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INFLUENCE OF SECTION THICKNESS ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF SQUEEZE CAST MAGNESIUM ALLOY AM60

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Abstract

Squeeze cast light alloys has been approved for advanced engineering design of light integrity automotive applications. An understanding of the effect of section thicknesses on mechanical properties of squeeze cast magnesium alloys is essential for proper design of different applications. The present work studied the microstructure and tensile properties of magnesium alloy AM60 with different section thickness of 6, 10 and 20mm squeeze cast under an applied pressure of 30MPa. The results of tensile testing indicate that the yield strength (YS), ultimate tensile strength (UTS) and elongation (E_f) increase with a decreasing in section thicknesses of squeeze cast AM60. The microstructure analysis shows that the improvement in the tensile properties of squeeze cast AM60 is mainly attributed to the low level of gas porosity and the high content of eutectic phases and fine grain structure which resulted from high solidification rates taking place in the thin section.

Introduction

Weight reduction and increasing on fuel efficiency have become a trend in automotive development. Magnesium is one-third lighter than aluminum, three-fourths lighter than zinc, and four-fifths lighter than steel [1,2]. Moreover, the combination of high specific strength and stiffness, and excellent castablity, high die casting rates and high dimensional accuracy qualify this interesting lightweight metal in the automotive industry. Potential applications of magnesium alloys on automotive could involve cross sections with different wall thicknesses and complex shapes. Squeeze casting is designed for production of relatively thick-walled parts and fine microstructure by means of slow filling velocity, semi-solid processing and solidification under high pressure [2].

Squeeze casting is termed to describe a process that involves the solidification of a molten metal in closed die under an imposed high pressure. This process has not been widely applied in the production of magnesium component in automotive industry. Thus, magnesium fabrication techniques must be varied and to extend the limits imposed by the current and traditional gravity and die casting techniques. The development of squeeze casting technique for magnesium alloys will enhance the competitiveness of magnesium components in the growing automotive market. In this work, magnesium alloy AM60 with various section thicknesses was squeeze cast under applied pressure of 30Mpa. The microstructure and tensile behaviour of alloy AM60 were studied. And, their relations with section thickness are presented. The mechanisms responsible for the resulted tensile properties are discussed based on the optical microstructural characterization [1-4].

Experimental Procedure

The base magnesium alloy selected for this study was the conventional magnesium alloy AM60. This alloy was used to produce step castings without any addition. The chemical composition of this alloy is shown in Table 1. A step mold made of tool steel was used to fabricate step squeeze castings. The thicknesses of each step were 6mm, 10mm and 20mm as shown in figure 1. The step casting was then cut for density measurement, porosity evaluation, tensile testing and microstructure analysis.

Table 1: Chemical composition of the investigated alloy (wt. %)

Alloy	Al	Mn	Si	Fe	Mg
AM60	5.93	0.18	<0.02	0.013	Bal.

During casting process, protective gas mixture of sulfur hexafluoride, SF_6 and carbon dioxide, CO_2 in which CO_2 acted as the carrier gas, was applied to protect the melt from any excessive oxidation or possible burning. All tools for melt processing were preheated to 150 °C on the top of a box furnace for at least 20 minutes. Both top and lower die were preheated to 300 °C before pouring.

Specimens for tensile test, density measurement, porosity evaluation and microstructure analysis were obtained by sectioning the steps of squeeze castings.

Porosity Measurement

Porosity was evaluated via density measurement. Following the measurement of specimen weight in air and distilled water, the actual density (D_a) of each specimen was determined using Archimedes principle based on ASTM Standard D3800 [5]:

$$D_a=W_aD_w/(W_a-W_w) \quad (1)$$

where W_a and W_W are the weight of the specimen in air and in water, respectively, and D_W the density of water. The porosity of each specimen was calculated by the following equation (ASTM Standard C948):

$$\%Porosity=[(D_t-D_a)/D_t]\times 100\% \quad (2)$$

where D_t is the theoretical density of the alloy AM60,which is 1.77 g/cm^3 [5].

Tensile Testing

The mechanical properties of the squeeze cast AM60 was evaluated by tensile testing. Subsize rectangular specimens were prepared according to ASTM standard B557M [6]. The gauge length and the width of the specimens were 25mm and 6mm, respectively. The thicknesses of specimens were kept the same as those of each step. The cross-section areas were measured after each specimen surface was polished in order to avoid stress concentration.

After preparation, the specimens were tested at ambient temperature on an Instron 8562 universal testing machine equipped with a computer data acquisition system. The outputted date (displacement and tensile load) was analyzed. The tensile properties, including ultimate tensile strength (UTS), 0.2% yield strength (YS), and elongation to failure (E_f) were obtained for each step thickness.

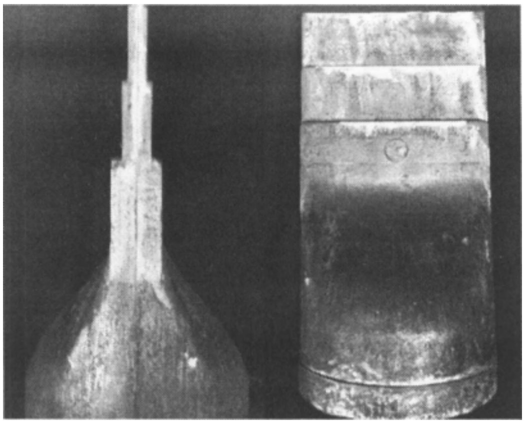


Figure 1: Schematic diagram showing a step squeeze casting.

Metallography

Specimens were prepared following the procedure which including: sectioning, mounting, grinding, polishing, T4 solution treatment and etching. Specimens were grounded using 240, 320, 400 and 600 grit silicon carbide papers, and ten polished using 1μm Al_2O_3 suspension. The etchant used was nitride (1ml HNO_3, 48ml ethanol). Etching was performed by merging the sample into the etchant for 30 seconds and ten washed the specimen surface with ethanol and running water. A Buehler optical image analyzer 2002 system was used to observe the grain structure.

Results and Discussion

Porosity Evaluation

Figure 2 shows the density and porosity measurement of squeeze cast AM60 with section thicknesses of 6, 10 and 20mm. It evident that the density of squeeze cast AM60 alloy samples increases and the porosity level decreases with an increase in section thickness. The porosity level of 6 mm specimen is significantly low (0.2%). The considerably low porosity level of the 6 mm sample may results from the high cooling rate. The numerical simulation of solidification of the step casting suggests the long solidification time should be responsible for the high level of porosity in the squeeze casting with thick cross-sections.

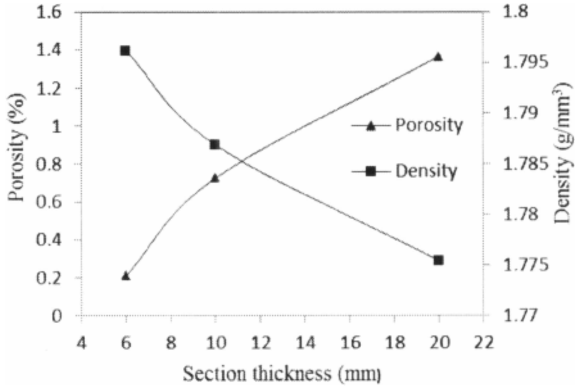


Figure 2: Porosity and density level of squeeze cast AM60 with thicknesses of 6, 10, and 20mm.

Tensile Properties

Figure 3 presents stress and strain curve for each step thickness of the squeeze cast AM60 alloy. For all three section thicknesses of specimens, the curves show that the alloy deforms elastically first under tensile loading. After the yield pointreaches, the alloy starts to deform plastically. It is obvious that the specimen with the thinner section (6 mm) has higher ultimate tensile strength, yield strength and elongation than those thicker specimens (10 and 20 mm). The variation of tensile properties with section thicknesses is summarized in table 2.

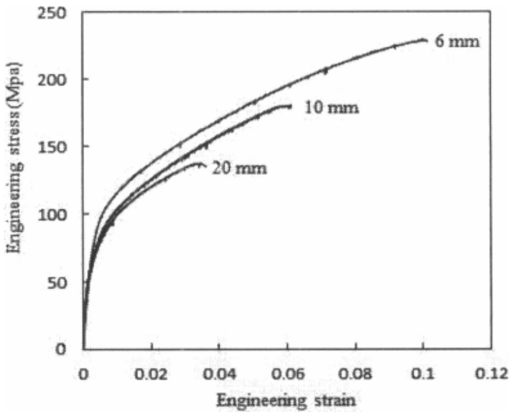


Figure 3: Typical engineering stress-strain curve of squeeze cast AM60 alloy.

Table 1: Effect of section thicknesses on UTS, YS and elongation.

Thickness (mm)	YS (MPa)	UTS (MPa)	E_f (%)
6	96	229.89	10.19
10	74	181.04	6.52
20	67	137.68	3.69

Figure 4 shows the effect of section thickness on UTS, YS and E_f. it shows that a decease in section thicknesses enhances the elongation with an 176% increment from 3.69% (20 mm) to 10.19% (6 mm). Also, there are 43% and 67% increases in YS and UTS over the 20 mm thickness, respectively. The improvement in the tensile properties should be attributed to the low porosity level and fine cell structure of thin specimen. In other words, the low strength and poor elongation of the thick specimen should be resulted from coarse microstructure and high porosity content.

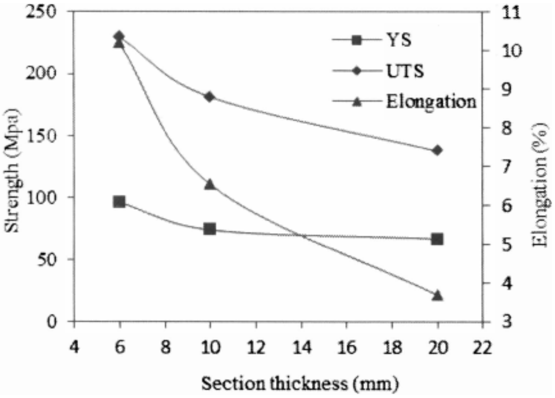
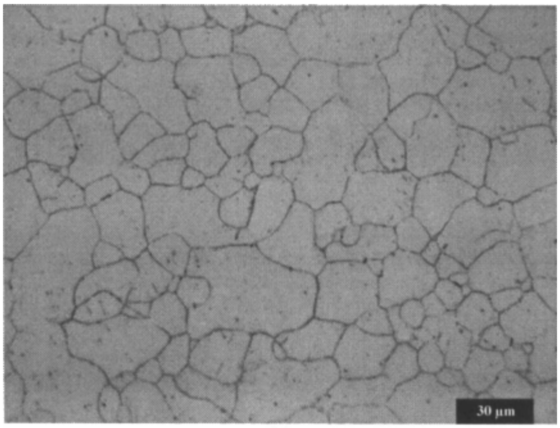


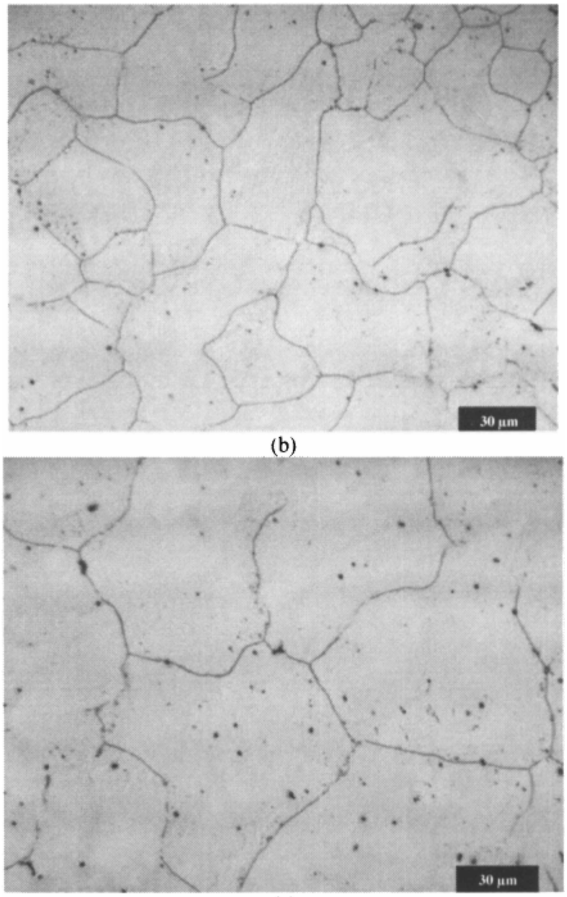
Figure 4: UTS, YS and elongation vs. section thickness.

Microstructure

Figure 5 parts presents optical micrographs generated at a magnification of 500X for squeeze cast AM60 specimens with the section thicknesses of 6 mm, 10 mm and 20 mm, respectively. Average grain size escalates from 16 μm for 6 mm specimen to 80 μm for 20 mm specimen. The greater total thermal energy in the thicker section of liquid metal requires more time for removal during solidification process if the thermal conductivity of the mold is the same for all sections [7-9]. As a result, the longer the time spent at elevated temperatures, the lager the grains grow. In other words, the thicker section in the same mold experienced a slower cooling rate and results in coarser microstructure.



(a)



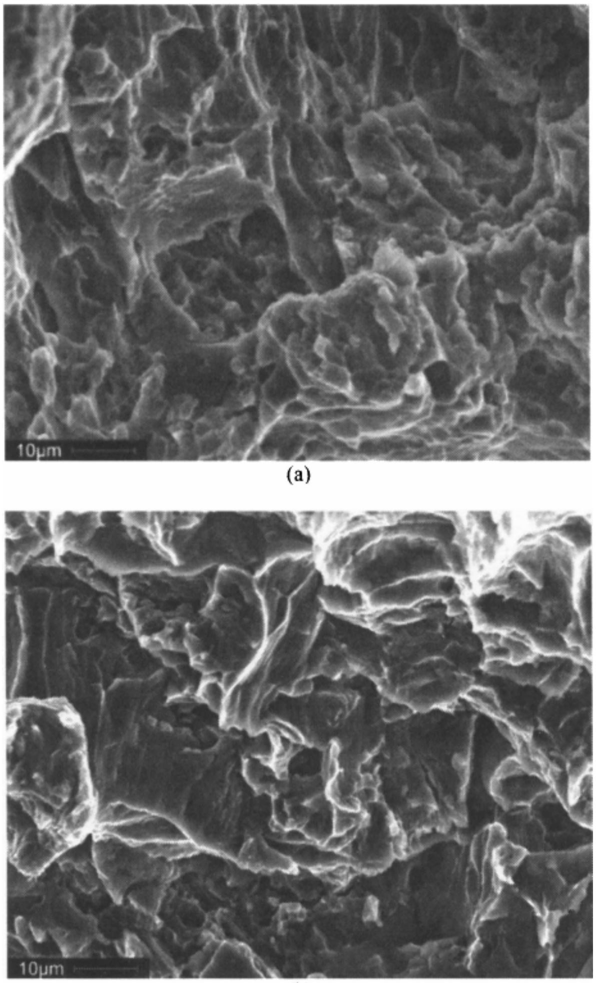
(b)

(c)

Figure 5: Optical micrographs showing grain structure of a) 6 mm b) 10mm and c) 20mm specimens.

The variation on grain size from one section to another has a large influence on the mechanical properties. It is especially true for the most prominent of the mechanical property degradation: elongation. As the grain size increases, the elongation drops significantly. This is in agreement with the results of tensile test data (table 2).

A severe embrittlement of the squeeze cast AM60 with increasing section thickness was observed. Fractographs in figure 6 (a) and (b) exemplify this range in fracture behaviour between the 6 mm and 20 mm thick specimens. Figure 6 (a) illustrate a ductile fracture surface containing dimples with dramatic height variation resulting from the elongated nature of the surface. In contrast, brittle fracture is shown in figure 6 (b) with the dominating presence of cleavage fracture, flat facets. In mechanism, the specimens fail by microvoid coalescence under tensile stress. The microvoid nucleate at the area of localized high plastic deformation which associate with second phase particles and grain boundaries. Eventually, continuous fracture surface forms as the microvoid grow. A considerable amount of energy is consumed of the formation of microvoids and finally leading to creation of cracks. Such embrittlement phenomena have been well documented elsewhere [10,11] for squeeze cast magnesium alloy including AM60.



(a)

(b)

Figure 6: SEM fractograph of a) 6 mm and b) 20mm squeeze cast AM60 specimens.

Conclusions

The influence of section thicknesses was investigated on tensile properties and microstructure of squeeze cast AM60 alloy. The significant increases in elongation (176%), UTS (67%) and YS(43%) of the 6 mm over the 20 mm section were achieved. The dependence of tensile properties on the section thickness should be attributed to the variation of solidification rates and the resulted microstructure of the squeeze cast AM60 alloy. The microstructure features of the 6, 10 and 20mm specimens were studied via optical metallography. The section thickness has significant influence on the grain size and porosity level of the squeeze cast samples. As the section thickness increased, the grain size porosity level increase and consequently reduced the tensile properties. The observation via SEM fractography illustrates that the fracture behaviour affected by the section thickness. The fracture of AM60 tends to transit from ductile to brittle as the section thickness increased.

Acknowledgements

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