Nanostructure and Mechanical Properties of Severe Plastic Deformed Al 6061 Alloy Processed by Constrained Groove Pressing

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Abstract - It is required to increase the life of any component, this can be achieved by using material having high strength or by increasing the strength of the material which are in use. Increasing the strength can be achieved by many processes and one of them is Severe Plastic Deformation (SPD) process. SPD is carried in many methods one of them is Constrained Groove Press (CGP). In the present investigation Al 6061 has been chosen to carry out tensile, hardness and micro structural tests of CGP process. Al 6061 plates of varied thickness of 3, 4 and 5 mm has been selected and subjecting them to 1, 3 and 5 number of passes. CGP on the specimen, changes the coarse grains into fine grain and it has been observed that the reduction is about 70%, hardness of the Al6061 increased by about 24% and tensile strength increased by about 40%.

Key words: CGP, Grain size, Nanostructure, Mechanical properties, Sever plastic deformation

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1 INTRODUCTION

The Aluminium alloys are low weight and high performance materials that have potential to replace high density materials such as steel in many advanced applications. The properties like mechanical, physical, chemical and other properties are mainly depend on the size of particles. As the particle size decreases, its properties increases, hence nanocrystaline materials exhibit superior properties in comparison with conventional coarse-grained polycrystalline materials [1]. The course grain materials have grain sizes in the range of 10-300 μm where as nanograin in the range of 1 to 10 μm. Severe Plastic Deformation (SPD) is a technique to produce Ultrafine Grain (UFG) materials which has attracted significant interest over the years [2]. Equal Channel Angular Pressing (ECAP) [3], Accumulative Roll Bonding (ARB) and Constrained Groove Pressing (CGP) are the most important SPD techniques [3, 4].

SPD processes, typically achieve grain refinement in the metal through the introduction of large strain. The accumulated energy of deformation aids in the formation of ultrafine grains in a continuous recrystallization process [5, 6], rather than a nucleation and growth process that is observed in traditional thermo mechanical processing. Another feature of SPD processes is that the external dimensions of the work piece remain unchanged, hence the SPD process can be performed many times to accumulate larger strains [7, 8]. Nanostructure obtained by SPD increases tensile strength in the order of 25 to 100% over conventional methods. Fatigue strength also increases as the grain size decreases [9, 10].

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Many of the Engineering applications such as aircraft structures, automobile structures and commercial applications such as medical implants, sports equipments use plate structures The improved mechanical properties of these materials may widen the application in various fields. It is clear that SPD technique is the most effective process for enhancing the properties of the metals [11-12]. But, most of the techniques developed were confined to billet shaped specimens and not much amount work was focused on the plate materials. The present work was focused on the effect of repetitive corrugation and straightening process using Constrained Groove Pressing (CGP) on microstructure and Mechanical properties of Aluminium alloy.

2. EXPERIMENTAL DETAILS

In the present investigation, in order to achieve the CGP on Al alloy test specimen, corrugated and flat dies are used. These dies are designed using analytical method on the basis of loading parameters and test specimen specifications. CATIA V5 tool was used for modeling of the dies according to design specifications and fabricated using shaping and milling machines. The key components of the dies are one pair of corrugated die, one pair of flat die, one pair of backup plates to absorb excess loads, eight allen screws and one pair of bevel pins for proper alignment. Final assembly was made by combining male and female dies along with the backup plates shown in the Fig. 1 (a) and Fig. 1 (b) shows the tilted view of the final assembly of corrugated dies and backup plates. Technical specifications of the corrugated die has the cross sectional area of 250 × 250 mm², Radius of the corrugated grooves is 20 mm, depth of the groove is 5 mm and the cross sectional area of flat die is 250 × 250 mm². The die material used is mild steel having overall tolerance of the geometry of ±1 mm. The material to be forged is aluminium having maximum yield strength 145 MPa, the area of the test specimens is to be forged is 20 × 100 mm² of various thicknesses of 3, 4 and 5 mm. The components of the dies are designed on the basis of loading conditions and test specimen specifications.. The pressing was performed in a Universal Testing Machine at pressing

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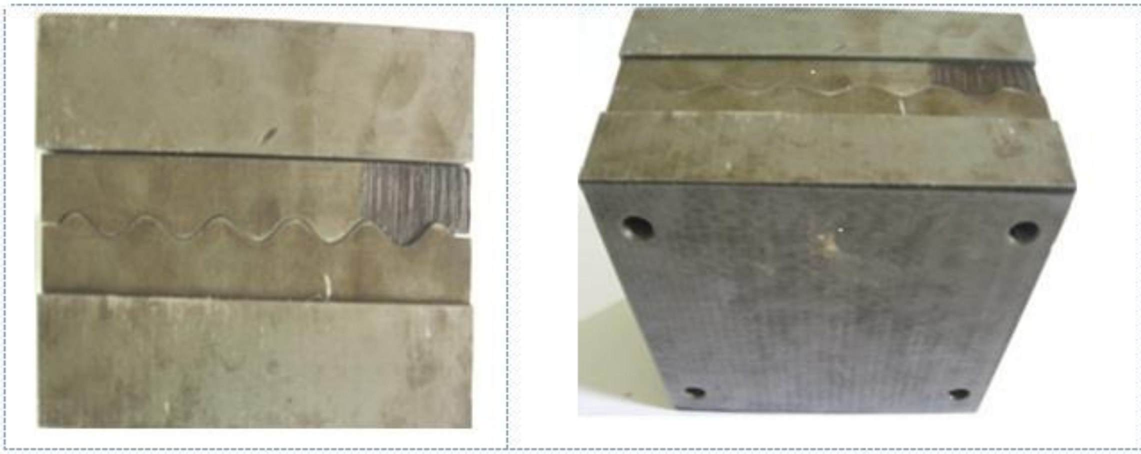
speeds of 1.5 mm/min.

0.15mm/s.



a) b)

Fig. 1 a) Assembly of male and female dies along with the backup plates and

b) Tilted view of the assembly of corrugated dies with backup plates.

According to the principle of CGP, plate material was subjected to repetitive shear deformation under plane strain conditions by pressing the sheet alternately between asymmetric grooved dies and flat dies. The operation consists of four steps of pressing in which two corrugation and two straightening process termed as one pass. When the Aluminum sheet is subjected to one complete pass, large amount of strain has been induced in the plate. The test specimens were prepared from the Constrained Groove Pressed plates as per ASTM standards for conducting microstructure, micro hardness and tensile tests. In the present study, material selected for the investigation is Al 6061 plates of various thicknesses mentioned. The chemical composition of the above material is mentioned in the Table 1.1.

accordance with ASTM-E112 standards using optical microscope on the specimens. The test specimens of Al alloy are of the size of 5 mm × 5 mm, were cut and the surface preparation are carried out by polishing the specimens made using the plates which
are not subjected to SPD and the specimens made using the plates which are subjected to SPD. Grain size was found by the magnification of 500X. The Vickers hardness (HV) of the test specimens were determined using Micromet-5101 device, with a load of 200 g and loading period of 20 seconds. The measurements of the hardness were carried out as per ASTM-E92 standards on all the specimens in three different locations on the specimen and average value of the reading was considered as final hardness value. Tests were conducted. Tensile test are conducted as per ASTM E8M standard on the specimen with

Table 1.1: 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

The samples were cut to a width of 20 mm and length of 100 mm, from 3, 4 and 5 mm thick plates. The Al alloy plates with above dimensions were pressed in a corrugated and flat dies and samples were prepared. The prepared samples were subjected to one, three, and five passes. At the first stage, the flat plate was corrugated using corrugated dies and then flattened die flattens the corrugated specimens. Two corrugations and two flattening process on the specimen are considered as one pass. The effective strain in the deformed region corresponding to one pass is 1.16 throughout the sample. By repeating the corrugation and straightening, a large amount of plastic strain can be accumulated in the work piece. Total strain of 3.48 and 5.80 was achieved at the end of three and five passes respectively. All the passes were carried out using Universal Testing Machine. the gauge length of 40 mm width 5 mm specimens machined from the bulk CGP Al 6061 structure were tested in Universal testing machine and at a displacement rate

3. Result and Discussion

3.1 Microstructure

Grain boundaries of specimen made using the plates which are not subjected to SPD for 3, 4 and 5 mm thickness respectively have the average grain size of 10μm for 3 and 4 mm thickness specimens respectively and 9.4μm for 5 mm thickness specimen. One pass of SPD aluminum alloy specimen resulted in the formation of non-uniform subgrain .The pres
ence of subgrains and dislocation cells substructure is evidence that the aluminum alloy in this region has undergone quite a large amount of plastic deformation. Total grain refinement of 20-30% was achieved in specimens after first pass and the refined grain size is from 8μm to 6.4μm has been achieved in the specimens for all the three different thickness plate.

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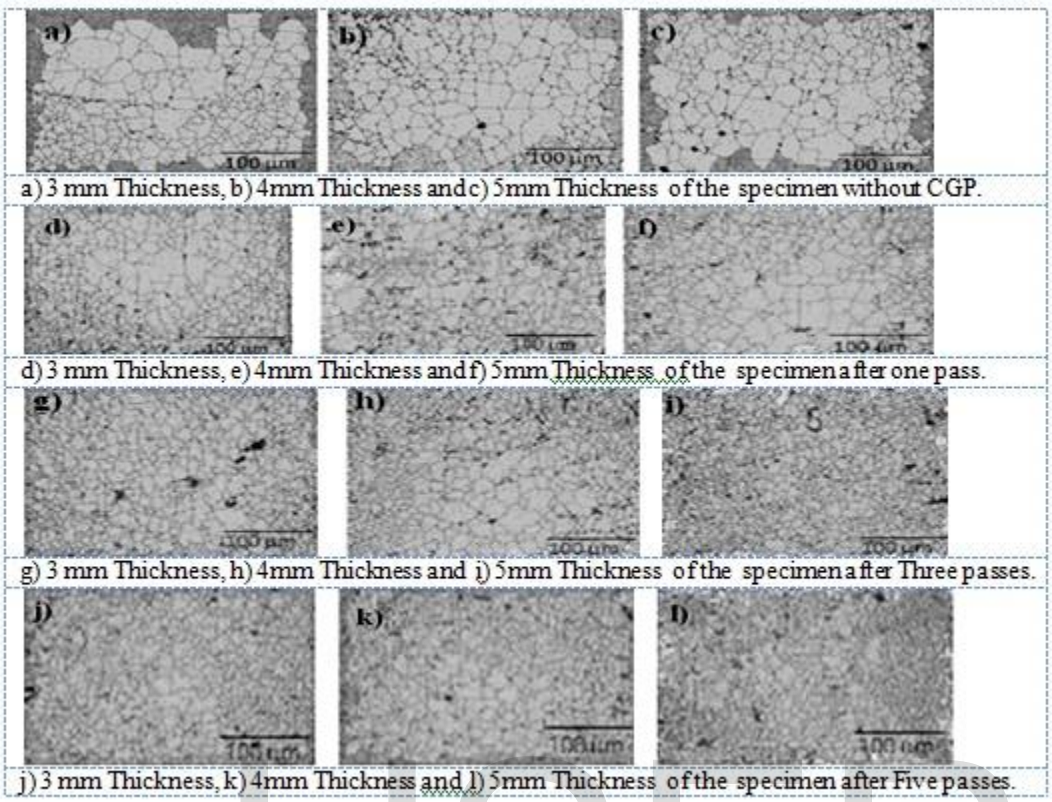

a) 3 mm Thickness, b) 4mm Thickness and c) 5mm Thickness of the specimen without CGP.

d) 3 mm Thickness, e) 4mm Thickness and f) 5mm Thickness of the specimen after one pass.

g) 3 mm Thickness, h) 4mm Thickness and i) 5mm Thickness of the specimen after Three passes.

j) 3 mm Thickness, k) 4mm Thickness and l) 5mm Thickness of the specimen after Five passes.

Fig.2: Optical micrographs of specimen grain structure without subjected to CGP and with one pass, Three passes and Five passes, for 3 mm, 4mm and 5mm Thickness specimens.

After third pass, the microstructure result is presented in the micrographs shows in Fig.2 more finely subgrain structures having grain size 6.4μm to 5μm, where former inhomogeneous grains are fragmented to smaller and more equiaxed subgrains. After the fifth pass, the micrograph shows finer grain size of 4.6μm to 3.1μm where previous subgrains are still smaller and more equiaxed subgrains. After each pass of corrugation and straightening, a high density of dislocations in the grains is achieved. The obtained grain boundaries are wavy and hill defined. The dislocation density decreases with increasing number of passes and the high angle grain boundaries are generated after five passes. The grain size after 1, 3, and 5 passes are measured and plotted in Fig.3.

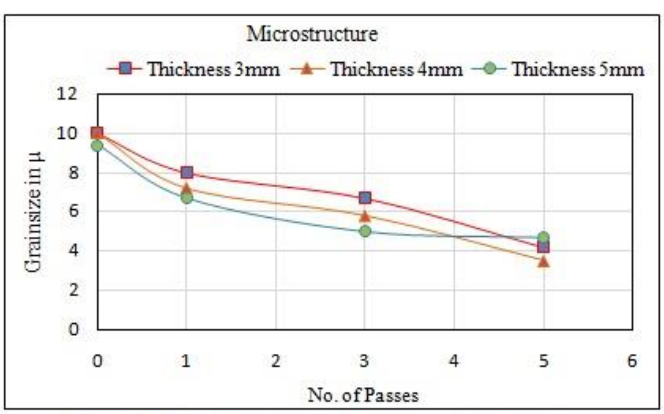

Fig. 3: Grain refinement according to number of passes.

3.2 Microhardnes after CGP

The initial hardness of the undeformed specimens of the Al 6061 alloy has 43.11 HV, 42.45 HV, and 41.16 HV for 3, 4 and 5 mm thickness specimen. The formation of substructure after one pass led to an increase in micro hardness to an average of 2 HV in all the three different thickness. Further the increase in hardness is about 24% after 5 passes. Fig. 4 shows the variation of microhardness with respect to the number of passes. After every pass of CGP, the hardness of the specimen shows increasing trend with an average increase in hardness of 1 to 2 HV in all the specimens.

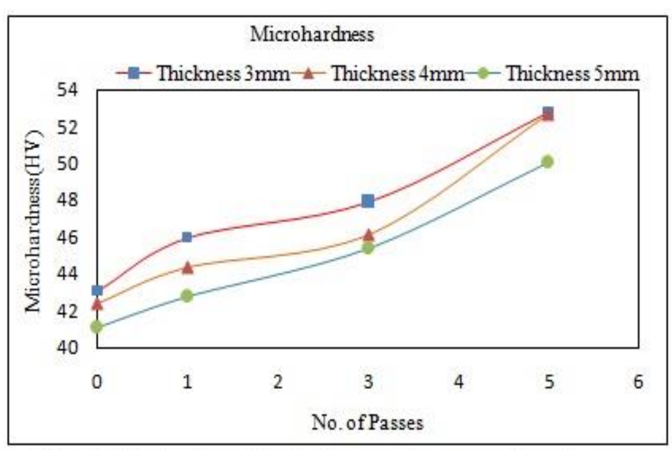

Fig. 4: Microhardness distribution according to number of passes.

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As per Hall-Petch equation the strength of any materials is inversely proportional to grain size, the same tendency has been observed in micro hardness of the specimens tested.

3.3 Tensile strength

The initial tensile strength of the undeformed specimens of the Al 6061 alloy is about for 3, 4 and 5 mm thickness specimen is about 90 MPa. After every pass of CGP, the tensile strength of the specimen shows increasing trend. Overall increase in tensile strength observed is about 21%, 35% and 15% for 3, 4 and 5 mm thickness specimen, for specimens after five passes. Fig. 5 shows the variation of tensile strength values after each pass of the specimens.

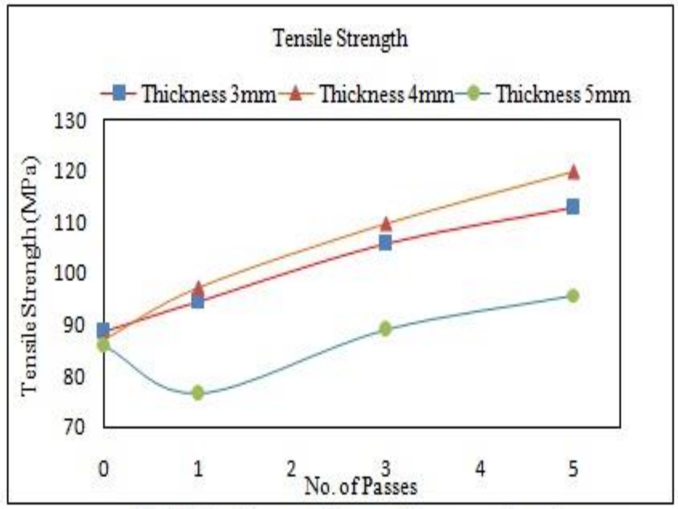

Fig. 5: Tensile strength according to number of passes.

4. Conclusions

- As the number of passes increased the grain size reduces which can be observed from the Optical Microstructure. This is because of recrystallization occurred in the material due to CGP.
- The result shows that the micro hardness and tensile strength increased, the increase in the mentioned properties may due to decrease in grain size of the specimen subjected to CGP and which is in concurrence with Hall – Petch equation.

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