EFFECT OF SOLUTION TREATMENT ON FATIGUE PROPERTIES OF MAGNESIUM ALLOY

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ABSTRACT

The effect of solution heat treatment on fatigue properties of AZ61 magnesium alloy was investigated. The test was done by using a pneumatic fatigue testing machine under constant amplitude loading of frequency of 10 Hz. The results showed that the difference of fatigue strength for solution treated and as-extruded specimen was 30 MPa. SEM fracture surface observation showed that there were foreign particles at the crack nucleation site for solution treated specimens. The foreign particles were identified as SiC particles. However, there was no foreign particle observed on the fracture surface of the as-extruded specimen and fatigue fracture origin was relatively flat.

***Keyword**:* Solution treatment, foreign particle, crack initiation, fatigue, magnesium alloy.

INTRODUCTION

Magnesium alloy is the lightest structural metal and used widely in industry due to their attractive properties such as low density, high damping capacity, high specific strength and stiffness. Recent development of magnesium alloys and processes have been driven by the requirements of the aerospace and automotive industries. It has successfully been introduced for high performance application in the automotive areas (Mordike *et al.,* 2001). However, low fatigue strength under service conditions has been an important factor in limiting the use of magnesium alloys in highly stressed design structures.

Magnesium alloys, normally exhibit relatively low mechanical properties compared to aluminium or other steel alloys because of their hexagonal close pack structure that results in limited deformation mechanism at room temperature (Cole *et al*., 1995). Due to this factor there is still a necessity to improve mechanical properties, which can be done through designing new alloys, improving the heat treatment process and its conditions, etc. Therefore, to understand of the behaviors and properties of magnesium alloys also has been the source for several recent investigations. Russel et al. found the mechanical properties of the magnesium alloy decreased when the surface defect occurred after the machining process (Russel *et al*., 2005). Srivatsan et al. found the fatigue life response was found to degrade with an increase in test temperature for magnesium alloy metal matrix composite (Srivatsan *et al*., 2005).

The objective of this study was to investigate the effect of solution treatment on fatigue properties of extruded AZ61 magnesium alloy.

EXPERIMENTAL PROCEDURE

The material used in this study was extruded AZ61 magnesium alloy. The chemical composition of the material used is shown in Table 1. AZ61 magnesium alloy contain about 6% of aluminium and 1% of zinc as its major alloying elements.

To investigate the effect of solution treatment on the fatigue performance of AZ61 magnesium alloy two type of samples were prepared: the solution treated and as-extruded samples. For the solution treated specimen, samples were heated in furnace at 400°C for one hour and then quenched in water. Samples were carefully polished using #200, #400, #800, #1000 and #1500 grit emery papers to obtain flat and smooth surface. Fatigue tests were conducted on a pneumatic fatigue testing machine with a maximum capacity of 14 kN. All fatigue test were performed under a load control of sinusoidal waveform with a stress ratio R = 0.1 and at a frequency of 10 Hz. The test was stopped when the specimen did not fail up to 10^7 cycles. The fracture surfaces and specimen surfaces were then observed under a scanning electron microscope (SEM). The tests were conducted in laboratory environment at temperature of 25°C.

Prior to the fatigue test, tensile test was done to obtain yielding stress and ultimate tensile strength of AZ61 magnesium alloy. The tensile test was performed at a fixed displacement rate of 1.2 mm/min. Vickers hardness test was also conducted to identify the charge in hardness property of both the as-extruded and heat treated samples.

Table 1: The chemical compositions of AZ61agnesium alloy. (wt.%)

Al	Zn	Fe	Ni	Cu	Si	Mn	Mg
6.53	0.96	0.002	0.001	0.001	0.024	0.164	Bal.

RESULTS AND DISCUSSION

Figure 1(a) and (b) showed the microstructures of extruded and solution treated materials, respectively. The average grain size for as-extruded material was about 12 μm. After solution treatment, the grain size increased to an average size of 20 μm. Some of the grains grew to more than 30 μm after the solution treatment at 400°C as shown in Fig. 1(b).

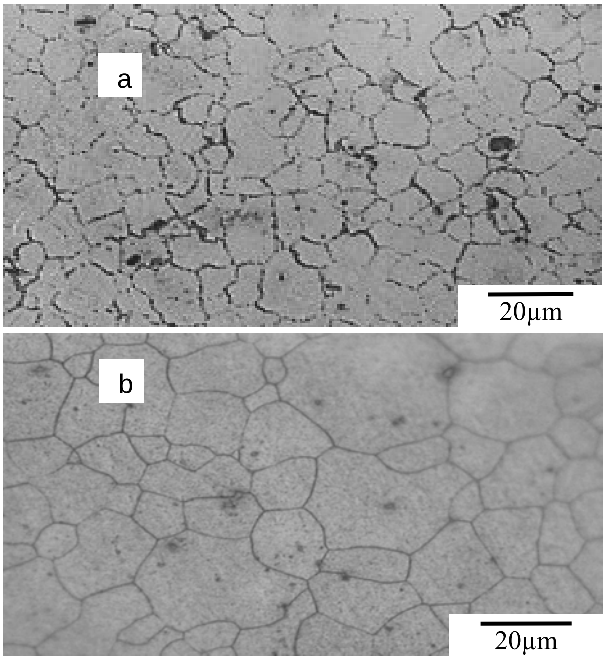


Figure 1: The optical micrograph of the specimens (a) as-extruded (b) solution treated

In the initial stage of fatigue test, specimen shape with thickness of 2 mm as shown in Fig. 2(a) was used. The specimen gage length was 15 mm and the smallest cross-sectional area of the specimen was 8 mm^2. During the test, it was found that fatigue crack initiated at the fillet part of the specimen which had a contact with the test jig. It seems that the stress raised very high at the contact point Eventually it became the fatigue crack initiation point and specimen fractured at the fillet position.

In order to make sure that the fatigue test data obtained is valid, the fatigue specimen must fail from the smallest cross-sectional area. To reduce the stress concentration at the fillet contact area, new specimen shape was designed and fabricated as shown in Fig. 2(b). The new cross-sectional area was 4 mm^2. Fatigue test was successfully conducted by using this new designed specimen shape.

Table 2 shows the mechanical properties for AZ61 magnesium alloy. The yield stress and ultimate tensile strength of the material were significantly improved after solution treatment. For as-extruded specimen, the yield stress and the ultimate tensile strength obtained were 249 and 300 MPa, respectively. For the solution treated specimen, the yield stress and the ultimate tensile strength obtained were 308 and 381 MPa, respectively.

The hardness values of as-extruded and solution treated specimens were 67 Hv to 71 Hv respectively. The increased in hardness for the solution treated samples to 71 Hv mainly owing to solid solution strengthening of α-magnesium (William, 2006).

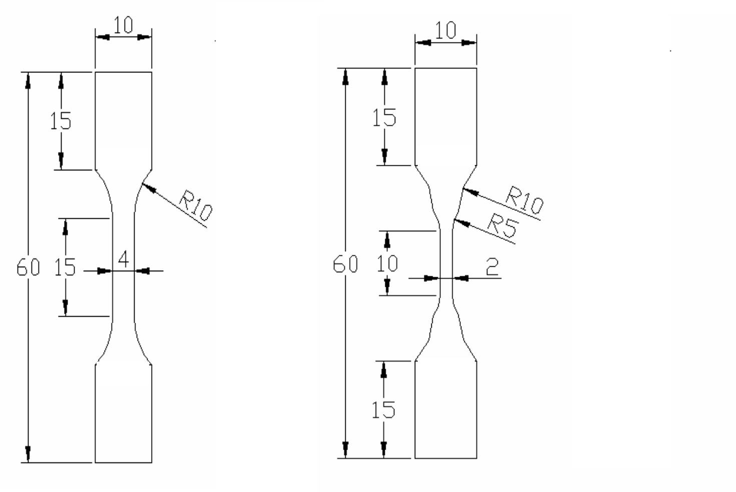


Figure 2: Specimen shape used for fatigue test.(a) Specimen shape (b) New design specimen shape

Table 2: Mechanical properties of AZ61 magnesium alloy

	Yield Stress σ_y (MPa)	Ultimate Tensile Strength σ_{uts} (MPa)	Young Modulus E (GPa)	Microhardness Vickers Hv
As-extruded specimen	249	300	43	67
Heat treated specimen	308	381	45	71

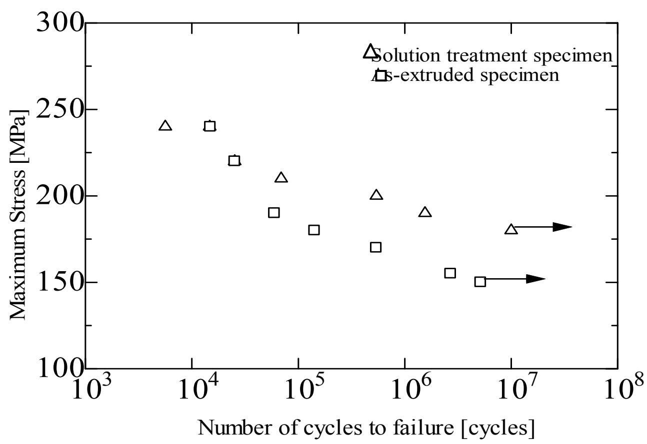
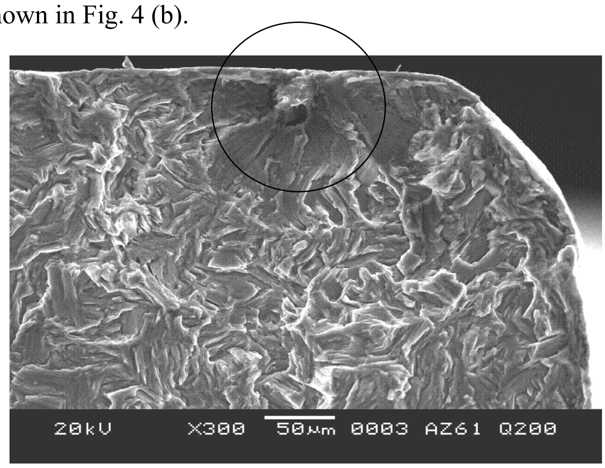


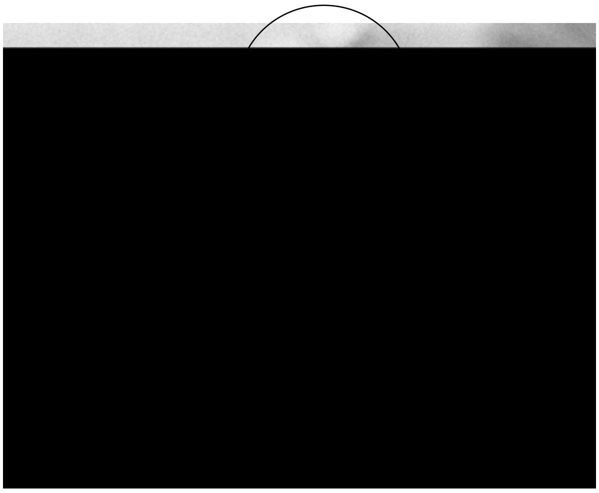
Figure 3: S-N Curve of Fatigue Test

Figure 3 shows the relationship between the maximum applied stress and number of cycles to failure (S-N curve) for as-extruded and solution treated AZ61 magnesium alloys. The S-N curve shows that, at higher maximum applied stress level, no significant difference was identified in fatigue strength for both specimens. However, at low stress level where the fatigue life was more than 10^5 cycles, the fatigue strength of as-extruded samples further reduced compared to that of the solution treated samples. The fatigue limit for the as-extruded samples was found at 150 MPa. In comparison, the fatigue limit for solution treatment samples was 180 MPa. The higher fatigue strength observed for the solution treated samples shown in Fig. 3 was believed due to higher tensile strength and higher hardness properties. These resulted in difficulty for the extrusion and intrusion of persistence slip bands to occur and consequently the fatigue crack tends to initiate at higher stress concentration site, which was at near to the foreign particle at sub-surface.

Detailed fracture surface observations showed that foreign particle was found at the fatigue fracture origin of the solution treated samples especially for the samples which exhibited higher fatigue life more than 10^5 cycles as shown in Fig. 4 (a). The foreign particle size observed was about 20 to 30µm. Pile-up of slip deformation at near the foreign particle during fatigue cycles contributed to high stress concentration at around the foreign particle and resulted in fatigue crack initiation. In contrast, SEM observation results on fracture surface of as-extruded samples showed that there was no evidence of foreign particle at the fatigue fracture origin. The fatigue crack initiation site was relatively flat as shown in Fig. 4 (b).

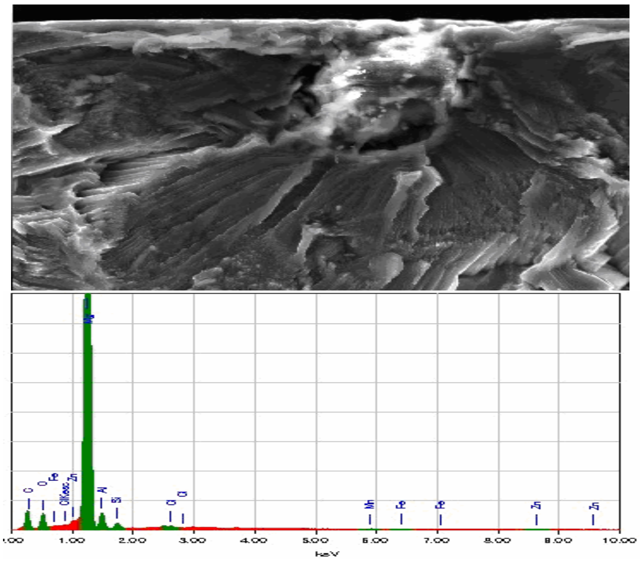


(a)

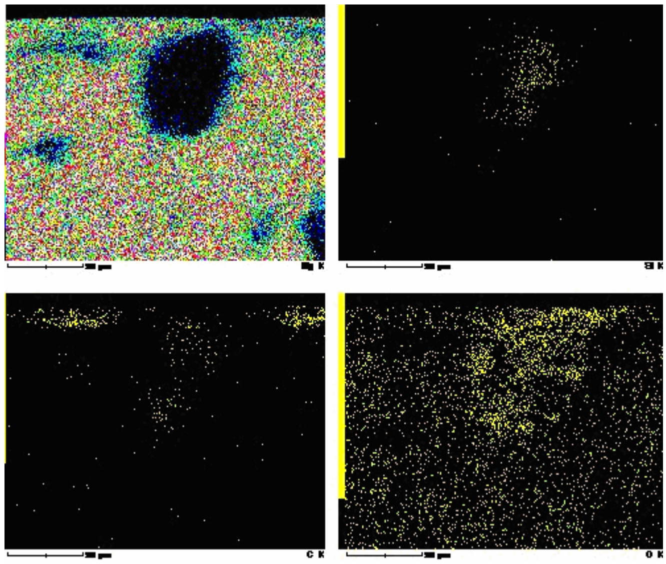


(b)

Figure 4: Observations were done using SEM equipped EDX. (a) Foreign particle (b) Flat surface



(a) Point analysis



(b) Mapping analysis

Figure 5: EDS mapping analysis from the fracture surface of the foreign particle

The foreign particles at the fatigue crack nucleation site were analyzed by using an energy dispersive X-ray spectroscopy (EDX) to identify constitutive elements. Figure 5 shows the result of EDS mapping and point analysis. From the figure it was found that the foreign particle mainly consists of carbon and silicon. It is believed that the foreign particle was a SiC particle that probably exists in the AZ61 alloy powder as an impurity.

CONCLUSION

The effect of solution treatment on fatigue properties of AZ61 magnesium alloy was investigated. Based on the results the following conclusions were made:

1. The fatigue limit of solution treatment specimen was 30 MPa higher compared to the fatigue limit of as-extruded specimen.

2. Fatigue crack initiated from foreign particle of SiC for olution treatment specimens and propagate to the final failure.

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