled to temperature of 660–730 °C after degassing. The slurry maker, i.e. the metal cup for preparation of slurry, was preheated to 530 °C in the heating furnace. Subsequently, certain amount of melt was poured into the metal cup followed by application of USV. The poured melt was cooled down to the temperature range of 580–630 °C through thermal balance between the melt and the cup. After being treated with USV at 615 °C for 0.6 min, the slurry was poured into the shot sleeve for die casting. Samples as indicated in Fig.1(a) were rheo-diecasted. The liquid die-casting (LDC) samples were made under the same condition but with a pouring temperature of 695 °C. The right two parts were used for mechanical property test, and their dimensions are shown in Fig.1(b). After forming, one of the two parts was T6

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heat-treated, while the other was in as-cast state. Both parts of the sample were tested for mechanical properties. Then, specimen of over 10 mm in length from position *A* shown in Fig.1(a) of every sample rod was cut for microstructure observation and metallographic analysis. After the specimens were embedded, polished and etched by 0.5% hydrofluoric acid solution, they were observed by an optical microscope or SEM, and several metallographs of each specimen were taken by a digital camera, and analyzed by a semisolid microstructure analysis software system.

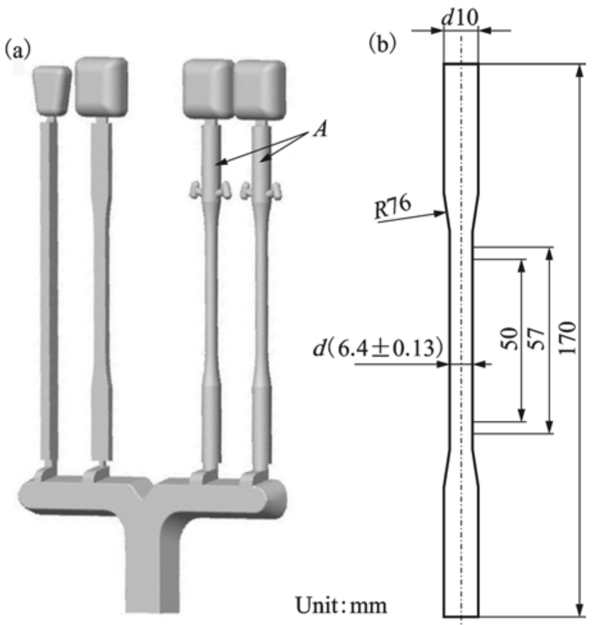

Fig.1 Diecast sample(a) and dimension of right two parts(b) (*A* is position where specimen is taken for microstructure observation)

3 Results and discussion

3.1 Microstructures and properties of as-cast A390 die-casting samples

Obvious difference in both the size and distribution of the primary Si particles for the LDC and RDC samples can be found in Fig.2. The LDC A390 alloy sample, even modified by 0.08% P, exhibits a non-uniform microstructure, and the primary Si particles with plate-like shape are severely agglomerated. In addition, the dendritic morphology for the primary α(Al) phase is observed in the microstructure of LDC sample. Fig.2(b) shows the typical microstructure of the unmodified A390 alloy produced by RDC. In comparison with Fig.2(a), it can be seen that, apart from the relatively large primary Si particles (marked as Si-1) formed inside the slurry maker, the solidification microstructure is mainly composed of the fine Si particles (marked as Si-3). This is caused by the solidification of the remaining liquid inside the die, which is referred to secondary solidification[14]. It is also noted in Fig.2 (b) that a few Si plate fragments (marked as Si-2) are present in the microstructure of RDC sample. It is believed that such plate fragments originated from the Si plates form in the shot sleeve of the die casting machine and during slurry transferring because of a quick drop of temperature. This triggers the nucleation of the Si crystals and allows them to grow plate-like as no ultrasonic acting outside the slurry maker. The primary Si plates are fragmented as they pass through the gate during the die filling process, resulting in the plate fragments in the final RDC microstructure. It is also noted that α(Al) particles are present in equiaxed morphology, and the dendritic morphology for the primary α(Al) phase is hardly observed in the microstructure of RDC sample.

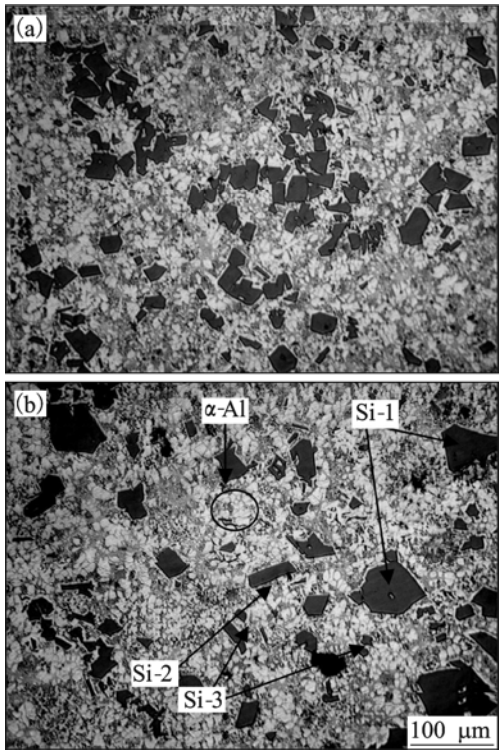

Fig.2 Microstructures of as-cast A390 samples: (a) Liquid die-casting of P-modified A390 alloy; (b) Rheo-diecasting of unmodified A390 alloy

In addition, whether modified or not, in the LDC sample there is a Si particles depleted layer towards the sample surface while many Si particles are concentrated in its central part and a fair amount of gas pores caused by gas entrapment are observed. On the contrary, for the RDC sample, the primary Si particles distribute uniformly throughout the section, and no apparent segregation is observed. As a consequence of laminar flow during mould filling, large pores caused by gas entrapment are also completely eliminated.

Fig.3 shows SEM images of LDC and RDC samples, which reveals clearly Al_2Cu metallic compound that is indistinct under optical microscope. It can be seen that the LDC sample has more Al_2Cu precipitates interconnected with each other and agglomerated severely, while the RDC sample presents a less, fine and scattered Al_2Cu phase.

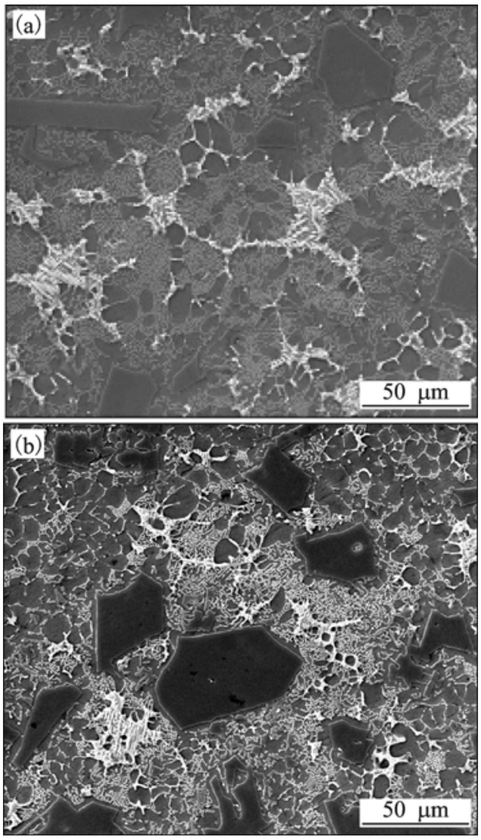

Fig.3 SEM images of as-cast LDC (a) and RDC(b) samples

Fig.4 shows the force—elongation curves of A390 alloy samples during tests. Though with similar trend, the RDC sample needs larger force for the same elongation than the LDC one, and it can achieve a higher elongation before fracture. The mechanical properties of LDC and RDC samples are listed in Table 1. It can be seen that, compared with that of LDC sample, the ultimate strength of RDC one is improved by over 25%, and the

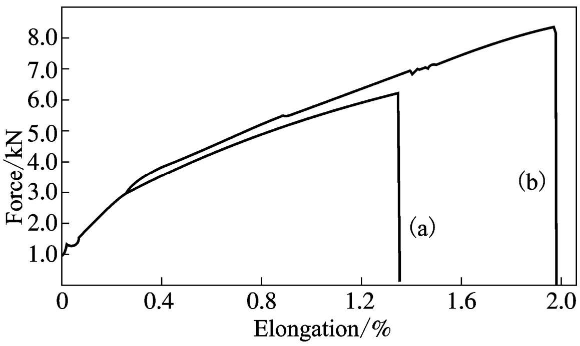

Fig.4 Force−elongation curve of LDC (a) and RDC (b) A390 alloy samples

Table 1 Mechanical properties of as-cast A390 samples

Sample	σ_b/MPa	δ/%	HB hardness
LDC	214	0.2	90
RDC	268	0.4	134

hardness increased by almost 50%. However, the elongation of both samples is less than 1%.

Meanwhile, further study proves that the wear resistance of the RDC sample is higher than that of the LDC one; the wear rate of the former is 3.1%, while that of the latter is 5.2%; and the wear scar of the latter is deeper than that of the former.

3.2 Microstructures and mechanical properties of A390 die-casting samples after heat-treatment

Fig.5 shows SEM images of LDC and RDC samples after T6 heat-treatment. Obviously, a great change takes place for the microstructures of both the LDC and RDC samples. In spite of no noticeable change for the morphology of primary Si particles, all the eutectic Si particles are converted into granular fine particles uniformly distributed in the matrix. Simultaneously, the amount of the Al_2Cu phase is reduced, and its morphology is changed into flocculent form for LDC sample and granular form for RDC sample.

As listed in Table 2, in contrast with those of LDC

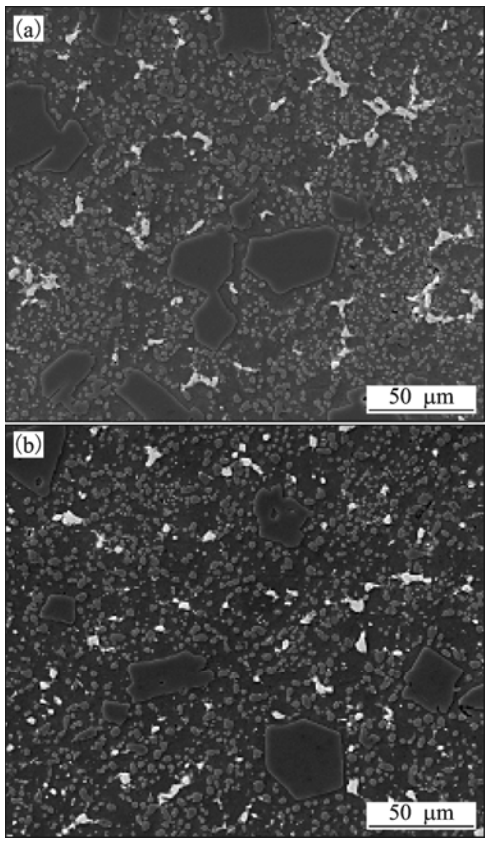

Fig.5 SEM images of LDC (a) and RDC(b) samples after T6 heat-treatment

sample, the ultimate strength, elongation and hardness of the RDC one are increased by 34.2%, 105.6% and 45.5% respectively after T6 heat-treatment. From Tables 1 and 2, it can also be found that the mechanical properties (excluding hardness) of RDC sample can be raised much more than that of LDC one by T6 heat-treatment.

Table 2 Mechanical properties of A390 samples after T6 heat-treatment

Sample	σ_b/MPa	δ/%	HB hardness
LDC	228	0.72	88
RDC	306	1.48	128

3.3 Effect of USV on RDC process

The unique microstructure and greatly improved mechanical properties of RDC samples can be attributed to slurry fabricated by USV. The application of USV would initiate cavitation and acoustic streaming, which induce high shear rate and high intensity of turbulence macroscopically and microscopically in melt[15]. The high shear rate and high intensity of turbulence homogenize the solute field and temperature field around primary Si particles, thus they would grow into spheroids with acceptable size[14]. Eventually, the primary solidification taking place under this condition results in a unique microstructure.

As for the effect of prior action of USV on the solidification of the remaining liquid alloy inside the die cavity, it can be reduced in two aspects: first, the cavitation creates a number of nuclei through activating the oxides such Al_2O_3; second, the uniform temperature and composition fields provide a favorable condition for nuclei growing at the same rate in all directions[16]. Consequently, very fine primary Si particles form under relatively high cooling rate during the secondary solidification. The above-mentioned effect is also responsible for the formation of equiaxed α(Al) phase and fine eutectic Si particles.

4 Conclusions

1) In contrast with the LDC sample, the RDC one has fine and uniform microstructure throughout the sample in as-cast condition. The average size of primary Si spheroids is 20–30 μm, and the intermetallic compounds in RDC sample are reduced and scattered.

2) The RDC sample has greatly improved tensile strength, ductility, hardness and wear resistance over the LDC one. T6 heat-treatment of the RDC A390 alloy can substantially improve its mechanical properties.

3) The unique microstructure and greatly improved mechanical properties of RDC sample can be attributed to the effect of USV on the primary and secondary solidification of slurry during RDC process.

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