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EFFECT OF HEAT TREATMENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AZ61 MAGNESIUM ALLOYS

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Abstract— **Magnesium alloys have been increasingly considered as an attractive material in the transportation industry. Extruded magnesium alloys have been found in the center of interest combining their lightweight, surface quality with the wide range of possible achievable geometries. In this study, the AZ61 alloy has been chosen for investigation as one of the most common commercial magnesium wrought alloys. The microstructure change and $Mg_{17}Al_{12}$ precipitate in the alloy had been investigated and its influence on hardness had been studied. After primary microstructure characterization and mechanical testing in the as-extruded condition the specimens have been subjected to heat treatment to the temperature 400°C for one hour followed by quenching in the water. Specimens treated were found to have a coarse grain, homogeneous structure with a substantial increase in grain size. Then the specimens are aged at temperature 200°C for half and two hours followed by quench in the water. Optical observations reveal $Mg_{17}Al_{12}$ precipitations grow in the form of needle shape within the grain after two hour aging. The hardness and mechanical properties of the AZ61 magnesium alloy is also found to increase owing to secondary hardening by precipitation strengthening.**

Keywords — **AZ61 magnesium alloy, heat treatment, $Mg_{17}Al_{12}$ precipitation, aging.**

I. INTRODUCTION

The use of magnesium alloy in automotive industry is promoted due to increased emphasis on weight reduction. Magnesium is two-third less dense than aluminum and one-fourth less dense than iron [1,2]. Substantial progress has been made in the last few years in the development of wrought magnesium alloys produced by thermo mechanical forming. The extrusion process results in creation of large range of possible geometries, which identified due to effect of a combination of several shapes. This feature eliminates joints and reduces fabrication costs. The wrought forms of magnesium have advantages of higher strength and ductility, as well as better formability than in the cast form.

Despite of these advantages, magnesium alloys, normally exhibit limited mechanical properties because of their h.c.p. structure which results in limited deformation mechanism, activated at room temperature [3]. Due to this fact, there is a necessity to improve materials properties parameter, which can be achieved by alloying or optimizing the process. Therefore to understand the behaviors and properties of wrought magnesium alloys has also been the focused source in several recent investigations [4,5].

In this study, microstructures change of AZ61 magnesium alloy due to the heat treatment and the precipitation of $Mg_{17}Al_{12}$ during aging process and also its effects on mechanical properties of the magnesium has been investigated.

II. METHODOLOGY

In this study commercial extruded AZ61 magnesium alloys with diameter 16 mm have been cut into 2 mm thick using the diamonds cutter. The chemical composition of the AZ61 magnesium alloys as shown in Table 1.0. Before the heat treatments, specimens were wrapped with the anti rust aluminum foil to protect the specimens from oxidations. Every specimen was heat treated to 400°C in one hour until the transition of phase occurred from (α+β) to α [6]. Figure 1 shows the equilibrium phase diagram of Mg-Al [7]. Then, the specimens were quenched in the water. After that, the specimens were put into aging at the temperature 200°C for 30 minutes and two hour to formed intermetallic β ($Mg_{17}Al_{12}$).

After the aging process, specimens were quenched in the water to maintain the internal microstructure. The next process is the specimens were polished with the emery paper grid from #200 till #1500. The final polishing was done by using synthetic leather cloth with the diamond paste solution size 0.5 μm. The final stage of metallographic preparation by etching the mirror-like specimens by using solutions of 6 gram of picric acid, 100 ml ethanol and 10 ml acetic acid. The etching time for each of the specimens were varied from 5 to 15 seconds.

Table 1. The chemical composition of AZ61 magnesium alloy (wt.%)

Al	Zn	Fe	Si	Mn	Mg
6.53	0.96	0.002	0.024	0.164	Bal.

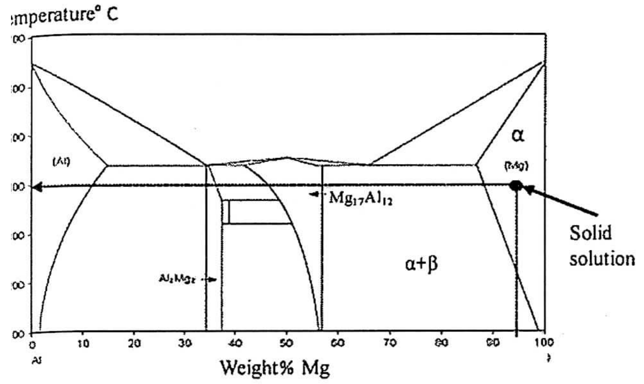


Figure 1. The equilibrium phase diagram of magnesium alloy

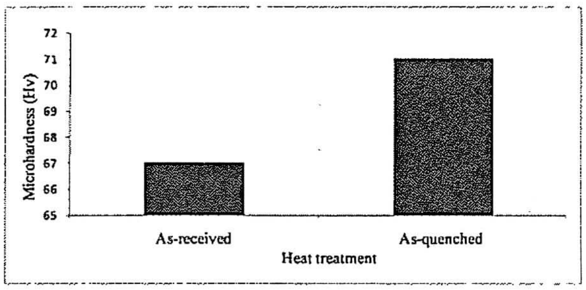


Figure 3. The hardness values of Magnesium Alloy

III. RESULTS AND DISCUSSION

3.1 Microstructure and hardness of as-received and as-quenched magnesium alloy

Figure 2 shows the microstructure of AZ61 magnesium alloy in (a) as-received extruded and (b) as-quenched magnesium alloy. As-quenched sample exhibits a typical stability homogeneous structure, coarse grain with a substantial increase in grain size. The quench reaction in magnesium is best known as a second step in the precipitation-strengthening process. The structure of alloy consists of a supersaturated solid solution of the α-magnesium phase [8].

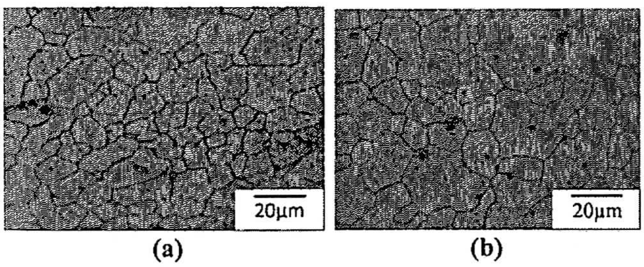


Figure 2. The optical micrograph of the specimens: (a) in as-received condition and (b) in as-quenched condition

The hardness values of as-received and as-quenched magnesium are shown in Figure 3. As-quenched hardness of magnesium alloy increases mainly owing to α-solid solution strengthening of Al and the hardness of magnesium containing solute Al of 6.0wt% reached value of 71HV. The increase of the as-quenched sample's hardness is thought to be due of the increase of solute α content as a result of formation of undissolved $Mg_{17}Al_{12}$.

3.2 Tensile strength of as-received and as-quenched magnesium alloy

Figure 4(a) and (b) shows the mechanical properties for AZ61 magnesium alloy. The yield stress and ultimate tensile strength of the materials were significantly improved after solution treatment. For as-extruded specimen, the yield stress and ultimate tensile strength obtained were 270 MPa and 308 MPa, respectively. For the solution treated specimen, the yield stress and the ultimate tensile strength obtained were 308 MPa and 381 MPa, respectively. The increment of yield stress and ultimate tensile value for solution treated sample is believed due hardness properties compared to that of the as-extruded.

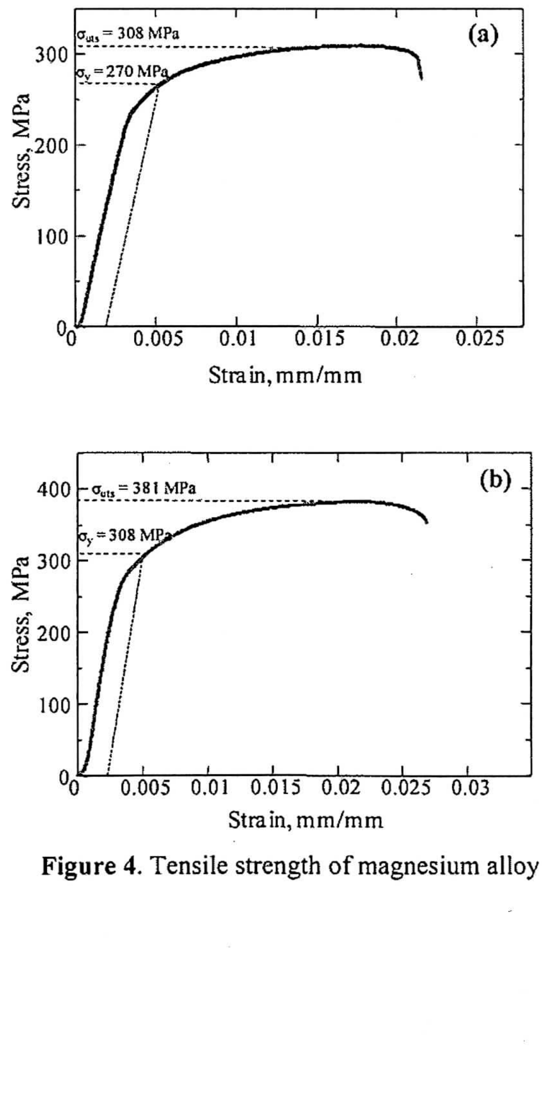
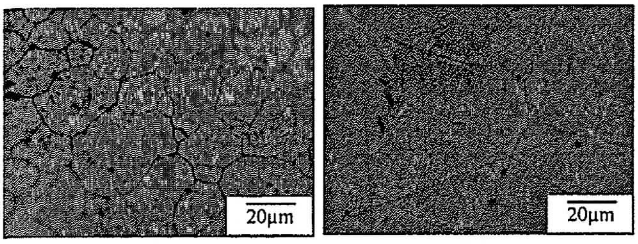


Figure 4. Tensile strength of magnesium alloy

3.3 *Aging behavior of AZ61 magnesium alloy*

Figure 5 shows the microstructures of aging samples. The samples were aging at 200°C for (a) 1800s and (b) 7200s. The 1800s-sample were still have undissolved precipitation in its microstructure. After holding for 7200 seconds, the grain boundaries completely covered by precipitation of intermetallic β ($Mg_{17}Al_{12}$)[9]. Furthermore, the intermetallic grows as needle-like shape within α.



(a) (b)

Figure 5. The optical micrograph of aging specimens for: (a) 1800s and (b) 7200s

Figure 6 shows the change in hardness of the magnesium as a function of holding time of aging for 1800 seconds, the hardness of the sample slightly decreased to 59HV. It is well-known that the aging is to relieve the stresses that are set up during the transformation of α to (α+β), and reduce the hardness [10]. Recovery of dislocation and the decrease in contribution of solid solution strengthening to precipitation $Mg_{17}Al_{12}$ on aging may cause the decrease in hardness.

The hardness of the aging-sample for 7200 seconds increases to 69HV. Besides increasing the toughness of the sample through aging, the hardness also can be increased similar to the as-quenched sample. It is thought that the formation of $Mg_{17}Al_{12}$ precipitation influences the increase in hardness.

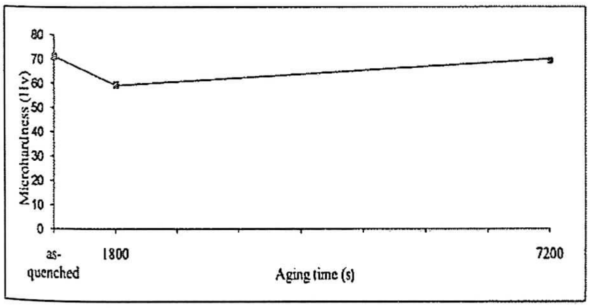


Figure 6. The hardness value of treated and aging magnesium alloy

3.4 *Fracture toughness of AZ61 magnesium alloy*

Figure 7 showed the load-displacement curves for heat treated and as-extruded samples. Load-displacement curves exhibited type I load-displacement record as shown in Fig. 8. P_Q is determined to be the valid value of maximum fracture load for calculation of fracture toughness. The mode-1 stress intensity factor at fracture K_Q was calculated using Eq. (1) based on the P_Q value obtained. The calculated values of fracture toughness K_C are shown in Table 2. The results showed K_C value for heat treated sample is 14.5 MPa√m and for as-extruded sample is 13 MPa√m. The increment of K_C value the solution treated sample is believed due to higher tensile strength and also higher hardness properties compared to that of the as-extruded [7].

Table 2. Fracture toughness value for extruded and heat treated of AZ61 magnesium alloy

Condition	As-Extruded	Solution heat treated
P_{max} (kN)	1.210	1.450
P_Q (kN)	1.100	1.220
K_C (MPa√m)	13.0	14.5

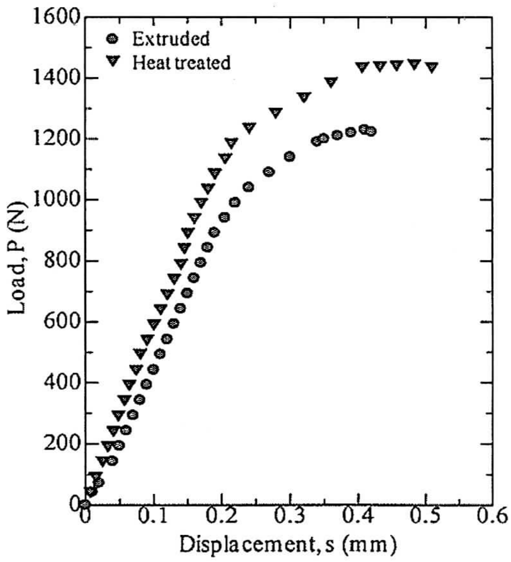


Figure 7. Load-displacement curve for as extruded and heat treated sample

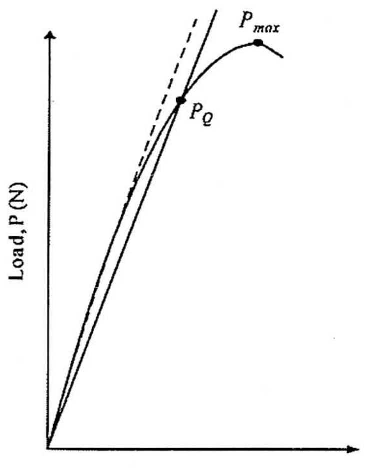


Figure 8. Type I of load-displacement records (ASTM E399, 2008)

3.5 Fatigue strength of AZ61 magnesium alloy

The comparison of fatigue strength of solution treated and extruded AZ61 magnesium alloy is shown in Figure 9. The figure shows that fatigue strength of the solution treated samples increase as that compared to the fatigue strength of the as-extruded AZ61 samples. The fatigue limit for solution treated and as-extruded AZ61 were 180 MPa and 150 MPa, respectively. The higher fatigue strength observed for the solution treated sample is believed due to higher tensile strength and also higher hardness properties compared to that of the as-extruded sample.

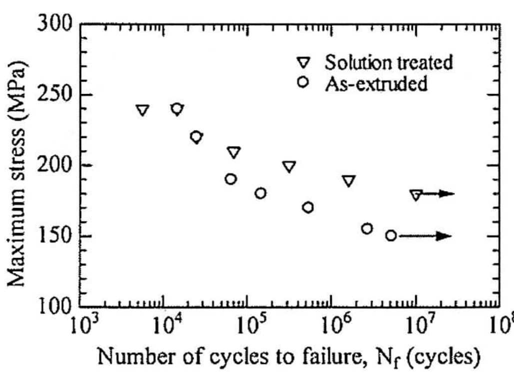


Figure 9. Fatigue strengths of solution treated and as-extruded samples

IV. CONCLUSIONS

The change in microstructure of AZ61 magnesium alloy and $Mg_{17}Al_{12}$ precipitation during aging had been observed for the effect on hardness. The microstructure of as-quenched sample consists of a supersaturated solid solution of the α-magnesium phase and retained as α while the aging microstructure completely covered by precipitation of intermetallic β ($Mg_{17}Al_{12}$). It is found that the hardness of aging sample increase similar to the as-quenched sample because of the formation of $Mg_{17}Al_{12}$ precipitation during aging. After heat treatment process the mechanical properties of heat treated samples increased compared to as extruded samples.

V. ACKNOWLEDGEMENT

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