Ultrafine Grain Structure Development in Aluminium Alloy by Strain Hardening using CCGP

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***DOI**: https://doi.org/10.34293/acsjse.v1i2.11*

Abstract - *Severe Plastic Deformation (SPD) processes are for developing ultrafine grained (UFG) structured materials for different Industrial applications. Cyclic Constrained Groove Pressing (CCGP) is a technique, produce fine grained structures in metallic sheets or plates in mass production. The objective of research work is to investigate the influence of CCGP processing on the super plastic behaviour of an Aluminium alloy. Samples in "ascast" materials processed by CCGP with as cast, 1, 2, 3 and 4 passes. Processed Material study for microhardness and Tensile strength mechanical properties test were done for different test specimens. Grain refinement, microhardness and Tensile strength increased with the number of CCGP passes.*
Keywords: *Groove pressing; SPD; Dislocations; Aluminum alloy; ultrafine grain*

I. INTRODUCTION

There have been great advancements in the development of the high-strength metals and alloys and there is always a need for additional enhancements in the properties of materials. Various industries have a need for structural components that are lighter and stronger, particularly in the automotive industries. One of the methods to enhance the properties of the materials is manufacturing the components with ultrafine Grain. Many methods have been used to synthesize materials with Ultrafine Grain (UFG) sizes (10–1000 nm), including inert gas condensation [1], high-energy ball milling and sliding wear [2], etc. These techniques are attractive for producing powders with grain sizes below 100 nm, but cannot be used to make bulk samples. To consolidate the nanometer-sized powders into bulk materials, high pressure and moderate temperature are usually needed. Grains might grow during consolidation, making the bulk materials partially or completely lose the nano-characteristics [3]. It is usually impossible to completely eliminate porosity, even in materials consolidated under very high pressure and temperature. In addition, nano-powders are highly susceptible to oxidation and absorb large quantities of impurities such as O_2, H_2 and N_2, making it difficult to obtain clean bulk materials. The porosity as well as impurities significantly affects the mechanical properties of the bulk materials, often making them brittle [4]. These problems prevent the researchers from studying the intrinsic properties of bulk nano-materials. As a consequence of these difficulties, much attention has been paid to alternative procedures of introducing ultrafine grains in materials by severe plastic deformation (SPD).

UFG materials refer to a class of materials with grain sizes in the range of 100 to 1000 nm, i.e., <1 μm. These materials have grain sizes larger than nano-materials which have now come to be accepted as those with grain sizes less than 100 nm.Methods to produce UFG materials can be grouped into two categories: Bottom-up approach: Bottom-up approach involves consolidating nano- or ultra-fine grain materials from the atomic scale. Examples of such processes include Inert Gas Condensation (IGC), and Chemical Vapor Deposition (CVD).Top-down approach: Top-down approaches involve the refinement of coarse grains to ultrafine grains by SPD techniques that subject the work-piece to high-accumulated strains [5].

SPD process may be defined as metal forming processes in which a large plastic strain is introduced into a bulk metal in order to create UFG metals. The main importance of a SPD process is to produce high strength and lightweight parts with less cost, minimum time and environment harmony. Since several years, it is known that SPD - the plastic deformation of a metallic material up to highest amounts of plastic strain (up to some thousands percent) at low homologous temperatures (typically below 0.3 times of the melting temperature) leads to a subdivision of the initially coarse-grained microstructure into a hierarchical system of cell blocks and dislocation cells. The grain size of the material decreases with the increase in straining of the material. At the same time, the disorientation difference in crystallographic orientation increases. In order to obtain smallest microstructure sizes plastic strains of more than 600 to 800% are necessary.

Conventional methods such as rolling and forging of material processing do not provide such a high straining of the material without failure. The special feature of all variants of SPD is that the cross section of the material remains constant during or after SPD processing. Thus highest degrees of plastic deformation are possible because one sample can be subjected several times to SPD in order to accumulate the total amount of plastic strain. Even though many different variants are known, only a few of them have industrial potential.SPD processes are typically achieving grain refinement in the metal or alloys through the introduction of large strain. The energy accumulated due to deformation helps in the formation of ultrafine grains in a continuous recrystallization process, rather than a nucleation and growth process that is observed in traditional thermo-mechanical processing operations. Another feature of SPD processes is that the external dimensions of the work piece remain unchanged. This allows for the repeated application of the process to accumulate larger strains[6].Grain refinement by SPD implies the creation of new high angle grain boundaries. This can be achieved by three mechanisms[7,8]: the first is the elongation of initial grains during plastic deformation, causing an increase in high angle boundary area, the second is the creation of high angle boundaries by grain subdivision mechanisms, and finally, an elongated grain can be split up by a localization phenomenon such as a shear band.Among the three of the mechanisms mentioned, second mechanism is the most important one. The grain subdivision starts at low to medium strains when grains break up in cells and cell blocks. With increasing strain, this substructure evolves towards a lamellar structure. During this process, new high angle boundaries are generated, it happens by the simultaneous action of a microstructural and a texture mechanism[9,10]. The former starts at low deformations and consist in the accumulation of dislocations in the cell and cell block boundaries in which the misorientions gradually increase with increasing strain. Some boundaries remain low angle boundaries but a significant fraction evolves into medium-high angle boundaries mostly in the range 15° - 30°. The texture mechanism involves the rotation of different parts of a subdivided grain towards different end orientations. This can generate very high misorientations in the range 20° - 60° [11].

II. EXPERIMENTAL PROCEDURE

In this paper, Aluminium alloy ingots material selected for the investigation. The alloy composition of the material is mentioned in the Table1.

Table 1: Chemical composition of Al 6061 alloy

Contents	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Weight %	0.62	0.23	0.22	0.03	0.84	0.22	0.10	0.10	Balance

Al6061 alloy ingots were pickled in 10% NaOH solution at room temperature for about 10 minutes.Using SiC particulates used for removing moisture contentents.These ingots were cleaned and dried in air. The cleaned and pickled ingots of the alloy, weighing around 700grams were placed in the aluminium crucible for melting. Argon gas was supplied at the rate of 5mm^3/hr continuosly into the melting chamber to aviod any accidents and damages [12].

Figure 1: a) Hydraulic Press and (b) Specimen Sandwich between the Corrugated Die and Flat Die

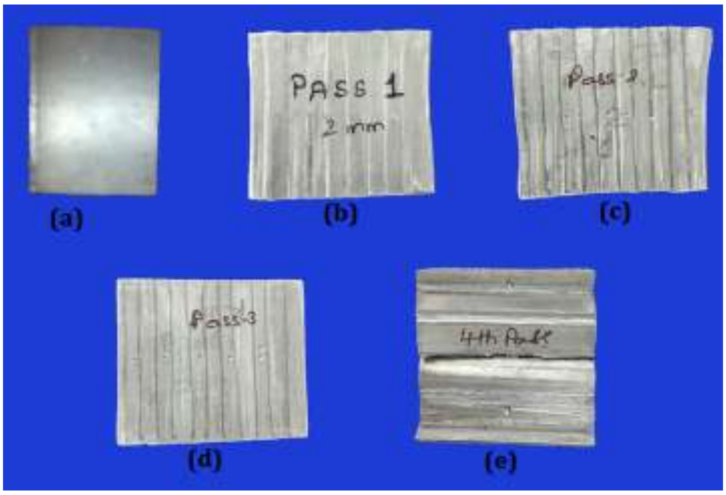

Figure 2: CCGP Specimens (a) As Cast, (b) 1st Passspecimens, (c) 2nd Pass (d) 3rd Pass and (e) 4th Pass Specimens

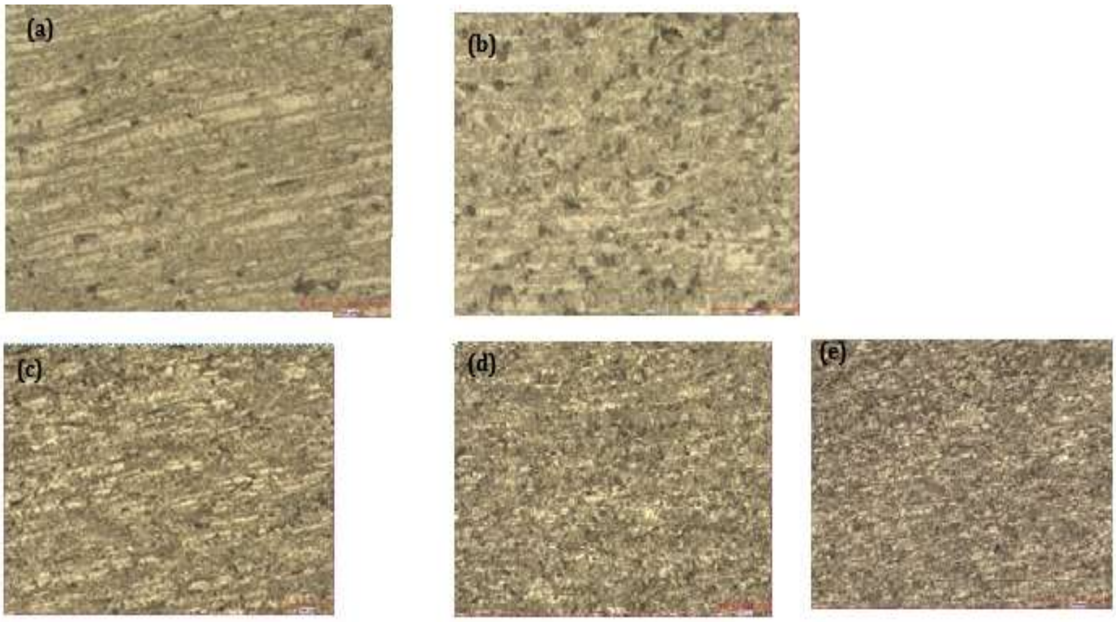

Figure 3: Optical Micrographs of CCGP Specimens (a) As Cast Specimen, (b) After 1st pass, (c) After 2nd Pass (d) After 3rd Pass and (e) After 4th pass

From the castings, the samples were cut to a 50mm x 70mmx 2mm thickness of several specimens [13]. The Al alloy plates specimens were pressed in a corrugated and flat dies, 1 to 4 passes of compression were considered. All the samples were processed at room temperature. Each pass of this process was consists of two stages and the process was carried out using a pairs of corrugated and flat dies. Fig.1 shows the a) Hydraulic Press b) specimen sand witch between the corrugated die and flat die, Fig.2 shows CCGP specimens a) as cast specimen without pressing, b) After 1st pass, c) After 2nd pass, d) After 3rd pass and e) After 4th pass. Fig.3 shows the optical micrographs of CCGP specimens a) as cast specimen without pressing, b) After 1st pass, c) After 2nd pass, d) After 3rd pass and e) After 4thpass[14].

III. RESULT AND DISCUSSION

Micro Hardness

Fig.4 shows the test statics for distribution of microhardness according to number of passes. The initial micro hardness of the zero press specimens has 29HV for 2mm thickness specimen. After one pass gives an increase in micro hardness to an average of 7 to 8HV. It is also observed that after two passes exhibit a further increase in micro hardness, i.e., average of 7HV. After every pass of CCGP, the hardness of the specimen shows increasing trend with an average increase in hardness of 3 to 4HV in all the specimens.

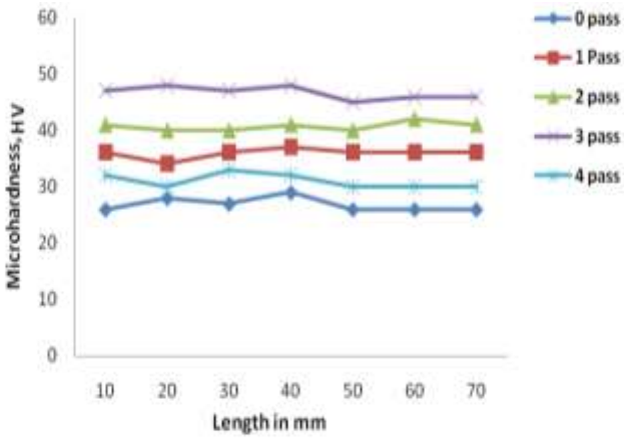

Figure 4: Micro Hardness Distribution According to Number of Passes

From the observations, higher refinement in the grain size leads to an increase in the hardness of the specimens. But the grain refinement is strongly influenced by the increase in strain. From results shows that, increased the No. of passes hardness going to increased. After 4th pass material get fails i.e fall of hardness that material loses it hardness. We can see that as dislocations formed in the coarse grains, the grain size decreased more and more refined grain size giving rise to the better hardness. The grain size is refined, thereby increasing the hardness during corrugation and straightening process.

Tensile Properties

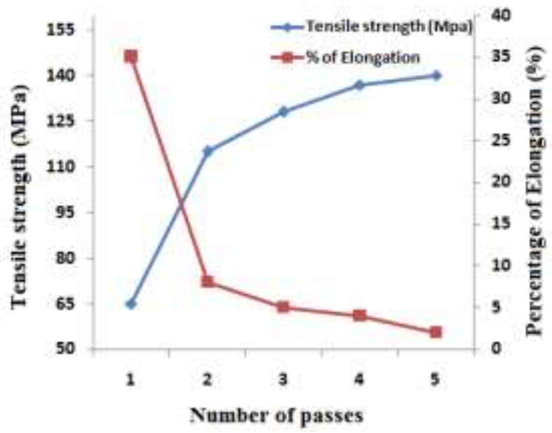

Figure 5: Variation of Tensile Strength and Elongation with Number of CCG Ped Passes

For the samples tested for tensile strength for various test specimens are shown in the graph for different number of passes. Its observed from the test results number of pass increases material properties are increased and percentage of elongation decreases. In this paper for the super plasticity of the material upto 4^{th} passes afterwards it decreases. Fig.5 shows the tensile strength and elongation of CCGPed passes.

IV. CONCLUSION

The effect of severe plastic deformations by Cyclic Constrained Groove Pressing process on the properties of Aluminium alloy at room temperature was studied. In investigation the following conclusions are summarized.

- Aluminium alloy was processed by CCGP from as cast condition with 1 to 4 passes. It was developed procedure to CCGP processing with a corrugated and flat dies.
- The microhardness of the material has been increased with the number of passes from 29HV to 50HV.
- Tensile strength of the specimen has been increased from 60 MPa to 145 MPa.
- It was concluded that the ductility will inevitably be detenorated with increase in density on dislocations of dislocations of grain boundaries, which directs the great enhance

V. REFERENCES

[1] R. Z. Valiev, Y. Estrin, Z. Horita, T. G. Langdon, M. J. Zechetbauer, and Y. T. Zhu, “Producing Bulk Ultrafine-Grained Materials by Severe Plastic Deformation", Journal of Materials, Volume 58, 2006, pp. 33-39.

[2] M. Morehead, and Y. Huang, “Machinability Research and Work piece Microstructure Characterization in Turning of Ultrafine Grained Copper”, American Society of Mechanical Engineers, Manufacturing Engineering Division, Volume 16, 2005, pp. 1167-1176.

[3] R. E. Barber, T. Dudo, P. B. Yasskinand, and K. T. Hartwig, “Processing Yield for ECAE Processing”, ScriptaMaterialia. Volume 51, 2004, pp. 373-377.

[4] Salem, Z. Horita, T. G. Langdon, T. R. McNelley, S. R. Kalidindi, and S. L. Semiati “Strain-Path Effects on the Evolution of Microstructure and Texture during the Severe-Plastic Deformation of Aluminum”, Metallurgical and Materials Transactions A, Volume 37, 2006, pp. 2879-2891.

[5] E. O. Hall, “Yield Point Phenomena in Metals and Alloys”,Proceedings of the Physical Societyof London. Volume 64, 1951, pp. 747-753

[6] N. J. Petch, J. Iron Steel Inst., London, Volume 173, 1953, pp. 25-31

[7] J. S. Hayes, R. Keyte, and P. B. Prangnell, “Effect of Grain Size on the Behavior of a Submicron Grained Al-3-wt% Mg Alloy Produced by Severe Deformation”, Materials Science and Technology, Volume 16, 2000, pp. 1259-1263.

[8] P. L. Sun, P. W. Kao, and C. P. Chang, “Characteristics of Submicron Grained Structure Formed in Aluminum by Equal Channel Angular Extrusion”, Materials Science and Engineering A, Volume 283, 2000, pp. 82-85.

[9] P. Apps, and P. B. Prangnell, "Grain Refinement Mechanisms Operating during Severe Plastic Deformation of Aluminium Alloys Containing Second Phase Particles", Ultrafine Grained Materials-III, TMS, Warrendale, Pennsylvania, 2004, pp. 131-136.

[10] N. A. Akhmadeev, N. P. Kobelev, R. R. Mulyukov, Y. M. Soifer, and R. Z. Valiev, "The Effect of Heat Treatment on the Elastic and Dissipative Properties of Copper with the Submicro Crystalline Structure", Acta Meteralia, 1993, Volume 41, pp.1041-1046.

[11] Z. Horita, T. Fujinami, M. Nemoto and T. G. Langdon, "Equal Channel Angular Pressing of Commercial Aluminum Alloys: Grain Refinement, Thermal Stability and Tensile Properties", Metallurgical and Materials Transactions A, Volume 31, 2000, pp. 691-701.

[12] S. Lee, P. B. Berbon, Z. Horita, T. Fujinami, M. Nemoto, N. K. Tsenev, R. Z. Valiev and T. G. Langdon, "Developing Super plastic Properties in an Aluminum Alloy through Severe Plastic Deformation", Materials Science and Engineering A, Volume 272, 1999, pp. 63-72.

[13] P. DeLo and S. L. Semiatin, "Hot Working of Ti-6Al-4V via Equal Channel Angular Extrusion", Metallurgical and Materials Transactions A, Volume 30, 1999, pp. 2473-2481.

[14] Z. Horita, T. Fujinami, and T. G. Langdon, "The Potential for Scaling ECAP: Effect of Sample Size on Grain Refinement and Mechanical Properties", Materials Science and Engineering A, Volume 318, 2001, pp. 34-41.