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Effect of Retrogression and Re-Ageing Treatment on Stressed Component of Wrought 6061 Aluminium Alloy

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ABSTRACT

This paper presents the effect of different heat treated to mechanical properties and microstructure of stressed component of wrought 6061 aluminium alloy. This alloy is known for their medium strength and high durability. These properties have made them useful in the aerospace, automobile industries and suitable for extrusion components. Precipitation hardening is a process to increase the strength and hardness by which aluminium alloys are heat and solution treated followed by artificial ageing (T6 temper). The strength of this alloy in T6 temper condition is increased but susceptible to fracture because of the applied stress. Over-ageing tempers was developed to improve stress resistance of wrought aluminium alloys by modifying the microstructure but significantly will reduce the mechanical strength. Retrogression and re-ageing (RRA) treatment was applied in order to minimise the wrought 6061 aluminium alloy prone to stress effect, while maintaining a higher mechanical properties. In this study the dumb-bell specimen of wrought 6061 aluminium alloy was retrogressed in stirred of engine oil followed by immediate quenched in plain water at room temperature and then re-ageing in an oven. The fractured surface of the specimens were analysed using Scanning Electron Microscopy (SEM) to investigate the microstructures changed. The tensile and indentation test results for T6 temper followed by RRA treatment revealed that the strength and hardness of wrought 6061 aluminium alloy are much better compare to over-ageing results.

Keywords: *precipitation hardening, retrogression and re-ageing, Wrought 6061 aluminium alloy*

Introduction

Pure aluminium is very ductile, malleable, and unsuitable as a structural material. Aluminium is one of the lightest engineering metals, having high strength to weight ratio like steel. Aluminium comes in heat treatable and non-heat treatable alloys. Heat treatable wrought aluminium alloys obtain their strength from an ageing process through the formation of precipitate at grain boundaries. These particles reduce slippage between "grains" which in turns increases material hardness and strength. The wrought 6061 aluminium alloy (heat-treatable Al-Mg-Si-alloys) is an excellent joining characteristic, good acceptance of applied coatings, good workability, susceptible to heat and high resistance to corrosion. It is known for their medium strength in tempered condition and high durability, and these properties have made them useful in the aerospace, automobile industries and suitable for extrusion components.

In the conventional technique (William, 2006), precipitation hardening in wrought aluminium alloys can be produced solution treatment, quenching and ageing. Gavgali et al. (2003) suggested that one of the known ways to improve the wear resistance of the heat treatable wrought 6063 aluminium alloys is by using the artificial ageing. This consists of heating the alloy to a temperature between 460 to 530°C at which all the alloying elements are in solution. By heating the solution heat-treated material in the temperature range from 160°C to 180°C and holding it there for 6 to 20 hours (Buha et al. 2004) the precipitation accelerates and the strength (T6 temper) is further increased compared to natural ageing.

According to Tsai and Chuang (1997), the 7xxx series aluminium alloy susceptible to stress-corrosion resistance at T6 temper. Thus, the alloys have to be treated to over-ageing temper. Over-ageing tempers was developed to improve stress-corrosion resistance of wrought aluminium alloys by modifying the microstructure. However, over-ageing temper products can be reduced about 10 to 15% in strength compared to the T6 temper (Robinson 2000; Chuang 1997).

Raizenne et al. (2002) reported that RRA heat treatment of 7075-T6 aluminium alloy developed by Cina and Gan improved stress corrosion resistance with little reduction in strength of the peak aged T6 temper. During retrogression the hardness and yield strength of the wrought aluminium alloys decreases rapidly as the Guinier-Preston (G-P) zones dissolve. In re-ageing stage, the hardness increases as the remaining η' grows to a near optimum size and distribution. The hardness reaches a maximum and then begins to decrease as this η' coarsens excessively and starts transforming to η. Robinson (2000) claimed that the range of retrogression temperatures is from 160 to 220°C and followed by re-ageing where a stage similar used to obtain the T6 temper. Viana et al. (1999); Raizenne et al. (1999) found a higher retrogression temperature will increased the dissolution degree, promotes the formation of more stable precipitates on re-ageing.

The investigation of the effect of the RRA (Grosvenor et al. 2004) shown a reduction in residual stresses induced by cold working. However, this test was conducted using aluminium alloy 7075 dog-bone specimen. The purpose of the present work was to study the effectiveness of the RRA using engine oil as a medium of heat treatment and tensile tests on round dumb-bell of wrought 6061 aluminium alloy.

Experimental Procedure

An extruded round bar of wrought 6061 aluminium alloy, with a diameter of approximately 25 mm and 1 m in length that has been used in this study was bought from a local market having the following chemical composition (wt %) as listed in Table 1. For the purpose of measuring the mechanical properties, two types of specimens were produced which consist of rectangular and round dumb-bell shapes.

Table 1: Chemical Composi6tion of the as Received Sample Wrought 6061 Aluminium Alloy.

Alloy	Mg	Si	Fe	Cu	Zn	Cr	Mn	Others	Al
6061	1.05	0.65	0. 61	0.28	0.25	0.21	0.14	0.15	Balance

Metallurgical analyses were performed on the polished surfaces of rectangular shape specimens. The microstructure is revealed by a surface treatment using an appropriate chemical reagent in a procedure termed etching. Electrolytic keller's etchant was obtained with a solution of 5ml HF, 3ml HCl, 5ml HNO_3 and 190ml distilled water. Etching was performed on each rectangular shape for 10 seconds. Immediately after etching, specimens were washed with water and dried with compressed air. After metallurgical analyses, specimens were once again used for hardness test. The hardness of the sample was measured using Vickers digital microhardness tester (diamond indenter) with 4.9035N load and 20 seconds dwelling time.

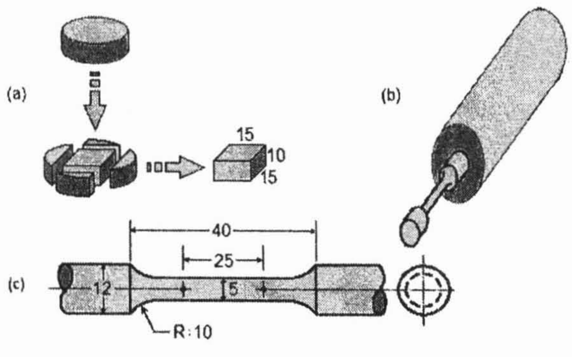

Figure 1: Sketches of the hardness (a), tensile (b) and detail dimensions of round dumb-bell (c) specimens employed in this study. All dimensions are in mm.

In this study, the round dumb-bell specimens (Figure 1c) were used as a stress component prepared by CNC turning machine (ASTM standards). Tensile test of a round dumb-bell specimen was done using Instron 8500 tensile machine. To ensure the roundness of gauge length uniformed and free from any scratches, the sample was clamped to chuck of the drill bench and abraded with 2000 grit abrasive paper followed by polishing process with 0.3 μm oil based diamond polishing agent. Prior to stress component testing, the 0.2 % strain offset line was constructed parallel to the elastic portion of the stress-strain curve which indicates the yield strength of the alloy.

Two types of heat treatment were employed to the wrought 6061 aluminium alloy; they are conventional method and Retrogression and Re-ageing (RRA) technique. The retrogression process was carried out using stirred oil bath, which placed on the hot plate as a medium to heat the specimen. A stirrer motor was used to distribute the heat homogeneously in the oil bath. A portable thermometer was immersed in the oil bath to control an accurate of the desired temperature. When achieved the desired temperature, the specimen was immersed in the oil at certain durations. Upon completion of the retrogression treatment the specimens were rapidly removed from the oil bath and placed them into the water at room temperature. After the retrogression process had been completed, the specimens were then brought to following process, which was the re-ageing process. The specimens were re-ageing in an electric oven at 120°C for long time period, before air cooling. All of the specimens by RRA treatment were then stored in a refrigerator to minimize natural ageing effect.

One of the specimens was treated into over-aged condition by ageing at approximately 176°C for 5 hours in an air circulating oven. Tests were conducted on the material in five different conditions as presented in Table 2. The performance of the T6 temper, RRA technique and over-ageing heat treatment were assessed by changes in mechanical properties and microstructures. For microstructural characterizing, all of the fractured surfaces of round dumb-bell specimens were investigated using Scanning Electron Microscopy (SEM).

Table 2: Codes Defining the Test Condition of Different Heat Treatments Process of Wrought 6061 Aluminium Alloy.

Code of Rectangular Shape	Test Condition	Code of Round Dumb-bell
RS 1	As-extruded specimen	DB 1
RS 2	T6 temper - solution heat treatment, (SHT) at 490°C for 30 minutes and quenching in water then followed by precipitate hardening at 120°C for 26 hours.	DB 2
RS 3	T6 temper then Retrogressed at 160°C for 29 minutes followed by Re-ageing at 120°C for 38 hours	DB 3
RS 4	T6 temper then Retrogressed at 220°C for 0.5 minutes followed by Re-ageing at 120°C for 24 hours	DB 4
RS 5	T6 temper then over-ageing, (T7) at 176°C for 5 hours	DB 5

Results and Discussion

Based on the metallurgical analyses of selected heat treatment process to the wrought 6061 aluminium alloy specimen (Figure 2), it shows that this alloy product has highly directional grain structure. The directional effects are related to the direction of extrusion and exhibited a fibrous grain structure. The highest resistance ratings of test direction of metals, especially wrought aluminium alloys to the extrusion bar product should be in longitudinal (L), followed by long transverse (LT) and lastly short transverse (ST). Grain coarsening increased proportionately with increasing of time and temperature (Hatch, 1995). Thus, the grain size produced by over-ageing specimen shows larger compared to the other specimens.

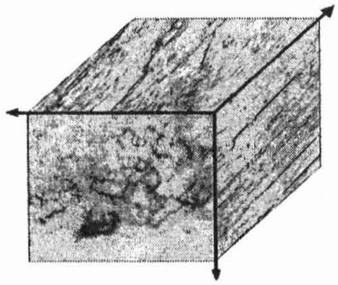

Figure 2: Composite Micrograph of Wrought 6061 Aluminium Alloy Specimen after Dilute Keller's etch (Mg: 200X)

The typical results of hardness tests in the different heat treatment process are summarized in Figure 3. An average hardness of the as extruded specimen of wrought 6061 aluminium alloy is in 157.5 HV. From this figure, it can be seen that the hardness values will be changing after several heat treatment processes. In the conventional technique, after artificial ageing at 120°C for 26 hours, the hardness values of wrought 6061 aluminium alloy was increased to 159.7 HV by the formation of dispersed particles of a second phase within the original phase matrix through the precipitation hardening processes. However, by extending the heat tréatment process to the specimen RS5 that called over-ageing was reduced the hardness to 156.3 HV.

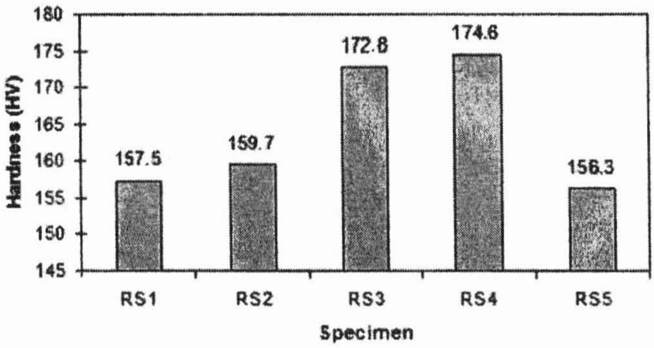

Figure 3: Hardness Test Results for Rectangular Shape Specimens.

In RRA technique, during retrogression the hardness decreases rapidly to a minimum and after re-ageing following short retrogression times, the hardness can be restored and increased above the original T6 level. Based on the result (Figure 3), the comparison hardness between T6 temper (RS2), both RRA technique (RS3 and RS4) and over-ageing (RS5), where it clearly be seen that the RRA method is better because it able to improve the hardness value compared to the conventional method.

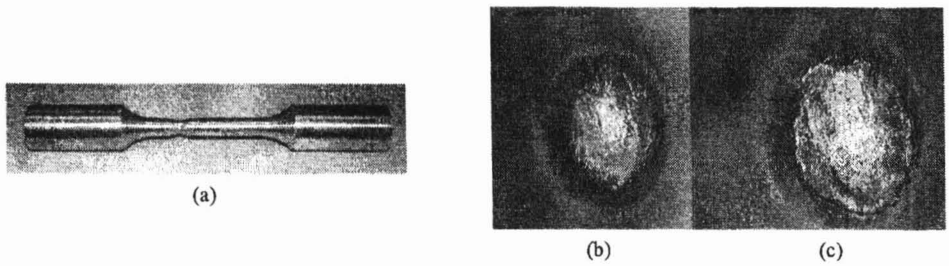

Figure 4: Round Dumb-bell of as Extruded Specimen Tensile Test. (a) Necking Immediately Prior to Fracture. Photograph of Typical Ductile Fractured using Stereo Microscope (b) Cup and (c) Cone Shape.

Ductility is a measure of the degree of plastic deformation that has been sustained at fracture. Based on the observation, when the applied load is increased, plastic deformation occurs and the 'neck' begins to form on the gauge length of the as extruded round dumb-bell (Figure 4a) specimen. The increased load coupled with the reduction in cross-sectional area in the region of the neck, results in the specimen being subjected to increased stress. This stress rapidly reaches a magnitude where small internal cavities start to appear. The formation of 'necking' and followed by typical 'cup and cone' (Figure 4b and 4c) fractured clearly shown that the wrought 6061 aluminium alloy can be classified a ductile alloy. Generally, after experienced RRA heat treatment process, the wrought 6061 aluminium alloy specimen exhibited quite brittle fracture surfaces, where the percent of elongation was decreased (Table 3).

Table 3: Mechanical Properties of Wrought 6061 Aluminium Alloy after Different Heat Treatment Process.

Code of Round Dumb-bell	DB1	DB2	DB3	DB4	DB5
Modulus Young, (GPa)	29.80	31.20	33.22	36.20	33.50
Yield Strength, (MPa)	210.4	267.1	440.3	450.2	272.3
Tensile Strength, (MPa)	600.92	563.00	560.83	580.28	510.62
Elongation, (%)	18.71	17.07	12.84	9.65	20.52
Hardness, (HV)	157.5	159.7	172.8	174.6	156.3

The specimen which retrogressed at 220°C for 0.5 minute and followed by re-ageing at 120°C for 24 hours shows the highest yield strength, which is 450.2 MPa (Figure 5) but lowest percent strain at maximum load which is 9.65%. This indicates that RD4 specimen is the most strength specimen compared to the others. The second specimen heat treated by RRA procedure (RD3) also had higher tensile strength and lower strain compared to the conventional method (RD5). The mechanical properties of formed RRA treated specimen has confirmed that this specimen is better than over-ageing method. During retrogression the hardness and yield strength of the wrought 6061 aluminium alloy decreases rapidly as the precipitate of Guinier-Preston (G.P) dissolves. This is a similar trend results (Poole et al. 1997) tested on Al-Mg-Si-Cu alloys.

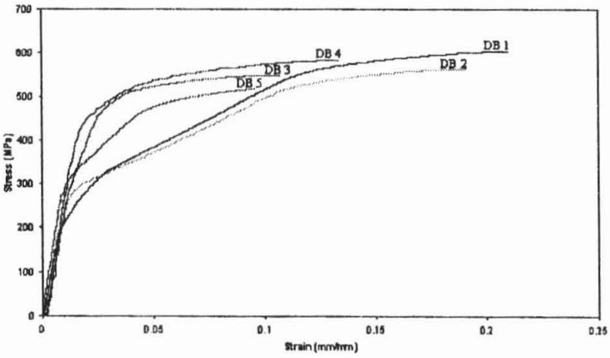

Figure 5: The Stress-strain Curves of Wrought 6061 Aluminium Alloy after Different Heat Treatment Procedures

Then during re-ageing process, fine precipitates were formed thus the hardness and yield strength increases significantly with artificially ageing time. The RRA processed result less ductile but increased significantly with the heat-treated wrought 6061 aluminium alloy specimens. These are believed to alter the stresses resistance in the applied stressed components. According to Cheng Liu (2004), the tensile strength decreases with decreasing hardness reducing since them both are indicators of a material resistance to plastic deformation. Figure 6 shows the relationship between yield strength and hardness for the specimens tested. Generally, the hardness and strength of this material is closely correlated.

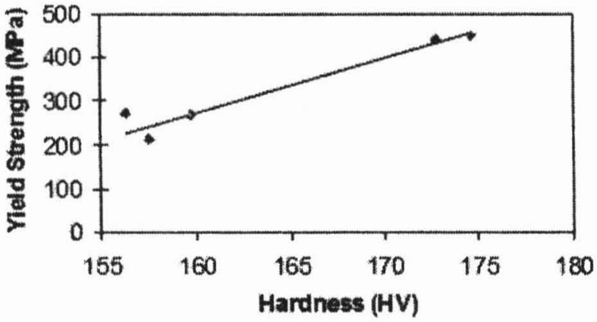

Figure 6: The Relationship of Yield Strength to Hardness for Wrought 6061 Aluminium Alloy

The fractured surfaces of round dumb-bell specimens were examined by Scanning Electron Microscopy (SEM) shown the variety direction of striations and size of microvoids in the crack propagations. The morphology of fracture surfaces of specimens produce by conventional technique as shown in Figure 7.

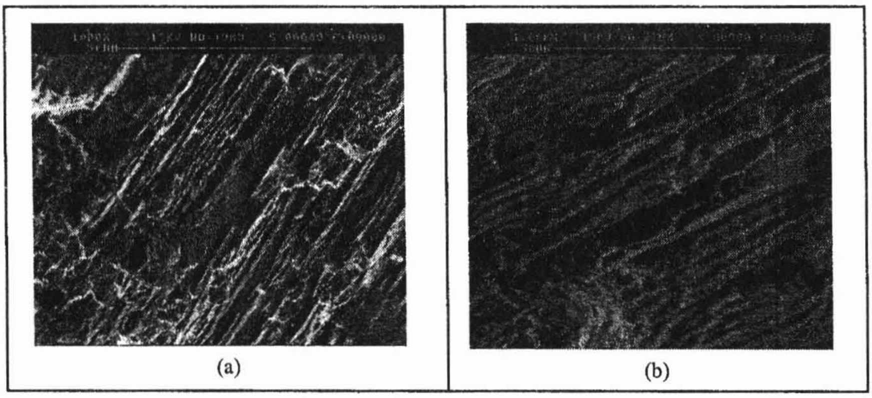

Figure 7: SEM Morphology of Fractured Surface of Round Dumb-bell Specimen of Wrought 6061 Aluminium Alloy which Produced by Conventional Technique. (a) T6 Tempers Condition, and (b) Over-ageing Condition.

From the SEM analysis of the fracture surfaces it is evidence that the type of fracture that occurred in the over-ageing round dumb-bell specimen more ductile compared to T6 temper and RRA specimens. It happens because of the large amounts of microvoid and the crack growth continuously in a direction parallel to a major axis of microvoids are contributed to the lowest yield strength. This observation has also been made by Lesmana (1999) on the dog-bone specimen tensile test.

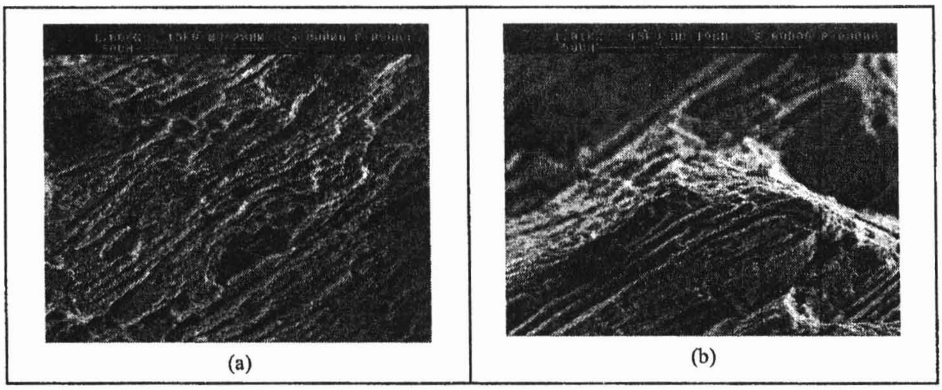

Figure 8: SEM Morphology of Fractured Surface of Round Dumb-bell Specimen of Wrought 6061 Aluminium Alloy which Produced Retrogression and Re-ageing Technique. (a) Retrogression 160°C for 29 minutes followed by Re-ageing 120°C for 38 hours, and (b) Retrogression 220°C for 0.5 minute followed by Re-ageing 120°C for 24 hours.

In RRA technique, the SEM morphology reveals the inconsistency directions of striations with less of microvoids on the both RRA dumb-bell specimens as presented in Figure 8. The coalesces of the striation had remove all the voids and make the specimen compact. As a result, the strength of the RRA specimens is much higher than that as extruded, precipitation heat treated (T6 temper) and over-ageing specimens. Generally, the striations pattern for specimen produced by the over-ageing procedures (DB5) is quite similar to the specimen heat treated by T6 temper (DB2).

Conclusions

The microstructural properties of wrought 6061 aluminium alloy which produced by conventional and RRA procedures are responsible for the improving the mechanical properties of stress component was the main objective of this study. The experimental results attained allow the following to be concluded.

- RRA heat treatment significantly has improved the tensile properties strength of wrought 6061 aluminium alloy in stress condition and also increased hardness.
- RRA heat treatment is more effective at the higher retrogressed temperature with soaking for short period of time.
- Using liquid bath (engine oil) as a medium for the RRA heat treatment makes the desired temperature easier to monitor because the temperature fluctuation can be minimised compared to the electric furnace.

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