AN EXPERIMENTAL STUDY OF MECHANICAL AND FATIGUE BEHAVIOR OF CRYOROLLED Al 6063 ALLOY

L. Kralia¹, I.V. Singh¹*, P.M. Pathak¹, and R. Jayaganthan²

1Department of Mechanical and Industrial Engineering, IIT Roorkee, UK, India
2Department of Metallurgical and Materials Engineering, IIT Roorkee, UK, India

*Corresponding author’s E-mail: ivsingh@gmail.com

Received 26 January 2011, Accepted 25 April 2012

ABSTRACT

The present work investigates the effect of cryorolling on the mechanical properties (yield strength, ultimate and hardness) of Al-6063 alloy along with its fatigue behavior. Al-6063 alloy is rolled for a thickness reduction up to 50% at liquid nitrogen temperature after subjecting it to the solution treatment for 2 hours at 520°C. The properties of this cryorolled alloy have been compared with the properties of its solution treated bulk alloy. On the basis of experimental study, it was observed that the mechanical properties of the cryorolled alloy were improved in comparison to the solution treated alloy. The fatigue life of the cryorolled alloy was also found higher than that of solution treated bulk alloy in axial loading.

Keywords: Al 6063 Alloy, Cryorolling, Mechanical Behavior, Fatigue

1. INTRODUCTION

Aluminum alloys have been extensively used in automobile and aerospace industries due to low weight in comparison to other alloy. The components fabricated from these alloys and their composites (Anilkumar et al., 2011) leads to overall weight reduction, and hence overall low operating cost of the vehicles. In addition to this, the extended life of the components fabricated from these alloys makes it a prime choice of designers for designing components. A major volume of Al-alloys is used in the form of sheets or foils. By using the grain refinement process, the mechanical properties of these alloys can be improved (Valiev et al., 2000). The fine grained alloys are produced by severe plastic deformation techniques. Cryorolling process (Wong et al., 2006) (rolling at liquid nitrogen temperature) has been found to be a potential method to produce the fine grained alloys in the form of sheets. The cryorolling process can produce fine grained alloys at higher production rates which meet the demand of industries. The fine grained alloys thus produced are reported to have improved mechanical properties (Panigrahi and Jayaganthan, 2008) than their bulk alloys. But the high strength materials may also fail during their service life when subjected to fatigue loading. Some earlier work reported in literature on fatigue behavior of the fine grained alloy shows that the fatigue life of the ultra-fine grained (UFG) materials is short in the low-cycle fatigue regime than corresponding conventional grain size specimen (Estrin and Vinogradov, 2010).

So far, equal channel angular pressing (ECAP) method has been used as grain refinement method for most of the fatigue work available in the literature (Estrin and Vinogradov, 2010; Cavaliere, 2009; Mughrabi et al., 2004; Hoppel, 2006). Therefore, in the present work, an attempt has been made to determine the mechanical properties and fatigue life of the cryorolled alloy subjected to axial fatigue loading. For this purpose, Al-6063 alloy has been used and it is subjected to cryorolling for a thickness reduction of 50%. The results of the cryorolled alloy are then compared with the solution treated bulk alloy. The fatigue life of the solution treated alloy has also been determined for fatigue loading in bending.

2. EXPERIMENTAL PROCEDURE

The detail experimental procedure carried out on bulk Al 6063 alloy in the present work is given below:

2.1 Cryorolling

The alloy was received in bulk form of rectangular bar with a cross-section of 75mm x 35mm. The alloy was then machined into small pieces having dimensions of 55mm x 35mm x 12mm and 75mm x 37mm x 12 mm for preparing cryorolling specimen for tensile and fatigue test respectively. After preparing the specimen for required dimensions, the plates were subjected to solution treatment at 520°C for 2 hours followed by water quenching. The solution treated alloy was then subjected to cryorolling, and a thickness reduction of 50% was achieved by this process. The specimen was immersed in liquid nitrogen for 30 minutes prior to each roll pass during the cryorolling process. The rolling was done at a speed of 8 rpm and the roll diameter was 110 mm.

2.2 Tensile Test

In order to determine the mechanical properties of the cryorolled and solution treated alloy, tensile test was conducted. The tensile test specimens for cryorolled alloy were prepared with their axis parallel to the rolling direction. The specimens were prepared as per ASTM-E8 sub size specifications. The specimen of cryorolled alloy is shown in Figure 1.

The tensile specimens of bulk alloy were given solution treatment and water quenching before testing them. The thickness of the cryorolled and solution treated tensile specimen was 6 mm and 3 mm respectively.
The specimens were gripped in the machine jaws and were axially loaded in tension till fracture to evaluate strength and ductility. The strain rate of 0.5 mm/s was chosen. The gauge length of the specimen was marked and polished before testing to maintain uniform width throughout the gauge length and to obtain scratch free surface. Testing was done at room temperature. The average value of tensile strength was calculated based on test carried out on six samples.

2.3 Fatigue Test

2.3.1 Axial Fatigue Test

In the present work, the fatigue life of cryorolled alloy has been determined by subjecting it to axial fatigue loading and the fatigue life of solution treated alloy has been determined for axial as well as bending fatigue loads. The axial fatigue test specimens were prepared according to ASTM E466. The dimensions of the fatigue test specimen are as shown in Figure 2.

The axial fatigue testing was performed on Material Testing System (MTS-810) having a force capacity of 100 kN. The axial fatigue test specimens of bulk and cryorolled alloy were tested on loads corresponding to the stress value of 0.95, 0.9, 0.85, 0.8, 0.75 and 0.7 times the strength of the alloy. The stress ratio of 0.2 was used and the number of cycles that a specimen can stand for a particular stress value was noted.

2.3.2 Bending Fatigue Test

For conducting bending fatigue test reverse cycle bending fatigue machine of W and T series was used. In this case, the specimen rotates about its axis and hence the stress value gets reversed after every half revolution. The speed of the motor of the machine was 1440 rpm.

The dimensions of the bending fatigue specimen are shown in Figure 3. The bending fatigue specimens of bulk alloy were tested on loads corresponding to the stress value of 0.95, 0.9, 0.85, 0.8, 0.75, 0.7 and 0.6 times the strength of the alloy. The numbers of cycles before failure were noted corresponding to the stress levels. The results of fatigue testing are represented by S-N curve.

2.4 Hardness Testing

Vickers micro hardness measurements were employed to characterize the mechanical Vickers hardness (HV) of solution treated and cryorolled specimen. The top surfaces of the specimen were polished using emery papers. After specimen preparation Vickers hardness (HV) was measured on the plane parallel to longitudinal axis (in rolling direction) by applying a load of 10 kg for 15 seconds. The average of at least 5 readings on the surface was taken to obtain hardness value.

3. RESULTS AND DISCUSSIONS

The experimental investigations show that the yield strength of the solution treated and cryorolled alloy is found to be 56.44MPa and 103.62MPa respectively i.e. an increase of 83.5% in the yield strength is observed after cryorolling up to 50% thickness reduction. The ultimate strength of the alloy has increased from 129.51MPa to 193.75MPa after cryorolling. In this case, an increase of approximately 50% in ultimate strength value is observed. The comparison of the yield and ultimate strengths of solution treated and cryorolled alloy is shown in Figure 4. The enhancement in the strength of cryorolled alloy is due to the effect of higher dislocation density, grain refinement, solid solution strengthening and suppression of dynamic recovery. The elongation decreases from 31.15% to 7.48% after cryorolling to 50% reduction. This is attributed to the lower dislocations movement after cryorolling.

The investigated mechanical properties of solution treated and cryorolled Al-6063 are shown in Table 1. From the results presented in Table 1, it is observed that...
the ultimate tensile strength (UTS) and yield strength (YS) of the cryorolled alloy is more than solution treated alloy.

The results obtained from the bending fatigue testing of solution treated alloy are represented by S-N curve as shown by Figure 5(a), and the results obtained from the axial fatigue test of solution treated and cryorolled alloy specimens are shown by Figure 5(b) and 5(c) respectively.

<table>
<thead>
<tr>
<th>Specimen type</th>
<th>YS (MPa)</th>
<th>US (MPa)</th>
<th>Elongation (%)</th>
<th>Hardness (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Treated</td>
<td>56.44</td>
<td>129.51</td>
<td>31.15</td>
<td>56</td>
</tr>
<tr>
<td>Cryorolled</td>
<td>103.62</td>
<td>193.75</td>
<td>7.48</td>
<td>90</td>
</tr>
</tbody>
</table>

From the Figure 5 (b) and 5(c), it is observed that the fatigue life of cryorolled alloy is more than the solution treated alloy for the same percentage of their stress value. Cryorolled alloy offers high crack propagation resistance due to increased dislocation density and suppression of dynamic recovery (Panigrahi and Jayaganthan, 2008) and hence fatigue life gets improved.

The comparison in hardness value of solution treated and cryorolled alloy have been shown in Figure 6. The hardness value of cryorolled specimen has increased to 90HV as compared to the hardness value of solution treated specimen which is 56HV. Therefore, an increase of 61% in the hardness value is observed by cryorolling. An enhancement in the hardness value of cryorolled alloy can be due to fine grain size, restrictive movement of
dislocations and suppression of dynamic recovery which leads to a higher dislocation density.

The results obtained by fatigue testing for solution treated and cryorolled alloy are also tabulated in Table 2. From the results presented in Table 2, it can be seen that, the fatigue life is quite less at higher stress level as compared to fatigue life at lower stress level. This is mainly because the specimen fails early due to increased amplitude of repeated loading at higher loads.

4. CONCLUSIONS

In the present work, the mechanical properties and fatigue behavior of solution treated as well as cryorolled Al-6063 have been investigated by experimental procedure. From the experimental results obtained in the present work, it is clear that after cryorolling, the yield strength of the alloy has increased from 56.44 MPa to 103.62 MPa (83% increase) and ultimate strength has increased from 129.5 MPa to 193.75 MPa (50% increase). The hardness of cryorolled alloy is found 61% more than solution treated alloy. The improvement in mechanical properties of cryorolled Al alloy such as yield strength, ultimate strength, hardness is at the cost of ductility. The fatigue life of cryorolled material is also found as compared to solution treated alloy in axial fatigue loading. The improvement in fatigue strength of cryorolled alloy may be attributed to increased dislocation density and the suppression of dynamic recovery, and hence the lower dislocation motion. The fatigue life of solution treated specimen is also investigated in bending fatigue loading.

In future, this work can be extended further for processing the alloy at -50°C and detailed grain refinement studies can be made using EBSD and TEM. Moreover, fatigue crack growth simulations can be performed and verified with experimental results.

REFERENCES


