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Impact of RCS- Cross Root Process and die design in commercial Brass Alloy Sheets

T.M. Tajuddin Yezdani , Shantharaja M

Abstract: *Commercial Brass Alloy Sheet are subjected to intense plastic deformation using RCS method to improvise its metallurgical / Mechanical properties. The impact of Repeated Corrugation and Straightening Process for a number of cycles using two different type of dies on hardness, homogeneity and grain structure in commercial Brass Alloy Sheet at room temperature is evaluated experimentally. Two types of V-grove corrugation dies (flat groove corrugated, and semi-circular grooved corrugated) and flattening dies were used in this work with a pressing velocity of 1mm/min. The modus operandi involves repeated and controlled corrugation followed by straightening for a number of cycles. In the process the brass sheets are made to undergo intense plastic deformation by repeated shearing using first flat groove corrugated dies followed by flattening of sheets using flat dies and in the second setup, semi-circular groove corrugated dies are used, followed by flattening of sheets using flat dies. In the samples processed using flat groove corrugated dies, the BHN increases from 95.47 to 234.34 upto 4th cycles and then decreased to 218.63 in the 5th cycle experimentally. In the samples processed using semi-circular groove corrugated dies, the BHN increases from 95.47 to 202.02 upto 4th cycle and then decreases to 194 for 5th cycle experimentally. The results of simulation studies done using the simulation software (AFDEX) are in consonance with the experimental results. Simulation analysis done to study the behavior of commercial Brass Alloy Sheet subjected to plastic deformation using Semi-circular groove corrugated dies shows that the effective strain has increased from 0.6442 for the 1st cycle to 2.94 at the end of 5th cycle, and for the flat grooved corrugated dies the effective strain increases from 1.17 for the 1st cycle to 6.21 at the end of 5th cycle. This RCS process can be used for bulk production of sheets with high hardness, fine grain structure and smoother surface.*

Keywords *: About four key words or phrases in alphabetical order, separated by commas.*

I. INTRODUCTION

The strength of metals is enhanced with reduction of its grain size specifically nanometer grain size having less than 100 nm and sub micrometer grain size having 100 – 1000 nm. These grain sizes can be obtained either by top-down or bottom-up method. In the later method, the nanostructure is obtained by atom-by-atom, layer –by layer. This approach results in porous material which adversely affects its properties [1]. In the top-down method, the microstructure can be changed to nanostructure, by numerous processes, one process is refinement of grains by severe plastic deformation (SPD). In SPD, dislocation density increases by severely straining the materials uniformly giving rise to dense dislocation walls and transforming dislocation walls into high grain boundaries. Many investigators have investigated different SPD processes and mechanisms of refinement of grain size [1,2]. Almost all of these processes are confined to batch production with geometric restrictions. Zhu et al.[3] proposed the technique of Repeatedly corrugating and straightening (RCS) to obtain fine grained metal. In sheet metal, the grain refinement is not uniform as some areas do not undergo SPD, this may be rectified by opting for optimal die design under favorable conditions of processing[4]. Non-ferrous materials like Copper and alloys of copper [5], Aluminum and alloys [6,7], Titanium alloys [8], Magnesium alloys [9], Nickel [10] , Steel [11] were extensively studied. Different SPD processes, RCSR [12], CGP [13], NWR [14] have been used for refining the grain in recent years. In the present work, Repetitive corrugation and straightening (RCS) process is modified to a technique which has been tentatively named as the Cross-Root Technique, by using this technique, an attempt has been made to get a homogeneous sheet whose grains have been reduced to nano size uniformly throughout. Commercially available Brass Sheet has been used in the experimentation.

The valuable properties of non-ferrous metal Brass Alloy and the ease of producing it, have made it the most commonly used metal with many applications that include the making of Nuts, bolts, Terminals, Jets, Taps, Pipe/water fittings, body of Valve, transport of water through pipes, in marine engines and pumps. The first commercial use of brass was on naval ships. Because of its non-magnetic nature, it is used in Clocks and watch elements, electrical terminals that will not be affected by magnetism. Due to a wide range of applications of this metal, it becomes imperative to enhance the properties, this can be done by repeatedly corrugate and straighten the sheets (RCS) by –Cross Root technique that is used in this work. In this process the sheet is bent with corrugated die and then flattened, without much change in the dimensions of the work piece, during this, good amount of plastic strains are induced into the material. In the present work, the authors have made an attempt to find the impact that different types of processing dies have on refining the grains in the material and get more or less homogeneous Brass Sheets. It is concluded that the RCS process carried out using flat groove corrugated die and flat die gives finer grain size and sufficiently improved properties but greater homogeneity is achieved by using semicircular groove corrugated die and flat die even if the
enhancement in the properties is not as significant as in the former case.

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The general-purpose metal forming simulator, namely the Adviser for metal Forming Process Design Expert (AFDEX) for Bulk Metal Forming Simulation (BMFS) is used. AFDEX works on theory of elasto-thermo-viscoplastic FEM. It uses quadrilateral finite elements. and tetrahedral elements for 2D and 3D analysis respectively. These are integrated die structural analysis programs that are interfaced with BMF simulators, they provide the users with true stress-strain curves for the materials in use. [15].

II. PREPRATION OF SPECIMEN AND DIES:

A. *Preparation of specimen*

Commercially available Brass sheets having chemical composition Cu: 65%, Ni: ≤ 0.30%, Pb: ≤ 0.10%, Fe: ≤ 0.10%, Sn: ≤ 0.10%, Al: ≤ 0.05% and balance Zn, this alloy has yield strength of 183 MPa was taken as the starting material, and specimen of 75 x 75 x 1 mm thick were cut from a larger sheet by wire cutting process. Two optimally designed corrugated dies having multiple teeth were made so as significant shear strain is induced in the samples during the process of corrugation.

B. *Specifications of the Dies*

Semi-circular groove corrugated die was designed using SOLIDWORKS for modelling. Technical specifications of the die being, upper corrugated die is 120x80 mm² and lower corrugated die are 120x120 mm², Radius of groves is 5 mm, depth is 4 mm. The upper flat die is 110x110 mm² and lower flat die is 130x130 mm², made of mild steel, overall tolerance in geometry is ±1mm.

Flat groove corrugated die was also designed using SOLIDWORKS for modelling. Technical specifications of the dies being, upper flat grooved corrugated die is 120x80 mm² and lower flat grooved corrugated die is 120x120 mm². Angle of groove is 45°, Width and depth of the groove is 5 mm and 3mm respectively. Upper flat die is 110x110 mm² and lower flat die is 130x130 mm², made of mild steel, overall tolerance in geometry is ±1mm.

III. EXPERIMENTAL PROCEDURE

Experiments were conducted at room temperature separately by using the two different dies.

The dies are attached to UTM for carrying out the RCS process. One cycle of the RCS process constituted of placing the sample on the lower corrugated die and placing the upper die over it. Load is applied slowly at crosshead speeds of 1mm/minute. Now the corrugated sample is flattened by flat dies, this is the 1st Pass. In the 2nd Pass, sample was flipped by 180° and the RCS process repeated. Then the sample was rotated by 90° in the 3rd Pass and the RCS process repeated, finally the sample was flipped again by 180° and the RCS process repeated in the 4th Pass. This constituted one cycle of the process.

A 40T hydraulic UTM was used in the processing. By increasing the number of cycles, large plastic strain gets accumulated in the work piece. After 5th cycle further processing was stopped as the Brinell hardness decreased. The strain kept on increasing up to five cycles in both cases. The different corrugated dies used for the experiments are given in fig.1(a), and fig.1(b) gives the Orientation for one cycle.

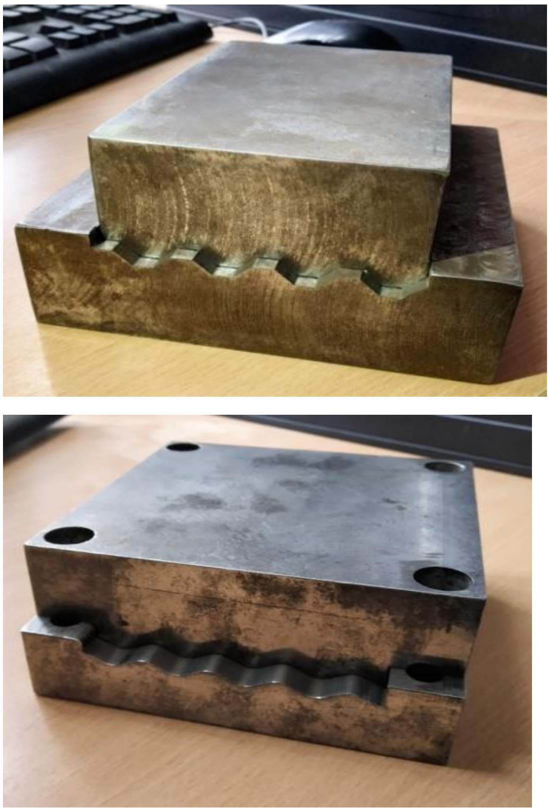

Fig.1(a), Flat groove corrugated die and Semi circular corrugated die

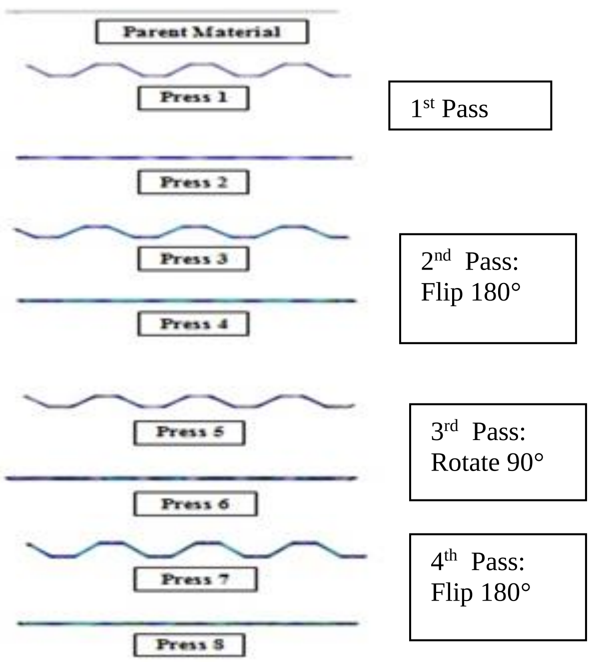

Fig.1(b) Orientation of the RCS process for one cycle.

A. *Brinell Hardness test:*

The Brinell Hardness (BHN) test was conducted and hardness values found as per ASTM E-10 standard. The ball indenter of diameter 2.5mm, with a load of 187.5 kgf was used, and load was applied for 30 seconds on the test specimens.

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The hardness was measured at 20 different places along its length, for samples subjected to one cycle upto five cycles. Average of eight nearest values were taken as final hardness value.

B. *Microstructural analysis:*

Microstructural analysis of the grain structures before and after severe plastic deformation was carried out to examin the bonding quality, the samples from all the RCS process were cut, mounted and metallographically polished with successively finer grades of Silicon Carbide papers The polished samples were etched with etchant having chemical composition of 4g- $FeCl_3$ +10ml-HCL+40ml- H_2 0. Microstructural studies were done using Inverted Optical Microscope having magnification of 800X.

IV. RESULTS AND DISCUSSION

The average strains obtained using the simulation software (AFDEX) after each cycle are plotted as given in the Fig. 2 (a) and Fig. 2 (b) It can be seen that strain has increased after each consecutive cycle to reach a maximum value after 5 cycles. It is also clear that the strains induced by the flat grooved corrugated die are significantly more than that produced by the samples processed by semi-circular groove corrugated die.

Samples prepared by flat groove corrugated dies had BHN increase from 95.47 to 234.34 up to 4th cycle and then fell to 218.63 for the 5th cycle. In the samples prepared by Semi-circular groove corrugated dies, had BHN increase from 95.4 to 202.02 up to 4th cycle and then fell to 194 in the 5th cycle.

It can be seen from Fig. 3(a), (b), that the average hardness on the specimen also increased after each cycle, and in 5th cycle, the average hardness decreased significantly in both cases. The average hardness obtained by processing the sample using flat groove corrugated die is almost 16% more than that obtained on the samples processed using semi-circular groove corrugated die.

Table-I: Average effective strain for Fig -2(a))

cycles	Average Effective strain
0	0.0001
1	0.6442
2	1.1897
3	1.7266
4	2.3685
5	2.9431

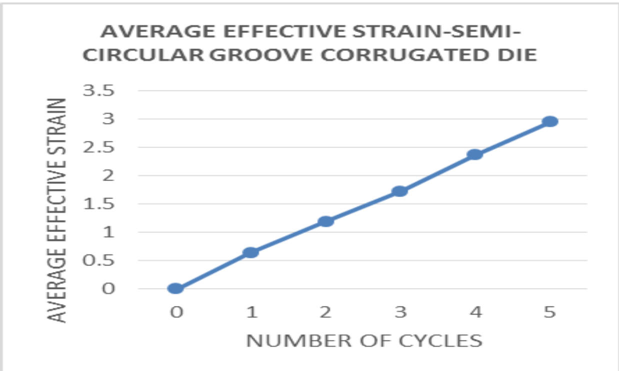

Fig. 2 (a)

Table-II: Average effective strain (for Fig -2(b))

cycles	Average Effective strain
0	0.001
1	1.1738
2	2.445
3	3.6768
4	4.668
5	6.21

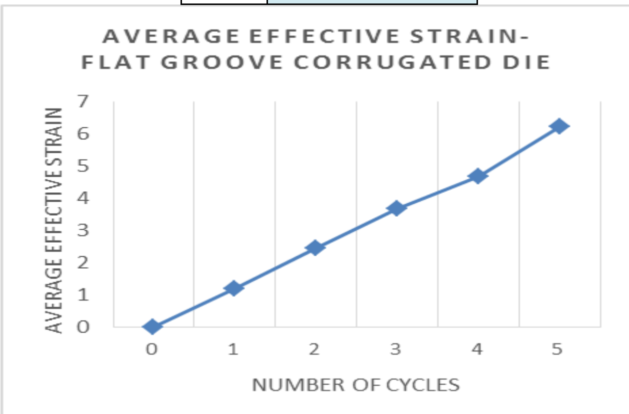

Fig. 2 (b)

Table-III : For Fig.3(a) and Fig. 3(b)

Number of cycles	Average BHN (Semi-circular groove corrugated die.)	Average BHN (Flat grooved corrugated die.)
0	95.4	95.4
1	154.92	163.8
2	173.41	189.52
3	184.64	201.52
4	202.01	234.34
5	194.3	219.52

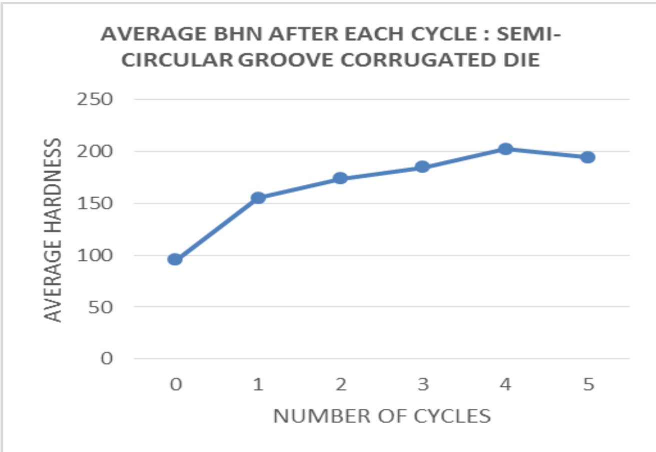

Fig.3(a)

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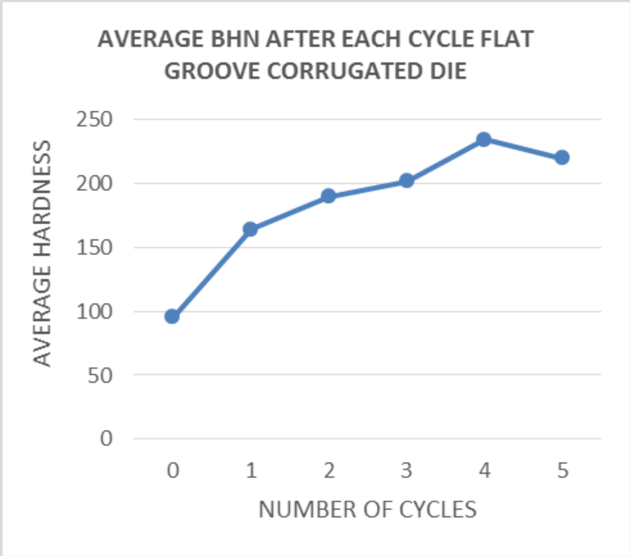

Fig.3(b)

The samples were checked for homoginiety after being processed for 5 cycles. This was done by finding the strains and hardness at 20 different locations along its length. Among this, 8 nearest values were taken and graphs are ploted as shown below.

Table - IV: For Fig.4(a)

istance in mm	(1 cycle)	(2 cycles)	(3 cycles)	(4 cycles)	(5 cycles)
0	0.6182	1.1617	1.5364	2.103	2.8033
10.39	0.6415	1.1588	1.7437	2.4037	3.0144
21.25	0.6096	1.2023	1.8032	2.376	2.9993
31.78	0.6457	1.2363	1.7296	2.4692	3.057
41.72	0.6555	1.2582	1.7372	2.4388	2.9801
51.61	0.6954	1.2303	1.7471	2.4688	2.9673
1.58	0.6283	1.1485	1.7271	2.3847	2.9033
70	0.6598	1.1218	1.789	2.3038	2.8201

Table - V: For Fig.4(b)

Distance in mm	(1 cycle)	(2 cycles)	(3 cycles)	(4 cycles)	(5 cycles)
0	1.1429	2.4074	3.5845	4.0051	6.1304
10.39	1.016	2.3256	3.7343	5.3011	5.6907
21.25	1.2176	2.5444	4.0253	4.7286	6.1893
31.78	1.0751	2.5269	3.8376	4.2525	6.8095
41.72	1.1729	2.7025	3.772	5.0205	6.7227
51.61	1.3075	2.1003	3.8089	4.8417	5.8932
61.58	1.1024	2.4085	2.9958	4.0923	6.5182
70	1.3562	2.5447	3.6564	5.1028	5.7266

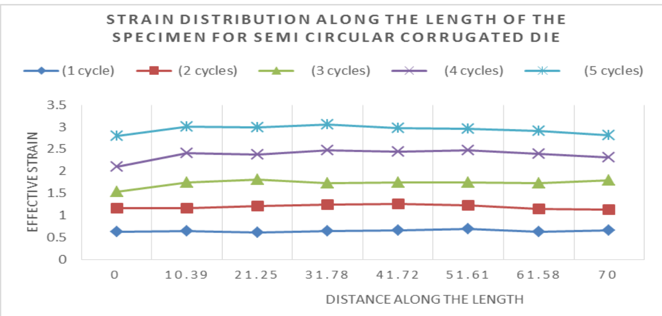

Fig.4 (a) Strains in specimen after each cycle for semicircular groove corrugated die.

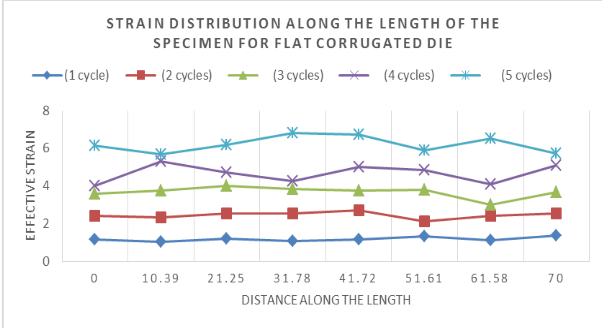

Fig.4 (b) Strain in specimen after each cycle for flat groove corrugated die.

In fig. 4(a), the effective strain distribution at different places on the samples subjected to 1to5 cycles of RCS using semi-circular groove corrugated die is shown. It can be seen that the distribution of strain is almost uniform throughout the length, whereas in specimens processed using flat groove corrugated die the strain distribution is uniform only for the 1st cycle, as seen in fig.4(b). In the subsequent cycles, even though the strain is higher the strain induced is not uniform

Table - VI: For Fig.5(a)

Distance in mm	(1 cycle)	(2 cycles)	(3 cycles)	(4 cycles)	(5 cycles)
0	155.61	187.23	180.23	198.48	194.63
10.39	155.61	167.28	187.23	206.52	194.63
21.25	155.61	170.33	187.23	198.48	198.48
31.78	152.87	167.28	183.68	194.63	198.48
41.72	155.61	170.33	180.23	206.52	206
51.61	152.87	167.28	194.63	198.52	187.23
61.58	155.61	170.33	180.23	206.52	187.23
70	155.61	187.23	187.23	206.52	187.23

Table -VII: For Fig.5(b)

Distance in mm	(1 cycle)	(2 cycles)	(3 cycles)	(4 cycles)	(5 cycles)
0	170.39	187.23	206.52	228.76	215.03
10	155.61	194.63	206.52	228.76	224.05
20	155.61	190.88	206.52	243.97	215.03
30	155.61	190.88	198.48	238.62	219.47
40	155.61	187.23	194.63	228.76	224.05
50	173.54	187.23	202.44	228.76	224.05
60	173.54	190.88	202.44	238.62	215.03
70	170.39	187.23	194.63	238.62	219.47

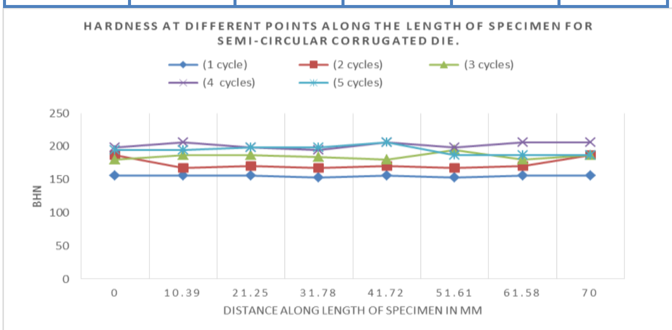

Fig.5(a)

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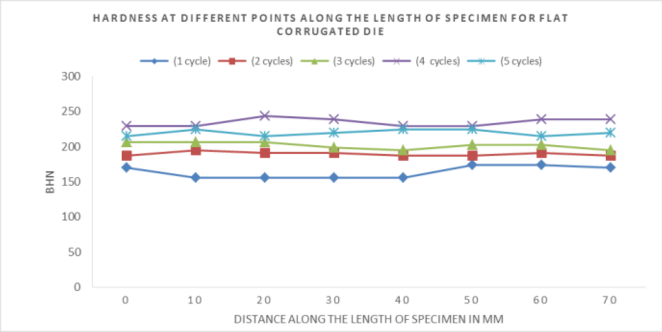


Fig.5(b)

Figures,5(a) and 5(b) gives the variation in BHN value at different locations of the samples processed by semi-circular groove corrugated die and flat groove corrugated die respectively. It is seen that even though greater hardness is achieved by using flat groove corrugated die, the distribution of hardness is not uniform. When semi-circular groove corrugated die is used it can be seen in fig.5(a) that the hardness is more uniform throughout the length .

A. *Comparison of average Brinell hardness in different die shapes:*

In Fig 6, the graph shows the variation of Brinell hardness in both cases. It is increasing from 1st to 4th cycle because of strain hardening effect and after 5th cycle reduces. The increase is because of grain refinement effect. After it reaches saturation, the hardness reduces as the material has reached its ultimate point.

Table-VIII: For Fig. 6(a) and Fig.6(b)

Number of cycles	Average BHN (Semi-circular groove corrugated die.)	Average BHN (Flat grooved courragated die.)
0	95.4	95.4
1	154.92	163.8
2	173.41	189.52
3	184.64	201.52
4	202.01	234.35
5	194.3	219.52

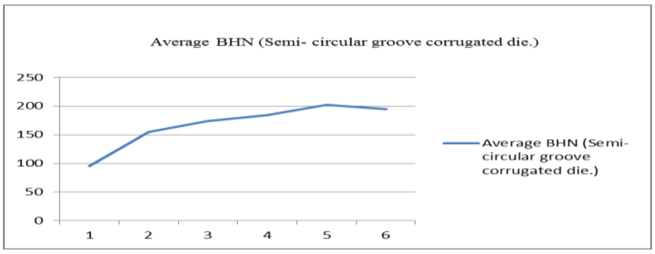


Fig. 6(a)

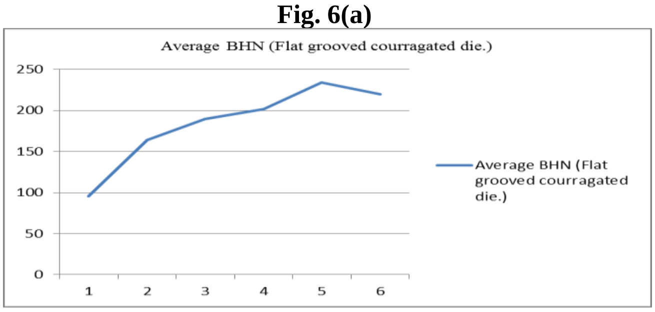
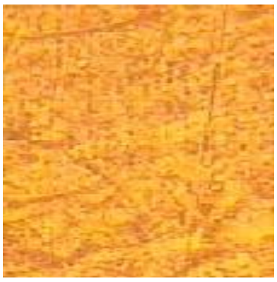


Fig. 6(b)

V. MICROSTRUCTURAL ANALYSIS OF SPECIMENS SUBJECTED TO RCS

(a) Parent material

(b) After 2 cycles



(c) After 4 cycles

Fig 7: Optical images of Commercial Brass alloy for different passes

In Fig 7(a) grain boundaries of raw commercial brass alloy is seen . Fig 6 (b). shows the grain structure after 2 cycles of RCS, non-uniform sub grains are seen, it indicates that dislocation cell structures are present. In Fig 6(c), the brass alloy has undergone large plastic strain. Analyzing the above figures, shows that low angle sub-grain boundaries are formed, that develops a deformed substructure, this leads to converting coarse grain structure in to fine grain structure.

VI. CONCLUSIONS

The experimental investigation revealed the following results. Variation of deformation homogeneity with regard to hardness distribution was found from Optical Micrograph . The results were corroborated with software simulation. Following are highlights of results obtained

- Hardness level of brass sheets is enhanced up to 4 cycles and there after decreases in the 5th cycle. This is due to microstructural strain hardening up to 4 cycles and thereafter there is reduction in strength as material has reached its Ultimate strength.
- Strain quantum and hardness level of brass sheets is enhanced more by flat groove corrugated dies in the RCS Process than by using semicircular groove corrugated dies.
- Grain homogeneity is significantly increased by using semicircular corrugated dies as seen in Fig.5(a).
- Simulation was also done for 5 cycles using AFDEX software, effective strain was found to increase in the Brass Alloy Sheet after every cycle of RCS cycle, from 0.66442 to 2.9431 after 5 cycles in case of semicircular groove corrugated dies and from 1.1738 to 6.2100 after 5 cycles in case of flat groove corrugated dies. That is, strain induced in later case is much more than in the former case.
- But considering Grain homogeneity, semicircular groove corrugated dies are best suited for this process.

- The RCS performed on the samples give high quality nanostructured materials, the surface smoothness also improves with each cycle. The improved softness enhances surface finish and ductility.
- This process is capable of producing materials, free from casting defects that affect their properties. This is due to the reducing of grain size.
- Microstructure studies of brass alloy shows non-uniform sub grains are formed, it indicates that dislocation cell structures are present. When the number of cycles increase, a deformed substructure is developed, thus making coarse grain structure in to fine grain structure.
- This RCS process can be used for bulk production of sheets with high hardness, fine grain structure and smoother surface.

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