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Research Article
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Mechanical Behaviour of Pure Aluminum Processed by Constrained Groove Pressing

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Abstract

Severe Plastic Deformation (SPD) process is capable of developing the submicron grain structures in metallic alloys and to improve the Mechanical properties. Constrained groove pressing is a processing method in which a metal is subjected to an intense plastic deformation through repeated dominant shearing and pressing (flatting) of plate. This method comprises bending of straight billet with corrugated tools and the restoring the straight shape of the slab with flat tools. The repetition of the process is required to obtain a large strain and desired structural changes. The Constrained Groove Pressing (CGP) processes are widely used in industries to compensate the high strength metal plates components used in automobiles. In the present work an attempt has been made to study the influence of CGP parameters like strain rate and number of passes to predict the degree of importance on grain size, micro hardness and tensile strength of CGP specimens. The results indicated that the number of passes has a major influence on the fine-grain refinement followed by strain rate.

Keywords: Aluminum; CGP; Sever plastic deformation; Grain refinement; Microstructure; Mechanical properties

Introduction

In recent years, the fabrication of bulk materials with ultra fine grain sized materials processed by SPD methods. Different techniques have been used to introduce large plastic strains in to bulk metals such as Equal Channel Angular Pressing (ECAP) [1-3], Accumulative Roll Bonding (ARB) [4-7], Repetitive Corrugation and Straitening (RCS) [8,9], Constrained Groove Pressing (CGP) [5] and Constrained Groove Rolling (CGR) [10]. Constrained groove pressing is a processing method in which a metal is subjected to an intense plastic deformation through repeated dominant shearing and pressing (flatting) of plate. This method comprises bending of straight billet with corrugated tools and the restoring the straight shape of the slab with flat tools. The repetition of the process is required to obtain a large strain and desired structural changes.

Unlike the widely used ECAP process for structure refinement, the CGP process has the advantage that severe plastic deformation can be applied to metals in plate form. CGP is the practical process to impose nearly uniform strain to specimen by asymmetrical grooved and flat dies. The schematic diagram of corrugated die and flattening die are presented in Figure 1a and 1b. At first stage, the flat Aluminum sheet (Figure 1c) became corrugated (Figure 1d) by corrugated die and then the flattening die flattened the corrugated plate (Figure 1e). It is worth to note in this stage, the plate was consisted of two sections with 0 and 1.16 strains, in order to homogenize the magnitude of strain the plate was rotated for 180^0 around it normal axis and then the above stages were repeated (Figure 1f and 1g). Therefore at the end of fourth stage, the plate has a uniform strain magnitude of 1.16.

In this present study morphological and mechanical behavior were predicted through statistical analysis of measured grain size, micro hardness and tensile strength at different conditions to find the effect of strain rate and number of passes influence on the fine grain refinement.

Experimental Procedures

In present study pure aluminum commercial plates with dimensions of 80mm × 50mm × 5mm were pressed up to five passes. Material selected for the investigation is an extruded commercial pure Al. The chemical composition of the test material is mentioned in the Table 1.

In order to achieve the CGP on Al test specimen corrugated and flat dies are used in the present research work. Theses dies are designed

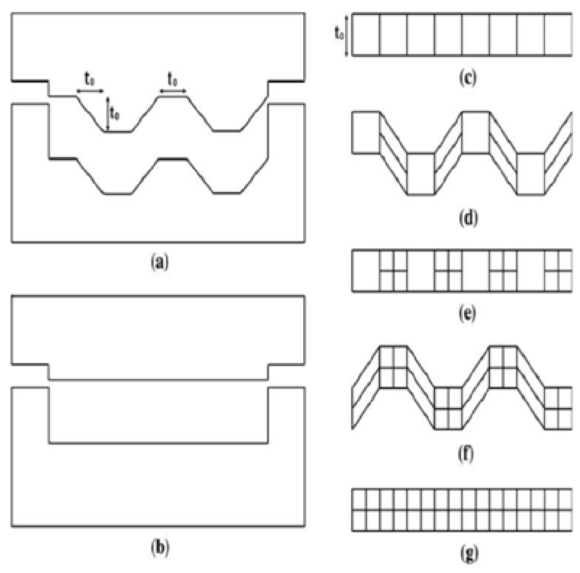

Figure 1: Schematic illustration of sequences of CGP technique.

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Contents	Al	Cu	Mg	Si	Fe	Mn	Ni	Pb	Sa	Ti	Zn
Percent	98.5	0.01	0	0.47	0.86	0.05	0.1	0.02	0.01	0.03	0.01

Table 1: Chemical composition of commercial Al plates.

using analytical method on the basis of loading parameters and test specimen specifications. Material to be forged is aluminum having maximum yield strength 145 MPa, thickness of the test specimens to be forged are 5mm, cross sectional area of the test specimens to be forged is 80mm × 50mm × 5mm, die material to be used is mild steel, overall tolerance of the geometry is ± 1mm. The components of the dies are designed on the basis of loading conditions and test specimen specifications. The key components of the dies are one pair of corrugated die, one pair of flat die, one pair of side plates to absorb excess loads, eight allen screws and one pair of bevel pins for proper alignment. Final assembly is made by combining male and female dies along with the side plates. The pressing is performed in a 250T oil hydraulic press at pressing speeds of 1 mm/min, 1.5 mm/min and 2 mm/min. In CGP process, plate material is subjected to repetitive shear deformation under plane strain conditions by pressing the sheet alternately between asymmetric grooved dies and flat dies. The sheets are subjected to total number of five passes of CGP and further processing could not be continued beyond due to cracking of plate. Specimens were prepared for microstructure, hardness and tensile specimen.

Polishing of the test specimens were conducted with different grade silicon carbide papers using automatic polishing machine on one side of the mounted Al specimens. The polishing procedure starts from polishing paper grade of 80, 100, 200, 400, 600, 800 and 1000 to get fine surface finish. To obtain mirror finish on the polished surface diamond paste having grade 0-0.5 and 2 were used. The Keller's reagent was used as the etchant and the chemical composition is 2ml Hydrofluoric acid (HF), 3ml Hydrochloric acid (HCl) and 5ml Nitric acid (HNO_3). After surface preparation, microstructure analysis was carried out on all the specimens using optical microscope. 500X magnification used for the analysis and the grain size was calculated in accordance with ASTM-E112. The Vickers Hardness (HV) of the test specimens were calculated using Micromet-5101 device, with a load of 200g and loading period of 20 seconds. Tensile tests were performed at room temperature with Universal testing machine at cross head speed of 0.5 mm/min. The size of gauge part of the tensile specimen was 5 mm width and 40 mm length. The tensile test specimens were prepared as per dimensions using milling machine.The details of experimental work as shown in Figure 2a flat dies with side plates, Figure 2b grooved dies. Figure 2c grooved alignment with flat specimen, Figure 2d flat dies alignment with corrugated specimen and Figure 2e. Deformed plate shape after the pressing and straitening.

Result and Discussion

Microstructure

Figure 3a show grain boundaries of as cast specimen (without SPD pressing) for 5 mm thickness. The average grain size for 5 mm thickness specimen has 9.4µm. After one pass of corrugation and straightening of SPD aluminum resulted in the formation of non-uniform and sub grain vary substantially. The presence of sub grains and dislocation cells substructure is evidence that the aluminum in this region has undergone large amount of plastic deformation. The detailed observation over large areas of structure suggests that dislocation behavior relating to the low angle sub grain boundaries formation were effective previously in time of first pass. The development of a deformed substructure developed after first pass is illustrated in Figure 3b. Total grain refinement of 20-30% was achieved in aluminum specimens after one pass and the refined grain size of 6.4µm to 8µm was developed in different strain rate.

The microstructure resulted from third pass is presented in Figure 3c. The micrographs shows more finer sub grain structures having grain size 6.7µm to 5µm, where homogeneous grains are fragmented to smaller and more equiaxed sub grains. The fragmentation of grains after each pass of the process leads to the formation of refined grain

Figure 2a: Flat dies with side plates.

Figure 2b: Grooved dies.

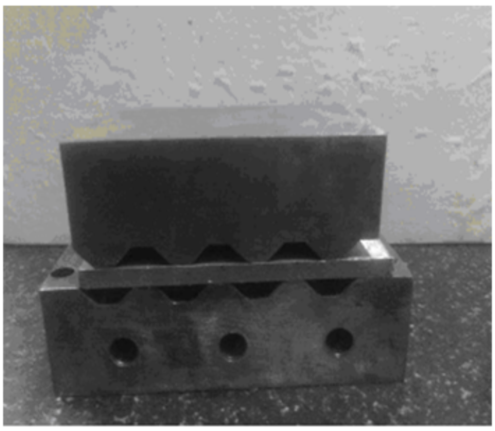

Figure 2c: Grooved die alignment with Flat specimen.

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Figure 2d: Flat dies alignment with corrugated specimen.

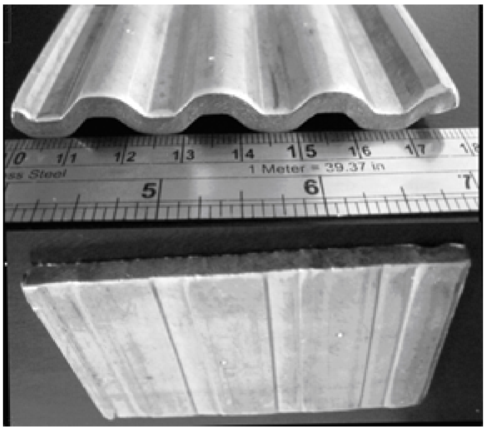

Figure 2e: Deformed plate shape after the pressing and straitening.

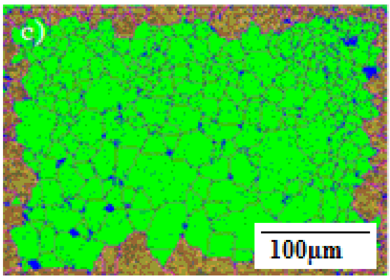

Figure 3a: Optical micrographs of as extruded specimen grain structure of 5mm thickness.

structures, which are severely banded due to the dominant shear stress, such deformed structure the formation of new equiaxed polygonized grains are deposited along the sub grains was observed.

The dislocation structure recovery and formation of polygonized grains was observed as local process and is attributed to deformation of heterogeneity distribution across the plate. The microstructure resulted from five pass is presented in Figure 3d. The micrographs shows more finer subgrain structures having grain size of 3.1 µm to 4.7 µm, where homogeneous grains are fragmented to smaller and more equiaxed subgrains.

In first pass of 1 mm/min strain rate, an average of 20% of grain refinement was achieved in 5mm thickness specimen. But in case of strain rate 1.5 mm/min and 2 mm/min, the grain size refinement was varied from 20% to 28%. In third pass of 1 mm/min strain rate, an average grain size refinement of 0.8 µm to 1.3 µm was achieved (8%-13%). In case of 1.5 mm/min, in third pass shows decrease in the grain refinement is 0.5 µm to 1.1 µm which is (5-11%). 2 mm/min strain rate pressing also shows a decrease in grain refinement is 0.8 µm to 1.2 µm (8-12%). The overall decrease in grain size after third pass is 36-44% compared to the initial test specimens. After five pass of corrugation and straightening, a total of 58% to 69% was achieved in all the three different strain rates. Figure 3e shows the grain size distribution according to the strain rate of pressing.

In 1 mm/min and 1.5 mm/min strain rates, there is an average of 1.9 µm (19%) and 2.5 µm (25%) refinement in grain size was achieved after each pass, where as in 2 mm/min strain rate, 1.2 µm (12%) was achieved. This causes the grain size points of 1 mm/min and 1.5 mm/min strain rate are after each passes were clearly separate from each other, but in 2 mm/min min strain rate they are nearly grouped towards one point. The formation of new deformation induced high angle grain boundaries by grain subdivisions at lower strain rates is because, it is energetically easier for a grain to deform if it splits into deformation bands (or cell blocks) that deform on fewer than the slip system required for constrained deformation.

Micro-Hardness after CGP

The initial hardness of the un-deformed specimens has 41.16 HV for 5 mm thickness specimen. The formation of substructure after one

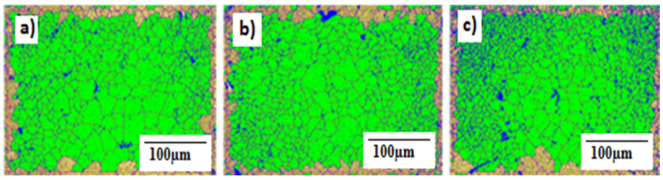

Figure 3b: Optical micrographs of grain structure 5mm thickness plate after one pass a) 1mm/min b) 1.5mm/min & c) 2mm/min.

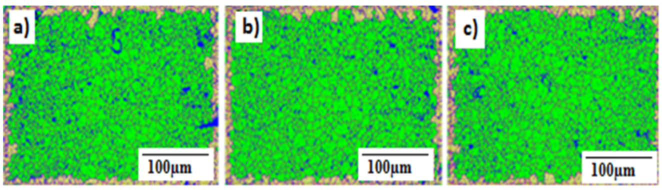

Figure 3c: Optical micrographs of grain structure 5mm thickness plate after Third pass a) 1mm/min b) 1.5mm/min & c) 2mm/min.

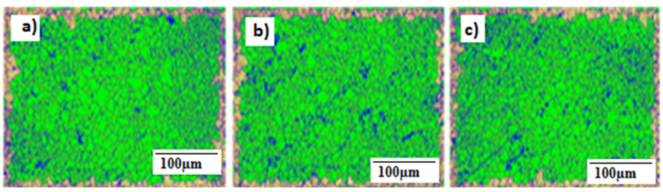

Figure 3d: Optical micrographs of grain structure 5mm thickness plate after Fifth pass a) 1mm/min b) 1.5mm/min & c) 2mm/min.

pass led to an increase in hardness to an average of 2 HV in all the three different strain rates. After every passes of CGP, the hardness of the specimen shows increasing trend with an average increase in hardness of 1-2 HV in all the specimens. The hardness was raised however due to dislocations formed in the grains, an important effect which could also affect the final hardness. Through the Hall-Petch equation [1,2] we can see that the grain size decreased more and more giving rise to the better hardness. The grain size would continue to be refined, thereby increasing the hardness during corrugation and straightening process. Figure 3f shows the hardness distribution according to strain rate of pressing.

As discussed earlier, higher refinement in the grain size will leads to the increase in the hardness of the specimens. But the grain refinement

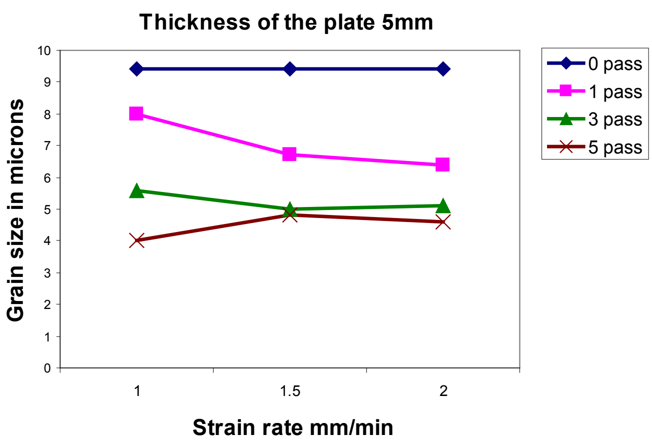

Figure 3e: Grain refinement according to strain rate at different number of passes.

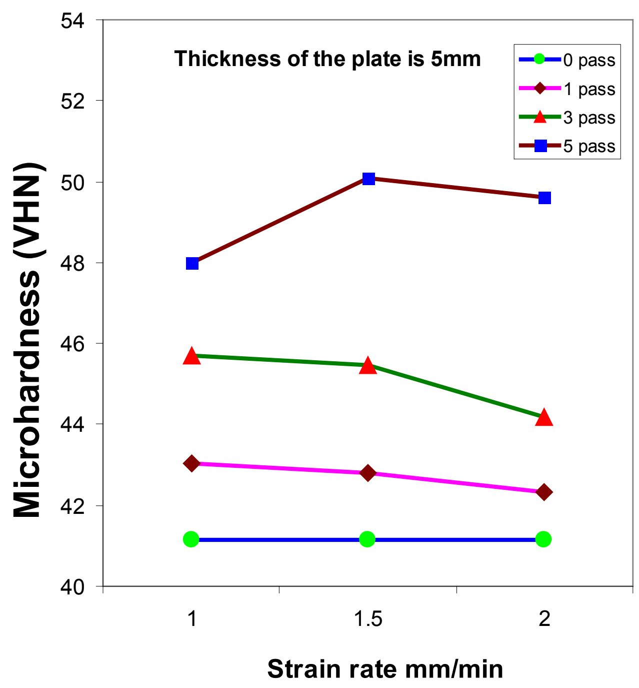

Figure 3f: Micro-Hardness according to strain rate at different number of passes.

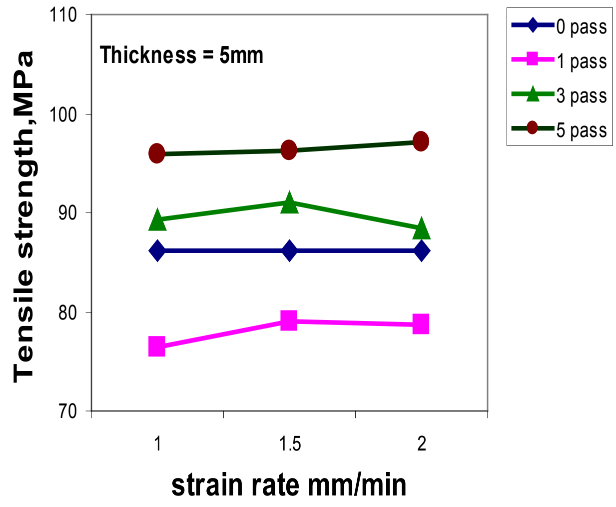

Figure 3g: Tensile Strength according to strain rate at different number of passes.

strongly influenced by the increase in strain. The above results shows, there is approximately equal amount of increase in hardness values of the specimens pressed using 1, 1.5 and 2 mm/min strain rates.

Tensile strength

Figure 3g shows the tensile strength distribution according to the different strain rates. The tensile strength showed no significant changes with strain rate. It shows the strain hardening of 5mm thickness plate. Even increase in strain rate not much change in the tensile strength for different passes.

Conclusion

Severe plastic deformation on by groove pressing of commercial purity Al at different pressing parameters like number of pass and speed of ram (strain rate). From the Experiments it is clear that the parameter number of passes has a highest amount of contribution on response values i.e., grain size convert from coarser to finer increase the ductility of the material in terms of tensile strength. Strain rate has the second highest contribution on the response values. For 5mm thick Al plate compressed by 1.5 mm/min strain rate up to 5 passes gives the lowest grain size of 3.5µm with hardness 50.13 Hv and tensile strength 97.01 N/mm^2. The groove pressing technique under both the condition has ability to produce ultrafine grained microstructure in aluminum.

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