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ECAP Die Design for Minimising Corner Gap

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Abstract

Abstract. In this paper strain distribution and deformation behaviour of 4 commercially available aluminium alloys with increasing range of hardness through ECAP process is studied. Present work shows the dependencies of corner gap formation on outer arc angle and materials hardness. A circular channel ECAP die is studied in this work, which is suitable for processing both hard and soft materials. For analysing the results FEM modelling approach has been adopted, and for validating the analytical results, FEM analysis and lab experiments are performed. FEM analyses are carried out with four different aluminium alloys i.e., AL99/AA1100, AL6061/AA6061, AL7075 and AL2014 with increasing hardness. It is concluded that with increasing hardness of material and increasing outer arc angle, the corner gap formation reduces and shifts towards the first channel, the lower corner gap formation also leads to uniform distribution of equivalent strain. It is also observed that ECAP die with 30^{o} outer arc angle, deformation is more homogenous without any strain concentration.

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1. Introduction

Equal Channel Angular Pressing (ECAP) [1, 2] has attracted a lot of attention among researchers globally because of its potential to be used at an industrial level [3] for grain refinement. In recent years, many researchers have studied the effect of outer arc angle / corner angle on strain distribution and homogeneity in the processed specimen [4- 7]. But the effect of material hardness on corner gap formation and its dependencies with Outer arc angle is yet to be reported. In this work a helpful in-site is given on right ECAP die selection (in terms of Outer Arc Angle (Ψ)) for suitable material (in terms of Brinell hardness (HB)). Experimental and FEM analysis, both are carried out for

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validating the facts. The results concluded that ECAPed specimen with high hardness results in smaller corner gap formation at the bottom of the die, it is also observed that with an increase in specimen hardness corner gap formation shifted towards the first channel (**Fig.1**). Smaller corner gap formation helps to achieve better strain distribution uniformity, throughout the section.

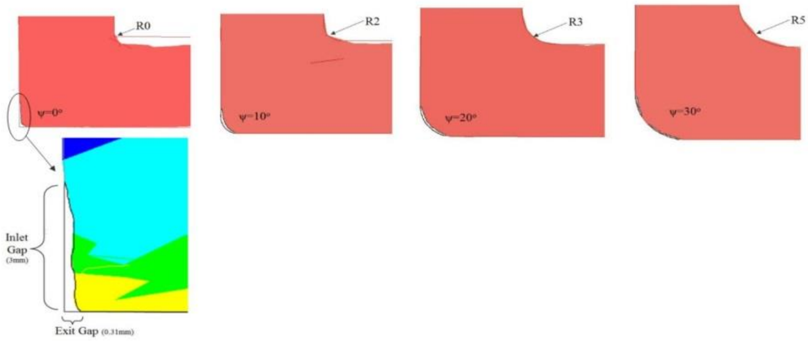

Fig.1: Corner gap formation

Nomenclature

Φ	Intersection angle
Ψ	Outer arc angle
HB	Brinell hardness (HB)

1.1 Results and discussion:

In this work FEM analysis is carried out at an ambient temperature (25^0C) on four different aluminium alloys , i.e., AL99/AA1100, AL6061/AA6061, AA7075 and AA2014 with increasing Brinell hardness as shown in (Table: 1). Four outer arc angles (Ψ), i.e., 0^0,10^0,20^0,30^0 are used for the investigation. FEM modelling and experiments are carried at 1 mm/second punch velocity, and at 2 different shear friction constants i.e., m=0.4 and m=0.05.

Aluminium Alloys		
Alloy Name		**Brinell Hardness (HB)**
Al99/AA1100		**20-23**
Al6061/AA6061		**35-40**
AA7075		**60-65**
AA2014		**105**

Table.1 Material hardness

1.1.1 Corner Gap formation:

During Experimental and FEM analysis a corner gap is observed at junction of entry and exit channel (**Fig. 2**). This gap is because of sharp edge present at junction of entry and exit channel, as corner angle (Ψ) increases, formation of corner gap reduces. In circular cross-section die formation of corner gap is asymmetric: the length of corner gap is more on the entry side than the exit side of the channel. At corner angle Ψ= 30^0 a minor gap is observed at entry and exit channel. As the corner angle increases above 30^0 corner gap doesn't observe at the exit channel and it starts to decrease on the entry side.

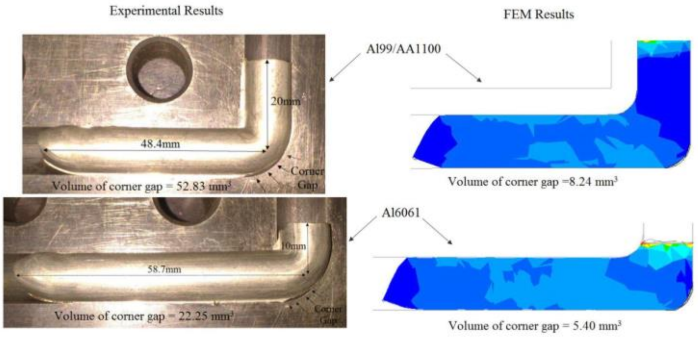

Fig.2: FE and experimental result comparison

1.1.2 Effect of Corner Gap on strain distribution from bottom to top layer:

The formation of corner gap affects strain distribution in processed billet. FEM Results concluded that in comparatively softer aluminium alloy at relatively smaller outer arc angle, the majority of plastic strain concentration takes place at the bottom layer of the specimen. For harder alloys and greater outer arc angle, strain concentration is more uniformly distributed from bottom to top of the specimen. Formation of corner gap and upper fillet radius is responsible for the strain distribution throughout the section. For outer arc angle $\Psi = 0^0$, at the top portion, a gap is formed due to which the specimen in this region is no longer in contact with the die. This reduces the deformation at the top portion of the specimen and lead to non-uniform distribution of the equivalent strain.

The plots of average Eq. strain concentration at top, middle and bottom layers are plotted (Fig.3). It observed that the uniformity of equivalent strain distribution increases from bottom to top of the specimen with an increase in outer arc angle (Ψ). From FEM analysis, it is also observed that ECAP dies having $\Psi = 30^0$ and inner fillet radius r=5mm, gives more uniformly distributed equivalent strain for all materials. In this case, for Al99 aluminium alloy Eq. strain concentration at bottom layer is about 9% and 20% more than the Eq. strain concentration at the top layer and middle layer, respectively. And for harder alloy Al2014 at (Ψ= 30^0), Eq. strain concentration at top layer is about 2% more than the strain concentration at the bottom layer. And Eq. strain concentration at bottom layer is about 6% higher than the total strain concentration at the middle layer

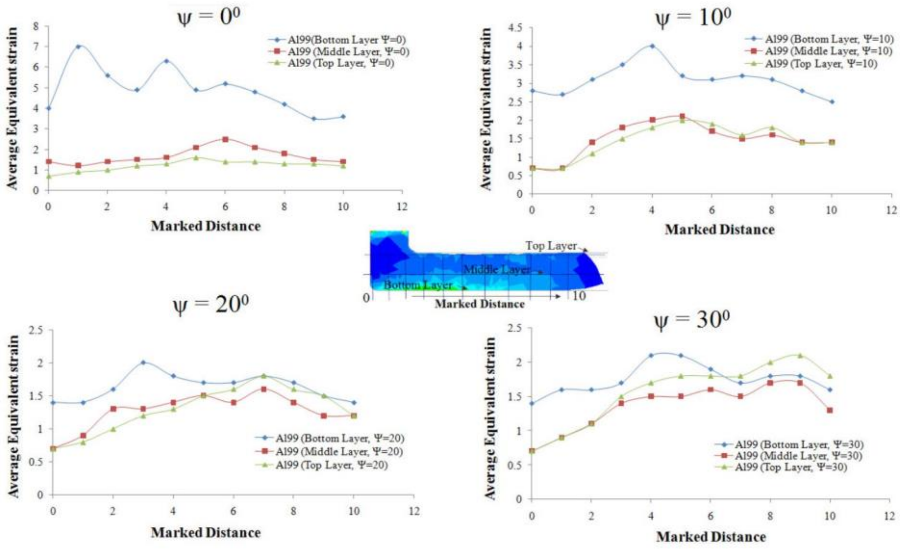

Fig.3 Equivalent strain distribution at top middle and bottom layer

1.1.3 Effect of friction and Corner Angle on strain concentration:

The effect of friction on Eq. Strain Distribution is shown in **Fig.4.** For shear friction factor m=0.4, a segment of a bottom layer of the processed specimen has a tendency to stick to the outer channel surface. For Ψ =0^0 at high Friction (m=0.4) a bottom layer segment is stick to the corner of the outer channel surface and does not move and creates a dead metal zone as shown in (**Fig.4**). As a consequence of this the strain at the bottom surface of the deforming specimen increases and strain distribution becomes highly inhomogeneous. Providing a corner angle (Ψ), helps to negate the effect of friction and make the strain distribution more homogeneous.

From the FEM analysis, it is also observed that in comparatively softer alloys (Al99, Al6061) at high friction (m=0.4), strains are more in-homogeneously distributed. In harder alloys (Al7075 and Al 2014) strain distribution is largely independent of friction, at both frictions (m= 0.05 and 0.4) it gives almost similar results. In order to avoid strain concentration, a corner angle is provided. From FEM results it is concluded that for all materials and frictions, in ECAP die with 30^0 outer arc angle and 5mm fillet radius, deformation is more homogeneous without any strain concentration.

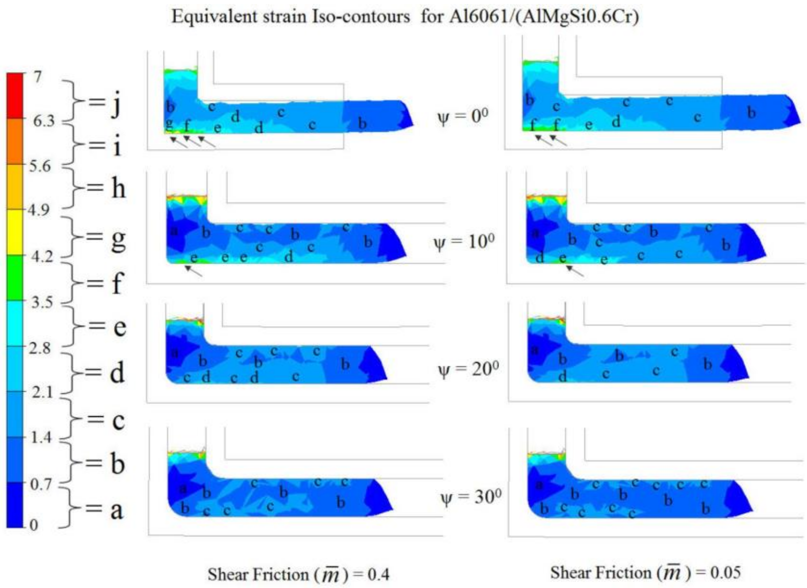

Fig.4. Equivalent Strain distribution at shear friction m=0.4 and 0.05

Conclusion

In this work FEM and experimental analysis has helped a lot to understand the deformation behaviour of material during ECAP. Numerical modelling on the effect of outer arc angle (Ψ) and formation of corner gap has provided a significant insight in the process. Formation of corner gap depends on outer arc angle (Ψ), with an increase in outer arc angle, formation of corner gap reduces. In circular die if corner angle increase >30^0 no corner gap has occurred. Outer arc angle (Ψ), corner gap, fillet radius and hardness of material have a significant role in distribution of equivalent strain. With increasing corner angle, strain get more uniformly distributed in the specimen and maximum strain concentration shifted from bottom to top layer. The same effect can also be observed with increasing hardness of the processed material. As the hardness of material increases strain gets more uniformly distributed from bottom to top layer in the specimen.

From the FEM analysis, it is observed that in comparatively softer alloys at high friction (m=0.4), strains are more in-homogeneously distributed. In harder alloys (Al7075 and Al 2014) strain distribution is largely independent on friction, at both frictions (m= 0.05 and 0.4) it gives almost similar results. In order to avoid strain concentration, a corner angle is provided. From FEM results it is concluded that for all materials and frictions, a ECAP die with 30^0 outer arc angle and 5 mm fillet radius, deformation is more homogeneous without any strain concentration.

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