

# EXPERIMENTAL AND COMPUTATIONAL SIMULATION OF CuZn37 BRASS ALLOY PROCESSED BY CGP USING FLAT GROOVE CORRUGATED DIES

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**Abstract** – Severe Plastic Deformation (SPD) is one of the methods of obtaining very fine crystalline structure in different bulk metals and alloys, which possess different crystallographic structure. In Constrained Groove Pressing (CGP), the metal is subjected to an intense plastic deformation through repeated dominant shearing and pressing (flattening) of plates or sheets. In this research, experimental and simulation analysis was done to investigate the plastic deformation behaviour of CuZn37 brass alloy sheet during its repetitive corrugation and straightening through a flat groove corrugated dies and flat dies. The effective strain has been increased from 1.1738 to 6.2100 at the end of 5<sup>th</sup> pass in the simulation software (AFDEX). The BHN has been increased from 95.4 to 234.35 until 4<sup>th</sup> pass and decreased to 219.52 in the 5<sup>th</sup> pass experimentally and from 91.25 to 232.07 until 4<sup>th</sup> pass and decreased to 222.02 in the 5<sup>th</sup> pass in the simulation.

**Key Words:** Severe Plastic Deformation, CGP, Brinell hardness, Grain refinement, Microstructure

## 1. INTRODUCTION

Severe Plastic Deformation (SPD) is one of the methods of obtaining very fine crystalline structure in different bulk metals and alloys, which possess different crystallographic structure. SPD causes the formation of micrometer and sub-micrometer sized sub-grains in the initially coarse grain materials. As a result of that, enhanced mechanical performance is observed [1]. Nowadays, due to their special properties, fine grained materials, with high strength to weight ratio, have been employed in many industries. There is a much current interest in producing materials with ultrafine grains. Severe plastic deformation is one of the most efficient ways to produce nanostructure (NS) or ultra fine grain (UFG) materials. UFG or NS materials processed by the SPD methods have appealed to an increasing number of specialists in material science [2]. Different techniques

have been used to introduce large plastic strains in to bulk metals such as Equal Channel Angular Pressing (ECAP) [3-5], Accumulative Roll Bonding (ARB) and Constrained Groove Pressing (CGP) [6-9], Repetitive Corrugation and Straightening (RCS) [10,11], and Constrained Groove Rolling (CGR) [12]. In the CGP process, a work-piece is repetitively bent and straightened without significantly changing the cross-section geometry of the work-piece, during which large plastic strains are imparted into the materials, which leads to the refinement of microstructure. In this present study, mechanical behaviour (Brinell hardness, effective strain and microstructure) were predicted through experimental and simulation analysis.

Adviser for metal Forming Process Design Expert (AFDEX) is a general-purpose metal forming simulator, which meets the following requirements for intelligent Bulk Metal Forming Simulation (BMFS). Currently, AFDEX is theoretically based on the rigid or elasto-thermoviscoplastic finite element method. AFDEX 2D and AFDEX 2D/DIE use quadrilateral finite elements. AFDEX 3D, AFDEX 3D/OPEN, and AFDEX 3D/DIE employ tetrahedral elements. AFDEX 2D/DIE and AFDEX 3D/DIE are integrated die structural analysis programs that accompany the respective BMF simulators, AFDEX 2D and AFDEX 3D. AFDEX MAT provides users with highly accurate true stress-strain curves for the materials in use at room or elevated temperature [13].

## 2. PREPARATION OF DIES AND SPECIMEN

### 2.1 SPECIMEN USED

In the present study, material selected for the investigation is CuZn37 Brass alloy Sheet. The chemical composition of the test material is mentioned in the Table 1.

Contents	Cu	Ni	Pb	Fe	Sn	Al	Zn
Percentage	62 - 65.5	≤ 0.30	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.05	Balance

**Table 1:** Chemical composition of CuZn37 Brass Alloy

The material to be forged is CuZn37 Brass alloy having maximum yield strength 183 MPa, thickness of the test specimens to be forged is 1mm and cross sectional area of the test specimens to be forged is 70x70mm<sup>2</sup>.

## 2.2 SPECIFICATIONS OF DIES

In order to achieve the CGP on Brass test specimen, flat groove corrugated dies and flat dies are used in the present research work. SOLIDWORKS was used for modelling of the dies according to design specifications. Technical specifications of the dies are, cross sectional area of upper flat groove corrugated die is 120x80 mm<sup>2</sup> and lower flat groove corrugated die is 120x120 mm<sup>2</sup>. Angle of the groove is 45°, Width and depth of the corrugated groove is 5 mm, cross sectional area of upper flat die is 110x110 mm<sup>2</sup> and lower flat die is 130x130 mm<sup>2</sup>, die material used is mild steel, overall tolerance of the geometry is ±1mm.

## 3. EXPERIMENTAL PROCEDURE

The basic parameters considered for the SPD are strain rate for compression of test specimen, thickness of the test specimen and number of passes. The specimens were processed at room temperature from one to five passes. The Fig 1 (a,b) shows the assembly of corrugated and flat dies. Each pass of this process consists of four presses and the process was carried out using a pair of flat groove corrugated and flat dies using Universal Testing Machine (UTM) which has a capacity of 400 KN with a pressing speed of 1mm/min.

During the first press, the flat sheet of CuZn37 Brass alloy was corrugated using corrugated dies. For second press, flat die was used to flatten the corrugated sheet. Before starting of the third press, the flat sheet is flipped by 180°, then corrugation and straightening processes is carried out as third and fourth presses, which completes the 1<sup>st</sup> pass of CGP process. Again during the fifth press, before pressing, the flattened sheet is rotated by 90° and then corrugation and straightening processes is carried out as fifth and sixth presses. Finally, the sheet is once again flipped by 180° and the flattened sheet is corrugated as seventh press and flattened as eighth press, which completes the 2<sup>nd</sup> pass of CGP process. Thus, four presses are considered as one pass of the sheet. The effective strain was accumulated in deformed region throughout the sample.

By repeating the corrugation and straightening process, a large amount of plastic strain can be accumulated in the workpiece. Similarly, the process was repeated up to five passes and further processing was not done due to decrease in Brinell hardness. Higher strain was achieved at the end of five passes.

Three-dimensional, plane-strain, Rigid-plastic FEM simulations of the CGP processing have been carried out using the commercial finite element software, AFDEX. In the simulation, the dies can be assumed as rigid bodies, since their strength is much higher than the workpiece material. Manual meshing was used to accommodate deformation during the simulations. The workpiece is meshed with tetrahedral elements. After meshing, software gives the output as model, which consists of 39715 nodes and 170799 elements. A self adaptive step length was used for the process to carry on the simulations. The friction between the workpiece and the die used was sticking, which was present in the library of the software.

### 3.1 Microstructure analysis

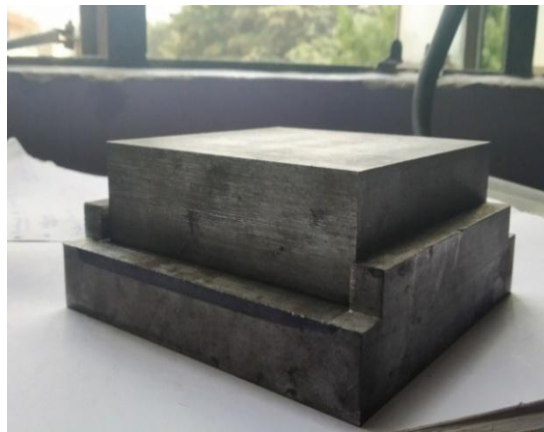
An analysis of the fine structures of the before and after CGP pressed Brass alloys are prepared as per the requirements. Microstructure study was carried out using Inverted Optical Microscope with a magnification of 800X. The test specimens were cut into to a size of 10mm x 10mm. The specimens were mounted using Bakelite powder. Prior to microstructure analysis, the surface preparation was made using polishing machine with different grades of Silicon Carbide papers and the etchant was used to exhibit the microstructure of the polished specimens. The chemical composition of the Etchant used is 4g-FeCl<sub>3</sub>+10ml-HCL+40ml-H<sub>2</sub>O.

### 3.2 Brinell Hardness

The Brinell Hardness (BHN) of the test specimens were calculated according to ASTM E-10 using ball indenter of diameter 2.5mm, with a load of 187.5 kgf and a loading period of 30 seconds. For obtaining reliable results, the measurements of the hardness was performed on all the specimens in 20 different locations and average of eight nearer values was considered as final hardness value.



**Fig 1 (a):** Assembly of upper and lower flat groove corrugated dies



**Fig 1 (b):** Assembly of upper and lower flat dies



**Fig 2 (b):** Flattening CGP process using flat dies

The images of the specimen obtained during experimental process at the end of each pass are shown in the Fig 3. The images of the specimen with different presses obtained in the simulation software (AFDEX) are shown in the Fig 4.

#### 4. RESULTS AND DISCUSSION

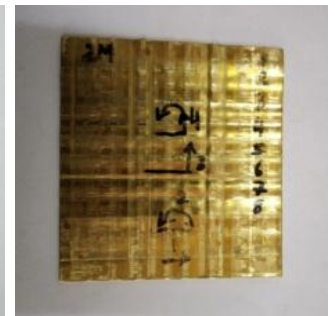
The experimental corrugation and flattening CGP process using flat groove corrugated and flat dies are shown in the Fig 2 (a, b).



**Fig 2 (a):** Corrugation CGP process using flat groove corrugated dies



1<sup>st</sup> pass



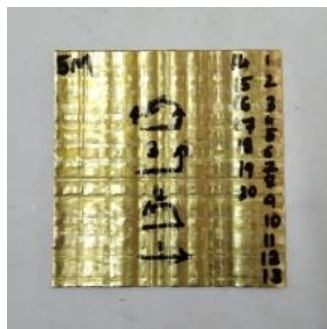
2<sup>nd</sup> Pass



3<sup>rd</sup> Pass



4<sup>th</sup> Pass



5<sup>th</sup> Pass

Fig 3: Images of the specimen with different passes

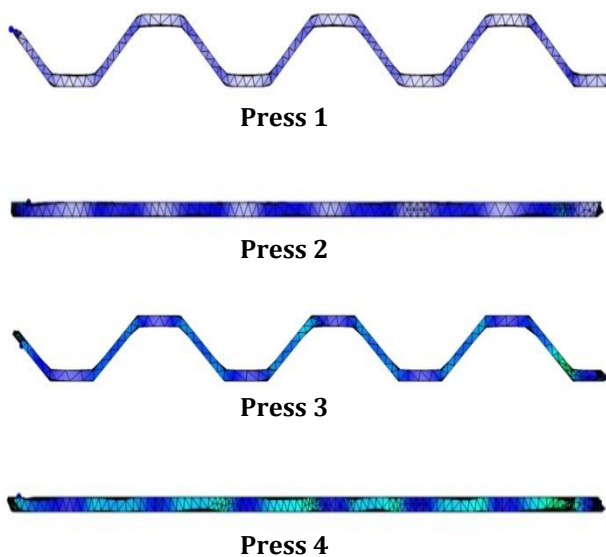
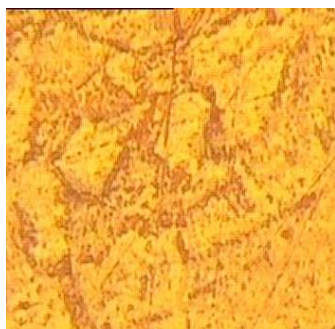


Fig 4: Images obtained in simulation with different presses passes

The CGP process of corrugating and straightening was continued up to 20 presses in the simulation software (AFDEX).

#### 4.1 Microstructural analysis of specimens subjected to CGP



(a) Parent material



(b) After 2 passes



(c) After 4 passes

Fig 5: Optical images of CuZn37 Brass alloy for different passes

The Fig 5 shows grain boundaries of CuZn37 brass alloy without CGP process. After 2 passes of CGP, CuZn37 brass alloy resulted in the formation of non uniform sub grains that vary substantially which indicates the presence of dislocation cell structure as observed in Fig 5 (b). From Fig 5 (c), it is evident that the brass alloy in this region has undergone quite large amount of plastic deformation. From the Fig 5 (a-c), the detailed observation reveals the dislocation behaviour relating to the low angle sub grain boundaries formation, led to the development of a deformed substructure, thus converting coarse grain structure in to fine grain structure.

#### 4.2 Effective strain distribution of different passes of CGP process

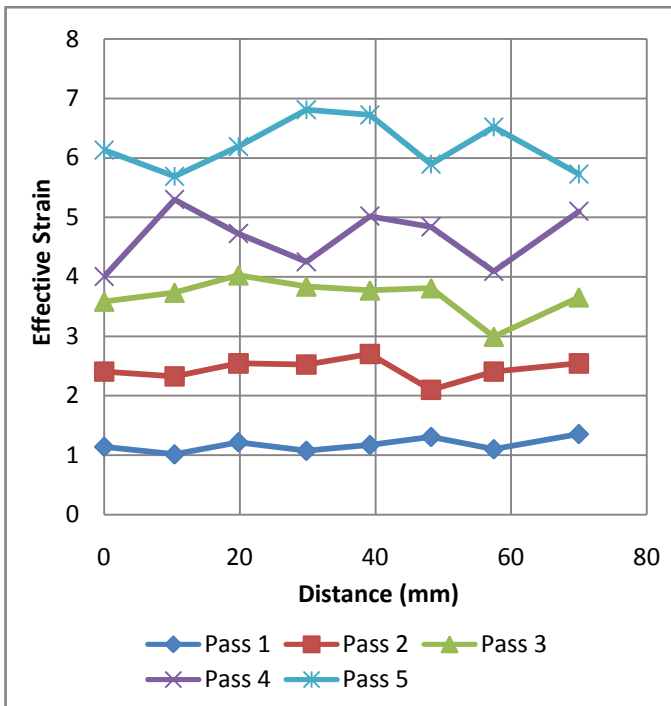


Fig 6: Effective strain distribution of different passes of CGP process

From the Fig 6, it can be seen that, in each pass the effective strain is not much varied throughout the material, which shows that the material is homogenous.

#### 4.3 Average Effective strain distribution of different passes of CGP process

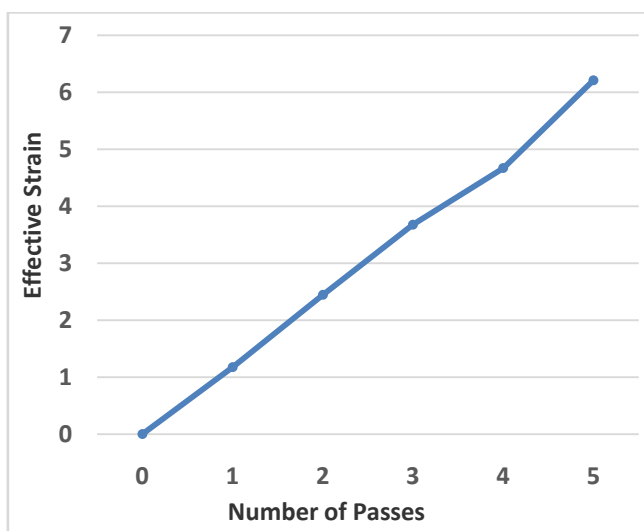


Fig 7: Average Effective strain distribution of different passes of CGP process

From the Fig 7, it can be seen that the effective strain induced in the material is gradually increased after every pass, due to refinement of the grains after each pass and also due to stress concentration effects at the inclined regions. The total effective strain induced after five cycles of CGP process is 6.21.

#### 4.3 Comparison of average Brinell hardness in different passes

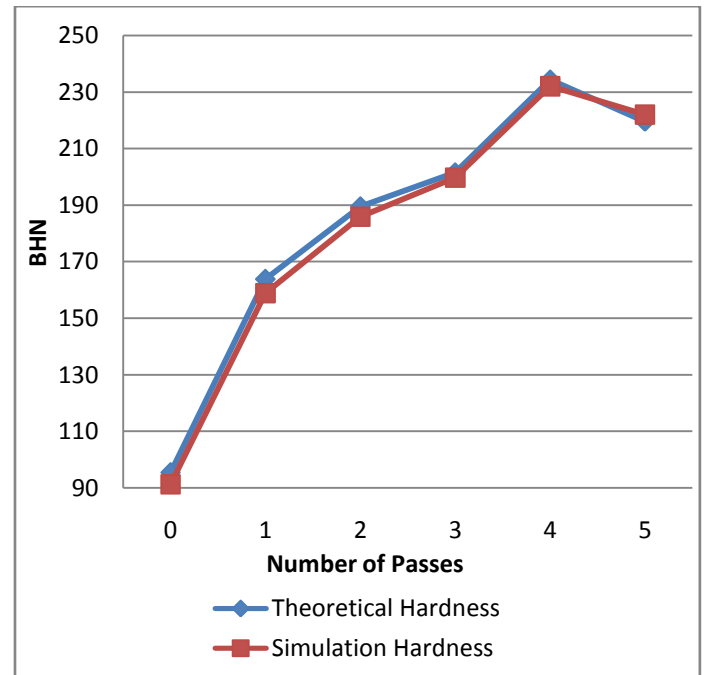


Fig 8: Average Brinell hardness of different passes of CGP processes

From the Fig 8, it can be seen that the Brinell hardness values in both i.e., simulation and theoretical result values has been increased up to the 4th pass which is actually due to the strain hardening effect and it has decreased in the 5th pass due to the grain refinement effect and it has reached its ultimate stress point.

### 5. CONCLUSIONS

- ❖ The flat groove corrugated dies and flat dies were used for the CGP process in which two corrugation and two straightening process was done and considered as one pass. The brass alloy (CuZn37) was pressed up to five passes. Simulation was also done for the same number of passes using AFDEX software.
- ❖ The CGP process produces high quality nanostructure materials, where, the quality of surface roughness improves with the increasing number of passes. Also, this process is concerned with producing metals and alloys

capable of controlling nanosized grains, and free from defects such as porosity, cracks, or other atomic scale defects that are known to compromise properties.

- ❖ Hardness (BHN) increased in the first four passes in both theoretical (95.4 to 234.35) and simulation (91.25 to 232.07) and then trend has been decreased slightly at the fifth pass in both theoretical (219.52) and simulation (222.02). Greater refinement of brass alloy microstructure and further increase in strength is expected to occur with large number of executed passes.
- ❖ The effective strain has been increased in CuZn37 brass alloy sheet after every CGP process from 1.1738 to 6.2100 after 5 passes, during the simulation in AFDEX software. This is because of large plastic deformation in the original grain structure of metals, develops a microstructure on a much smaller scale. Extended dense dislocation walls separating regions of relatively low dislocation densities, between these regions lattice misorientations develop with increasing strain.
- ❖ Microstructure analysis of CuZn37 brass alloy resulted in the formation of non uniform sub grains that vary substantially which indicates the presence of dislocation cell structure. With increased number of passes, it led to the development of a deformed substructure, thus converting coarse grain structure in to fine grain structure.

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