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Advancement in Die Design of Equi-Channel Angular Pressing (ECAP) Process: A Review

Paramjit Thakur[1], **Prathamesh Surve**[2], **Sunil Sanas**[3]
[1]Assistant Professor, Saraswati College of Engineering, India, paramjit3010@gmail.com
[2]Student, Saraswati College of Engineering, India, prathameshsurve131@gmail.com
[3]Student, Saraswati College of Engineering, India, sunilsanas612@gmail.com

Abstract: Equi-channel angular pressing also known as ECAP is one of the most efficient process to impart high strength, hardness and toughness to the materials without changing its dimension by refinement of grains. But the conventional ECAP process gives drawbacks like buckling of extruding ram and surface defects. Hence there has been tremendous growth in the improvement of ECAP in terms of die design and in ECAP process. This paper describes the various types of newly developed dies used for ECAP process for reducing the plunger force or for the ease with which the process can be performed. The two newly developed ECAP processes, namely ultrasonic assisted ECAP and Torsional ECAP, are also described in this paper. It was found that various advancement in ECAP led to improvement in its performance characteristics.

Key words: ECAP, Ultrasonic vibration, Split die, Rotary die.

INTRODUCTION

ECAP is the one of the severe plastic deformation process in which the material is subjected to the high plastic deformation without changing its cross-sectional area [1]. This imparts high strength, hardness with high effective toughness. There is great amount of refinement of grains and increase in the complexity of the microstructure which imparts high strength, hardness and toughness to the material [2].The processing of material by ECAP has undergone active development in several areas. These areas include development of many Nano-scale metals and commercial production of semi-finished products within the ultra-fine grained structures. The application of ECAP is currently under the investigation for many different materials ranging from aluminum, copper, magnesium and nickel alloys. The conventional ECAP die consist of two channels which intersect at 90 or 120 degrees, where the materials is passed through one end of the channel and allowed to or pulled from the other end. But in conventional die large amount of pressure is required for the deformation of the material which leads to bending of plunger. Surface defects on the processed material are also prominent in conventional ECAP. Hence in order to remove the drawbacks of conventional ECAP, improvement in die design was done by the various researchers. This paper presents the various types of dies like spring loaded die, rotary die, split die, T-shaped die and spiral die, which led to the improvement in the performance of ECAP process. Ultrasonic assisted ECAP and Torsional ECAP are the two newly developed assisted processes which also contribute towards the betterment of this process. Hence, this paper reviews the various advancements in ECAP process in terms new die designs and assisted ECAP processes.

CONVENTIONAL ECAP

The ECAP die is formed from two channels of same cross-section, intersecting to form a corner as shown in Fig 1. The cross-sectional area can be square, rectangular or circular in shape. The inner surfaces of the die are highly polished and lubricated for easy flow of material and to reduce surface defects due to friction. The channel angel (φ) and the curvature angle (ψ) play an important role in inducing strain in the material. Mostly the channel angle of 90 or 120 degree is used. The material to be processed is made similar to the cross-section of the channel. The material is inserted in the inlet channel and extruded out from the outlet channel. The deformation occurs at the die corner as the billet is pressed. The ECAP technique is always conducted with the high plunger speed. In case of hard materials, the billet is preheated to enable easy deformation and to reduce the plunger force. The ECAP is now being used for manufacture of ultrafine grained structures of different materials. The products made from ECAP process include fasteners, plates etc.

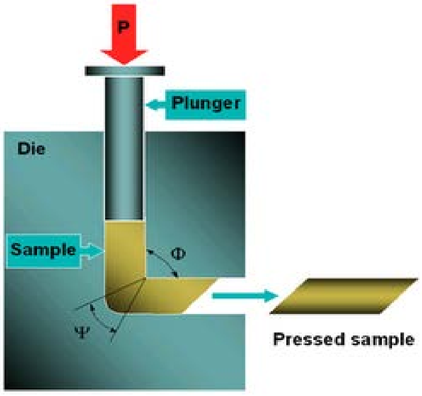

Fig 1: Conventional ECAP process

Langdon et al [3] studied the effect of various routes on the processing of the material in ECAP and it was found that, type of route plays an important role in evolution of grains. Nakashima et al [4] performed experimentation on commercially pure aluminum in ECAP and studied the effect of channel angle on grain characteristic. It was found that the better grain size and orientation was obtained with the channel angle close to 90 degree. Yamashita et al [5] conducted tests on various samples of aluminum alloys to study the effect of pressing temperature on material characteristic. It was found that the measured grain size tend to increase with increasing pressing temperature. Fukuda et al [6] processed low carbon steel by ECAP and found that ECAP increased the 0.2% proof stress and the ultimate tensile strength (UTS) but there was a corresponding decrease in the elongation to failure. Shin et al [7] investigated the development of microstructure during equal-channel angular pressing (ECAP) of commercial-pure titanium and the mechanisms of grain refinement and strain accommodation.

NEWLY DEVELOPED ECAP DIES

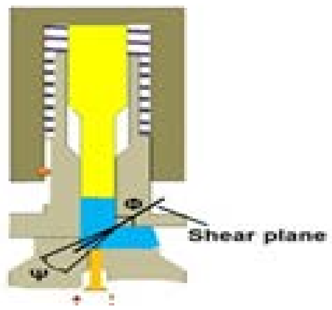

Fig.2 Spring Loaded Die

Spring loaded Die

The Spring loaded die is shown in the Fig. 2 which consist of two parts, upper die and lower die.The upper die consist of Case, sliding tool, spring and upper pin, while the lower die consists of lower pin which can act as ejector. Here the sliding tool forms the input channel and bottom die forms the exit channel, when the case moves with the punch towards the bottom die. This movement results in a die, with channel angle (Φ) of 90◦ and die corner angle of 20◦. The upper pin pushes the specimen to the shear deformation zone of the channel, and simple shear deformation occurs. During this operation, the coil spring suppresses separation between the sliding tool and the bottom die producing the ECAPed specimen without flash. After completion of the ECAP, the sliding tool retreats and the deformed specimen is kicked out from the die by the lower pin. In this way, the specimen is deformed in the same manner during a cyclic processing.

Jin et al [8] conducted the bolt forming of Aluminum alloy 6061 with spring loaded ECAP and it was found that the force required for extrusion in this process was considerably less also the production rate was increased considerably. Here the material removal from the die was made simple and easy with the ejector mechanism.

Rotary Die

The rotary die is used when the material under ECAP requires multiple passes. Here the multiple passes of the material is achieved without removing the material from the die. The Fig.3 shows the setup of the rotary die. The rotary die consists of a die holder with side plates and a die. The die has four channels in such a way that, the adjacent channels meet each other at 90 degree. The working of the die is as follows: suppose the raw material is to be inserted in the channel 1, then in channel 2, 3 and 4 movable punch or the confined punch is placed. Hence in channel 2 movable punch is placed and in channel 3 and 4 confined punch is placed. The confined punch helps to guide the material in the required direction and the movable punch moves in backward direction as the plunger advances. As the plunger touches the top surface, the extrusion takes place. Now for the second pass, instead of removing the material from the die, the die is rotated by 90 degree. Now the channel 2 becomes the main channel of raw material and channel 3 becomes the movable die and 4 becomes confined. Hence the raw material need not be removed out of the die in every pass.

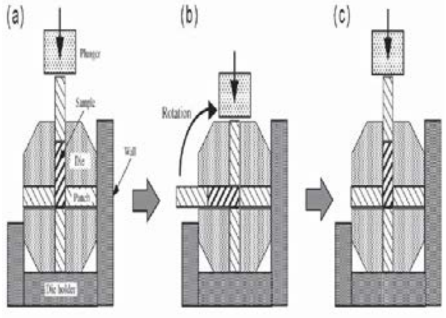

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Fig.3 Rotary Die

Ma Aibin et al [9] used Al-Mg-Si alloy as sample with the billet size of 9.5 mm in diameter and 40 mm in length. The alloy was pressed at the rate of 1mm/s for 20 times at 573k. It was observed that the larger number of passes were required than the conventional method but the rate of passes and ease was increased tremendously. Nishida et al [10] investigated the microstructural development and mechanical properties of commercial Al-Si-Mg alloy after processing it in rotary die. After multiple passes, the sample showed clean surface without any surface defect or crack. There was drastic decrement in grain size and microstructure was found to be almost homogeneous. Yoon et al [11] applied finite element method to analyze the plastic flow and strain hardening behavior of pure copper subjected to rotary ECAP. It was observed that the deformation became inhomogeneous as the number of passes increased.

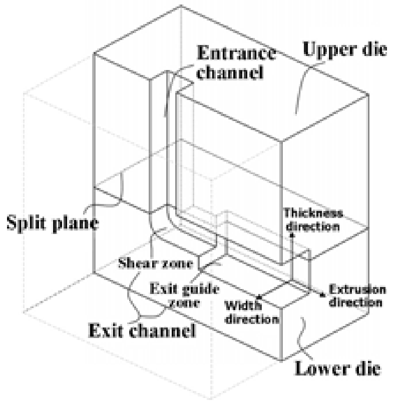


Fig.4 Split Die

Split Die

Split die is used for easy removal of material and reducing the back pressure which is developed due to friction produced between the die and the material. As shown in the Fig.4 the split die consist of upper and lower dies which are bolted together. Hence the material can be removed easily by unbolting and separating the dies. The width and the thickness of the lower part of the exit zone is increased as compared to the other parts to reduce the back pressure.

Zhi Chao Duan et al [12] tested the high purity aluminium with split die for multiple passes. The aim of the experiment was to produce high degree of homogeneity in a given material, but the result demonstrated that, after 2 passes the homogeneity of the material decreases. Although this die was found ineffective comparatively, but it made material removal very easy and increased the productivity. Jahadi et al [13] studied the effect of Split die-ECAP process on the microstructure and mechanical properties of wrought AM30, Magnesium alloy. The process was performed up to 4 passes and it was observed that the grain structure got refined from 20.4 µm to 3.9 µm. The comparison of the various test showed the reduction in the asymmetry in yield as the number of passes increased.

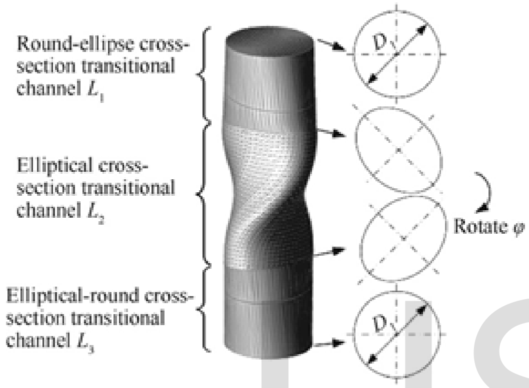


Fig.5 Spiral Die

Spiral die

The elliptical cross-section spiral equal-channel extrusion (ECSEE) can aggregate the torsional shear, extrusion and upsetting deformation. The schematic diagram of blank via the channel of ECSEE die is shown in Fig. 5. ECSEE is based on extruding out a round-bar blank through the die with a profile consisting of three channel regions: round-ellipse cross-section transitional channel L1, elliptical cross-section torsional transitional channel L2 and ellipse-round cross-section torsional transitional channel L3. The blank undergoes severe deformation while maintaining its original cross-section. This property allows the blank to be extruded repeatedly in order to accumulate deformation, which changes the microstructure & properties of the blank.

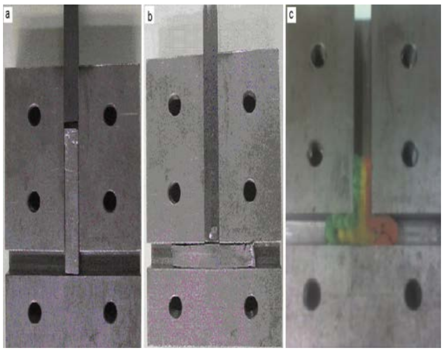
Wang et al [14] optimized the process parameters of ECSEE and found the optimal combination of process parameters to be: φ of 120°, m of 1.55, L_1 of 7 mm, $L2$ of 10 mm, and L_3 of 10 mm.

T-shaped die

The T shaped ECAP pressing apparatus as shown in the Fig.6 which consist of two blocks, one block has the T shaped channel and the other block is just used to cover the first block. Both the channel has same cross section. In this apparatus the material to be extruded is place in the channel 1 as shown in the figure and then pushed with the plunger ,the marking is made on the plunger to stop at the place where the horizontal cross section start. Hence the material gets extruded from the vertical channel to the horizontal channel.

V.SrinivasRao et al[15] performed experimentation on Pb-Sn eutectic alloy in T shaped ECAP. The extrusion was done for several passes. It was observed that the hardness decreased in every pass. The hardness value remains constant for every sample along their length, except at the center, where the hardness value shows the peak. There was tremendous microstructural refinement of about 230%. Nagashekar et al [16] used the DEFORM tool to study the strain hardening behaviour of the processed material. It was found that the deformation behavior was more complicated and the strain was more localized. The simulation results were in good agreement with the actual experimentation process. In addition to this, the load requirement was more as compared to conventional ECAP.

Fig.6 T-Shaped Die

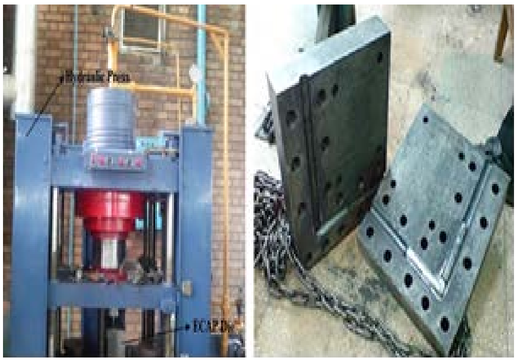


ECAP WITH ASSISTED PROCESSES

Ultrasonic assisted ECAP

In ultrasonic ECAP process the ultrasonic vibration is applied to the die which is used during processing of material in the ECAP process. The application of high frequency ultrasonic energy to the specimen during compression and tension reduces the yield strength of the material. This is due to the acoustic softening which happens during the application of ultrasonic vibration to the metal during the metal forming process. Also, the ultrasonic energy helps to reduce wrinkling and cracking of the material during the forming process. The Ultrasonic assisted ECAP process is shown in the Fig. 7.

Fig. 7 Ultrasonic assisted ECAP



R.Naseri et al [17] conducted experiments on AA 1070 with ultrasonic ECAP to study the effect of ultrasonic vibration on the average load applied. Here the study of different parameters like die geometry, friction factor, amplitude and frequency was done and compared with that of conventional ECAP process. It was observed that there was 13% reduction in average force at amplitude of 2.5 µm and frequency of 20 kHz. Faraji et al [18] investigated the influences of ultrasonic vibration (UV) amplitudes in axial and radial directions on the deformation behavior and required punch force of T-ECAP process using finite element analysis. The numerical results indicated that the magnitude of imposed effective strain and the uniformity of strain distribution are enhanced by applying ultrasonic vibration. The simulated results showed that application of ultrasonic vibration needs lower pressing force to carry out ultrasonic assisted tubular channel angular pressing process.

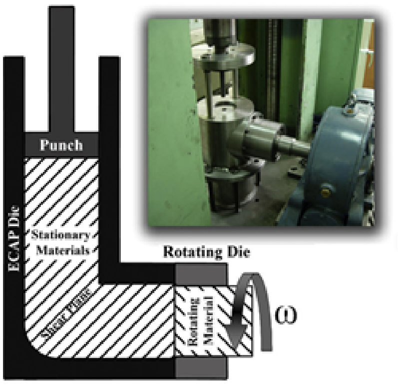


Fig.8 Torsional ECAP

Torsional ECAP

In both ECAP and Torsional-ECAP techniques the material bent through an angle (channel intersection angle; ϕ) from vertical channel into horizontal (exit) channel. The main difference between these two processes is that a part of the exit channel in the T-ECAP process rotates around its axis in contradiction to ECAP process as shown in the Fig. This imparts faster grain refinement and requires lesser number of pass as compared to the conventional ECAP process.

Behtash Mani et al [19] performed experimentation on AA1050 with Torsional ECAP and conventional ECAP. It was found that there was decrease in the load requirement and the distribution of hardness was more uniform in Torsional ECAP as compared to conventional ECAP. Li et al [20] conducted experimental study on Torsional ECAP technology for deformation and densification of pure Al and Mo powder sintered materials and compared the results with that of ECAP. The results showed that there was stronger severe plastic deformation during the process of Torsional ECAP. In this process after three passes, the grain size of powder reduced up to 200%.

CONCLUSION

In this paper, the conventional ECAP process is compared with ECAP of the new die designs and it was found that the new designs gave some advantage over the conventional die of ECAP process.

The spring loaded ECAP system decreased the plunger force tremendously and also increased the productivity. The rotary die increased the productivity and solved the problem of removing the material. The T-shaped die gave the maximum deformation of the material with almost same ductility. The split die led to the refinement of the grains at higher extent and maintained the homogeneity of the material. The newly introduced assisted processes helped in decreasing the yield point of the material during forming. Hence the load required for deforming the material decreased tremendously in assisted ECAP process.

Hence, this paper reviewed the various changes in the die design of ECAP for improvement in performance characteristics of the process.

REFERENCES

[1] S. T. Adedokun, "A Review on Equal Channel Angular Extrusion as a Deformation and Grain Refinement Process," *Journal of Emerging Trends in Engineering and Applied Sciences* , vol. 2, pp. 360-363, 2011.

[2] T. G. Langdon, M. Furukawa, M. Nemoto and Z. Horita, "Using equal-channel angular pressing for refining grain size," *JOM*, vol 52, pp. 30-33,2000

[3] Y. Iwahashi, Z. Horita, M. Nemoto and T.G. Langdon, "The process of grain refinement in Equi-Channel Angular Pressing," *Acta Materilia*, vol 46, pp.3317-3331, May 1998.

[4] K. Nakashima, Z. Horita, M. Nemoto and T. G. Langdon, "Influence of channel angle on the development of Equi-channel angular pressing," *Acta Materilia*, vol 46, pp.1589-1599,March 1998.

[5] A.Yamashita, D. Yamaguchi, Z. Horita and T. G. Langdon, "Influence of pressing temperature on microstructural development in Equal-Channel Angular Pressing," *Acta Materilia*, vol 287, pp.100-106, July 2000.

[6] Y. Fukuda, K. Oh-ishi, Z. Horita and T. G. Langdon, "Processing of a Low Carbon Steel by Equi-Channel Angular Pressing," *Acta Materilia*, vol 50, pp.1359-1368.

[7] D. H. Shin, I. Kim, J. Kim, Y.S. Kim and S.L.Semiatin, "Microstructure development during Equal-Channel angular pressing of Titanium," *Acta Materilia*, vol 51, pp. 983-996, February 2003.

[8] Y. G. Jin, H. M. Baek and B. C. Jeon, "Continuos high strength aluminium bolt manufacturing by spring loaded ECAP system," Journal of Material processing Technology, vol 212, pp. 848-855, April 2012.

[9] Aibin Ma, Yoshinori Nishida, Kazutaka Suzuki, Ichinori Shigematsu, Naobumi Saito, "Characteristics of plastic deformation by rotary-die equal channel angular pressing, " Scripta Materialia, Vol. 52, pp. 433-437, March 2005.

[10] J. C. Kim, Y. Nishida, H. Arima and T. Ando, "Microstructure of Al-Si-Mg alloy processed by Rotary –Equichannel Angular Pressing" , *Materials letter*, vol. 57, pp.1689-1695, March 2003.

[11] S. C. Yoon, M. H. Seo, A. Krishnaiah and H. S. Kim, "Finite element analysis of Rotary die Equi channel angular pressing," *Material Science and Engineering*,, vol.490, pp.289-292, August 2008.

[12] Zhi Chao Duan, Terence G. Langdon, " An experimental evaluation of a special ECAP die containing two equal arcs of curvature", *Material Science and Engineering*, Vol. 528, pp. 4173-4179, May 2011.

[13] R. Jahadi, M. Sedighi and H. Jaged, "Ecap effect on the microstructure and mechanical properties of AM30 Mg alloy", *Material Science and Engineering*, vol.593, pp. 178-184,January 2014.

[14] C. Wang, F. Li, H. Lu, Z. Yuan and B. Chen, "Optimization of structural parameters for elliptical cross-section spiral equal-channel extrusion dies based on grey theory", vol.26, pp.209-216, February 2013.

[15] V. S. Rao, B. P. Kashyap, N. Prabhu, P. D. Hodgson, "T-Shaped Equi-Channel angular pressing of Pb-Sn eutectic and its tensile properties", *Material Science and Engineering*, vol.486, pp.341-349, July 2008.

[16] A. V. Nagasekhar and H. S. Kim, "Analysis of T-Shaped angular pressing using finite element method",*Metals and Materials Internationals*,vol. 14, pp.565-568, October 2008.

[17] F. Djavanroodi, H. Ahmadian, K. Koohkan and R. Naseri,"Ultrasonic assisted ECAP", *Ultrasonics*, vol. 53, pp. 1089-1096, August 2013.

[18] G. Faraji , M. Ebrahimi and A.R. Bushroa, "Ultrasonic assisted Tubular Channel angular pressing process", *Material Science and Engineering*, vol, 599,pp.10-15, 2014

[19] B. Mani, M. Jahedi and M. H. Paydar, "A modification in ECAP process by incorporating torsional deformation", *Material Science and Engineering*, vol. 528, pp.4159-4165, May 2011.

[20] Y. Z. Li, X. B. Bai, Y. M. Xie and K . M. Xie, "Equal Channel Angular Pressing and Torsion (ECAPT) for Densification and Strengthening Properties of Powder Sintered Materials", *Advanced Materials Research* , vol. 146, pp.101-104, 2011.