International Journal of Scientific & Engineering Research Volume 11, Issue 6, June-2020
ISSN 2229-5518

Evolution of Mechanical Properties of Al-Zn-Mg Alloy Processed by Equal Channel Angular Pressing

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Abstract— Equal channel angular pressing (ECAP) is one of the severe plastic deformation (SPD) techniques used to develop ultrafine-grained (UFG) materials. In this technique, large amount of shear strain is introduced in the material, without any change in the cross sectional dimensions. Aluminium-Zinc-Magnesium (Al-Zn-Mg) alloys are promising light weight high strength materials, wherein precipitation strengthening will be possible. In the dissertation work, Al-Zn-Mg alloy was processed by ECAP technique. ECAP processing was carried out in a die having an internal angle between two channels (Φ) of 120º and outer arc curvature (ψ) of 30º. The processing was attempted at lowest possible temperature in route B_C. To assess the mechanical properties, microhardness measurement and tensile tests were conducted. Wear properties were also evaluated before and after ECAP processing. After ECAP processing, significant improvement in the mechanical properties of the alloy were perceived. Microhardness and ultimate tensile strength (UTS) were increased with the increase in the ECAP passes. While elongation to failure of the alloy was decreased with the increase in the ECAP passes. ECAP processing leads to considerable improvement in the wear resistance of the alloy. Also, Coefficient of friction of the alloy was decreased with the increase in the ECAP passes.

Index Terms— SPD, ECAP, Al-Zn-Mg alloy, Grain refinement, Hardness, Tensile properties, Wear characterstics

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1 INTRODUCTION

Grain size of a material plays a very significant role in the mechanical properties of the materials. According to Hall-Petch equation, the strength of the material increases with decrease in the grain size. This lead to increase in the interest in developing materials with extremely small grain sizes. Due to a number of benefits, interest is towards development of new techniques to produce ultra-fine grained (UFG) materials. UFG is accomplished either by bottom-up approach or top-down approach [1]. In the bottom-up approach, individual atoms or molecules or consolidated into bulk materials, whereas, in top-down approach, solid materials usually having coarse grain (CG) structure are refined into fine grain structures [1]. Top-down approach could be accomplished by severe plastic deformation (SPD) techniques. SPD techniques result in high degree of grain refinement along with formation of high angle grain boundaries. It also leads to accumulation of high plastic strain in the materials [2]. The presence of a high fraction of high angle grain boundaries is very important to achieve significant improvement in mechanical properties. SPD is a metal forming technique in which very high plastic strain is imposed on the material without any significant change in the overall dimensions. Numerous techniques are established for SPD processing of materials. Among these techniques, equal channel angular pressing (ECAP) technique is very effective because of its simplicity.

Segal and co-workers were the first to introduce the equal channel angular pressing. ECAP is an innovative process of severe plastic deformation capable of producing large plastic strain in polycrystalline materials. In ECAP process, the deformation takes place by pure shear. The setup consists of die having channels of equal cross-section which are intersecting at an angle. A sample of uniform cross-section (may be of circular or square cross-section) is pressed through these channels. Large amount of shear strain is induced in the sample as it passes the plane of intersection of the two channels which in turn causes significant reduction in the grain size. The significant feature of ECAP is that the dimension of the sample is unchanged during deformation; therefore the same material could be processed respectively to induce very high strains and to produce UFG structure [3].

Aluminium and its alloys are considered as the reliable materials in the field of engineering applications. The Al-Zn-Mg alloys are identified as the strongest and hardest alloys among the aluminium alloys family [4]. The Al-Zn-Mg alloys possess high strength and toughness characteristics. The Al-Zn-Mg alloys have a wide acceptance in the fabrication of engineering equipment's where high strength to weight ratio is an important criterion. The important applications of these alloys are in aerospace, military equipment's and light weight structures. In the present work, hardness, tensile properties and wear properties of the Al-Zn-Mg alloy before and after ECAP processing were studied.

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2 EXPERIMENTAL PROCEDURES

The Al Al-Zn-Mg alloy studied in the present work was received in rolled condition as shown in Fig. 1. To remove the residual stresses present in the as-received material due to rolling, annealing treatment was carried out. Annealing was carried out 480 ºC upto 6 hours. For ECAP processing, annealed material was machined to a diameter of 16 mm and a length of 80 mm parallel to the ingot shown in Fig. 2.

Fig. 1. As-received material

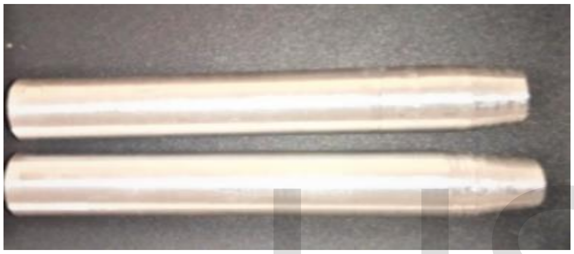

Fig. 2. Samples machined for ECAP processing

The ECAP die was fabricated in split type design (2 piece die) and align pins were provided for proper alignment. The ECAP die was machined with two channels of 16.1 mm diameter intersecting at an internal angle (Φ) of 120° and outer arc of curvature (ψ) of 30°. The equivalent strain imposed on the sample with these angular values in each pass is 0.667. The ECAP die and the punch were machined from H11 tool steel and heat treated. Holes are provided in the ECAP die for placing heating coils to heat the die to the required processing temperature. ECAP processing was carried out in a 40 ton universal testing machine (UTM). In the present work, route B_C was adopted, since it results in uniform distribution of the strain in the material compared to other routes. The ECAP process was carried out by pressing the sample at a constant speed of 0.5 mm/s and the processing was attempted at lowest possible temperature. In order to reduce the friction between the die and the sample molybdenum disulphide (MoS_2) was used as the lubricant. Prior to each pass, the die was heated upto the processing temperature and then the sample was inserted in to the die and kept for 15 min so that the equilibrium temperature was established in the sample and the die. While processing, the whole die setup was maintained at the processing temperature using an inbuilt heater.

To assess the mechanical properties of the alloy's mechanical tests, such as microhardness measurement, tensile test and wear test will be conducted on the unprocessed and the processed samples. Microhardness of the sample was measured by using Vickers microhardness tester. The values of the Vickers micro hardness, Hv, were determined by imposing a load of 50gm for 15sec according to ASTM E834 standard. To achieve optimal results in hardness measurement, center portion of the sample was selected. On each sample, 10 hardness measurements were carried out and the average value of microhardness was calculated. To evaluate the ultimate tensile strength (UTS) and the elongation to failure (ductility) of the unprocessed and processed samples, tensile tests were conducted at room temperature and at a constant cross head speed of 0.1 mm/min. For tensile testing unprocessed and processed samples were machined to tensile test samples as per the ASTM E8 standard. In each condition, three samples were tested to confirm the repeatability of the results and average values were considered.

Dry sliding wear test experiments were carried out by using pin on disc type test setup according to ASTM G-99 standard. The wear tests were carried out at room temperature and at a relative humidity of 50 ± 5%. Samples for the wear test were machined into cylindrical pins of 10 mm diameter and 28 mm in length. Samples were made to slide against EN31 steel disc having hardness of 62 HRc and surface roughness 0.3 µm. Wear test were conducted at two test conditions. One test at 20 N load & 1 m/s sliding speed, and other one at 40 N load & 2 m/s sliding speed. Each of these tests was taken place at a sliding distance of 1000 mm at 120 mm diameter track. The wear resistance was measured by weight loss method using a microbalance. The coefficient of friction ($\mu = F_f/P$) values were calculated by using frictional force data recorded in the computer and the applied load. In each condition, three samples were tested to confirm the rrepeatability of the results and the average values were taken into consideration.

3 RESULTS AND DISCUSSION

Literature on the ECAP processing indicates that the optimum mechanical properties could be achieved by processing the material at lowest possible temperature. In this regard, alloy was processed at minimum possible temperature. Table indicates the condition of the samples after processing at different temperatures. Alloy was failed during the first pass at room temperature as shown in Fig. 3. Only at 150 °C, alloy was successfully processed upto four passes in route B_C without failure. After four passes, processing was stopped, since in route B_C deformation restores the equiaxed microstructure in all planes after every four successive passes.

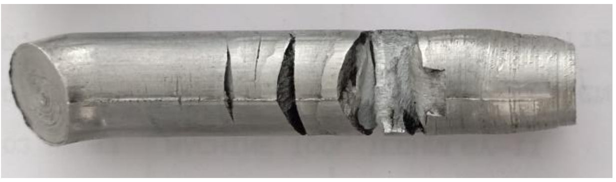

Fig. 3. Sample processed at room temperature

Figure 4 shows the microhardness of the alloy in different conditions. In annealed condition, the microhardness of the alloy is 120 ± 9 Hv. Noticeable improvements in the microhardness of the alloy was observed after processing. After ECAP processing, the microhardness of the alloy is increased to 195 ± 8, 210 ± 6, 222 ± 6, and 230 ± 5 Hv in the first, second, third and fourth passes respectively. After the first, second, third and fourth passes, the microhardness is increased by 63%, 75%, 85% and 92% respectively from the initial condition. The increase in the microhardness of the alloy after ECAP processing is attributed grain refinement, strain or work hardening effect [5].

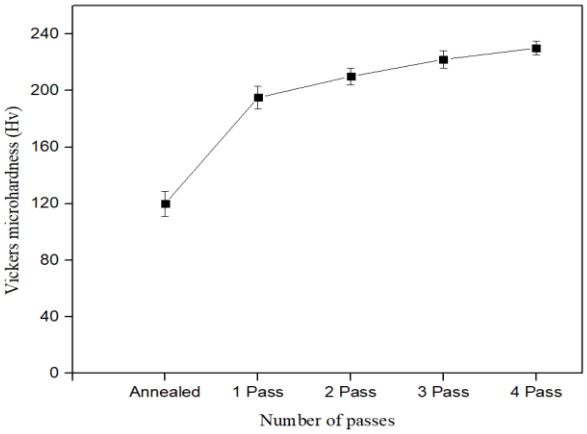

Fig. 4. Microhardness of the alloy in different conditions

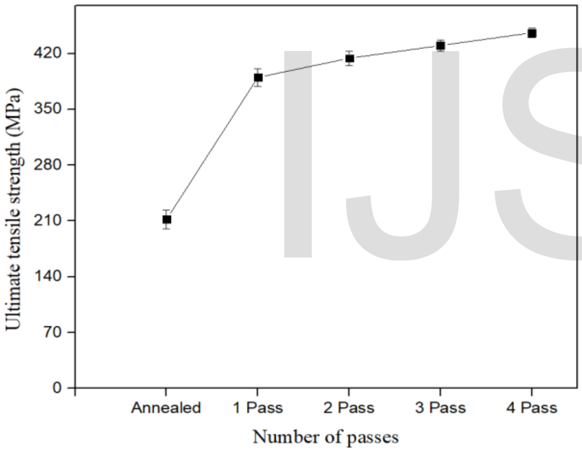

Fig. 5. Ultimate tensile strength of the alloy in different conditions

Figure 5 shows the Ultimate tensile strength (UTS) of the alloy in different conditions. In annealed condition, the UTS of the alloy is 212 ± 12 MPa. ECAP processing leads to a drastic improvement in the strength of the material. After ECAP processing, the UTS of the alloy is increased to 390 ± 11, 414 ± 9, 430 ± 7 and 446 ± 6 MPa in the first, second, third and fourth passes respectively. After first, second, third and fourth passes, UTS is increased by 84%, 95%, 103% and 110%, respectively, from the initial condition.

Figure 6 shows the elongation of the alloy in different conditions. The elongation to failure of the alloy in the annealed condition is 18 ± 1.2%. ECAP processing lead to a noticeable decrease in the ductility of the material. After ECAP processing, elongation to failure of the alloy is decreased to 12.5 ± 0.9 % in the first pass, 10.7 ± 0.8 % in the second pass, 8.1 ± 0.8 % in the third pass and 6.2 ± 0.6 % in the fourth pass, respectively. Since strength is interdependent on the hardness; UTS of the material increased after ECAP processing. Ductility is inversely proportional to strength; ductility of the material is decreased after ECAP processing. The decrease in the ductility of the alloy after ECAP is attributed strain hardening [6].

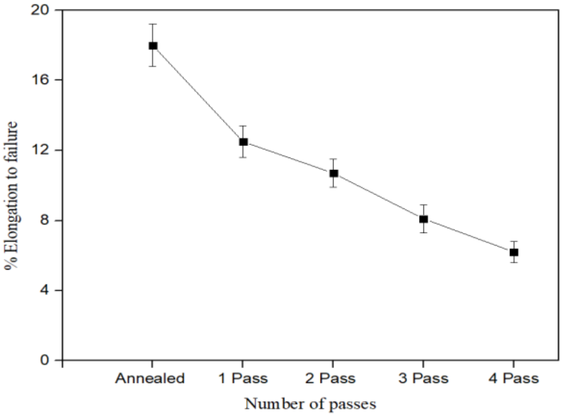

Fig. 6. Ductility of the alloy in different conditions

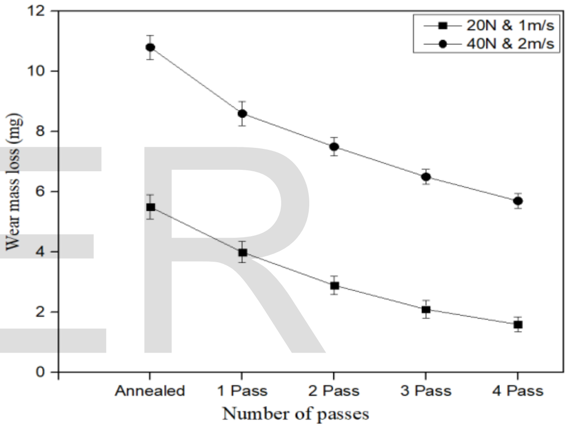

Fig. 7. Wear mass loss of the alloy in different conditions

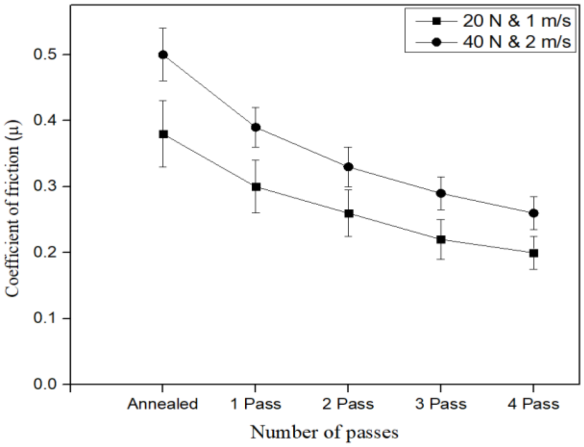

Fig. 8. Coefficient of friction of the alloy in different conditions

Figure 7 shows the wear mass loss of the alloy under various conditions. It is noticed that, for the same load and the sliding speed, ECAP processed samples exhibits higher wear resistance than the unprocessed sample. Wear resistance of the alloy increased with increase in the ECAP passes. Also, for the same condition, the mass loss is increased with increase in the applied load and the sliding speed. The improvement in the wear resisting capability of the material after ECAP processing is in the consistent with the earlier observations [7]. It was observed that, processing by ECAP has positive effect on the wear properties. Among all cases, mass loss is highest in annealed and lowest in the four ECAP pass sample.

Figure 8 shows the coefficient of friction of the alloy under various conditions. It is noticed that, the coefficient of friction of ECAP processed samples is lower than the annealed samples. Also, coefficient of friction reduced with increase in the ECAP passes. For the same condition, the coefficient of friction is increased with increase in the applied load and the sliding speed. In all cases, the coefficient of friction is highest in annealed and lowest in four ECAP pass sample. The decrease in the coefficient of friction with EACP processing is in consistent with earlier observations [8]. The increase in the wear resistance and decrease in the coefficient of friction of the material is attributed to the increase in the hardness of the material after ECAP processing.

4 CONCLUSION

In the present work, Al-Zn-Mg alloy was processed by ECAP in the die having an internal angle between two channels (Φ) of 120°. The processing was carried out in route B_C. Based on the experimental results obtained and the discussion presented, the following conclusions are drawn:

Microhardness of the alloy was increased with increase in the ECAP passes. Tensile strength of the alloy was increased with increase in the ECAP passes. While, the elongation to failure of the alloy was decreased with increase in the ECAP process. Wear resistance of the alloy increased with increase in the ECAP passes. While, the coefficient of friction of the alloy was decreased with increase in the ECAP process. Compared to the annealed Al-Zn-Mg alloy alloy better mechanical and wear properties were observed in after ECAP processed alloy.

ACKNOWLEDGMENT

The authors wish to thank Dr. P Shyama Raju, Chancellor, REVA University for providing opportunity to carryout this work at REVA University. The authors also wish to thank Dr. K S Narayanaswamy, Director, School of Mechanical Engineering, REVA University for providing excellent laboratory facilities for this work. The authors also wish to thank technical staff of School of Mechanical Engineering, REVA University for assisting to carryout the experiments.

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