Effect of Processing Routes for Enhanced Grain Refinement by Equal Channel Angular Pressing Technique

Dr. N. Nandakumar
Associate Professor
Department of Mechanical Engineering, Government College of Technology, Coimbatore
Anna University, Chennai, Tamilnadu, India
Email – nannthu@yahoo.com

Abstract: *Severe plastic deformation methods for producing the ultra-fine grain size in materials is the most effective process for equal channel angular pressing Technique. This process involves introducing large shear strain in the work piece by passing it through a die that consists of two channels with the same cross-sectional shape that meet at an angle to each other. In the present experimental investigation, the Al-5052 alloy was subjected to equal channel angular pressing at room temperature. It has been subjected to different processing routes such as R_{BC} and R_C. The Al-5052 alloy was subject to annealing treatment at 420ºC for an hour prior to the ECAP process. In order to evaluate the influence of different processing routes, the ECA Ped Al-5052 alloys were investigated for its enhanced with mechanical properties. The hardness of the ECA Ped alloy is improved as compared to base alloy, where maximum value is 120 HV by route R_{BC}. The tensile test results also indicate a strong influence of the ECAP process. The maximum tensile strength is found to be 386 MPa for the processed by route R_{BC}. The experimental results revealed the increase in yield and ultimate tensile strength and hardness as compared to the base material.*

Key Words: *Severe Plastic Deformation (SPD), Al-5052 alloy, Grain Refinement, Mechanical Properties.*

1. INTRODUCTION:

Severe plastic deformation is metal forming procedure in which a high strain is imposing on a solid material without the reduction of any significant change in the overall dimension in the work piece. These techniques are popular due to ability to produce the grain refinement. By these methods to enhanced the phase evolution and mechanical properties such as high tensile strength, high toughness and low temperature super-plasticity. Equal channel angular pressing (ECAP) is a severe plastic deformation technique capable of introducing severe plastic strain in bulk metals, leading to significant grain refinement to sub micrometer or even to nanometre level A billet of the test material is pressed through a die of two channels with identical cross sections, intersecting at an angle of 90º. The four different processing routes are R_A, R_{BA}, R_{BC}, R_C. Various combinations of these routes are possible, such as combining route B_C and C by altering rotation through 90º and 180º after every pass. In the present study the two different processing routes such as route R_{BC} and R_C are comparing to the base material.

To enhance the grain refinement and mechanical properties Aluminium alloys are extensively used in manufacturing several parts in automobile, aircraft industries as well as marine applications due to their light weight material. Al 5052 is an aluminium alloy with magnesium and chromium as the alloying elements. It has generally strain hardening, high strength, high toughness and corrosion resistance even in salt water. An effective method to overcome these drawbacks of aluminium alloy is to develop the ultra-fine-grained aluminium alloys. In the present study, Al 5052 alloy was ECA Ped at room temperature in two different processing routes up to two passes. To study the phase evolution of microstructure and enhanced the mechanical properties of ECA Ped Al5052 alloy. In this study, we attempt to decrease the grain size and increase the mechanical properties such tensile strength and hardness were observed under route R_{BC} and R_C up to 2 passes.

2. MATERIALS AND METHOD:

2.1 Materials and processing:

The chemical composition of Al 5052 alloy used in this study is given in table 1. The given specimen was machined to the required dimensions of length = 60mm, breadth = 14mm and height = 14mm as per the die specification of the ECAP machine. The given alloy was ECAPed at room temperature in the ECAP machine with a main pressure of 0.76 MPa and clamping pressure of 1.1 MPa. The die used for the ECAP process, can do the operation for specimens having square cross section and the channel angle of the die was 90º. The sample and die were coated with lubricant, MoS_2 since lubrication is very important to reduce the friction between the sample and the channel inner wall and to remove the sample from the die after the process was completed. The sample was pressed up to four passes and ECAP was done for two different processing routes namely route R_{BC} and R_C. Thus, two samples of each route were machined for the microscopic and mechanical studies.

Table 2.1 Chemical Composition of Al 5052 Alloy

Elements	Mg	Mn	Zn	Cr	Si	Fe	Cu	others	Al
Composition (wt.%)	2.80	0.10	0.10	0.35	0.25	0.40	0.10	0.20	Rest

2.2 Microstructure Analysis

The microstructure observations were performed by using optical microscopy. The specimen was cut along the extruded and the transverse planes of the samples were prepared for optical microscopy observation. The specimen was prepared by polishing and then followed by etching process. In polishing, we may use the abrasive paper or different emery papers and then polished using diamond paste. Then the sample was etched using 50% nitric acid and 50% ethanol for around 10 seconds. It is then cleaned using tap water. The next step was to dry the sample and make it ready for the microstructure analysis.

2.3 Vickers Hardness test

It was conducted to evaluate the mechanical properties of base alloy and ECAP specimen. Micro-hardness testing, is used to study fine-scale changes in hardness, either intentional or accidental. In the Vickers test, the load was applied smoothly, without impact, forcing the indenter into the test piece. The indenter was held in place for 10 or 15 seconds. The physical quality of the indenter and the accuracy of the applied load must be controlled in order to get the correct results. After the load was removed, the two impression diagonals were measured. Vickers hardness Tests was conducted with a 0.3kg load for a dwell time of 15sec with a 50X magnification of objective lens.

2.4 Micro Tensile test

Tensile properties of the sample were analysed by carrying out test on the micro tensile testing machine. The specimen for the test was cut using EDM cutting machine. The load was gradually increased until the tensile sample was broken and from the load value, the ultimate strength and yield strength are calculated. During the tests, the load elongation data was captured by induced software, whose data was used for further analysis. It was conducted to evaluate the tensile property of base sample and ECAPed sample such as route R_{BC} and R_C.

3. RESULTS AND DISCUSSION

3.1 Microstructure Analysis

The optical microstructure of base Al 5052 alloy and ECAP samples such route B_C and C are shown in figure 3.1. The equiaxed elongated grains were observed in optical microscope image. The grain size can be calculating by using linear intercept method. The microstructure of base sample exhibits the coarse-grained size and it measured the grain size is 25 µm. After the ECAP process, the coarse grain (CG) is converted into ultrafine grain (UFG) structure. It may be processed up to 2 passes and the average ultrafine grain size is 13 µm. The microstructures further reveal the non-uniform grain size throughout the sample. The grains obtained are coarse grains since no severe plastic deformation was done. The average grain size of the alloy was found to be 13 µm. In route C sample the average grain size is 16 µm. The angle of orientation decreases as the number of passes increases. The decrease in orientation angle, after the two passes of ECAP indicated that the grain size could be reduced. The elongated grains contain dislocation grain boundaries which influence the mechanical properties and the orientation of the gains. The microstructure analysis of Al 5052 alloy was observed between the before ECAP and after ECAP specimen, the grain size is reduced up to 13 µm after 2 passes under route B_C. While comparing the microstructure of Al 5052 alloy base and ECAPed sample has obtained in route BC sample.

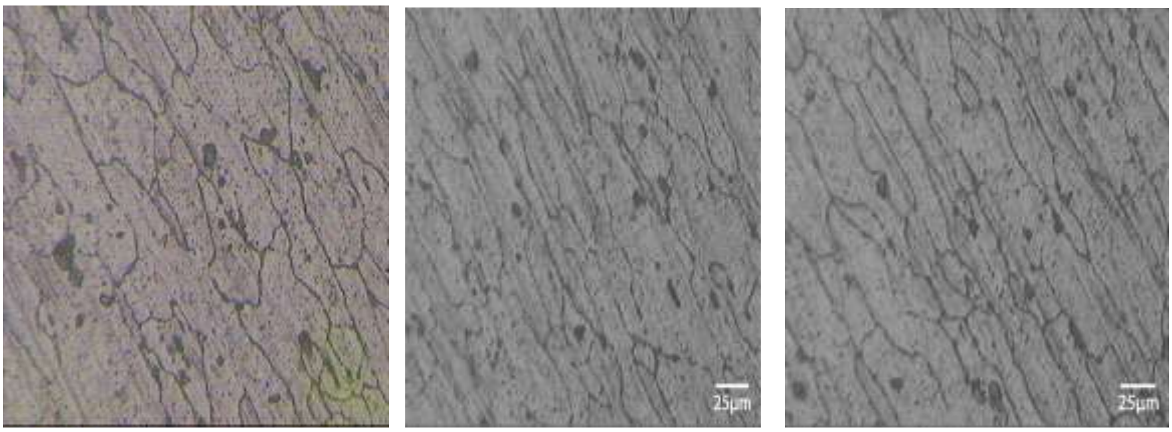

Figure 3.1 Microstructure of Al 5052 Alloy (a) Base alloy, (b) Route BC (c) Route C.

3.2 Vickers Hardness Test

The hardness was obtained using Vickers hardness machine for the base and the ECAP samples. The micro hardness test shows that the improvement in hardness values when it compares the both base sample and ECAP sample. The base alloy has hardness value very low compared to the ECAP samples because as the alloy is deformed the grain size decreases and the grain boundaries increase which the dislocation of the grains thus increasing the hardness value of ECAP sample. It can be observed that the hardness of specimen before ECAP is slightly higher than that of the specimen after ECAP.

The micro hardness values increased from 72 HV to 120 HV were observed in 2 passes under route B_C. the average hardness of route C sample is 108 HV. While comparing the routes B_C has the maximum hardness because the grains are equi-axed and the shear occurs in all the three planes. While the hardness of route C specimen has more hardness than base sample since C undergoes a redundant strain process. While the value of route C is less than route BC because there is no deformation occurring in the Z plane for route C. In present study, the hardness values were increased up to 43 % obtained after 2 passes in route B_C. The hardness result suggests that the precipitates and deformation path in ECAP has strong influence on work hardening behaviour of Al 5052 alloy.

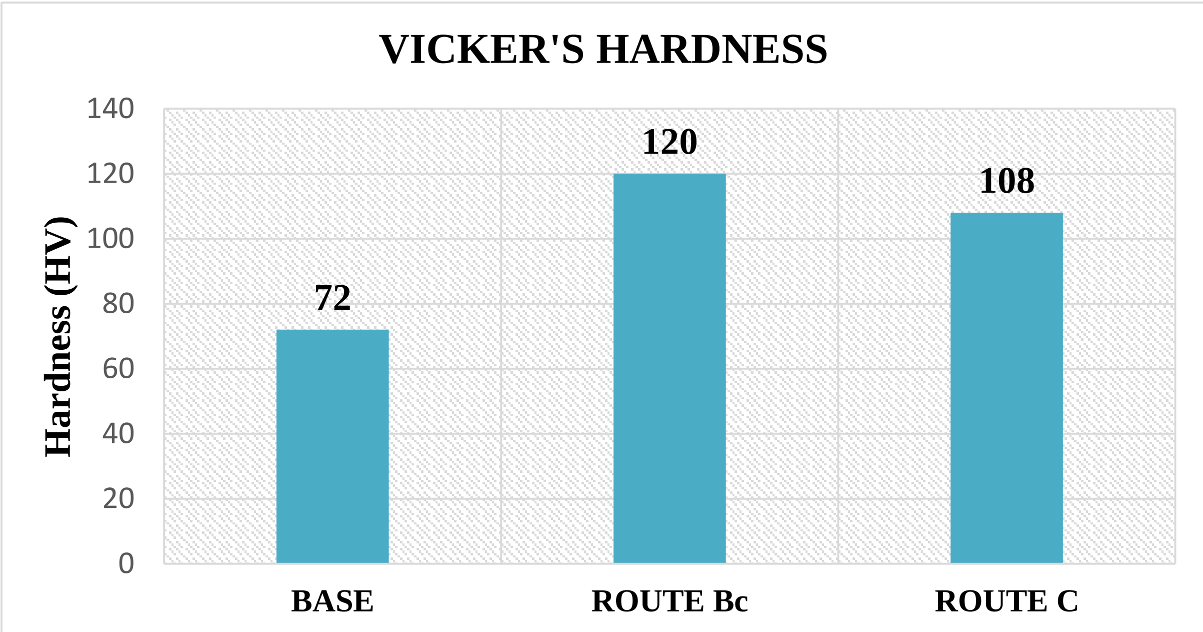

Figure 3.2 Comparison of hardness value

3.3 Micro Tensile Test

The tensile test was conducted using Tinius Olsen machine. In the study the base alloy has the largest grain size compared to other ECAP samples. So, the strength is minimum. As compared with the other specimens which has undergone the ECAP process with different routes we can see that route B_C has the maximum yield stress and ultimate stress, followed by route C.The analysis of the ductility column shows that for base alloy it is maximum (58%) whereas it is low for the ECAP samples. This is because as grains get refined, the dislocation movement retards as a result of which strength increases while the ductility decreases.

The comparison of the True Stress vs. Strain graph shows that the average tensile strength of base sample is 228 MPa and route B_C sample is 386 MPa. The average ultimate tensile strength of route c is 276 MPa. Hardness gradually increases with increasing the number of passes after ECAP in route C. The ultimate tensile strength increases as the number of passes increase is in line with the increase in hardness. However, in route B_C % of elongation increases as the number of passes increases. The ECAPed sample route B_C is slightly higher than the base and route C sample. It also means that the ductility decreases from base alloy to the ECAPed samples.

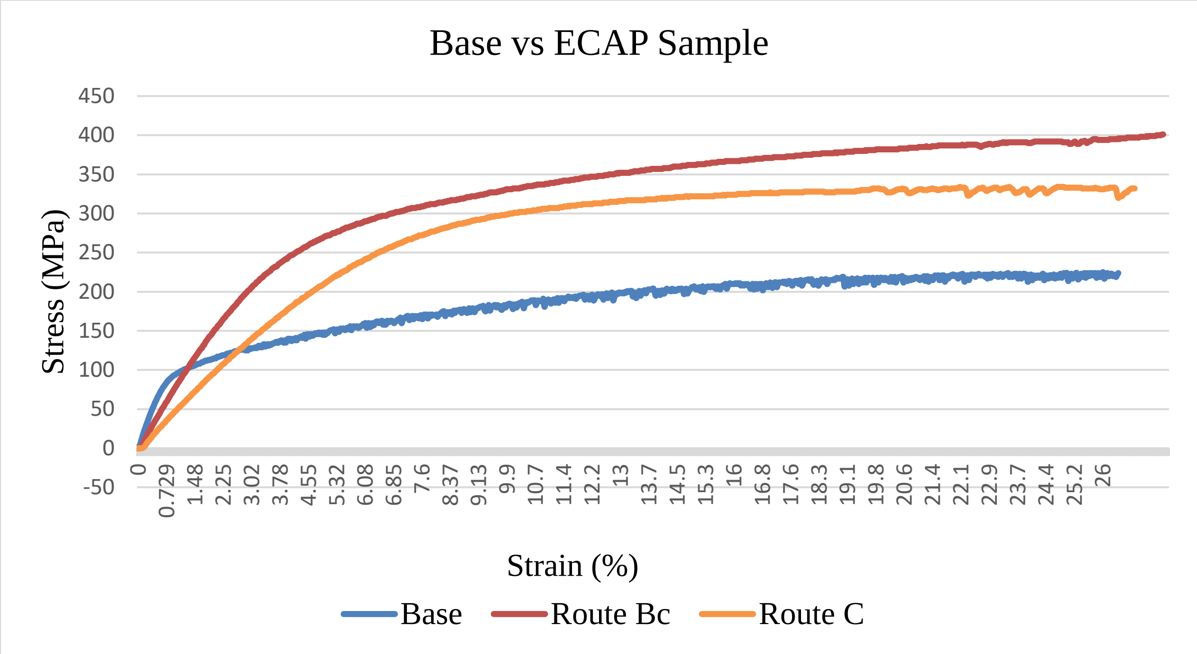

Figure 3.3 Comparison of ultimate tensile strength

4. CONCLUSION :

The Al-5052 alloy was successfully ECAPed without any crack in the two processing routes namely R_{BC}, R_C. Improvement in microstructural and mechanical properties of Al 5052 was studied when subjected to ECAP deformation process. The following conclusions and major observations are made based on the results obtained.

- Crystallite size and dislocation density were determined for reduced after the ECAP passes. The crystallite size increased as the number of ECAP passes increased as against decrease in grain size.
- Due to more uniform strain during the processing, integrity of the parts was obtained even after a number of passes. It takes up to multiple passes to produce an ultrafine grain structured sample.
- Significant improvement for all the ECAPed samples. The ECAP processed samples have higher hardness and tensile strength than the base samples to the same strain rate.
- The tensile test indicated the strong influence of ECAP process as there was a huge increase in the yield as well as ultimate strength after the process
- The hardness values also proved the same effect as that of the tensile test with a huge increase in hardness values of ECAP process; where the base alloy indicated a value of 72 HV whereas the maximum hardness was obtained for RBC with a value of 120 HV.

It was concluded that use of equal-channel angular pressing provides a simple and effective procedure for improving the mechanical properties of the Al-5052 alloy and can provide new capabilities in many engineering applications.

REFERENCES:

1. Agus Pramono, Investigation of Severe Plastic Deformation Processes for Aluminium Based Composites. *Materials Science Forum*, 2016, 504. 37-43.
2. Bert Verlinden, Severe Plastic Deformation of Metals. *Metalurgija - Journal of Metallurgy*, 2004, pp. 165-182.
3. Chao-lanTang.;Hao LI.; Sai-yi LI.; Effect of processing route on grain refinement in pure copper processed by equal channel angular extrusion. *Transactions of Nonferrous Metals Society of China*, 2016,26, 1736-1744.
4. Dang-Hwan kang, Tae-Won Kim, Mechanical behaviour and microstructure of commercially pure titanium in enhanced multi-pass equal channel angular pressing and cold extrusion. *Material and Design*. 2010,31, 554-560.
5. Ehab A, El-Danaf, Mechanical properties, microstructure and texture of single pass equal channel angular pressed 1050, 5083, 6082, 7010 aluminium alloys with different dies. *Materials and Design*. 2011,32,3838-3853.
6. I.A. Shahara, Hosaka, S. Yoshihara, Mechanical and Corrosion Properties of AZ31 Mg Alloy Processed by Equal-Channel Angular Pressing and Aging. *Advances in Material & Processing Tech*ology.2017, 184, 423-431.
7. Jun Hwan Park.; Kyung-Tae Park, Yong Shin Lee, Won Jong Nam, Microstructure developed by compressive deformation of coarse grained and ultrafine grained 5083 Al alloys at 77K and 298K.*Materials Science and Engineering*.2005,408,102–109.

8. Jens Christofer Werenskiold, Equal Channel Angular Pressing (ECAP) of AA6082: Mechanical Properties, Texture and Microstructural Development. *Transactions of Nonferrous Metals Society of China*, 2016,109, 72-79.
9. Kátia Regina Cardosoa, Marcela Lieblichb, David Morris, Effect of Equal Channel Angular Pressing on Microstructure and Properties of Al–FeAlCr Intermetallic Phase Composites. *Material and Design*, 2014,58, 77-84.
10. Kyung-Tae Parka, Seong-Hyun Myung, Dong Hyuk Shin, Chong Soo Lee.; Size and distribution of particles and voids pre-existing in equal channel angular pressed 5083 Al alloy: their effect on cavitations during low-temperature superplastic deformation. *Materials Science and Engineering*.2004,371, 178–186.
11. Kazeem O. Sanusi, Oluwole D. Makinde, Graeme J. Oliver, Equal channel angular pressing technique for the formation of ultra fine-grained structures. *Transactions of Nonferrous Metals Society of China*. 2012,108, 9-10.
12. Leilei Gao, Xianhua Cheng, Microstructure and mechanical properties of Cu-10%Al-4%Fe alloy processed by equal channel angular extrusion (ECAE). *Material and Design*.2008, 29, 904-908.
13. M. Cheginia, A. Fallahib, M.H. Shaeri, 2015, Effect of Equal Channel Angular Pressing on Wear Behaviour of Al-7075 Alloy. *Procedia Materials Science*,2015, 11, 95 – 100.
14. M.A. Valdes-Tabernero, R. Sancho-Cadenas, I. Sabirov, Effect of SPD processing on mechanical behaviour and dynamic strain aging of an Al-Mg alloy in various deformation modes and wide strain rate range.*Materials Science & Engineering*.2017,696, 348-359.
15. Mohammad Javad Bagheri, Payam Saraian, Investigation on the effect of Equal Channel Angular Pressing process on the pure copper grain size .*Cumhuriyet University Faculty of Science Journal*, 2015,36, 239-247.
16. Muneer Baig, Ehab El-Danaf, Jabair Ali Mohammed, Thermo-mechanical responses of an aluminium alloy processed by Equal Channel Angular Pressing. *Materials and Design*,2014, 57, 510-519.
17. Mohammad Javad Bagheri, Payam Saraian, Investigation on the effect of Equal Channel Angular Pressing process on the pure copper grain size. *Cumhuriyet University Faculty of Science Journal*,2015, 36, 239-247.
18. N. Fakhar, F. Fereshteh-Saniee, R. Mahmudi, Significant improvements in mechanical properties of AA5083 aluminium alloy using dual equal channel lateral extrusion. *Transactions of Nonferrous Metals Society*,2016,26, 3081-3090.
19. N. Fakhar, F. Fereshteh-Saniee, R. Mahmudi, High strain-rate super plasticity of fine and ultrafine-grained AA5083 aluminium alloy at intermediate temperatures. *Materials and Design*,2015,85, 342-348.
20. P. Venkatachalam, S. Ramesh Kumar, B. Ravisankar, Effect of processing routes on microstructure and mechanical properties of 2014 Al alloy processed by equal channel angular pressing, *Transactions of Nonferrous Metals Society of China*,2010,20,1822-1828.
21. Puertas, J.Leon, R. Luri, Design and mechanical property analysis of AA1050 turbine blades manufactured by equal channel angular extrusion and isothermal forging, *Material and Design*,2013,52,774-784.
22. Ruslan Z. Valiev, Terence G. Langdon, Principles of equal channel angular pressing as a processing tool for grain refinement,*Progress in Materials Science*,2006, 51, 881-981.
23. R. Luri, C.J. Luis Perez, D. Salcedo, I. Puertas, Evolution of damage in AA-5083 processed by equal channel angular extrusion using different die geometries,*Journal of Materials Processing Technology*,2011, 211, 48-56.
24. Si-Young Changa, Byong-Du Ahn, Sung-Kil Hong, Shigeharu Kamado,Tensile deformation characteristics of a nano-structured 5083 Al alloy,*Journal of Alloys and Compounds*,2005,386, 197–201.
25. S. Malopheyev, R. Kaibyshev,Strengthening mechanisms in a Zr-modified 5083 alloy deformed to high strains,*Materials Science & Engineering*, 2015,620, 246-252.
26. V.M. Segal, Equal channel angular extrusion: from macromechanics to structure formation.*Materials Science & Engineering*,1999,271, 322-333
27. W. Skrotzki, N. Scheerbaum, C.-G. Oertel, H.-G. Brokmeie, I. Sabirov, Texture formation during ECAP of aluminium alloy AA 5109, *Materials Science Forum*,2006,503, 99-106.
28. T. Camalet, A.Rusinek, R. Bernier, M. Karon, R. Massion, G. Z. Voyiadjis,Effect of Severe Plastic Deformation by 120° ECAP or Shock Impact on 6061 Aluminum Alloy at High Strain Rates,*Journal of Engineering Materials and Technology*,2017,DOI: 10.1115/1.4039690.
29. Xianhua Cheng, Zhenhua Li, Guoquan Xiang, Dry sliding wear behaviour of TiNi alloy processed equal channel angular extrusion, *Material and Design*,2007,28, 2218-2223.
30. Zhang Kai-Feng, Yan Hong-Hua, Deformation behaviour of fine-grained 5083 Al alloy at elevated temperature,*Transactions of Nonferrous Metals Society of China*, 2009,19,307-311.