Consequences of Severe Plastic Deformation on the Mechanical Properties and Microstructure of AA-6061

Sunil Kadiyan[1*], Parveen Kumar[2], Bhuvnesh Kumar[3]

[1]Deenbandhu Chhotu Ram University of Science & Technology
Murthal, Sonipat - 131039 India
[2]Department of Mechanical Engineering
BITS, Sonipat, India
[3]Department of Mechanical Engineering
SRM UNIVERSITY DELHI-NCR
Sonipat, India

*Corresponding Author:sunkadiyan@gmail.com, +91-9728950888

Abstract

Most unique technique for producing ultra-fine grain is severe plastic deformation (SPD). Sample can be deformed multiple times without any change in its original dimensions by using a unique technique i.e. Equal Channel Angular Pressing (ECAP) Technique. In the present work, a die having special features is designed. Sample of Aluminum Alloy 6061 is deformed by using a plunger. The change in the mechanical properties and microstructure of the deformed sample can be observed by using characterization techniques like Vickers hardness and optical microstructure. The deformed sample is found unique in properties as compare to the parent material. The sample may be useful in the field of automobile and defense industry.

Keywords

Severe plastic deformation (SPD), Microstructure, Hardness, Equal channel angular pressing (ECAP), Mechanical Properties

DOI: 10.31838/ecb/2022.11.5.011

1. Introduction

Presently industries required light in weight and high strength materials[1]. Face centered cubic (FCC) materials are light in weight materials[2]. The strength of the FCC alloys are very low. These materials can be deformed and the properties can be improved[3]. The deformation in the material can be of elastic and plastic type. Severe plastic deformation is introduced by P.W. Bridgman in 1930[4]. It is a technique for producing very high strain in the metal[5]. Very high plastic deformation can be produced by bending, forging, wire drawing etc. Many techniques come under severe plastic deformation technique. Some of them are Equal Channel Angular Pressing (ECAP)[6], Tubular Angular Pressing Technique (TCAP)[7], Accumulative Roll Bonding Technique (ARBT)[8], and Constrained Groove pressing Technique (CGPT)[9],High Pressure Torsion (HPT)[10].

Equal Channel Angular Pressing (ECAP) Technique is found best suited[11]. This technique can produce highly deformed material without any change in the shape and size. In other techniques of SPD, the material is deformed but the shape and size changed drastically[12]. So, the application of ECAP deformed material is high as compare to the other techniques[13]. The amount of deformation produce in the sample depends on many parameters in ECAP[14]. The most important process parameters are, number of passes, die channel angle, die back angle and type of routes. Figure 1 represents the ECAP die having dual pins.

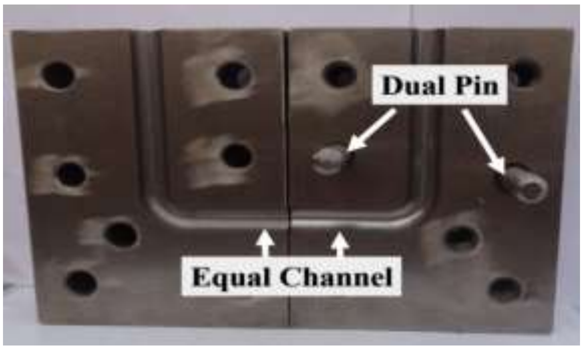

Figure 1 ECAP Die having dual pins

In the present paper, the authors design a modified die having dual pins for better alignment of the die parts. High deformation is produced in the sample by multiple passes through the die. Deformed sample had improved mechanical properties as compare to the parent material. Hardness in the sample increased. ECAP technique is found a unique technique for grain refinement. Microstructure is represented by the optical microscopy.

2. Experimental Procedure

D2 die steel was used for making ECAP die parts. ECAP die having dimensions 110*30*110. The die have die channel angle of 90˚. A plunger is designed with same D2 material. The function of plunger is to apply the pressure over the top of billet. It will insert the billet inside the die cavity. A load of more than 75KN was applied during the process. Aluminum Alloy 6061 was selected for the deformation process. The dimension of AA-6061 billet is taken as 65mm length and 12.7mm diameter. UTM was used for performing the experiments. The ECAP die was clamped with the help of nut and bolts. Three Billets were passes 2, 4 and 6 times. The vital property of AA-6061 is high ductility. Aluminum can be deformed repeatedly inside the die repeatedly. Lubricant was used for reducing the friction between die walls and billet during the deformation process. . After passing the billet through the ECAP die. A sample was taken from the deformed billet. Sample was prepared by using polishing machine. Emory paper of different grades like 400, 800, 1000, 2000, 2500 was used for preparing sample. Velvet cloth and diamond past for used for final cleaning of samples. Keller’s etchant was used for revealing the grains. Figure 2 represents the Experimental setup of ECAP.

Figure 2 Experimental setup of ECAP

3. Results and Discussion

Samples were examined for calculating the hardness and for observing the microstructure of the deformed sample.

3.1 Vickers Hardness

After sample preparation Vickers hardness test was perform on the two different positions of the sample for understanding the homogeneity. Figure 3 represents the Sample with Vickers Hardness testing points. First point of testing Vickers hardness was taken at the corner of sample and other is taken at centre. The Vickers hardness of the sample without deformation was found 80HV. As the second sample is deformed two times the hardness of the sample increased drastically and became 129 HV. The third sample was deformed four times through the die produce hardness value is 135HV and last sample presented the value of hardness is 137HV. It represented that the hardness increased at rapid pace in the beginning, but reduced with further passes. Table 1& Figure 4 represents the relationship between Vickers Hardness and number of passes.

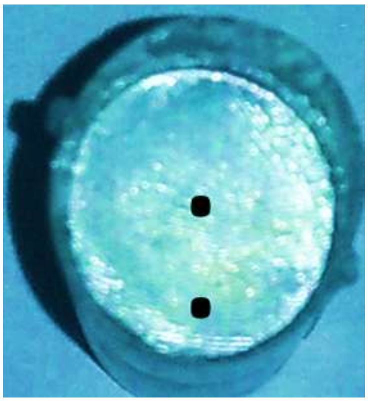

Figure 3 Sample with Vickers Hardness testing points

Table 1 Relationship between Vickers Hardness and number of passes.

S. No.	Number of Passes	Vickers Hardness (Mean) (HV)
1	0	80
2	2	129
3	4	135
4	6	137

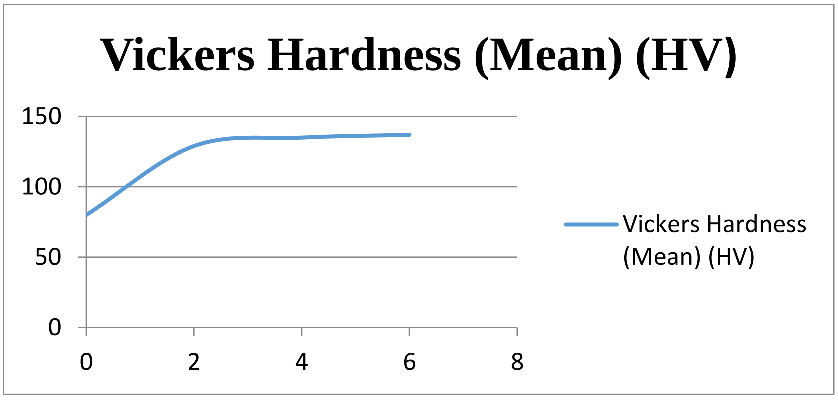

Figure 4 Relationship between Vickers hardness and number of passes.

3.2 Optical Microstructure

Figure 5 (a) represents the optical microstructure of parent material. Most of the grains are having size more than 30µm. The grain size was observed by image J software. Figure 5 (b) represents the grain size after two passes through the ECAP die. The deformation pattern can be easily seen. Grain size reduced up to 15µm. The grains look deformed and elongated in the direction of deformation. The figure 5 (c) represents the sample after four passes. The grains further elongated and the average gain size was found 13µm. There is no specific clusters of grains. The figure 5(d) represents the grain size after six passes through the ECAP die. The grains size reduced up to 8µm.

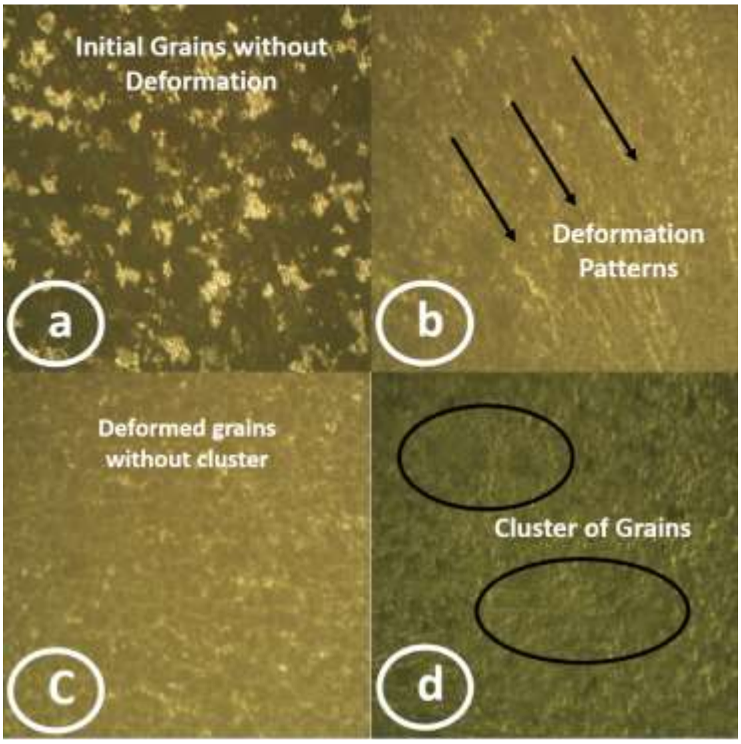

Figure 5 (a) optical microstructure of parent material, (b) optical microstructure after two passes, (c) optical microstructure after four passes, (d) optical microstructure after six passes

4. Conclusion

Present paper represents the properties and microstructure of the deformed and un-deformed sample. The mechanical properties in terms of Vickers Hardness and microstructure in terms of optical microstructure was discussed and presented. The key findings of the characterization were followings.

1. Initially the Vickers Hardness was 80HV of the parent sample which was increased up to 137 HV after passing through ECAP die up to six passes.
2. The grain size of the parent sample was 30μm, which was reduced up to 8μm after six passes at room temperature.
3. As the Vickers Hardness increased the grain size reduced, which justify the Hall Petch Theory.
4. The optical microstructure represents that the cluster of grains formed more closely after six passes.

References

[1] S. Kadiyan and B. S. Dehiya, "Evaluating the influence of various routes on micro-structure and mechanical properties of AA-6063 after equal channel angular pressing," *Mater. Res. Express*, vol. 6, no. 8, p. 0865f9, Jun. 2019, doi: 10.1088/2053-1591/ab2618.

[2] O. Sitdikov, E. Avtokratova, and T. Sakai, "Microstructural and texture changes during equal channel angular pressing of an Al-Mg-Sc alloy," *J. Alloys Compd.*, vol. 648, pp. 195–204, 2015, doi: 10.1016/j.jallcom.2015.06.029.

[3] C. F. Gu and L. S. To, "Effect of strain reversal on texture and grain refinement in route C equal channel angular pressed copper," vol. 65, pp. 167–170, 2011, doi: 10.1016/j.scriptamat.2011.04.009.

[4] S. Kadiyan and B. Dehiya, "Comparison of Enhanced Mechanical Properties and Texture of Pure Aluminium & Its Composite Processed by Powder Metallurgy and Equal Channel Angular Pressing," *Euro. J. Adv. Engg. Tech.*, vol. 5, no. 1, pp. 75–79, 2018.

[5] M. Farshidi and M. Kazeminezhad, "The effects of die geometry in tube channel pressing: Severe plastic deformation," *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.*, vol. 230, no. 1, pp. 263–272, 2016, doi: 10.1177/1464420715569289.

[6] S. Kadiyan and B. S. Dehiya, "Effects of severe plastic deformation by ECAP on the microstructure and mechanical properties of a commercial copper alloy," *Mater. Res. Express*, vol. 6, no. 11, p. 116570, 2019, doi: 10.1088/2053-1591/ab4a44.

[7] M. H. Shaeri, M. Shaeri, M. T. Salehi, S. H. Seyyedein, and F. Djavanroodi, "Microstructure and texture evolution of Al-7075 alloy processed by equal channel angular pressing," *Trans. Nonferrous Met. Soc. China*, vol. 25, no. 5, pp. 1367–1375, 2015, doi: 10.1016/S1003-6326(15)63735-9.

[8] Y. Murata, I. Nakaya, and M. Morinaga, "Assessment of Strain Energy by Measuring Dislocation Density in Copper and Aluminium Prepared by ECAP and ARB," *Mater. Trans.*, vol. 49, no. 1, pp. 20–23, 2008, doi: 10.2320/matertrans.ME200707.

[9] D. H. Shin, J. J. Park, Y. S. Kim, and K. T. Park, "Constrained groove pressing and its application to grain refinement of aluminum," *Mater. Sci. Eng. A*, vol. 328, no. 1, pp. 98–103, 2002, doi: 10.1016/S0921-5093(01)01665-3.

[10] Y. Ito, K. Edalati, and Z. Horita, "High-pressure torsion of aluminum with ultrahigh purity (99.9999%) and occurrence of inverse Hall-Petch relationship," *Mater. Sci. Eng. A*, vol. 679, pp. 428–434, 2017, doi: 10.1016/j.msea.2016.10.066.

[11] S. Kadiyan, "Influence of Equal Channel Angular Pressing Modified Die on the Mechanical Properties & Micro Structure of Copper Alloy," vol. 4, no. 8, pp. 828–832, 2017.

[12] S. Khalilpourazary, M. Zadshakoyan, and S. H. Hoseini, "Fatigue Life Improvement of Copper Processed by Equal Channel Angular Pressing," *Exp. Tech.*, vol. 43, no. 3, pp. 237–244, Jun. 2019, doi: 10.1007/s40799-018-00299-4.

[13] Y. L. Wang, R. Lapovok, J. T. Wang, Y. S. Qi, and Y. Estrin, "Thermal behavior of copper processed by ECAP with and without back pressure," *Mater. Sci. Eng. A*, vol. 628, pp. 21–29, 2015, doi: 10.1016/j.msea.2015.01.021.

[14] G. Zhao, S. Xu, Y. Luan, Y. Guan, N. Lun, and X. Ren, "Grain refinement mechanism analysis and experimental investigation of equal channel angular pressing for producing pure aluminum ultra-fine grained materials," *Mater. Sci. Eng. A*, vol. 437, no. 2, pp. 281–292, 2006, doi: 10.1016/j.msea.2006.07.138.