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# Influence of Pressing Factors on The Mechanical Properties of Al6061 Alloy During Cross-Route Severe Plastic Deformation Technique

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**Abstract:** Over the last decade, research work in the area of severe plastic deformations (SPD) has grown extensively to wide verity of materials like Al, Cu, Mg and Ti alloys. In this present work, an attempt has been made to study the influence of pressing parameters like strain rate, number of passes, and plate thickness to produce grain refinement in al6061 alloys through cross route and evaluating the mechanical properties up to three passes. One pass of this process includes eight stages (four corrugations and four flattening) and involves 90° cross-rotation between each two stages. Experiments were based on the Taguchi method was an effective tool to predict the degree of importance of the pressing parameters on mechanical properties of CCGP specimens. The results indicated that the number of passes has a major influence on the mechanical properties, followed by Al plate thickness and strain rate. The values of micro hardness exhibits significant increase up to 30% and ultimate tensile strength increase about 35%.

**Keywords:** *CCGP, Plastic Deformation, Al6061, Mechanical properties, Taguchi method*

## I. INTRODUCTION

Structural changes in materials subjected to SPD and their effect on properties have been investigated for more than two decades. In the last ten years, our knowledge of the governing phenomena has been largely extended. However, the SPD-processed metals have ultra-fine grained structures that cannot be obtained through conventional thermo-mechanical processes. As a result, the SPD metals exhibit unique and excellent properties such as high strength, compared with the conventional materials having a coarse grain size of over several tens of micrometers [1]. Since SPD was demonstrated as an effective approach to produce UFG metals, extensive research has been carried out to develop SPD techniques and to establish processing parameters and routes for fabricating UFG metals and alloys with enhanced properties. ECAP and ARB are the SPD techniques [2,3] that were first used to produce nanostructures metals and alloys possessing sub micrometer or even nano-sized grains. There were many researches were carried out to trim down the drawbacks of the earlier ECAP and ARB processes by changing routes and die angles. Theses ECAP and ARB techniques directs the evolution of other SPD technique like HPT. This nonstop work on researching SPD techniques has a recent development of a number of other SPD processes like HPT, TW, MDF and RCS [4, 5]. Over the past decade, new methods such as constrained groove pressing (CGP) [6] and constrained groove rolling (CGR) [7, 8] have been investigated. These two new methods have been capable of producing plate-shaped ultrafine-grained materials. CGP as a severe plastic deformation was initially proposed by Shin et al. [6]. Based on the principle of CGP, a material is subjected to repetitive shear deformation under plastic strain deformation conditions by utilizing asymmetrically grooved dies and flat dies through alternate pressing [9,10]. Present scenario, SPD techniques are emerging from the domain of laboratory-scale research into commercial production of various ultra-fine-grained materials. It is only the matter of time to unearth new and superior SPD technique [10, 11]. In the present study, an interesting route of CGP process named constrained groove pressing-cross route (CGP-CR) is suggested. Each pass of CGP-CR [12] process included eight stages (four corrugating and four straightening) and hence imparted a strain of € = 2.32 into the sheets. Dies and processed sheets have a square cross-section, and the process includes 90° rotation between each two stages and an analytical equivalent strain in the range of 0‑4.64 imparted into them.

## II. EXPERIMENTAL DETAILS

In order to achieve the CGP-CR on an Al6061 test specimen, corrugated and flat dies are used in this research work. These dies are designed using an analytical method on the basis of loading parameters and test specimen specifications. The thicknesses of the test specimens to be forged are 2 mm, 3 mm, and 4 mm; die material to be used is mild steel; and the overall tolerance of the geometry is ±1 mm. 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 backup 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 backup plates. The pressing is performed in a 250T oil hydraulic press at pressing speeds of 1mm/min, 1.5 mm/min, and 2 mm/min. In CGP-CR 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 a total number of three passes of CGP-CR, and further

Processing could not be continued beyond due to cracking of the plate. The specimens were prepared for hardness and tensile specimen. The Vickers hardness (HV) of the test specimens was calculated using a Micromet-5101 device; with a load of 200 g and loading period of 20 s. Tensile tests were performed at room temperature with universal testing machine at crosshead 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.Fig.1 (a-b) shows die assembly with flat and corrugated specimen. A standard Taguchi experimental plan with notation $L_{27}$ was chosen. In this method, the optimal combination of the process parameters can be predicted. The experiments were carried out for analyzing the influence of testing parameters on micro hardness and tensile strength of CGP-CR specimens. The code and levels of control parameters are shown in Table.1 This table shows that the experimental plan had three levels. On conducting the experiments as per orthogonal array, the Micro hardness and tensile strength results for various combinations of parameters were obtained.

Table.1 the experimental plan- three Factors & levels

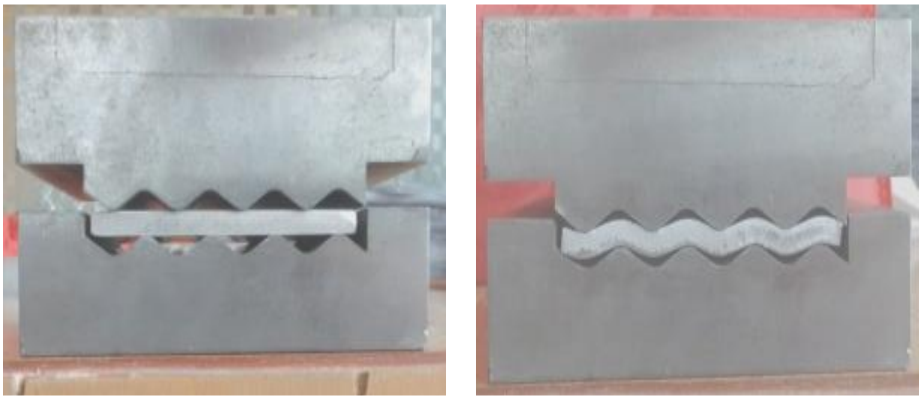

Fig.1 a) die assembly with flat specimen and b) die assembly with corrugated specimen

## III. RESULTS & DISCUSSIONS

| **Symbol** | **Factors** | **Unit** | **Levels** | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| A | Strain rate | mm/Min | 1 | 1.5 | 2 |
| B | No.of Pass | --- | 1 | 2 | 3 |
| C | Thickness | mm | 2 | 3 | 4 |

### 3.1 Micro-Hardness after CGP-CR

The initial hardness of the un-deformed specimens has 29.11 HV (2mm thickness specimen), 32.45 HV (3mm thickness specimen) and 36.16 HV (4mm thickness specimen). The formation of substructure after one, two, three pass led to an increase in hardness to an average of 20-25 HV in all the three different thickness and strain rates.Fig.2(a)shows the Main effect plots of micro hardness by cross-route. After every passes of CGP-CR, the hardness of the specimen shows increasing trend with an average increase in hardness of 10-15 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 [2, 3] 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.Fig.2(b) shows interaction plot for micro hardness, the results indicates that the number of passes having more effect on the improvement of Micro hardness about 10 to 40% .effect strain rate at about 6% and thickness as very less changes at about 1.5%.

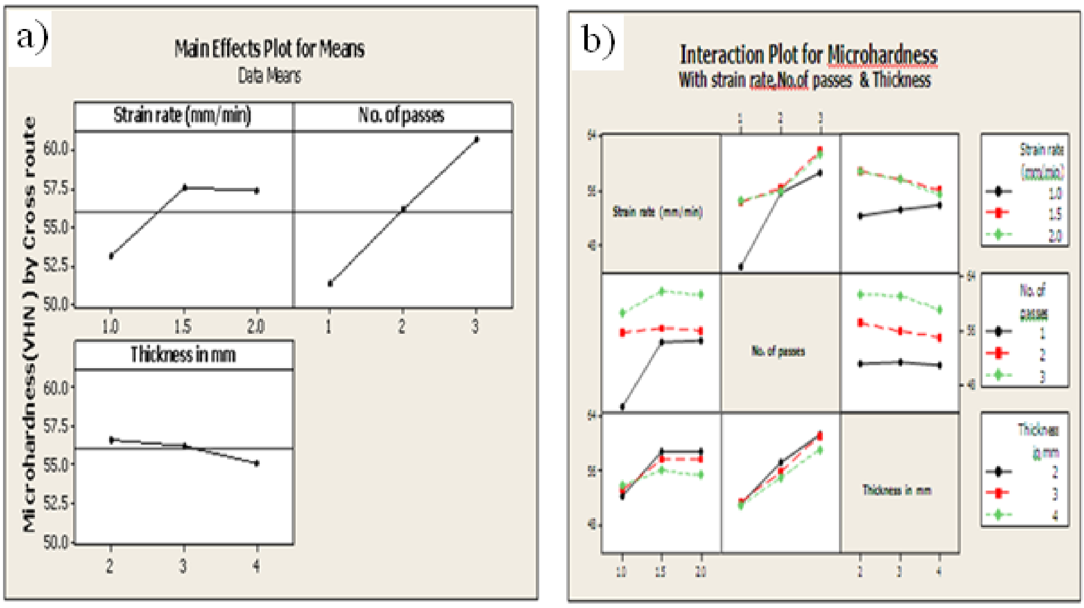


Fig.2 (a) Main effect plots of micro hardness & Fig.2 (b) Interaction effect plots of micro hardness by cross-route.

### 3.2 Ultimate Tensile strength after CGP-CR

Fig.3 (a) shows the distribution of tensile strength values after each pass of the specimens. An average of 6-7 % tensile strength increase was achieved in all the three different strain rates and thickness of the specimens. Strain rate remain almost same in all three different levels. But number of passes increases the micro hardness also increases.Fig.3 (b) shows the tensile strength distribution according to the different specimen thickness. The tensile strength showed very little significant changes with thickness and strain effect is 4-5% only on the UTS.

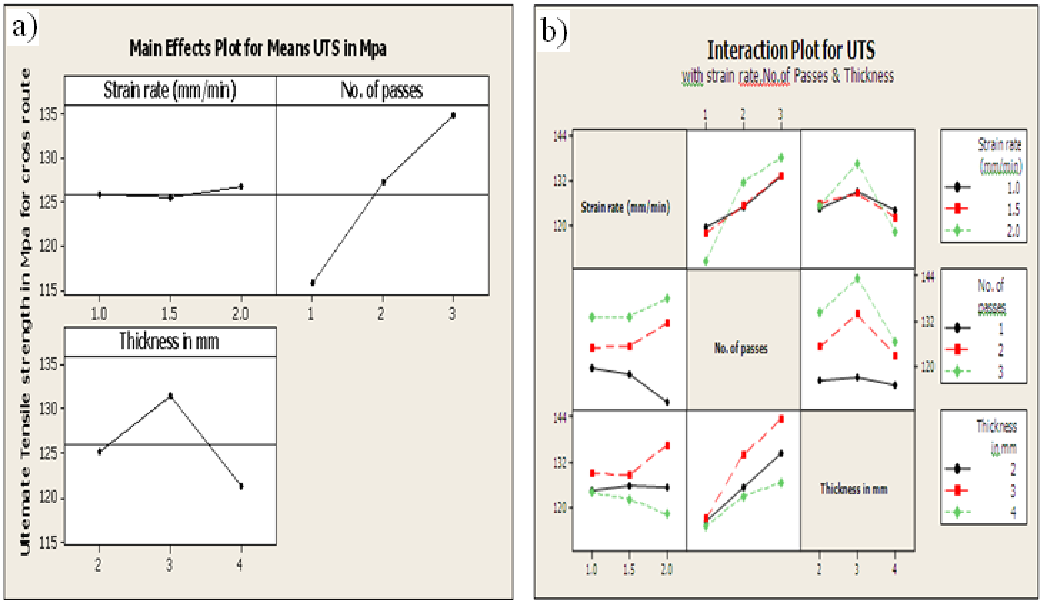


Fig.3 (a) Main effect plots of Ultimate tensile strength & (b) Interaction effect plots of Ultimate tensile strength by cross-route.

## IV. CONCLUSIONS

It is demonstrated that the extrusion strain rate of CGP-CR for aluminum alloy must be higher than the eutectoid reaction temperature of the alloy. The alloy has a more homogeneous fine-grained structure than the as-received one and some equiaxed grains occur in some areas. The fraction volume of the second phase increases after one pass, while it does not increase during the subsequent pass. From the Taguchi analysis, it is concluded that, the number of passes has the highest contribution toward the response values obtained, and the strain rate occupies the second highest contribution rate. The probability of contribution for number of pass and strain rate is 83.7% and 12.1%. The remaining parameters such as specimen thickness and combining effects of strain rate, number of passes and thickness is less significant toward the response values.

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