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RESEARCH ARTICLE

Experimental Investigation of Microstructure and Mechanical Properties of Al 5052 Processed by Equal Channel Angular Pressing Technique

***N Nandakumar[1], V Ranjithkumar[2]**
[1]Assistant Professor, Department of Mechanical Engineering, Government College of Technology, Coimbatore-641013, Tamil Nadu, India.
[2]PG Scholar, Department of Manufacturing Engineering, Government College of Technology, Coimbatore-641013, Tamil Nadu, India.

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ABSTRACT

Equal Channel Angular Pressing (ECAP), a Severe Plastic Deformation (SPD) processes is generally employed to produce the ultrafine grain structured materials. ECAP has been effectively used in the microstructural refinement of almost all the structural materials. In the present investigation on Al-5052 alloy, an effort has been put forward to report the effects of route A on the microstructural characteristics. Prior to the ECAP process, Al 5052 alloy is subjected to the annealing treatment to relieve the thermal stress introduced during machining. ECAP has been performed at room temperature with the die angle of 90º. The evolution of microstructure is carried out using optical microscopy and correlated the grain refinement with the mechanical properties like microhardness and tensile property. The experimental result reveals that ECAP process exhibits increased yield, tensile strength and microhardness when compared to base material and this occurs due to the attribution of grain refinement.

Keywords: Al-5052, ECAP, Microstructure, Microhardness, Tensile property.

1. INTRODUCTION

ECAP is one of the SPD techniques [1], which possesses unique physical and mechanical properties related to ultrafine grained materials and provides multiple advantages when compared to other methods, especially the bottom up approach [2]. A bar shaped specimen is machined to fit into a channel contained within a die and is pressed using a plunger [3] that consists of two channels of equal cross sections at 90º. ECAP allows to introduce large strain to a work-piece without changing the processed work-piece. In this technique, the coarse grain is reduced into ultra-fine-grained and nano grained structure in pure metals and alloys. A significant advantage of the ECAP process is to apply large strains in material without changing the cross-section area of the materials. By changing the billet orientation after each press, the shear plane and direction are modified thus making it possible to reduce grain size. In ECAP technique, route specifies the processing side of the specimen, which comprises route A, B, C and D. In route A, ‘n’ number of time can be processed under normal position without rotating the specimen side.

Aluminum alloys are extensively used in manufacturing several parts of automobile, aircraft and marine applications due to their light weight material. Al 5052 is an alloy of magnesium and chromium, which has generally high strain hardening, strength, toughness and corrosion resistance even in salt water [4-6]. To further improve its effectiveness, ultra-fine-grained aluminum alloys are developed. Aluminum alloys such as 1050, 5083, 6082 and 7010AA [7] are

*Corresponding author. Tel.:+919994496070
Email address: nannthu@yahoo.com (N.Nandakumar)
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processed using ECAP technique in which 6082 and 5083AA possess similar hardness and stress strain behavior. The microstructural characteristics of the alloys are influenced by the low angle grain boundaries. Heat rolled aluminum bronze alloy is subjected to Equal Channel Angular Extrusion (ECAE) [8], and the microstructure, phase transformation behavior and mechanical properties are investigated. The obtained results indicate that grain size decreases with increase in ECAE passes. Also ECAE processed alloy exhibits improved mechanical properties and reduced phase transformation temperature. The effect of SPD on Al-Mg alloy based on mechanical behavior and dynamic strain aging [9] is analysed, where ECAP processed alloy reduces the strain rate sensitivity and the localized plastic flow, and changes the stress-strain curve. The microstructure and mechanical property of Al-7075 alloy are explored using ECAP where an increment in tensile yield strength, ultimate tensile strength and micro hardness is observed by 168%, 73% and 93% respectively [10]. The mechanical properties such as hardness and yield and tensile strength increase by 64%, 107% and 46% for AA5083 using Dual Equal Channel Lateral Extrusion (DECLE) [11] technique due to reduced temperature and high grain deformation. When the microstructures and mechanical properties of commercially pure titanium [12] are experimented using multi-pass ECAP process and cold extrusion, an increment in ultimate tensile strength from 791.9 to 292.5 MPa is observed with considerable microstructure refinement. The properties of AA5083 alloys investigated using ECAP are reported in [13-16].

The main objective of the present investigation is to enhance the microstructural characteristics and mechanical properties, where an attempt is made to decrease the grain size and increase microhardness and ultimate tensile strength in route A.

2. EXPERIMENTAL PROCEDURE

The experiments are carried out using Al 5052 alloy as the ECAP material [17]. Table 1 shows the chemical composition of Al 5052 alloy. Prior to the ECAP process, Al 5052 alloy is subjected to annealing treatment at 420°C for an hour and is then air quenched to determine the thermal stress introduced during machining.

Table 1.Chemical composition of Al 5052 alloy

Mg	Cr	Cu	Fe	Mn	Si	Zn	Others	Al
2.80	0.35	0.10	0.40	0.10	0.25	0.10	0.20	balance

ECAP specimen is kept at room temperature with the die angle of 90º. The die and the punch are made up of H13 hardened steel and it is heat treated to hardness of 60 HV [18]. Rectangular punch is used to press materials from vertical channel to the horizontal channel of the die. The clearance between the punch and channel wall is 100 µm. The specimen is pressed up to 2 passes at room temperature processing under route A. Figure 1 shows the schematic diagram of ECAP die. ECAP die with a plunger is used to push the specimen out of the die immediately after pressing it by a plunger from the feed.

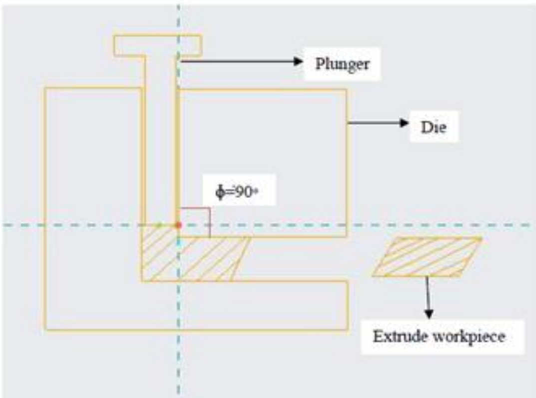

Figure 1.Schematic diagram of ECAP die

The specimen is cut into rectangular pieces using the electric discharge machine. The billet is coated with lubricate material such as molybdenum disulphide (MoS_2). Lubrication is important to reduce the friction between the sample and the channel inner wall and also to remove the sample from the die after the process is completed. The extrusion speed of both materials is maintained at 1 mms^{-1} for all the passes. The billet is pressed through a rectangular channel die at 90º (Φ=90º). The main advantage of using the plunger is the shorter time that the specimen is exposed to the operating temperature of the ECAP process, thus minimizing the microstructural changes.

2.1. Microstructure analysis

The microstructure of base alloy and ECAP specimen are examined with meta-tech optical microscopy. The specimen is cut along the extrusion direction. The specimen is prepared by polishing and then followed by etching process. In polishing, the abrasive paper or different emery sheet grades such as 400, 600, 800 and 1200 are used. After polishing, the specimens are etched by immersing in a solution of 1 ml HF, 2.5 ml HNO_3, 1.5 ml HCl and 95 ml H_2O for 15 s. The microstructures are photographed using Envision 3.0 and image analyzer software. The misorientation angles are calculated for each pass along the cross sectional, longitudinal and transverse direction of the microstructures.

2.2. Microhardness test

Vickers microhardness measurements are obtained from Wilson HMV 2000. Microhardness tests are performed to analyse the microstructure homogeneity after different stages of the work piece. In this method, the evolution of mechanical properties depending on the increasing number of ECAP passes [19] is examined to evaluate the mechanical properties of base sample and ECAP sample of Al 5052 alloy.

To determine the microhardness tests, the samples are cut from billets and polished till 1 µm using abrasive papers and emery sheets in different grades. For all tests, a grid of indents 10x10 with a 0.8 µm step is used. The test is carried out by applying loads of 300g for a dwell time of 10 s. It is performed for all the co-ordinate planes namely XY, YZ and XZ after two passes. The microhardness values are obtained by taking the average of 5 measurements.

2.3 Tensile property

The tensile property of base sample and ECAP sample are analyzed using Tinius Olsen machine setup. Tensile deformation test provides characteristics corresponding to time and applied force. The tensile strain comprises the elastic and plastic strains of the specimen, in which the elastic strain is subtracted during the measurement evaluation. In the plot, the elastic region is interpolated by tangent in the area of maximum applied force. The tensile strength deformation test is examined at room temperature using a constant strain rate of $1\times10^{-3}\,s^{-1}$.

3. RESULTS

3.1. Microstructure analysis

Figure A1 shows the optical images of the base and ECAP sample after 2 passes. The equiaxed elongated grains are observed in the images of optical microscope and is calculated using linear intercept method. The microstructure of the specimen before ECAP exhibits the coarse-grained structure with grain size and average width 28 µm respectively. After one pass, [20] the microstructure of the alloy structure comprises a small fracture in low angle grain boundaries. After all the passes, the coarse grain is converted into ultrafine grain structure in Al 5052 alloy. It may be processed up to 2 passes and the average ultrafine grain size is 16 µm.

3.2. Microhardness test

The microhardness values of Al 5052 alloy are measured using Wilson HMV 2000 for all passes. The applied load and dwell time is considered to be 0.3 kg and 10 sec respectively. The hardness comparison graph between base and ECAP sample is shown in figure 2.

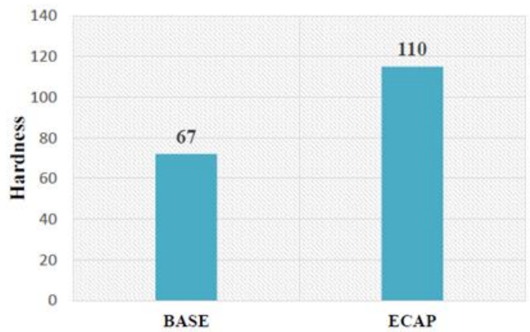

Figure 2.Comparison of microhardness test

The hardness value increases with increase in the number of passes. The obtained comparison graph shows that the [21] Vickers hardness test is processed up to 2 passes through route A, in which the readings are obtained at the middle part of the plate shaped sample (cross plane), perpendicular to the extrusion plane. The microhardness values of base and ECAP samples are found to be 67 HV and 110 HV respectively.

3.3. Tensile property

Tensile stress-strain curve obtained for the base and ECAP processed sample of Al 5052 alloy are presented in figure A2. Tensile test is carried out on the dog-bone shaped base and ECAP samples. The initial strain rate is 1×10^{-3} s^{-1}. The tensile test results depend on the yield strength with increasing number of ECAP passes. Al 5052 alloy exhibits the maximum value of the yield and ultimate tensile strength after 2 passes. The gradually processing of ECAP led to a continuous increase of the yield and ultimate tensile strength at 2 passes and is then followed by saturation. The evolution of the ultimate tensile strength is similar to the yield tensile strength. The base and ECAP sample exhibit an increase of the ultimate tensile sample values after 2 passes. The evolution of the ultimate tensile strength in Al 5052 alloy is the same as the evolution of the yield tensile strength, and the ultimate tensile strength at 2 passes increases continuously.

4. DISCUSSION

4.1. Microstructure analysis

The angle of orientation decreases with increase in number of passes. The decrease in orientation angle, after two passes of ECAP indicates the reduction of grain size. The elongated grain structure consists of dislocated grain boundaries, which influence the mechanical properties and the orientation of the gains. The significant difference in the initial grain size results in a different evolution of microstructure with increase in number of ECAP passes. The grain refinement of the base and ECAP sample is almost complete within the first two passes, and after 2 passes, the grain size distribution is uniformly within an average of 28 µm and 16 µm respectively. The microstructure analysis of Al 5052 alloy is observed between the base and ECAP sample, in which the grain size is reduced from 28 µm to 16 µm after 2 passes under route A.

4.2. Vickers microhardness test

The microhardness test shows the improvement in hardness values, when comparing to both the base and ECAP samples. It can be observed that the hardness of ECAP sample is slightly higher than that of the base sample. This is due to the increase in dislocation density during SPD process. Hardness of Al 5052 alloy base sample is 67 HV, which gradually increases to 110 HV in 2 passes under route A. It is observed that hardness increases as grains reduction increases in both base and ECAP samples. In the present study, the hardness values are increased till obtaining 43% after 2 passes under route A.

4.3. Tensile property

The ultimate tensile stress of the sample increases as the number of passes increases with increase in hardness. The minimum increase is observed in the number of passes. In general, as the strength increases, the ductility decreases during ECAP. However, in this work as the strength increases the percentage of elongation also increases after the two passes. The improvement in ultimate tensile strength is due to hardening and multiple grain dislocation during ECAP. The tensile strength result suggests that the precipitates and deformation path in ECAP has greater influence on hardening behavior of Al 5052 alloy. In this work, the ultimate tensile strength has increased from the range of 226 MPa to 355 MPa for 43% increase after 2 passes under route A.

5. CONCLUSION

The improvement in microstructure and mechanical properties such as hardness and tensile property of Al 5052 is studied when subjected to ECAP process. The results reveal that,

- Due to more uniform strain during the process, ultrafine grain structured samples are produced and are compared with the base samples.
- The ultimate tensile strength increases from 226 MPa to 355 MPa for 43% increase, when compared to both base same and ECAP sample in route A.
- In Vickers hardness test, it is demonstrated that the ECAP processed Al 5052 alloy has better hardness than base Al 5052 alloy sample.

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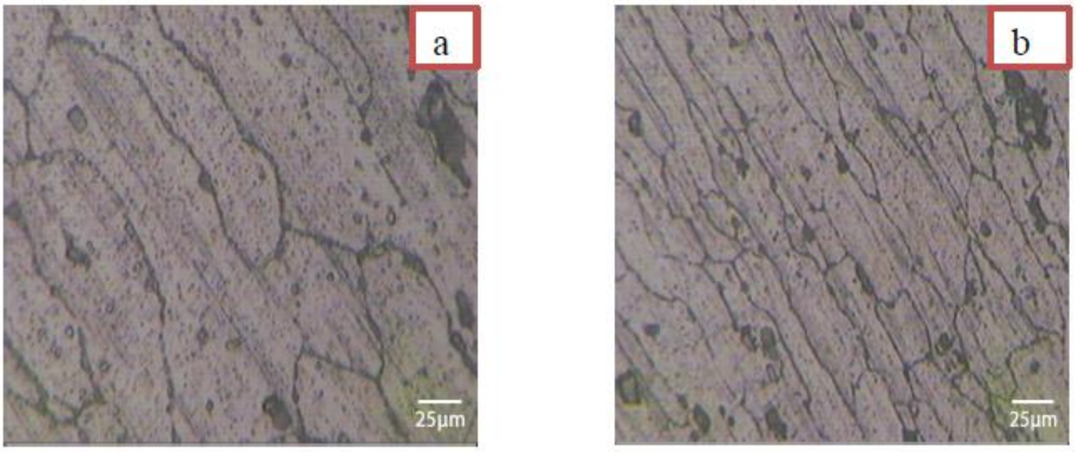
APPENDIX A



a) Base sample b) ECAP sample

Figure A1.Microstructure analysis of Al 5052 alloy

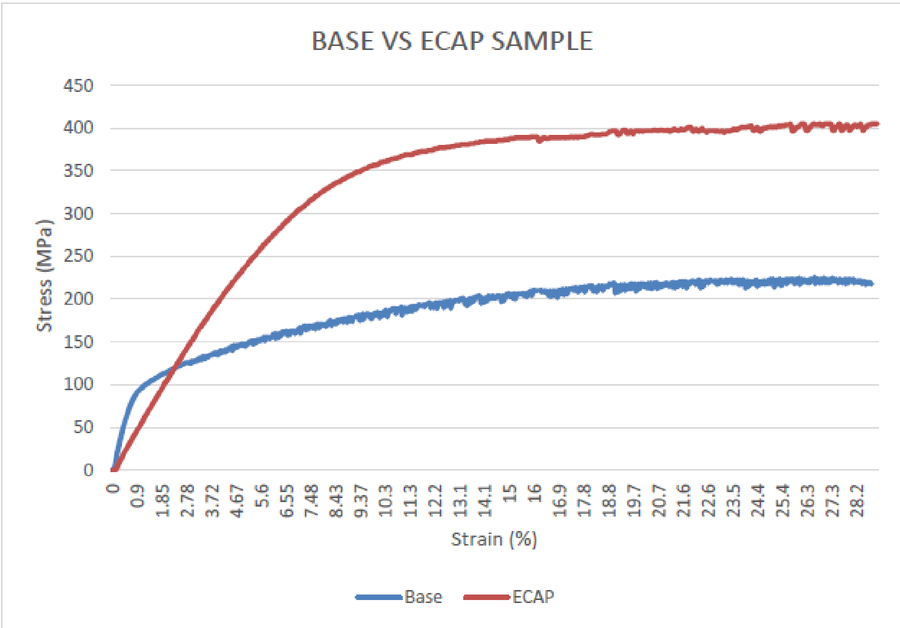


Figure A2.Comparison of ultimate tensile strength