

Experimental Findings on the Influence of Back Pressure on Equal Channel Angular Pressing of Copper Processed Through Powder Metallurgy Route

Venkatakrishnan S¹, Shruthi S², Raghuraman S³, Venkatraman R⁴

B.Tech, Dept. of Mechanical Engineering, Student, School of Mechanical Engineering, SASTRA University,
Thanjavur, India¹

M.Tech, Adv. Mfg. (Int.) Student, School of Mechanical Engineering, SASTRA University, Thanjavur, India²

Professor, School of Mechanical Engineering, SASTRA University, Thanjavur, India³

Director, Shanmuga Precision Forging, Thanjavur, India⁴

ABSTRACT: Equal Channel Angular pressing is a unique Severe Plastic Deformation Process for producing ultra-fine grain sized materials. Experiments are conducted on 99.5% pure Copper samples manufactured through Powder Metallurgy route and sinter extruded. The experiments are carried out on cylindrical samples having an aspect ratio of 1 (Height/Diameter). The sinter-extruded samples are then subjected to ECAP punch and die set-up having a channel angle of 110° in a 100 ton hydraulic press. As the samples are subjected to ECAP one after the other, the first sample will not realize the influence of back pressure and the subsequent samples are influenced by back pressure since the first sample acts as a back pressurizing agent for the subsequent samples that undergo ECAP. The influence of back pressure during ECAP helps in prevention of Chevron crack in the sample along with enhancement in mechanical and metallurgical properties such as pore closure, increase in hardness and increased density.

KEYWORDS: Powder Metallurgy route, Equal channel angular pressing, pore closure, densification, Back pressure.

I. INTRODUCTION

Powder metallurgy is a method of producing components of metals and composites from their powdered form. Components that have complex structure and those that are difficult to manufacture via conventional metal forming routes are manufactured in the PM (powder metallurgy) route, making the process simple, highly accurate and facilitates for near-net shape manufacturing. Although PM route has the fore mentioned advantages, the presence of pores and relatively low strengths have always been of concern. In order to overcome the disadvantages, Equal Channel Angular Pressing can be adopted.

Back pressure is an important parameter affecting the process of ECAP as it meters the amount of material passing through the channel at any given point of time. In this process, back pressure is provided by the inertial resistance offered by the samples that have passed through the channel prior to any sample at a particular point of time. This is found to be an effective way of providing back pressure to the samples as the die and process design are in such a way that providing back pressure through any other way would have been a challenge. Strain hardening, densification, grain refinement, and pore closure are expected after passing the samples through the ECAP die for a number of times and for different routes. It is seen that the above mentioned properties are achieved after the first pass itself if sufficient back pressure is provided, paving a way for increased productivity. The purpose of this work is to find the dependence of the ECAP process on the back pressure acting on the samples its effect in reducing Chevron cracks in the sample. The

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

effect of back pressure is profoundly seen on the samples undergoing the process and the findings are discussed here in this paper.

II. RELATED WORK

Equal-channel angular (ECA) pressing is a processing procedure in which a sample is subjected to a very intense plastic strain by pressing through a special angular die. ECAP is known to produce ultrafine grains in FCC metals (Al) ^[1]. These ultra-fine grains seem to have physical properties that differ drastically as compared to their counter coarse grains ^[2]. ECAP also results in reducing the diameter of the pore although the process does not result in complete closure of pores ^[6] that arise as a result of the Powder Metallurgy route adopted. This reduction in volume of the pore increases density of the material. The load is applied on the ECAP punch acts on the samples in the ECAP die causing it to pass through an angular channel at 110°. Effective grain refinement is found in dies with Φ (channel angles) between 90° and 157° ^[3]. From the work of Raja Mohan R et al ^[4], it is found that, for constant $\Psi=45^\circ$ the effective strain imparted is more for channel angle $\Phi=90^\circ$, but the strain in-homogeneity is also high. $\Phi=120^\circ$ has less strain in-homogeneity but the strain imparted is less such that there is no improvement in properties. An intermediate angle is selected wherein the strain imparted is high enough to improve the properties and the strain in-homogeneity is also low. The effective strain imparted is also found to be homogeneous for channel angles, $\Phi=110^\circ$, 115° , 120° . Hence the channel angle of $\Phi=110^\circ$ is chosen for the experimental work where strain imparted is higher compared to 115° and 120° .

III. EXPERIMENT

The material considered for the research work is commercially pure Copper in powder form with a particle size of 50 microns and the purity is 99.5%. Cylindrical compacts are prepared from 96 grams of metal powder per specimen under a pressure of 600 MPa using Universal Testing Machine^[7]. The height obtained after compaction is around 25-28 mm and the diameter obtained is around 23-26 mm to restrict the aspect ratio of the sample to 1. Then the samples were subjected to sinter-extrusion, a process where sintering and extrusion are carried out sequentially. The green compacts are firstly placed in oil-fired furnace at atmospheric pressure and the temperature is gradually raised at proper intervals till it attains temperature of 880°C and soaked at 880°C for 30 minutes^[7]. Then the samples hot-extruded using friction screw press with 11 mm diameter and approx. 90 mm in length for further processing in ECAP die. Then the specimens were trimmed to remove the flashes as shown in Figure 1. Further, sinter-extruded specimens are subjected to annealing heat-treatment at 425°C with a soaking time of 2 hours to remove the internal stresses developed during the sinter-extrusion ^[5]. After heat treatment, the samples are subjected to ECAP wherein load is applied using hydraulic press. The ECAP die and the punch are made of commercial grade die steel and hardened for obtaining the necessary strength. The die of Φ (channel angle) =110° and Ψ (corner angle) =45° and channel diameter of 12mm is designed as split die, for facilitating the removal of the work piece after the process. The whole die setup, as shown in Figure 2, is arranged on the base of the hydraulic press and the automatic loading is applied until the required length of the specimen passes through the angular channel. After passing the first specimen, the next specimen is made to pass through the channel for which the back pressure is provided by the previous specimen. The Load Vs Displacement graph for each sample is shown in Figure 3(a), 3(b), 3(c) and 3(d). The ram speed for the whole process is 3mm/min. Number of passes for each sample through ECAP die is restricted to one. The lubrication provided for the process is graphite powder mixed with engine oil as lubrication is very crucial for compaction and ECAP process. Absence of lubrication would result in severe friction and shearing on the surface of the sample.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

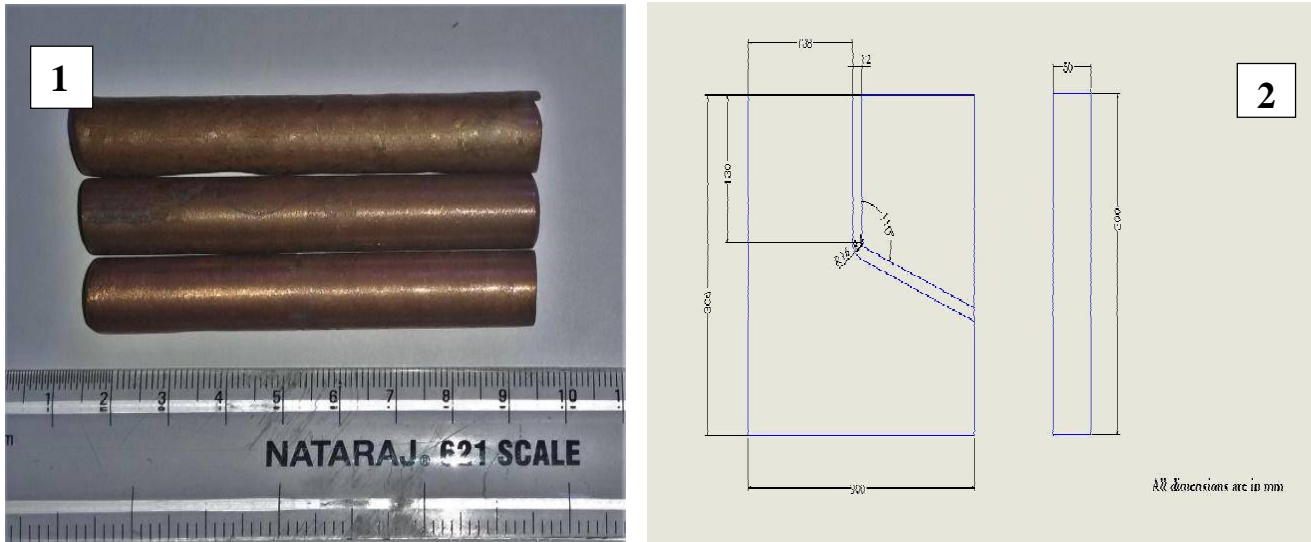


Figure 1: Extruded Specimen (after finishing operation); 2: Line diagram of the die and punch.

IV. RESULTS & DISCUSSION

a. Back Pressure

In this experiment, four copper specimens of diameter 11 mm are passed through the die progressively one after another wherein each specimen produces back pressure for the subsequent specimen. Every specimen is inserted into the die after the previous specimen is passed through the angular channel. All the four samples underwent one pass through the die.

The first specimen is passed into the angular channel, with the ram speed of 3mm/sec. When the specimen reached the angular channel (displacement of the ram is 12mm) there is a drop in the load imparted to the specimen by the ram from 9.4kN to 8.2kN, the corresponding stress at this displacement is 83.19MPa. The drop in the applied load is because of propagation of Chevron cracks from the surface to the core of the specimen. This is the first point during the whole experiment where the sample fails due to propagation of Chevron cracks. From the Figure3(a), it is inferred that there are many stages where there is fluctuation of load which indicates that at each of these dips, the sample fails due to Chevron crack initiation and propagation. As this is the first specimen, to pass through the angular channel, there is no back pressure for this specimen and the maximum load imparted to this sample is 37.5kN and the corresponding true stress is 380 MPa.

When the second sample is passed through the die, the maximum load imparted to the specimen is 76.45kN and the corresponding true stress is 776 MPa. The presence of peaks and valleys in Fig. 3(b) indicate that the sample has developed cracks when it passes through the angular channel but the distance between the peaks and valleys in the plot is low when compared to the first specimen which is also an indication of the extent to which Chevron cracks have propagated from the surface to the core; hence the propagation of crack is less deep as compared to the first specimen. This is due to the back pressure imparted by the first specimen on the second specimen. The back pressure acting on the second sample is the difference in the stress between first and second specimen; the corresponding load is the difference in load between first and second specimen under the assumption co-efficient of friction between walls of the channel and test specimen is zero as the walls are well lubricated with lube oil. The maximum back pressure and load on the second specimen is 396 MPa and 39kN.

For third specimen, the depth of cracks are still lower as compared to the second specimen, as the distance between the peaks and valleys for the third specimen is lower (as shown in the Figure3(c)) than first and second specimen. The maximum load imparted to the third specimen is 92.75kN and the corresponding stress is 941 MPa. The maximum back

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

pressure and load on the third specimen is 561 MPa and 55.25kN. The effective back pressure on the third specimen is due to the cumulative effect of both second specimen and first specimen.

For fourth specimen, the cracks are still lower as compared to all the previous three. It is inferred from the Figure3(d) that, fourth sample has very insignificant variation in load and stress as compared to first, second and third specimen. The fourth specimen is more densely packed and extruded out without any failure or cracks in the specimen. The maximum load imparted to the fourth specimen is 117.75kN and the corresponding stress is 1195 MPa. The maximum back pressure and load on the fourth specimen is 815 MPa and 80.25kN. This is due to the cumulative back pressure offered by all the previous three samples.

From the Figure4, it is observed that the back pressure plays a vital role in ECAP as it aids in extrusion of specimen by avoiding failures like Chevron cracks as flow is controlled as the shear deformation reduces with subsequent specimen passing through angular channel. For electrolytic copper specimens processed through powder metallurgy route, back pressure is one among the major criteria to obtain a properly processed crack-free samples. Higher the back pressure, lesser the cracks in the specimen and hence greater the quality of extruded product. The effective back pressure on a specimen is due to the cumulative effect of all the previously extruded specimen. It is also observed that, as the number of specimen increases, the effective back pressure imparted on the last specimen also increases. Due to the back pressure, the specimen is imparted with a force in opposite direction to the movement of ram. The back pressure force and the force imparted by the ram act as compressive force on the specimen; but due to movement of the ram the sample is made to pass through the angular channel. This compressive force prevents initiation of cracks on the surface of the specimen and also obstructs propagation of crack to the core of the specimen if they are already present on the surface of the specimen. The micro-hardness of the specimens are taken using Shimadzu HMV-2; the micro-hardness before and after ECAP are found to be 90.9 HV and 115.3 HV. Thus, increase in hardness values also confirms that specimens were strain hardened due to severe plastic deformation.

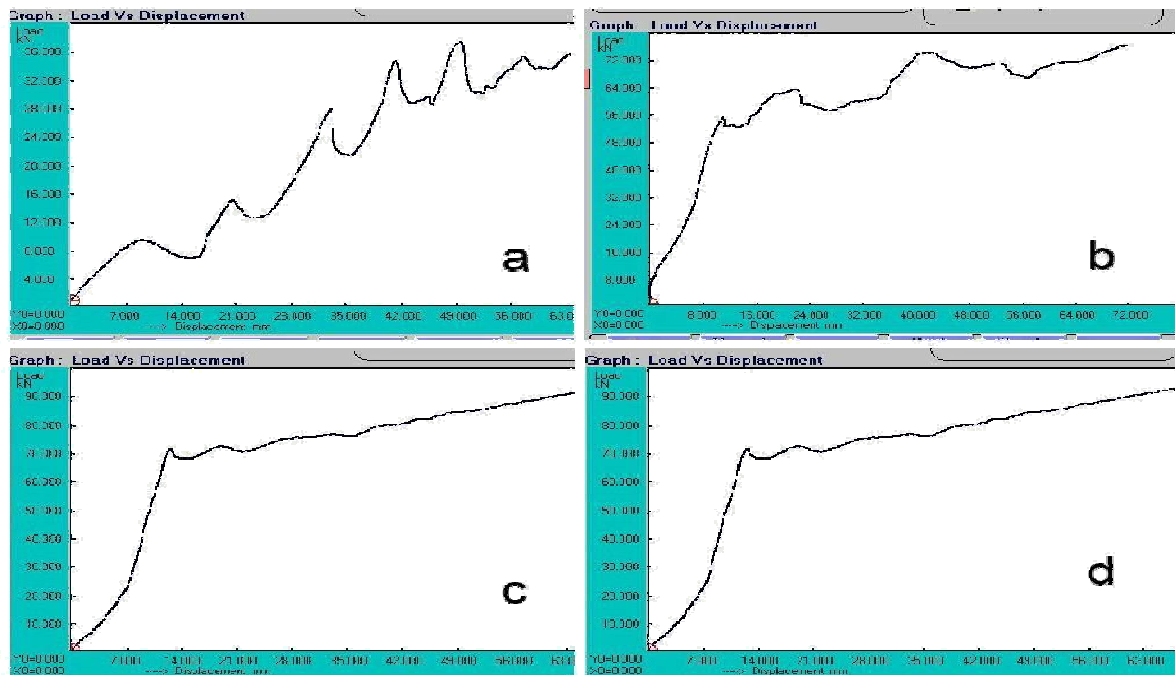


Figure 3(a): Load Vs Displacement of 1st sample through the channel; (b): Load Vs Displacement of 2nd sample through the channel; (c): Load Vs Displacement of 2nd sample through the channel; (c): Load Vs Displacement of 3rd sample through the channel; (d) Load Vs Displacement of 4th sample through the channel.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

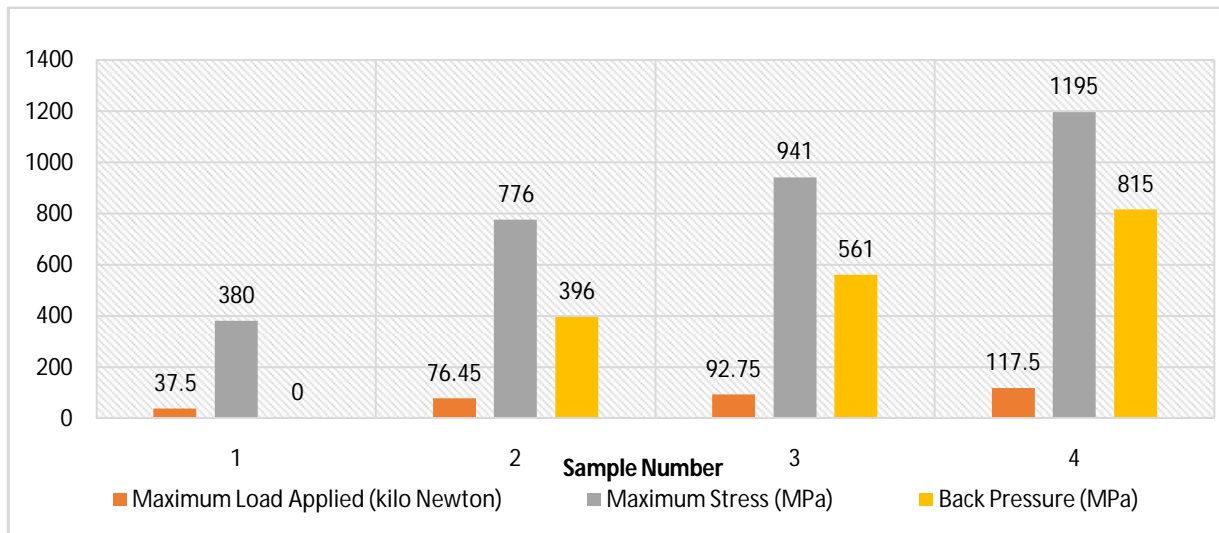


Figure4: Maximum Load Applied (Mega Newton), Maximum Stress (MPa), Back Pressure (MPa) Vs Sample number (in successive order of loading).

b. Pore Closure

Porosity is an inherent and inevitable characteristic of the powder metallurgy route. Back pressure in addition to prevention of cracks also has other important effect on pore closure during ECAP. Back pressure acts as compressive force in the specimen reduces the size of the pores. The pores of size 2-3 μ m in the extruded specimen as shown in Figure 5(a), reduces to a size of 0.5-1 μ m after ECAP as shown in Figure 5(b). The black spots in the SEM image denote pores in the specimen. From the SEM image, it can be observed that pores did not get closed completely but the diameter of the pore decreases by ECAP. As this experiment is restricted to one pass, if the samples are subjected to more number of passes pore size will further reduce but will not close completely. The pore which is spherical in extruded specimen is seen elongated after one pass in ECAP die. This is due to high strain rate in one particular direction compared to other mutually perpendicular axes and also due to the variation in nature of forces acting on the pore when the specimen is passed through the die. The forces acting on the specimen are compressive force offered by the specimen, compressive force by the die walls and more importantly, back pressure acting on the specimen which is offered by the previously extruded specimen. The nature of the forces acting on the specimen after it passes the angular channel is not clear as the constraint changes [8]. On the whole, the forces acting on the specimen are not of same nature and this variation of forces from all the three directions either tensile or compressive. This variation is due to the fact that the strain rate at a point during ECAP process is not homogeneous^[4]. The same is verified from the simulated result from the doctoral thesis work by VenkatramanR^[6] in DEFORM 3D software. Thus, due to combination of various forces including back pressure and strain rate aid in pore closure i.e. reduction in diameter of the pore and elongation in one particular direction.

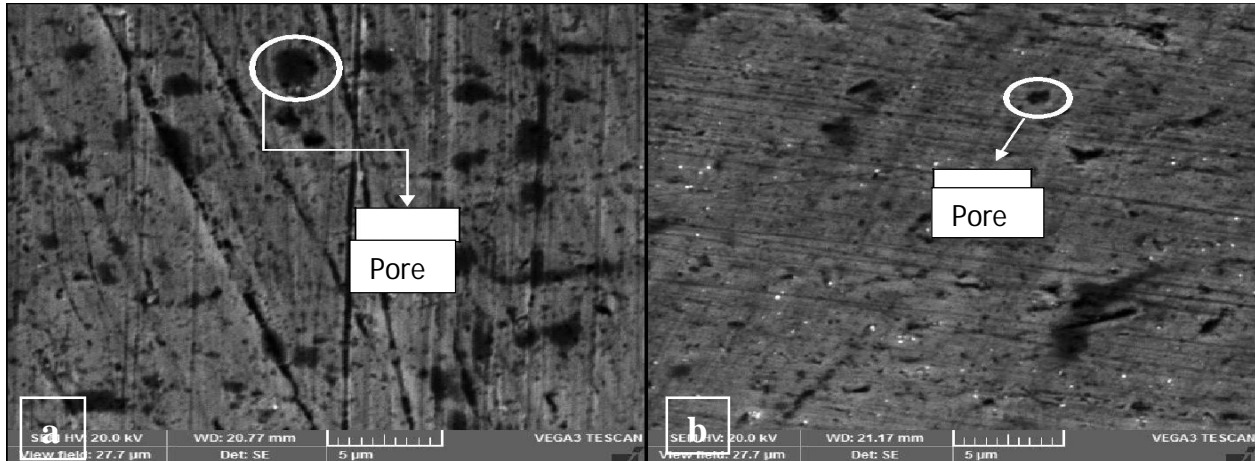


Figure 5 (a): SEM image of Sinter-Extruded Specimen showing pores; (b): SEM image of ECAP Specimen showing pores (Magnification-5000X).

c. Densification

As the back pressure is seen to increase for every sample that passes through the die, it can be concluded that there is an increase in the amount of compressive load acting on each sample.

The average density of the samples is measured using Shimadzu AUX 220 and found that in the as sinter-extruded state the density is 8.2680g/cc while that of solid copper is 8.96g/cc. This difference in density shows that, a large volume of pores being present in the samples.

The first sample after passing through the angular channel, with no apparent back pressure has a density of 8.27g/cc after it has passed through the channel (which is 92.29% the theoretical density of Copper). The second sample, with a back pressure of 396MPa achieves greater densification when compared to the first sample. The density of the second sample on completely passing through the channel is found as 8.32g/cc which is 92.85% the relative density of Copper. Similarly there is an increase in the amount of back pressure acting on the third sample (which is 561MPa) and as it is passing through the channel, is seen to have been densified more to a density of 8.64g/cc, which 96.43% the theoretical density of Copper. The fourth sample with a maximum back pressure of 815MPa, is seen to have a final density of 8.89g/cc, which is 99.22% the theoretical density of copper. Thus, density of samples increases with an increase in back pressure as shown in Figure 6.

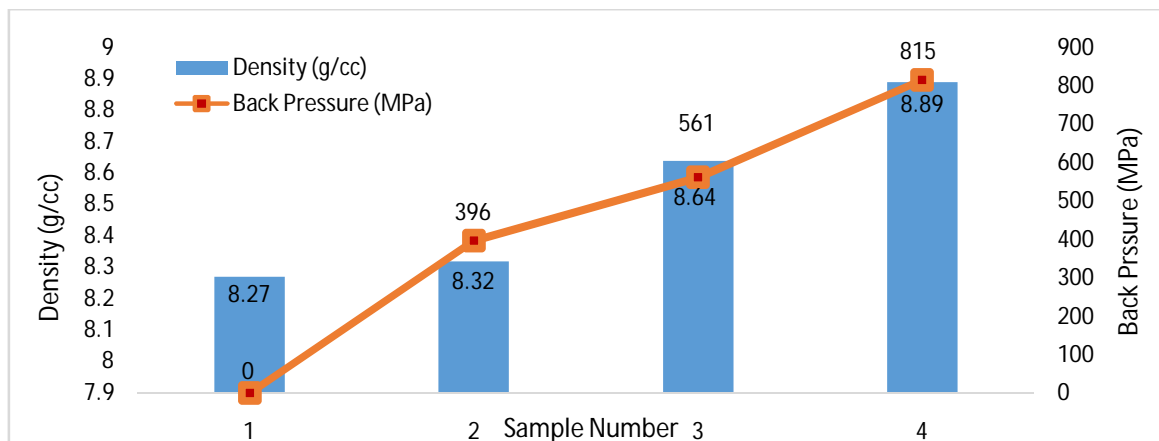


Figure 6: Graph showing the increase in densification with the number of samples.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

V. CONCLUSION

- For copper, processed through powder metallurgy route, ECAP could be effective if the specimens are extruded with a back pressure greater than 0.815MPa. For samples processed with back pressures lower than 0.815MPa, Chevron cracks were observed.
- As the back pressure increases, compressive force on the specimen increases and hence the specimen is less prone to development of cracks.
- To obtain sufficient back pressure, specimen(s) of similar material or any other material of same dimensions as that of test specimen can be inserted into the die prior to the insertion of test specimen.
- Back pressure on the specimen takes the form of compressive force resulting in prevention of crack initiation on the surface of the specimen and also reduces propagation of crack to the core of the sample.
- The reduction in pore diameter of ECAP specimen as compared to sinter-extruded specimen is due to back pressure along with other combination of forces acting on the specimen.
- Reduction in volume of pores in powder compacts is observed with an increase in back pressure acting on the specimen. This reduction in porosity owing to the increase in magnitude of back pressure results in densification of sample during ECAP (i.e) greater the back pressure leads to higher densification of the sample.
- Higher densification of powder compacts, processed through ECAP owing to reduction in porosity can be achieved with increase in back pressure.
- In ECAP of copper, processed through powder metallurgy route, the density of 8.89g/cc (with reference to actual density of copper, 8.96g/cc) is achieved in the first pass itself.

REFERENCES

- [1] I. Sabirov, M.T. Perez-Prado, M. Murashkin, J.M. Molina-Aldareguia, E.V. Bobruk, N.F. Yunusova, R.Z. Valiev, "Application Of Equal Channel Angular Pressing With Parallel Channels For Grain Refinement In Aluminium Alloys And Its Effect On Deformation Behavior"; Int J Mater Form, Vol. 3 Suppl 1, pp. 411-414, (2010).
- [2] Z. Horita, T. Fujinami, M. Nemoto, T.G. Langdon, "Improvement Of Mechanical Properties For Al Alloys Using Equal Channel Angular Pressing", Journal of Material Processing Technology, Vol. 117, pp. 288-292, (2001).
- [3] Kiyotaka Nakashima, Zenji Horita, Minoru Nemoto and Terence G. Langdon; "Influence Of Channel Angle On The Development Of Ultrafine Grains In Equal-Channel Angular Pressing", Acta mater, Vol. 46, No. 5, pp. 1589-1599, (1998).
- [4] Raj Mohan R, Venkatraman R and Raghuraman S, "Analysis on deformation behaviour for pure copper processed through equal channel angular pressing die", International Journal of Research and Reviews in Applied Sciences, Vol. 12-3, pp. 477-480, (2012).
- [5] ASM Handbook, Vol 4, pp. 1962, (1991).
- [6] Venkatkrman R, "Experimental Investigations, Modelling and Analysis on Equal Channel Angular Pressing (ECAP) of Aluminium processed through powder metallurgy", Doctoral Thesis, SASTRA University, Thanjavur, India, (Jun 2014).
- [7] ASM Handbook, Vol 7, pp. 2155-2162, (1998).
- [8] R. Venkatraman, S. Raghuraman, R. Balaji, K. K.S. Ajay, M. Viswanath, "Investigation of Tensile Property and Pore Closure Behavior and the Influence of Processing Route during Equal Channel Angular Pressing of Pure Aluminum Powder Compacts", Applied Mechanics and Materials, Vols. 592-594, Pg. 444-450, (2014).