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Investigation of the Effect of Channel Angle and Outer Corner Radius in Equal Channel Angular Pressing (ECAP) Process

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Abstract**—** *Equal channel angular pressing (ECAP) is one of an effective process technique that is widely used to get fine grained microstructures in metal* and *alloys with retaining of billet cross-section. In the present study, finite element methods (FEM) performed using ABAQUS software to investigate the effect of die geometry and ECAP process parameters on pressing force and equivalent plastic strain* (*PEEQ*). The results *confirm a significant effect of die geometry and coefficient of friction on pressing force and equivalent plastic strain in such a manner; as outer corner radius* and *channel angle increase, the pressing force and equivalent plastic strain decrease. While when the friction coefficient increases, both of pressing force and equivalent plastic strain increase. On the other hand, the corner cap decreases with increasing the friction of coefficient.*

Keywords**—** *Equal channel angular pressing (ECAP), pressing force, the outer corner radius, equivalent plastic strain (PEEQ), die geometry and corner gap.*

I. INTRODUCTION

Among others, equal channel angular pressing (ECAP) is an effective process which use to produce ultrafine-grained microstructures with increased mechanical properties of metals and alloys. ECAP's die consists of two equal cross-sectional areas of channels intersect at a specified angle. The channel intersection angle varies between 90^o and 120^o. The billet is pressed through an ECAP die, then it undergoes intense plastic deformation in the intersection corner region of the two channels without any change in its shape and size. So, it can be useful to press the billet several times until reaches the desired amount of accumulation plastic strain [1].

By assumptions, uniform plastic deformation, a frictionless condition, no corner gap and ideal plastic behavior of the material used in the process, V. M. Segal et al. [2] in 1995 deriving the following equation to calculate the theoretical equivalent plastic strain ($\acute{\varepsilon}_p$) after N passes:-

$$\bar{\varepsilon}_p = \frac{2N}{\sqrt{3}}\cot\ \phi \qquad (1)$$

where: Ø is the intersection channel angle.

Then, in 1996, Iwahasi et al. [3] was modified equation No. (1) by using a rounded corner die model. He proposed equation No. (2) as following:-

$$\bar{\varepsilon}_p = \frac{1}{\sqrt{3}}\left[\cot\ \left(\phi+\frac{\psi}{2}\right)+\psi\cos ec\left(\phi+\frac{\psi}{2}\right)\right] \qquad (2)$$

where: ψ is the corner channel angle.

Both above equations don't show any details about predicted strain distribution across the billet's cross-section. The strain distribution is affected by the friction condition during the process and geometry of die such as channel angles (Φ and Ψ). The predicts of strain distribution can be obviously obtained by Finite Element Method (FEM).

Basavaraj V. [1] reported, the inhomogeneity in strain distribution decreases with increasing the friction, and also the corner gap decreases as friction increases. 3D finite element analysis has been carried out for different outer corner radius in ECAP with a certain channel angle die [4]. The authors revealed that both equivalent plastic strain and strain affected by the radius of the outer corner of the die and the inhomogeneity was high for large outer corner die. Gholami J. et al. affirmed that the average amount of plastic strain is reduced with increasing the outer channel angle, while it increases by increasing the coefficient of friction [5]. The effect of friction condition and the geometry of ECAP die on the irregularity of shear strain and mechanical properties of billet in the ECAP process, have been investigated by Parshikov R. A. et al. [6] using experimental and finite element analysis. Their study obviously emphasised that, equal channel angular pressing process characterized by the irregular distribution of shear strain and can be reduced by the applicable selection of die geometry and friction coefficient.

Anibal de Andrade Mendes et al. [7] proposed guidelines for die design and manufacturing of ECAP die. Also, the effect of operating parameters of the process on the deformation level, homogeneity of product and process safety and control were studied. Mechanical properties such as microhardness and strength of aluminum alloy after ECAP process studied by Shaeri M. H. et al. [8]. They found, these mechanical properties increase by increasing the process temperature until 120^oC, while when the temperature increases above 120^oC upto 180^oC, they are decreasing. Furthermore, they concluded, the increasing of process temperature has an influence on grain size and dislocation density. Djavanroodi F. et al. [9] simulated the ECAP process model using commercial purity aluminum as a billet material. The authors investigated the effect of die channel angle, outer corner angle and pass number of billet on the magnitude of effective strain and strain

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distribution behavior. Their study revealed the decisive role of a number of passes that causes high strain distribution heterogeneity and confirmed with increasing yield strength and ultimate tensile strength and reduction of grain size. Followed by Muralidhar Aviaries at el. [10] study identified the significant effect of a number of pass and process temperature on the improvement of mechanical properties, the percentage elongation, and grain size.

The Aim of the Present Study

The goal of the present study is to investigate the influences of die geometry and friction condition on the ECAP process. The finite element method (FEM) has been employed to reveal the effect of the ECAP process's parameters and die geometry on pressing force and equivalent plastic strain (PEEQ). FEM was carried out using ABAQUS ver.6.18 [11].

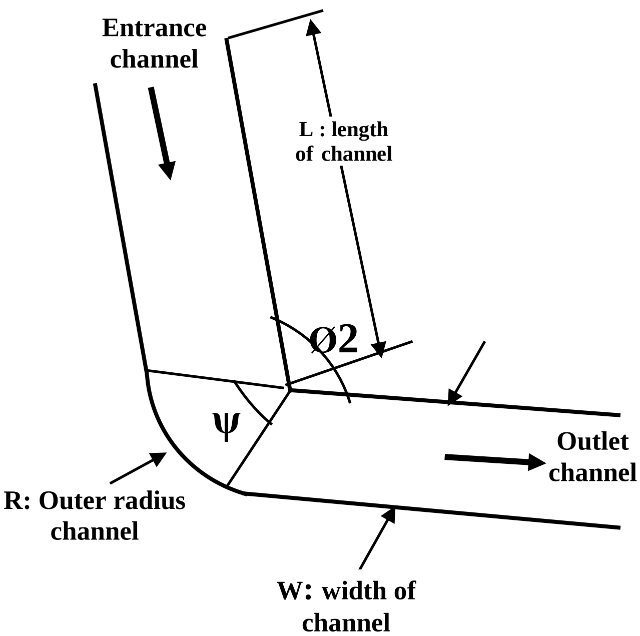
II. Materials and Finite Element Model

For FEM simulation, aluminum alloy considered as a billet material with flow stress given by ($\sigma_o = 208\varepsilon^{0.25}$) [12]. While Yield stress, the Poisson ratio and Young's modulus were assumed (75.8 MPa, 0.33 and 69 GPa) respectively.The billet is assumed to be a rectangular cross-section area with a length of (100 mm) and of (10 mm) width.

Finite Element Simulation

Because of the symmetry about parting surface, soonly half a portion of billet and die was considering for modeling. The billet was modeled by using (4-nodes bilinear plane stress [1]. While the channels were made of steel and defined as discrete rigid.

Figure (1) illustrates the ECAP die and billet model using in ECAP process simulation. The billet is inserted in the entrance channel then pressed to move through the die. So intense plastic deformation takes place in the intersect channel region with retaining its cross-sectional geometry [6].



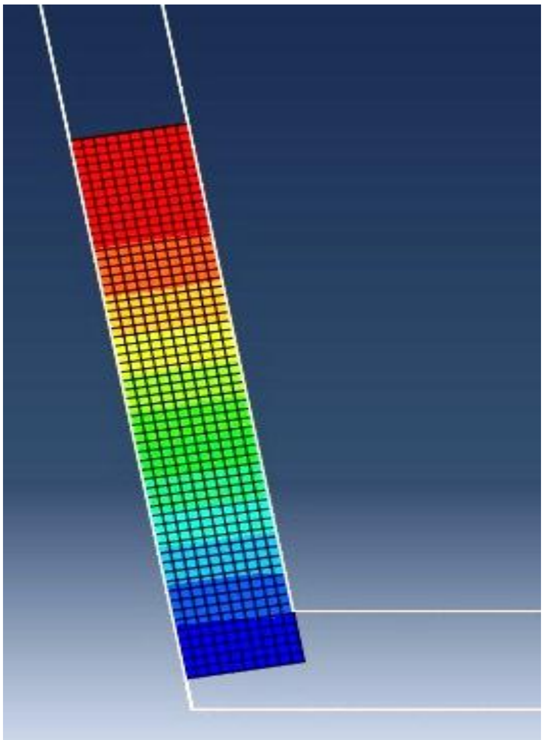


Figure 1. ECAP die geometry and billet

III. Results and Discussion

Both SEGAL et al. [2] and IWAHASI et al. [3] equations [Ref; 1&2] are stating to the relationship between the theoretical equivalent plastic strain and die geometry with some assumptions have been done to deriving equations (2) as a frictionless process, ideal plastic deformation of billet material, no corner gap exit and uniform plastic deformation [1]. Hence, these equations don't explain any details about neither the density variation of strain nor the strain distribution a cross the billet because of the existence of friction between any two sliding surfaces and also strain-hardening behavior of work-piece materials are anticipated [1].

FEM can be attained by the explaination of that relationship with respect to study the effect of die geometry with different outer corner radiuses, die angle and friction coefficient on the strain distribution in different zones of work-piece [1&2].

3.1. Effect of Die Geometry & Friction Coefficient on Pressing Forces

3.1.1. Effect of die geometry on pressing force

Figures (2) show the effect of the outer corner radius on the pressing force which needs to press the billet in the entrance channel of die then move along it. The relationship affirms, as an outer channel radius increases, the pressing force decreases. Meanwhile, the same trend can be seen in figure (3) as a channel angle increases, the pressing force decreases. This can be mention to the easy movement of billet along the channels when the outer corner radius and channel angle increase.

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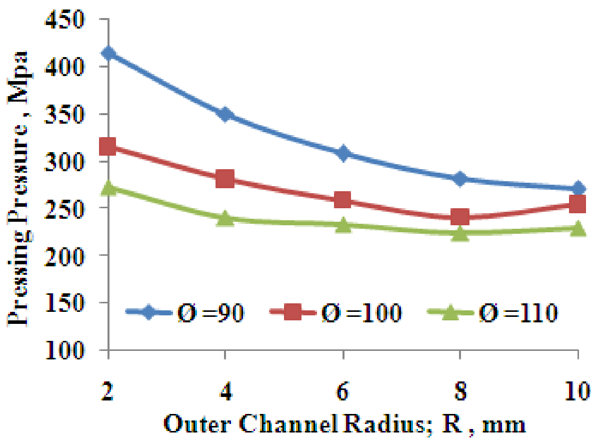


Figure 2. Effect of outer channel Radius on pressing force at different Channel angles (Ø)

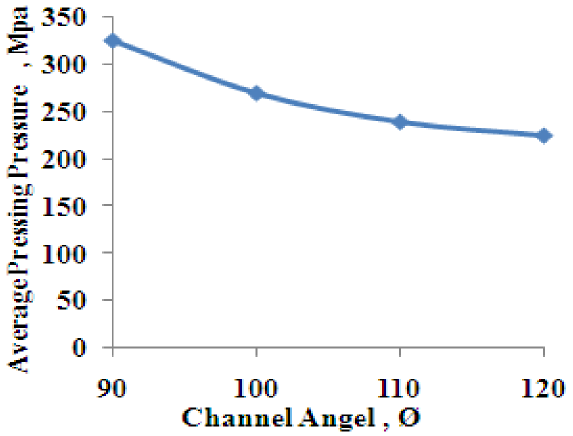


Figure 3. Effect of channel Angle on pressing force

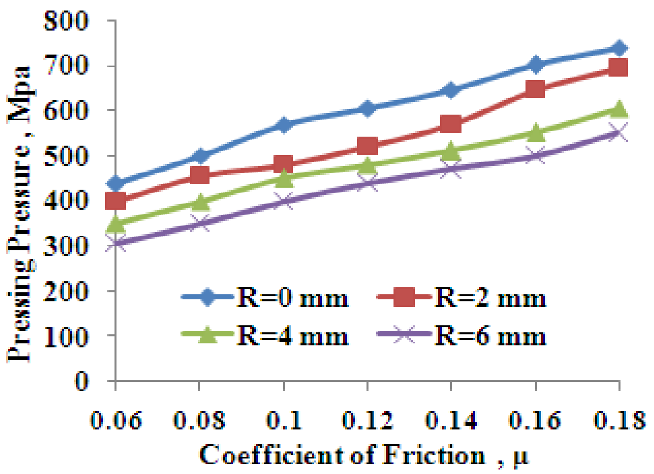


Figure 4. Effect of Coefficient of friction, µ ; on Pressing Pressure at different outer channel radius & Ø = 100^0

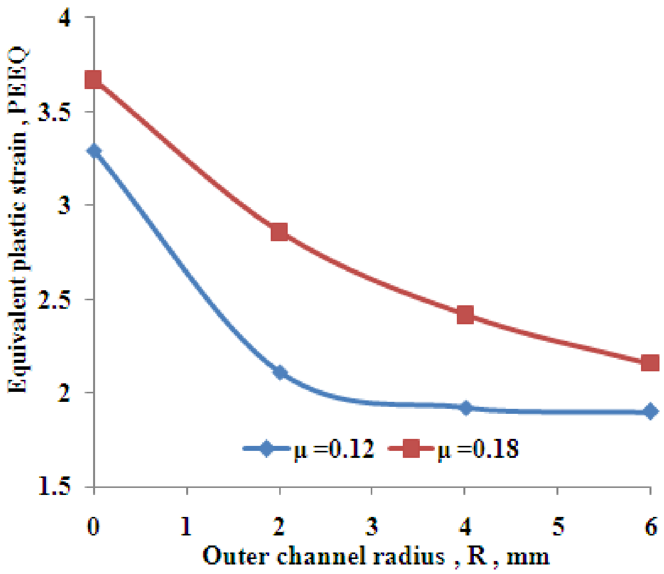
3.1.2. Effect of the coefficient of friction on pressing force

Figure (4) illustrates the relationship between the pressing force and friction coefficient. It is clear that; as a coefficient of friction increases; the pressing forces increase with different outer corner radius. This can be clarified by: the increasing of the coefficient of friction leads to increasing the friction forces that hinder the movement of billet through the channel; consequently larger pressing forces need to overcome on generated friction forces.

3.2. Effect of Die Geometry & Friction Coefficient on Plastic Deformation

3.2.1. Effect of die geometry on equivalent plastic strain (PEEQ)

Figures (5&6) confirm the significant effect of the outer corner radius on equivalent plastic deformation (PEEQ). It can be seen; as outer channel radius increases; the PEEQ decreases at the different coefficient of friction. This may be attributed to a difficult flow of billet through the channel especially in intersect channels zone, whereas the flow of billet is more easier when the outer corner radius is larger.



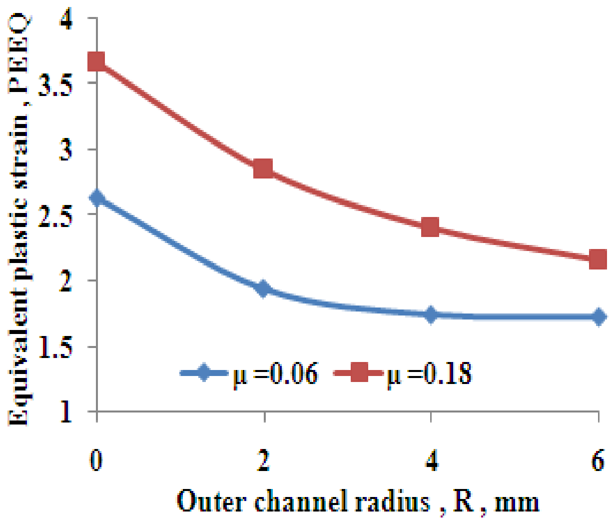


Figure 5: Effect of Outer channel Radius; R, on Equivalent plastic strain (PPEEQ) at &Ø = 100^0

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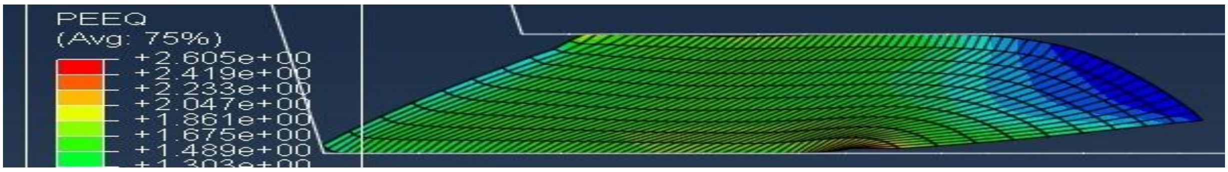
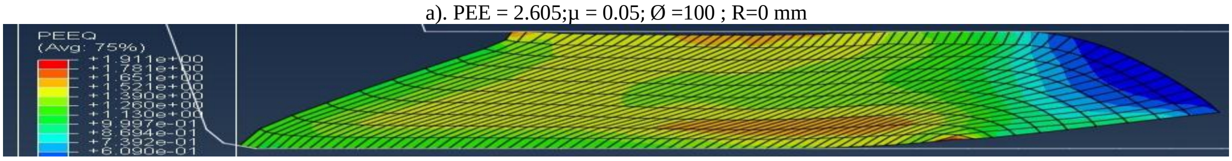
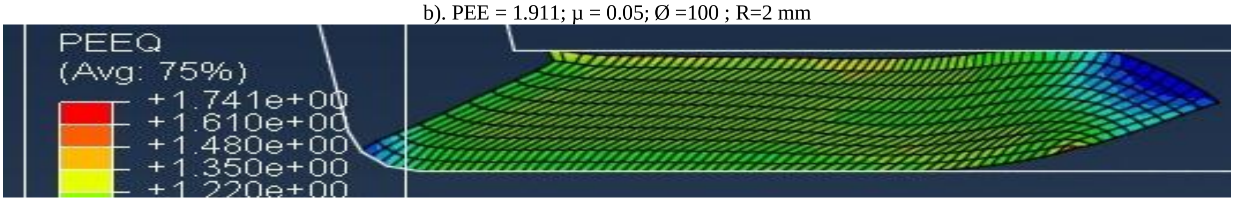


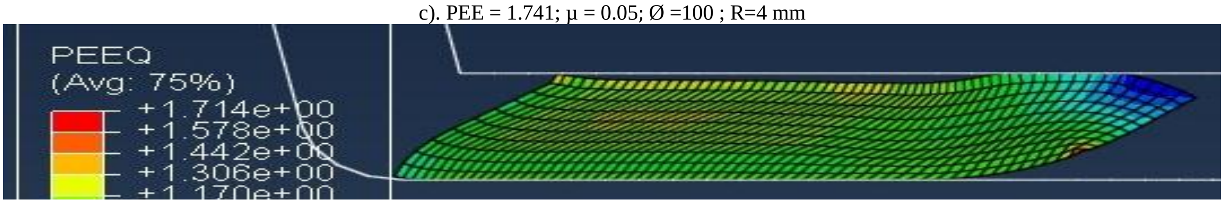
a). PEE = 2.605;μ = 0.05; Ø =100 ; R=0 mm



b). PEE = 1.911; μ = 0.05; Ø =100 ; R=2 mm



c). PEE = 1.741; μ = 0.05; Ø =100 ; R=4 mm



d). PEE = 1.714; μ = 0.05; Ø =100 ; R=6 mm

Figure (6): The effect of outer channel radius on equivalent plastic strain(PEEQ) at channel angle Ø =100^o .

3.2.2. Effect of the coefficient of friction on Equivalent plastic strain (PEEQ)

Figures (7&8) demonstrated the relation between equivalent plastic strain (PEEQ) and coefficient of friction. It is clear that, the increasing friction coefficient leads to an increase in equivalent plastic strain (PEEQ). This can be attributed to existence a corner gap at the beginning of the process then as the process continues, it is partially filling with the material. This agrees with BasavarajV. et al. [1].

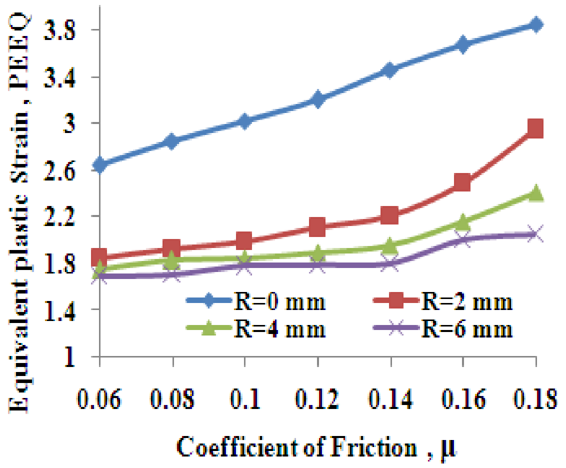


Figure 7. Effect of coefficient of friction (μ) on equivalent plastic strain (PEEQ) at different outer channel radius.

3.3. Effect of the Coefficient of Friction on Corner Gap

The occurrence of the corner gap is anticipated through the ECAP process. Figure (9) reveals the relationship between the coefficient of friction and the corner gap. For all study values of friction coefficient, a corner gap is present, but there is a significant influence by the value of the coefficient of friction in such a manner; the bigger value of friction coefficient leads to a smaller corner gap. This is due to a frictional drag that generated in the exiting channel as a result of increasingcontact between the billet and the channel surfaces. Moreover, for the frictionless case, the corner gap is remaining constant without change during the process.

IV. Conclusion

Finite element analysis was employed for different die geometry and friction coefficient values to investigate their influence on equal channel angular pressing (ECAP) process. The results of the present study revealed some of the conclusions as following:-

1. As an outer channel radius increases, the pressing force decreases too. Also in the same way, when the channel angle increases, the pressing force decreases.
2. The relationship between the coefficient of friction and pressing force affirm; by increasing the friction coefficient, the pressing force and equivalent plastic strain decrease. Moreover, the friction coefficient has a significant influence on the corner gap; in summary, the increasing of friction coefficient leads to a smaller corner gap.

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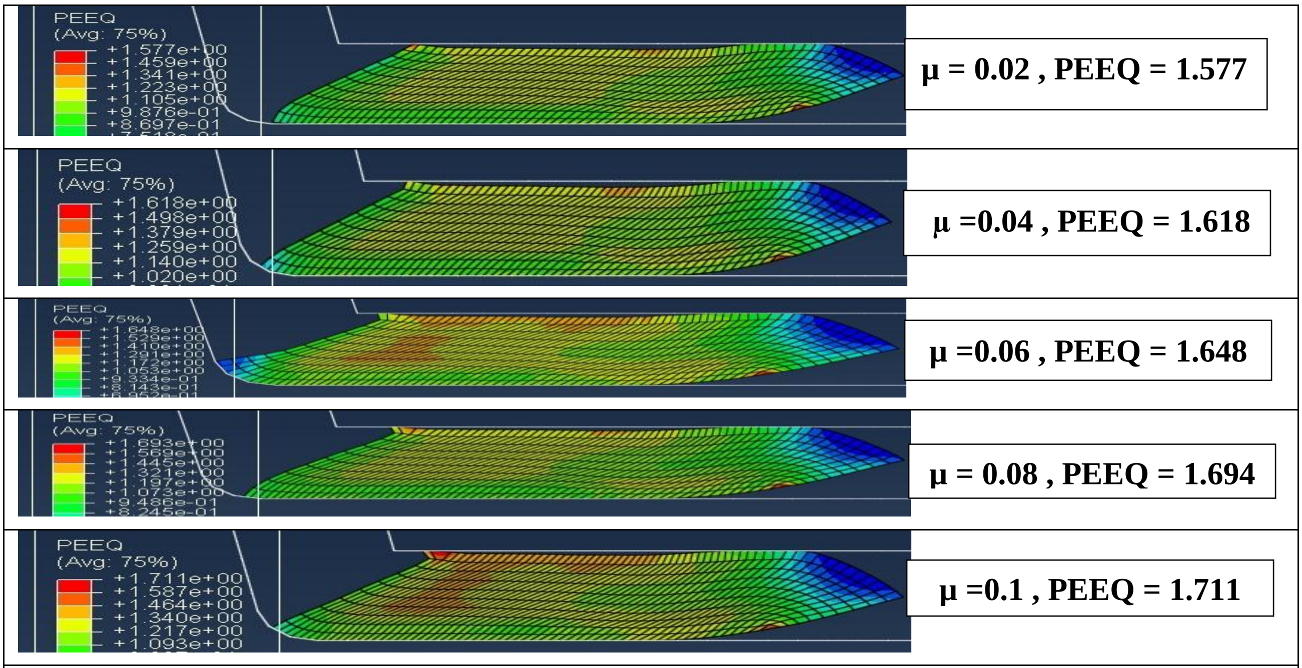

Figure 8. The effect of coefficient of friction on equivalent plastic strain (PEEQ) at Ø =100° ; R=4mm.

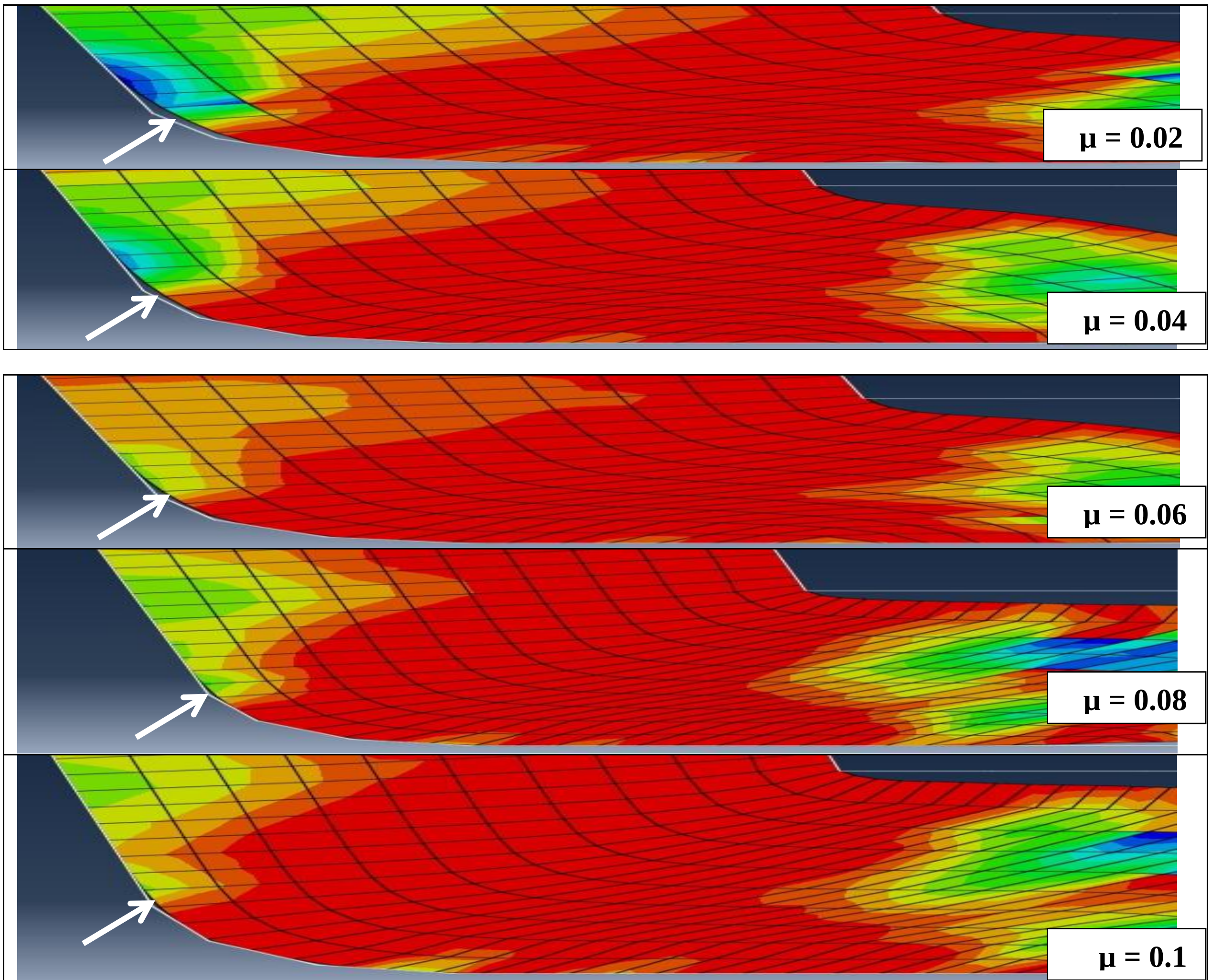

Figure 9 : The effect of coefficient of friction on corner gap at Ø =100 ; R = 4 mm

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3. Both of outer channel radius and channel angle affect on equivalent plastic strain (PEEQ) in such a manner, by increasing the outer channel radius and channel angle, the equivalent plastic strain decreases. On the other hand, the increasing of friction coefficient increases the equivalent plastic strain.

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