

Application of Separated Die Design To Production of Ecap Dies

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Abstract. Metal forming processes with principally shear stresses that very high plastic strains are obtained in one pass are defined as severe plastic deformation (SPD) processes. Strain values can additionally be increased with additional passes throughout the process. Equal channel angular processing (ECAP) is the most applied method among the SPD processes due to relative ease of die manufacturing. On the other hand, die failures like corner cracking are frequently observed due to high notch effect and therefore use of the dies is limited. In the presenting study multi element die design(separated die design) approach was applied to production of ECAP dies in order to eliminate die failures and 5083 Aluminum alloy specimen were deformed with several passes. Although some additional development for die arrangement and fixation are needed, corner cracking was never observed and dies could be used safely.

Introduction

Among the plastic deformation processes, severe plastic deformation methods are the most effective ways to obtain high strength increase and especially grain size refinement by relatively simple dies and die arrangements [1, 2, 3]. In the equal channel angular pressing (ECAP), entrance and exit cross sections of the material are same but there is an angular difference(Φ) between them[1, 2]. Basic die geometry and the die arrangement are shown in figure 1.

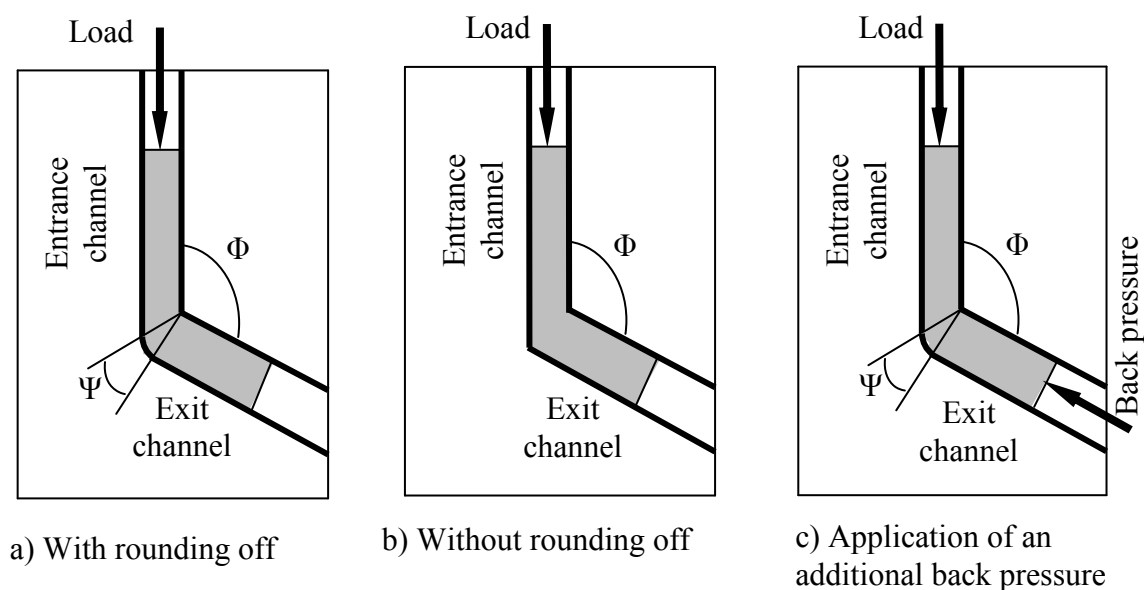


Figure 1. Basic die geometry and process parameters for the ECAP processes.

In classical ECAP applications entrance and exit cross sections are produced as square in shape, and the dimensions vary according to the available press loads, material properties and frictional conditions. Equal channel dimensions permit the specimen repeatedly be deformed in order to obtain higher strain values. The average strain value obtained in one pass is calculated as given in Eq. 1 [1,2,3]:

$$\varepsilon = (1/\sqrt{3})[2(\cot((\Phi/2)+(\Psi/2))) + \Psi \operatorname{cosec}((\Phi/2)+(\Psi/2))] \quad (1)$$

If there is no curvature between the channels (Fig. 1b), Ψ becomes zero and considering the number of the passes as N , total strain after N passes is given with a simpler form in Eq. 2:

$$\varepsilon = (N/\sqrt{3})[2(\cot(\Phi/2))] \quad (2)$$

According to the second equation, very high equivalent strains can be obtained after several passes in ECAP processes. In some cases, additional back pressure (Fig. 1c) is applied in order to increase workability of the processed material [1,2,4].

In addition to obtaining very high strains and strengthening, average grain sizes are considerably decreased in severe plastic deformation processes by high shear strains. Ultra fine grains are obtained by the process and the subject regarded in nano-structure applications. There are several articles about the grain size effects on the mechanical properties [1,2,3,4,5].

On the other hand, besides the achievements on mechanical properties, there are some problems about the ECAP dies. Increasing overall strains require high extrusion forces. This also increases the frictional forces between material and die walls even lubricants are used. High total load requires high strength materials for the punch and die design and weakens the buckling stability of the long punches. Additionally, for square and rectangular cross section impose very high stress concentration on the die corners causing cracking [3,6].

There are several works on the alternative die design to decrease frictional effects thus total loads, to facilitate the material flow around the corners, to use classical extrusion combining with an ECAP die [7,8,9,10,11]. In order to overcome the buckling risk, punches are sometimes be made as short pieces and put into the dies orderly. In some cases channel cross sections are made as circular in order to minimize the notch effect and thus the crack formation [3].

In the presented study an alternative die design is proposed and applied in order to eliminate cracking around die corners. ECAP die has been made four pieces and the pieces placed in a die holder cylinder in order to keep them together during the process. Because of the dies have already been separated along the corner regions, there is no risk of cracking.

Die geometry and special considerations

Among the ECAP dies, the zero rounding off ($\Psi = 0$ in Fig.1a) and perpendicular channel ($\Phi = 90^\circ$) is the most applied form with approximately 115% equivalent strain in one pass, easiness of machining and with maximum grain refinement. This type of geometry was chosen in this study. Channel cross sections are machined as $8 \times 8 \text{ mm}^2$ and length of the channel is 60 mm.

Considering the harsh frictional conditions and high pressure in the channel region, die parts are machined AISI H13 hot work tool steel, hardened at 1040°C and tempered at 600°C to 50 HRC hardness level. After the heat treatment, dies were polished before the tests. Punches were cut from $8 \times 8 \text{ mm}^2$ high speed tool steel cutters.

Die parts were machined from four rectangular tool steel bars so the perpendicular cross section of the channel was formed among the four separated parts. Then the vertical channel was machined at the bottom of the Number 1 part of Figure 2 in a milling machine. After the machining the channels, rectangular die parts were rounded off with lathe machining to 28 mm diameter.

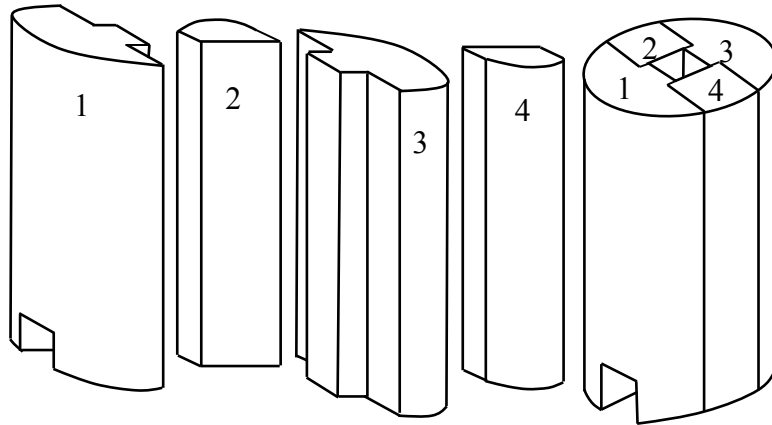


Fig. 2 Separated ECAP elements and the die assembly

All the parts were placed into a 28 mm diameter thick walled cylindrical hole of the main die assembly as tight fit. Probable vertical movement of the ECAP parts are prevented using bolted joints between the rest of the main assembly and the thick walled cylinder. Photos of the parts and the die assembly are given in Figure 3.

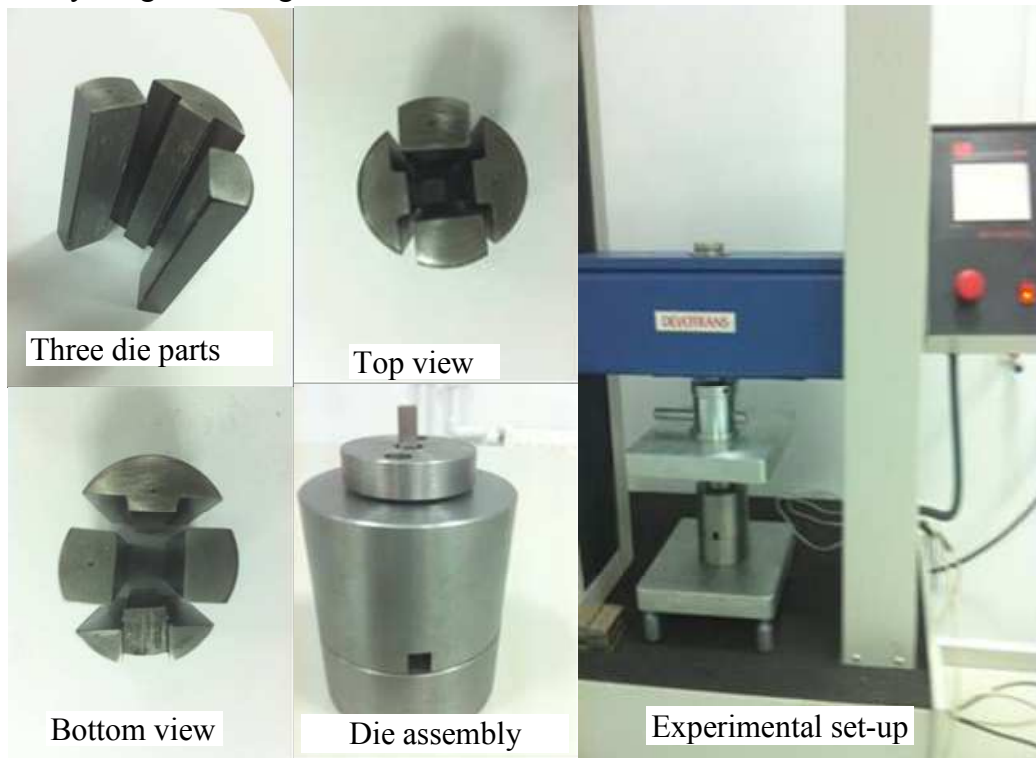


Fig. 3 Photographs of the separated die elements and the die assembly.

Specimen and die walls were lubricated prior to each test. After finishing the test, dies and ECAPed specimen were taken off from the die holder cylinder using ejector punches due to high blocking pressure between die parts and the holder.

Experimental Study

In the experimental work of the study, specimen were ECAPed using a 100 kN screw driven universal material testing machine with constant cross-head speed of 10 mm/sec. Due to the low load capacity of the machine, cross sections of the test specimens and their lengths were machined

as 8x8 mm² and 30 mm length from H32 grade AA5083 aluminum alloy sheet. Average hardness of the specimens was measured as 85 HV before the ECA processing. This value is very close to the test material's standard values [12].

Test pieces are taken off the dies after various punch travel in order to observe the material flow during the process. Some pairs of 15mm high specimens were put into the die channel on each other, pushed through the exit channel and taken off the die for various punch travel. Photographs of some test pieces are shown in Figure 4. During the upsetting period test loads increased sharply up to approximately 60 kN, and begun to decrease slightly due to decrease in the length of entrance(upset) channel as expected. Hardness distribution on the specimen in entrance and exit channels regions was measured.



Figure 4. Photographs of the ECAPed test pieces.

In the upset channel hardness values were measured around 100-110 HV and 140-150 HV in the exit channel. Main hardness increase occurred in the narrow corner region. This variation was observed in all the test specimens. Hardness increase due to ECA processing can be calculated approximately 40% between entrance and exit channels and 65% with respect to initial material hardness. This values are harmonious with the literature [1,3,11].

This results indicate that the ECA processing in this study can be regarded as successful and the dies can be used such experimental studies.

Conclusion

Presented study is conducted to propose and make an alternative die design in order to eliminate corner cracking during ECA processing of square cross sectioned test pieces. Dies were produced as separated four pieces and fixed together in a cylindrical die holder. No corner cracking have been observed on the separated dies. Some additional developments for die arrangement and fixation are needed in order to decrease testing time and increase the automation facilities. From the experimental results, the study can be regarded as successful and dies can be used safely.

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