Mechanical Properties of Magnesium Alloys Produced by Centrifugal Casting Process

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Abstract: The variation rules of the tensile strength, yield strength, elongation, micro hardness and wear properties of magnesium alloys in different centrifugal radius and rotation speed have been investigated. The results shows that, the tensile and wear properties of magnesium alloy castings improve with the increase of rotation speed in the same centrifugal radius, besides, when the centrifugal radius is larger, the mechanical properties increases much more with the increase of rotation speed. The effects of the centrifugal radius are similar to that of rotation radius. The mechanical properties are greatly improved due to the finer microstructure and the strengthened grain boundary and then resulting in the increase of the resistance to dislocation slipping.

1 INTRODUCTION

Magnesium is one of the lightest mental commonly used. Its desirable features including low density, high specific strength and specific stiffness make it an attractive structural material (Pan, 2010; Zha, 2009; Le, 2009). Nowadays, it has been applied to industries such as automotive, communications, electronics and aerospace (Wang, 2006). Mechanical properties is the first thing to consider when applying to industries. However, the absolute intensity of the magnesium is low, especially at high temperature. The fact that the poor flow ability makes it easy to emerge holes, which not only effect the integrity of the filling, but also does harm to mechanical properties.

The centrifugal casting method greatly improves the flow ability of the magnesium melt, increases the feeding pressure during solidification as well as reduces casting defects as shrinkages (Li, 2006;Chirita, 2008). Therefore, centrifugal casting method can obtain compact castings and excellent mechanical properties than that in conventional gravity field (Xu, 2013).In this paper, we introduce centrifugal casting method to magnesium casting. Using centrifugal casting method can not only shorten the time of filling, but also slow down the downward trend of the melt temperature. The mechanical propertiesdiversionwith rotation speed and centrifugal radius undercentrifugal force fieldhas been discussed.

2 EXPERIMENTS

The AZ91D magnesium alloys were prepared with a resistance furnace by melting pure Mg (99.9wt%), Al (99.9wt%) and Zn (99.9wt%) raw materials (according to the ratio) in a graphite crucible at 730 ℃ for 5 min. When the centrifugal turntable vertically rotated smoothly, the melt was poured into the mould made of 45 carbon steel which was preheated at 100℃. The mould rotation speeds used in the experiment were 0 rpm, 200 rpm, 400 and 600 rpm, respectively. The rotation direction was clockwise.

The sheet tensile specimens were selected along with the direction of centrifugal radius and perpendicular to the casting surface, selected parts were at centrifugal radiuses of 0.100m, 0.125m, 0.150m, 0.175m and 0.200m respectively. At each position, a tensile specimen was selected every2mm.The mean value of fives pecimens was taken as the tensile data for each position. The dimension of the sheet tensile specimens shows in Figure 1, and the thickness is 2mm.

Tensile tests were conducted onInstron5569 Omnipotence Electron Material Test Machine at room temperature, with the gauge length 10mm and the loading speed 1mm/min. The extension rates were directly measured from samples before and after fracture. In this experiment, the HV120tester was used to measure the micro hardnesse of the five specimens mentioned above, each specimen was measured in 10 different positions and the mean value was taken as the hardness value of the specimen likewise. The test load was 100g, and the loading time was 15s.

The abrasion tests were conducted on M20000 wear testing machine. The casting specimens were worn on 10×10×10mm square columns at five positions mentioned above. Friction pair material were rings with a diameter of 40mm. This experiment was dry friction, and the applied loads of relative wear surfaces were 10N, 20N, 30Nrespectively.The rotation speed was 300rpm. The lost weight during abrasion is measured by SARTORIUS electronic balance with accuracy of microgram. Sample of both before and after the abrasion test were washed by absolute ethyl alcohol and dried afterwards for measurement accuracy.

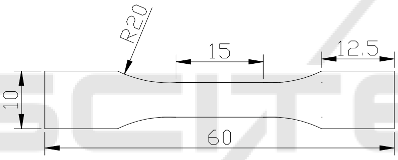

Figure 1: Dimensions of magnesium alloy sample for tensile test (mm).

3 RESULTS AND ANALYSIS

3.1 Tensile Properties and Hardness

Figure 2 and 3 show the influence of centrifugal radius and rotation speed on the tensile mechanical properties of magnesium alloy castings respectively. It can be seen from the figures: tensile strength, yield strength and specific long ation increase with the increase of rotational speed under the same centrifugal radius, and the tendency to increase gradually slows. The greater the rotation speed is, the more excellent tensile mechanical properties are, and under greater centrifugal radius, tensile properties increase more with the increasing of rotation speed. Similarly, the influence of the centrifugal radius on the tensile properties of magnesium alloy is alike, but the influence is comparatively small.

According to the average microhardness values of the measure dpositions and the centrifugal radius and rotational speed values of these five positions, we draw the curves of microhardness varying with the centrifugal radius and rotation speed under centrifugal field, the results are shown in Figure 4a) and Figure 4b) respectively. The variation trend of microhardness HV with the centrifugal radius and rotation speed can be seen from the figures. If one of the parameters remains unchanged, the microhardness will increase with the increase of another parameters, but the influence of the centrifugal radius is smaller.

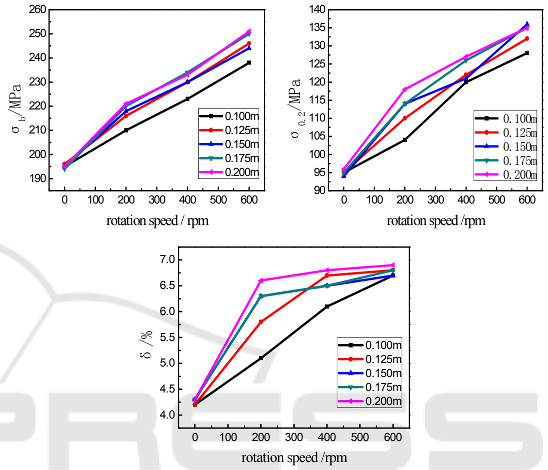

Figure 2:Effects of rotation speed on the tensile property of magnesium alloy castings:(a)tensile strength; (b)yield strength; and(c)specific elongation.

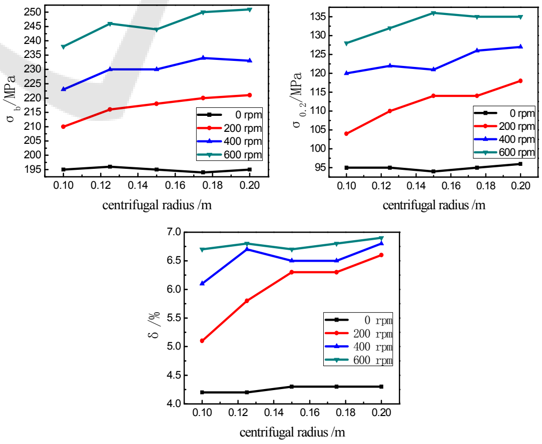

Figure 3:Effects of centrifugal radius on the tensile property of magnesium alloy castings:(a)tensile strength; (b)yield strength; and(c)specific elongation.

The experimental results above can be explained by the following analysis. As is well known that plastic deformation is caused by the shear changes of dislocations in the close-packed directions on close-packed slip planes in crystals. When the shear stress in this directions reaches a critical value, the plastic deformation begins with the slipping and climbing of dislocations. Obstacles hinder the slipping and climbing, which constitutes dislocation piles. The dislocation piles can cause high internal stress then prevent further deformation, thus increase resistance.

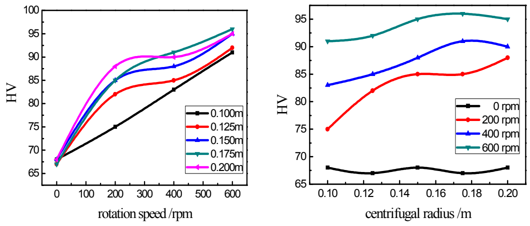

Figure 4:Effects of rotation speed and centrifugal radius on the hardness of magnesium alloy castings: (a) rotation speed; (b) centrifugal radius.

The grain boundaries are the major obstacles for dislocation motion. In a grain, sufficient dislocation can provide the necessary stress to stir the dislocation sources in adjacent grains and produce macroscopic plastic deformation. The smaller the grain size, the more the grain boundaries. Thus, the obstacles for dislocation motionincreases, the average length of the dislocation pile-up groups in grains decreases, and deformation enhances. When the slipping expands from one grain to another ,the dislocation piles will emerge, slipping will then be hindered. The smaller the grains are, the greater the stress values is. And the hindering of small grain boundaries causes difficulty for plastic deformation to pass from one grain to another. This phenomenon confines the deformation to a small area, the entire casting shows a uniform plastic deformation, so that the plastic is improved.

For the microstructure, as the grains become smaller, the precipitated phases are also relatively smaller. The effect of second-phase strengthening is increased. In addition, for coarse grains, the grain boundaries are relatively straight and have weak obstruction effect, cracks spread easily in them. There are relatively larger numbers of grains when grains are smaller, the stress concentration in grain boundaries relieves easily through the coordination of boundaries between grains, so that the nucleation is difficult for cracks.

The increase of centrifugal radius and rotation speed can decrease the grain sizes of magnesium alloy castings, thus make the microstructure more compacted and have fewer defects, enhancing the tensile properties. The microhardness of alloys has a positive growth with the tensile strength, so the microhardness of magnesium alloy castingsdemon strates the variation rules above under centrifugal force field.

3.2 Friction and Wear Properties

3.2.1 Effect of Rotational Speed

Figure 5showsthe effect of rotational speed on the wear quality and friction coefficient of magnesium alloy castings. The loading force is 20N, the load time is 50min. It can be seen from the figure that the wear quality and friction coefficient of magnesium alloys gradually decrease with the increase of rotation speed under the same centrifugal radius, and the decrease trend of wear quality tends to be steady, while the centrifugal radius substantial, the rangeabilityof wear quality increases with the rotation speed. However, the impact of centrifugal radius on the rangeability of friction coefficient is small.

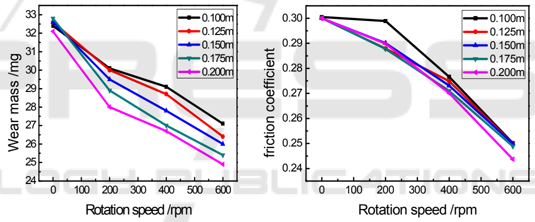

Figure 5: Effects of rotation speed on the wear mass and friction coefficient of magnesium alloy castings:(a) wear mass; (b) friction coefficient.

3.2.2 Effect of Centrifugal Radius

Figure 6 shows the influence of centrifugal radius on the wear quality and friction coefficient of magnesium alloys. The loading force is 20N, the load time is 50min.It can be seen from the figure that the wear quality of magnesium alloy castings gradually decreases with the increase of centrifugal radius under the same rotation speed, but the rangeability is small. When the rotation speed is zero, the wear quality and friction coefficient does not decrease with the increase of centrifugal radius, and remain unchanged. The results show that the influence of centrifugal radius on the wear quality and friction coefficient is small, playing a supporting role.

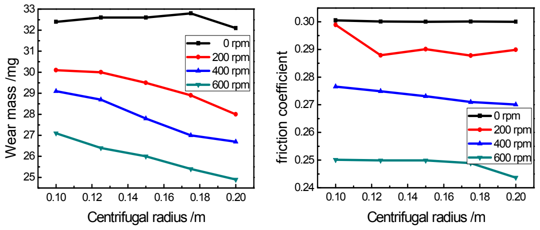

Figure 6:Effects of centrifugal radius on the wear mass and friction coefficient of magnesium alloy castings:(a)tensile strength; (b)yield strength.

The reasons of influence of centrifugal radius, rotation speed, loading force and loading time on the wear properties are mainly asfollows: the wear properties of castings are related to the strength and hardness of materials to some degree. In order to find the variation rules amongt he three propertiesintuitively (Shu, 2007; Venneker,2002;Lee,2005), we take samples under the radius of 0.150m and different rotation speed for example, the tensile strength, yield strength and wear quality data are graphed as Figure7 and Figure 8.

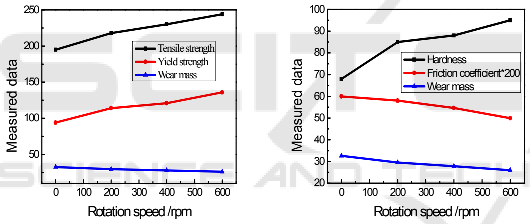

Figure 7: The comparison of variation rules: (a) strength and wear mass; (b)hardness and wear mass.

It can be seen from figures above that, with the increase of rotation speed under the same centrifugal radius, the tensile strength, yield strength and hardness increase while the wear quality decreases, that is, the wear properties increase. This is due to the wear properties of material to some degree is proportional to the strength and hardness of material. With the increase of the centrifugal rotation speed, the grain size of castings decreases, the strength and hardness of materials increase, which improves the wear properties. In addition, the increase of rotational speed and centrifugal radius make the castings more compact, and the defects are decreased, therefore, improve the wear properties of material to some extent.

4 CONCLUSIONS

(1)The tensile strength, yield strength, elongation and microhardness of magnesium alloy castings produced by centrifugal casting process increase with the increase of the centrifugal radius and rotation speed in vertical centrifugal force field, but the increase trend slows down. When the centrifugal radius (or rotational speed) is larger, the rangeabilityof these properties increases with the increase of the rotational speed (or centrifugal radius).

(2)The increase of the centrifugal radius androtation speed can enhance the effect of the fine grain strengthening and second phase strengthening, and hinder crack propagation, thereby improve the tensile properties and hardness of magnesium alloy castings.

(3) The wear properties of magnesium alloys produced by vertical centrifugal casting process improve with the increase of the centrifugal radius and rotation speed in centrifugal force field, but the influence of centrifugal radius is relatively smaller. The reason is that the wear properties of material to some extent are proportional to the strength and hardness of materials.

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