Effect of Aging on the Microstructures and Mechanical Properties of AZ80 and ZK60 Wrought Magnesium Alloys

Y. J. Wu¹*, Z. M. Zhang¹, B.C. Li²
¹ National Key Laboratory of Science and Technology on Electronic Test and Measurement, 030051 Taiyuan, Shanxi Province, China
² Ministry Education, Engineering Research Center Magnesium Base Materials Processing Technology, 030051 Taiyuan, Shanxi Province, China

Abstract:
In this paper, the effects of solution and aging on the microstructures and mechanical properties of AZ80 and ZK60 wrought magnesium alloys are investigated by optical microscope, electronic scanning microscope and mechanical testers. The result shows that both the tensile strength and elongation of AZ80 alloy increase firstly and then decrease with the increasing of the aging temperature, the peak values appear when the aging temperature is 170 °C. The hardness of ZK60 alloy increases firstly and then decreases with the increasing of the aging temperature, and the hardness reaches its peak value at 170 °C. However, the toughness of the alloy is just the opposite. Moreover, ZK60 alloy has good performances in both impact toughness and other properties at the aging temperature from 140 to 200°C.

Key words: Solid-solution aging; Microstructure; Mechanical properties; AZ80 magnesium alloy; ZK60 magnesium alloy

Introduction
Magnesium, because of its high specific strength, high shock-absorbing capacity, good performance in electromagnetic resistance, and good performance in recycling [1], is widely used in the aerospace industry, automobile industry and military industry etc. At present, the most widely used magnesium alloys are AZ91 and AZ31, however, these alloys hold comparatively low strength; AZ80 and ZK60, because of their high strength, have attracted a great deal of interest [2-3]. Nowadays, many researchers have investigated the effect of the texturing process and alloy element on structure and property. For example, ToshijiMukai made an attempt to improve the ductility of magnesium alloy by controlling the alloy’s crystal-grain structure [4]; Hidetoshi Somekawa studied the mechanical property of AZ31 magnesium alloy by using the Equal Channel Extrusion technology (ECAE) [5], Song Pei-wei et al. studied the microstructure and the mechanical properties of magnesium alloy by reciprocating extrusion of magnesium-ingot [6], N. Balasubramani et al. studied the aging precipitation behavior, microstructure, and the mechanical properties of the magnesium alloy by adding alloy [7-9]. Other researchers made attempt to improve the properties of magnesium alloy through heat treatment. Ma Yan-long studied the effect of heat treatment on the microstructure of ZK60 magnesium alloy [10]; Wang Hui-min studied the aging process

* Corresponding author: wyj@live.nuc.edu.cn
of Mg-Al alloys [11]; D. Duly et al. studied the solution process of the Mg-Al alloys [12]; Porter and Xiao Xiao-ling et al. studied the precipitated way of the Mg$_{17}$Al$_{12}$ phase of the Mg-Al alloys [13; 14]. However, research efforts on the effects of solution and aging on the microstructures and mechanical properties of AZ80 and ZK60 wrought magnesium alloys are rather limited.

Therefore, the objective of the present work was to investigate the effects of solution and aging on the microstructures and mechanical properties of AZ80 and ZK60 wrought magnesium alloys so that the laws of structure formation of the products could be understood, which should provide guidance for the alteration and control of the structure of the product phases.

2. Experimental procedures

Mg-8.9wt%Al-0.53wt%Zn magnesium-alloy and Mg-(5.0-6.0)wt%Zn-(0.3-0.9)wt%Zr magnesium-alloy ingot were used for this experiment. Firstly, the alloys were machined to the cylinders with the diameter of 15mm along the axial direction. Secondly, the annealing treatment: the slab was heated at 400°C for 12h in the furnace with a heating rate of 15°C/min and then air cooled to the room temperature in the open air. Thirdly, the solution treatment: AZ80 magnesium alloy after the annealing treatment was heated at 420°C for 5h and then cooled to the room temperature in the air; ZK60 magnesium alloy after the annealing treatment was heated at 500°C for 2h and then cooled to the room temperature in the air; Finally, aging treatment: the AZ80 and ZK60 magnesium alloy were heated at 110°C, 140°C, 170°C, 200°C, and 230°C separately for 10h and then cooled to room temperature in the air.

After heat treatment, the tensile tests were carried out by WEW-E100D electronic universal testing machine (the strain rate is 3mm/min, and the specimen shape is as shown in Fig.1). The impact strength (the specimen shape is as shown in Fig.2) was measured by XJJ-50 strut-beam impact machine at room temperature and the hardness was measured by HB-3000 Brinell hardness tester (There are 3 groups for testing, and the data for the experiment can be obtained by averaging values.). The microstructure was observed by s2530 scanning electron microscope and ZEISS digital microscope.

Fig. 1 Dimension of the tensile specimen

Fig. 2 Dimension of the impact specimen
3. Results and discussion
3.1 The effect of aging temperature on mechanical properties of AZ80 & ZK60

Fig. 3 shows the effect of the aging temperature on the impact toughness, it can be seen that the impact toughness of AZ80 magnesium alloy decreases with the increasing of the aging temperature. However, the impact toughness of ZK60 magnesium alloy decreases firstly and then increases with the increasing of the aging temperature, its impact toughness reaches its minimum value at 170°C.

Fig. 4 shows the effect of the aging temperature for the ultimate tensile strength, it can be seen that the aging temperature has similar effect on the ultimate tensile strength of AZ80 and ZK60 magnesium alloy. The ultimate tensile strengths increase firstly and then decrease with the increasing of the aging temperature, and that the ultimate tensile strength curve of ZK60 magnesium alloy varies more gently than that of the AZ80 alloy. At 170°C and 200°C, the ultimate tensile strengths of AZ80 and ZK60 magnesium alloys reach their peak values, the ultimate tensile strengths of ZK60 and AZ80 alloys are 263Mpa and 258 Mpa respectively. Normally speaking, ZK60 magnesium alloy has a higher ultimate tensile strength than AZ80 alloy. It maybe attribute to the β-Mg17Al12 phase precipitates from the supersaturated α-Mg solid solution during aging process, and the amount of β-Mg17Al12 phase increases and the morphology changes greatly with the increasing of the aging temperature, which results in the change of the alloy’s ultimate tensile strength.

Fig. 5 shows the effect of the aging temperature on the elongation, it can be seen that the aging temperature has similar effect on the elongation of AZ80 and ZK60 magnesium alloy. The elongations first increase and then decrease with the increasing of the aging temperature, the elongation curve of ZK60 magnesium alloy varies more gently than that of the AZ80 alloy. In addition, the elongation of ZK60 magnesium alloy is greater than that of the AZ80 magnesium alloy in low-temperature interval (between 110 and 140°C) and high-temperature interval (between 200 and 230°C). The reason for the decrease in the elongation may be as follows: the dislocation resistance gradually increases when the β-Mg17Al12 phase is precipitated with the increasing of the aging temperature, which results in the dislocation piling up and the increasing of the stress, so the elongation gradually decreases.

Fig. 6 shows the effect of the aging temperature on the hardness. It can be seen that the hardness of AZ80 magnesium alloy increases with the increasing of the aging temperature, the hardness of AZ80 alloy reaches its peak value at 170°C. However, the
hardness of ZK60 alloy increases firstly and then decrease with the increasing of the aging temperature, the hardness of AZ80 magnesium alloy is greater than that of the ZK60 alloy in both low-temperatures interval (between 110 and 140°C) and high-temperature interval (between 200 and 230°C). The reason for the increase in the hardness of AZ80 alloy may be as follows: with the increasing of the aging temperature, the β-Mg17Al12 phase precipitating from the supersaturated α-Mg solid solution gradually hardening, which results in the decrease of the toughness, when the temperature reaches 230°C, the Nucleation becomes very easy, and the grain is refined, so the hardness increases. The reason for the change in the hardness of ZK60 alloy may be as follows: the amount of the precipitated β-Mg17Al12 phase gradually increases with the increasing of the aging temperature, which results in the increase of the hardness. However, with the temperature further increases, the grain of the precipitated β-Mg17Al12 phase growth, which results in the over aging phenomenon, so the hardness decreases.

Fig. 5 The effect of the aging temperature on the elongations of AZ80 and ZK60 alloys

Fig. 6 The effect of aging temperature on the hardness of AZ80 and ZK60 alloys

3.2 The effect of the aging temperature on microstructures of AZ80 & ZK60

Fig. 7 shows microstructures of AZ80 Mg alloy under different situations. It can be seen from Fig. 7(a) that the microstructures of the as-cast magnesium alloy (α-Mg solid solution and β-Mg17Al12 precipitated phase) are characterized by the uneven network structures with the serious segregations; the structure of the as-cast magnesium is uniformed and the segregation is eliminated after homogenization treatment (Fig. 7(b)); the majority of eutectics are dissolved to form a homogeneous solid solution after solid-solution treatment (Fig. 7(c)); during low-temperature aging (Fig. 7(d-e)), a portion of the secondary phase precipitate along the grain boundary, and the structures are characterized by irregular-bone distribution or irregular petal distribution with the aging twins. When the aging temperature increases, the amount of the secondary phase increases and the aging twins increase; when the temperature reaches 170°C (Fig. 7(f)), the amount of the secondary phase reaches its peak value, and the structures are characterized by the uniform tiny sheet distribution, when the aging temperature further increases, the growth of the secondary phase grains is observed (Fig. 7(g)); and when the temperature reaches 230°C, the structure turns into network distribution (Fig. 7(h)).
Fig. 7 Microstructures of AZ80 Mg alloy under different situations (a) As-cast state; (b) The homogenizing treatment; (c) The solid solution treatment; (d) The aging treatment at 110°C; (e) The aging treatment at 140°C; (f) The aging treatment at 170°C; (g) The aging treatment at 200°C; (h) The aging treatment at 230°C.

Fig. 8 shows microstructures of ZK60 Mg alloy under different situations. It can be seen that the microstructure is α-Mg solid solution in the as-cast condition (Fig. 8 (a)). But a portion of the secondary phase precipitates along the grain boundary during low-temperature aging treatment (Fig. 8 (d) and Fig. 8 (e)), and with the increasing of the aging temperature, the amount of the secondary phase increases. When the temperature reaches 200°C as shown in Fig. 8 (g), the amount of the secondary phase reaches its peak value. When the temperature further increases, the precipitation phase begins to decrease. Comparing with AZ80 and
ZK60, it can be seen that the structural evolution of ZK60 magnesium is similar to that of the AZ80; the microstructures of the as-cast ZK60 magnesium alloy are characterized by the uneven network structures with the serious segregations (Fig. 8 (a)). But the structure of ZK60 is smaller than that of the AZ80 at the same aging temperature.

**Fig. 8** Microstructures of ZK60 Mg alloy under different situations
(a) As-cast state; (b) The homogenizing treatment; (c) The solid solution treatment; (d) The aging treatment at 110°C; (e) The aging treatment at 140°C; (f) The aging treatment at 170°C; (g) The aging treatment at 200°C ; (h) The aging treatment at 230°C.
4. Conclusions

(1) For the AZ80 magnesium alloy, the hardness increases and the plasticity decreases with the increasing of the aging temperature. The tensile strength and elongation firstly increase and then decrease with the increasing of the aging temperature.

(2) For the ZK60 magnesium alloy, the hardness firstly increases and then decreases with the increasing of the aging temperature. On the contrary, the impact toughness firstly decreases and then increases with the increasing of the aging temperature. When the aging temperature is 170°C, the alloy has the maximum hardness and minimum impact toughness. The tensile strength and elongation of the alloy firstly increase and then decrease with the increasing of the aging temperature.

3) The optimum aging temperature of AZ80 magnesium alloy is 170°C, and that of the ZK60 magnesium alloy is 200°C. At the same aging temperature, ZK60 alloy has a better performance than AZ80 alloy.

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после смањује са температуром старења, максимуми се појављују када је температура старења 170°C. Тврдоћа ЗК60 легуре се прво увећава а онда смањује са повећањем температуре старења и достигне максималну вредност на 170°C. Међутим, чврстоћа легуре се понаша супротно. Легура ЗК60 има добре перформансе у чврстоћи на удар и друга својства на температурама старења од 140 до 200°C.

Кључне речи: Старење чврстог раствора, микроструктура, механичка својства, АЗ80 легура магнезијума, ЗК60 легура магнезијума.