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Numerical Study of the Die Geometry and Friction Effect on the Forming Load and Material Flow in Injection Forging Process

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Abstract: In this study, the effects of some die geometry parameters such as: relative gap height, die corner radius and friction coefficient on the forming load and material flow were studied by simulation work. The numerical analysis of the injection forging process was performed in two cases: case I, forcing a cylindrical billet against a flat die and case II, forcing the same billet by moving both the upper and the lower dies in opposite directions. The work piece material was AISI 1006 steel and the simulation work was performed by the rigid-plastic finite element method. The validity of the simulation results obtained in this study was verified by using the experimental data reported in the literature. When comparing the forming load obtained from simulation study and experimental data, the effect of die geometry parameters such as relative gap height, die corner radius, friction coefficient on forming load and material flow were presented. The simulation results show the effectiveness of gap to billet diameter ratio (s/d) on forming load in each two cases. The separation height decreases in case I, when increasing (s/d). In case II, by increasing (s/d) the flange angle and diameter increase too. Effect of decreasing the separation height, when increasing friction coefficient in case one is significant, where friction coefficient is 0.3, the separation height is near the zero.

Key words: Injection forging, die geometry, FEM, relative gap height, die corner radius

INTRODUCTION

The injection forging also termed as radial extrusion, lateral extrusion, sideway extrusion or radial forging is an important branch of the extrusion process in which the cylindrical solid or tubular billet contained in the chamber is pressed by one or two opposite simple punches, causing the radial material flow through a fixed die cavity. The machine components with complex flange geometry or segmented protrusions such as gears and splines, which are very difficult to produce by the conventional forging, can be easily produced by the injection forging to near or net shaped parts. The injection forging method will allow reducing the subsequent operations such as machining. Its important characteristics features of this method in relation to conventional forging are that it consumes low energy and offers better die filling for complex parts. Qin and Balendra (1998) and Balendra and Qin (2000, 2004a, b) have studied effects of process parameters on material flow and load requirement for complete flanges. They have been defined an aspect ratio of primary deformation zone (the ratio of gap height to billet initial diameter, T = s/d) for complete flanged part produced by this method. When T<0.8 acceptable material flow can be obtained but required force increase since metal flows into narrow die gap. Lee *et al.* (2001) and Choi and Choi (2001) studied the effect of punch diameter and the friction factor on the forming load by the FEM on the combination of lateral and forward or backward extrusion. Altinbalik and Can (2006) studied the barreling profile and effect of aspect ratio on material flow in lateral extrusion of gear-like forms by using upper bound solution and experimentally. Du Ko *et al.* (2001) studied the effect of die geometry parameters on material flow in this process. They showed a certain pattern in the material flow in each deformation case and studied the some die geometry parameters on the material flow into the flange gap by FE simulation method.

In this study, the forming load and material flow into the flange gap in two variant injection forgings of a solid cylindrical billet is analyzed by extensive finite element simulation study. The major process parameters considered in this work are the relative gap height, die corner radius and friction factor. The analysis procedure is as follows: first, the results of simulation performed under the same condition as for experiment are compared with experimental data that obtained by Pale *et al.* (1989), and reported by Du Ko *et al.* (2001), in terms of forming load. This comparison is to verify the validity of the rigid-plastic finite element method. Second, extensive

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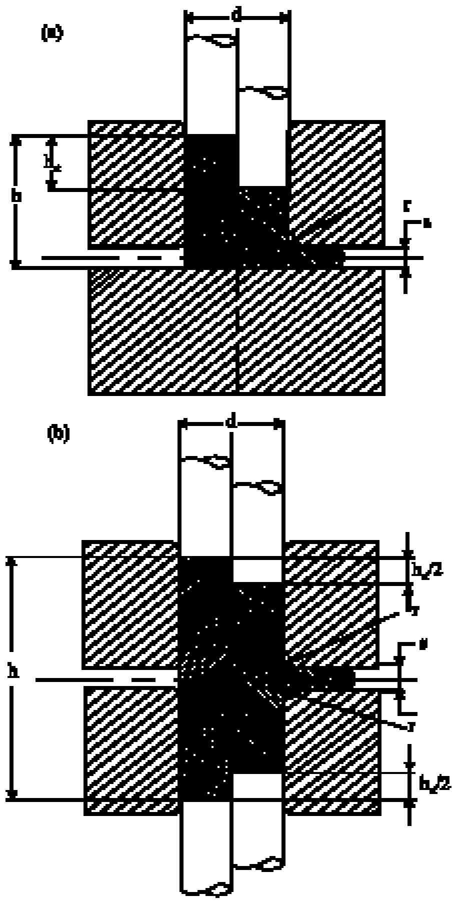

Fig. 1: The die geometry of injection forging in (a) case I and (b) case II

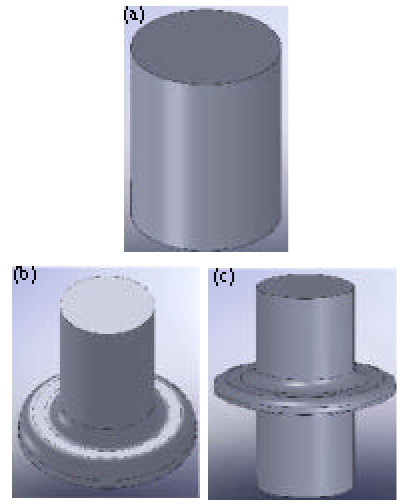

Fig. 2: (a) The initial billet and final formed parts in, (b) case I and (c) case II

simulation work for various combinations of parameter value was performed and then the main characteristics of the forming load and deformation patterns of each case are observed to define the terms which represent the forming characteristic of the flange.

MATERIALS AND METHODS

The geometrical parameters in injection forging: This study investigates two basic variants of injection forging, as shown in Fig. 1. Figure 1 shows the principle of two processes and the geometrical parameters utilized in this study. Case I involves forcing of a cylindrical billet by a punch against a flat die which is stationary. In case II, both upper and lower punches move together toward the center of the billet. The initial billet and the final product of two cases are shown in Fig. 2. The major process parameters are identified as the relative gap height (s/d), the relative deformation (hst/d) and the die corner radius (r). To investigate the influence of relative gap height (s/d), die corner radius (r) and friction coefficient (m) on the material flow and forming load, finite element analysis is performed for different values of gap height (s), friction coefficient (m) and die corner radius (r) selected.

Basic equations of rigid-plastic FEM: This study performs rigid-plastic finite element simulations using DEFORM™2D software (DEFORM™2D Software User Manual, 2005). The material employed in the simulations is AISI1006 steel.

The flow stress-strain relationship of this material at room temperature can be modeled as Eq. 1. The friction coefficient at the die-material interface is assumed to be 0.1 in the cold forging of steels, using conventional phosphate-soap lubricants or oil (Kobayashi and Altan, 1989).

$$\sigma = 629\,\epsilon^{0.31}\ \text{(MPa)} \tag{1}$$

The basic equations of the rigid-plastic finite element are as follows:

Equilibrium equation:

$$\sigma_{ij,j} = 0 \tag{2}$$

Compatibility and incompressibility equations:

$$\dot{\epsilon}_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}), \quad \dot{\epsilon}_v = u_{i,i} = 0 \tag{3}$$

Constitutive equations:

$$\bar{\sigma} = \sqrt{\frac{3}{2}(\sigma'_{ij}\sigma'_{ij})}, \quad \sigma'_{ij} = \frac{2\bar{\sigma}}{3\bar{\dot{\epsilon}}}\dot{\epsilon}_{ij}, \quad \bar{\dot{\epsilon}} = \sqrt{\frac{3}{2}(\dot{\epsilon}_{ij}\dot{\epsilon}_{ij})} \tag{4}$$

Boundary conditions:

$$\sigma_{ij} n_i = F_j \quad \text{on} \quad S_F, \quad u_i = U_i \quad \text{on} \quad S_U \tag{5}$$

where, σ_{ij} and $\dot{\epsilon}_{ij}$ are the stress and the velocity, respectively, $\bar{\sigma}$ and $\bar{\dot{\epsilon}}$ are the effective stress and the effective strain velocity, respectively, F_j is the force on the boundary surface of S_F and U_i is the deformation velocity on the boundary surface of S_U.

The weak form of rigid-plastic FEM can be determined by applying the variation method to Eq. 1-4, i.e.,

$$\int \left(\frac{2\bar{\sigma}}{3\bar{\dot{\epsilon}}}\right) \dot{\epsilon}_{ij}\, \delta\dot{\epsilon}_{ij}\, dv + \int k\,\dot{\epsilon}_{kk}\, \delta\dot{\epsilon}_{ij}\, dv - \int_{S_F} F_i \delta u_i\, ds = 0 \tag{6}$$

where, V and S are the volume and the surface area of the material, respectively and k is the penalty constant. The Newton-Raphson iteration method is applied to obtain the solution of the equations. The frictional boundary condition is given by the vector form:

$$f = -\frac{2}{\pi} mk \tan^{-1}\frac{|V_s|}{u_0} t \tag{7}$$

In which m is the friction coefficient, k is the local flow stress in shear and u_0 is a very small positive number in comparison with $|V_s|$, where V_s is the velocity vector of the work piece relative to the die and t is the unit vector in the direction of V_s.

RESULTS AND DISCUSSION

The results obtained from FE simulation are given and analyzed in the following two sections, showing the influence of some major parameters mentioned above on the forming load and material flow. The first section consists of validating the model used in this study. So, the results obtained from simulation in this study compared with the experiments data were obtained from the reaserch study perform under the same conditions, exactly. The essential contribution here consist to high lighting the effectivness of die geometry parameters on the forming load, that it is not the same in the reaserch study presented by Du Ko *et al.* (2001).

The influence of some basic geometric parameters such as s/d, r and m on the forming load and material flow into the flange gap investigated, the results are discussed.

FE model validation: Here, to verify the modeling and simulation work for injection forging process, the load-stroke relationships obtained by FE simulation are compared with the experimental data that obtained by Pale *et al.* (1989) reported by Du Ko *et al.* (2001). The FE

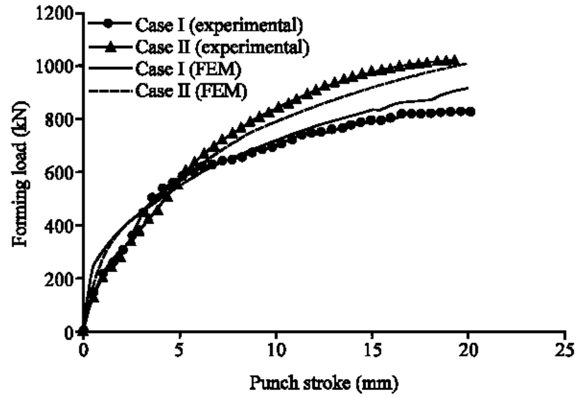

Fig. 3: Comparison of the simulated and experimental curve of forming load for (s/d = 0.25, r = 5, d = 32)

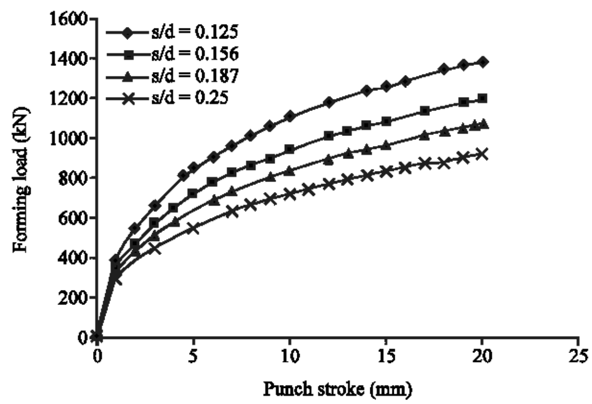

Fig. 4: Effect of s/d on forming load in case I

model is performed under the same conditions of relative gap height s/d = 0.25, die corner radius r = 5 mm, billet diameter d = 32 mm, for AISI 1006 steel. The load-stroke curves of simulation and experimental data for two cases are shown in Fig. 3. There is a significant correlation between the results in each case and FEM analysis results obtained in this study are more closely to experimental data in comparison with FEM results that reported by Du Ko *et al.* (2001).

Influence of geometric parameters: In these subsections, the influence of parameters such as s/d, r and friction coefficient (m) on material flow and required forming load investigated.

Influence of s/d in case I and case II: The simulation study is performed exactly at the same condition of those in validation condition, the flange gap to billet diameter ratio (s/d) is varied between 0.125 and 0.25 in case I and the load-stroke curves are shown in Fig. 4. In case II, the (s/d) parameter increases from between 0.125 to 0.5, the

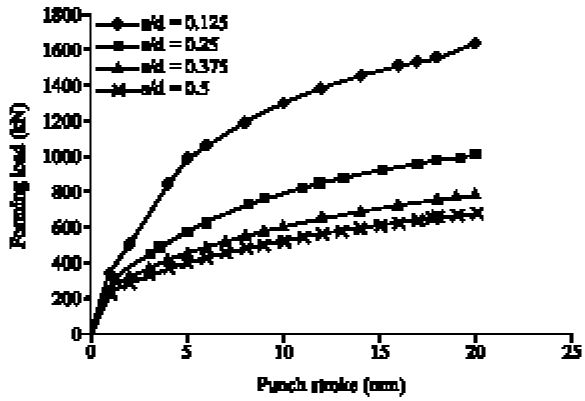

Fig. 5: Effect of s/d on forming load in case I

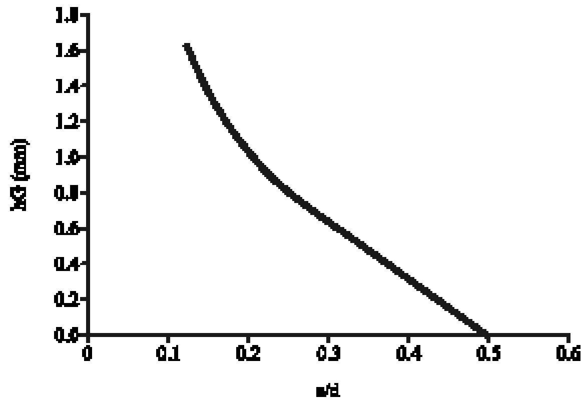

Fig. 7: Effect of s/d on separation height (hG) defect in case I (r = 5, d = 32, m = 0.1)

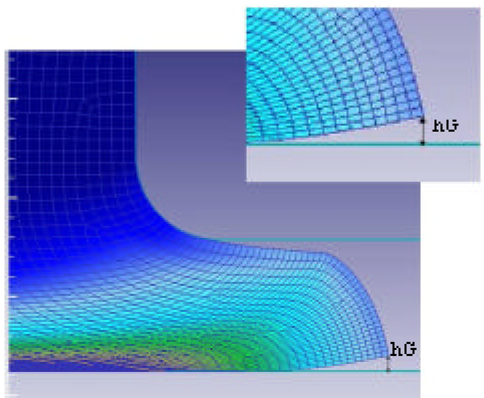

Fig. 6: Separation height (hG) defect in case I

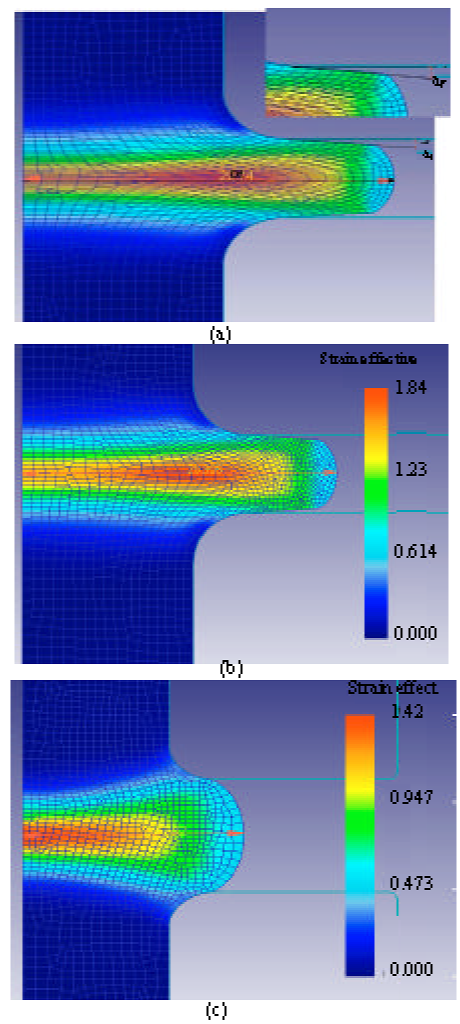

Fig. 8: (a) Flange angle defect in case II, (b) s/d = 0.125, $a_f = 8°$, in case II and (c) s/d = 0.5, $a_f = 38°$, in case II

friction coefficient is considered to be 0.1, the results show in Fig. 5. The results obtained show the increasing (s/d) cause decreasing the forming load in each two cases, but in the case II, the required forming load at each stroke is high for lower gap to billet diameter ratio (s/d = 0.125) in comparison with forming load due to (s/d = 0.5).

Figure 6 shows the separation height (hG), one of the important deformation characteristic of injection forging process. The lower hG was obtained at higher (s/d) values, Fig. 7 shows that in case I the hG value tend to zero at s/d = 0.5.

Figure 8a shows the flange angle defect in case II, Fig. 8b and c show effect of (s/d) on the flange angle (α_f). It is considerable where, increasing (s/d) from 0.125 to 0.5, cause increasing α_f from 8° to 38°. On the other hand the better material flow can be obtained with the lower (s/d).

Influence of die corner radius in case I and case II: The simulation work were performed in each two cases to show the influence of die corner radius, r. This parameter is important die design item. Figure 9a and b shows the effect of die corner radius on the required forming load in

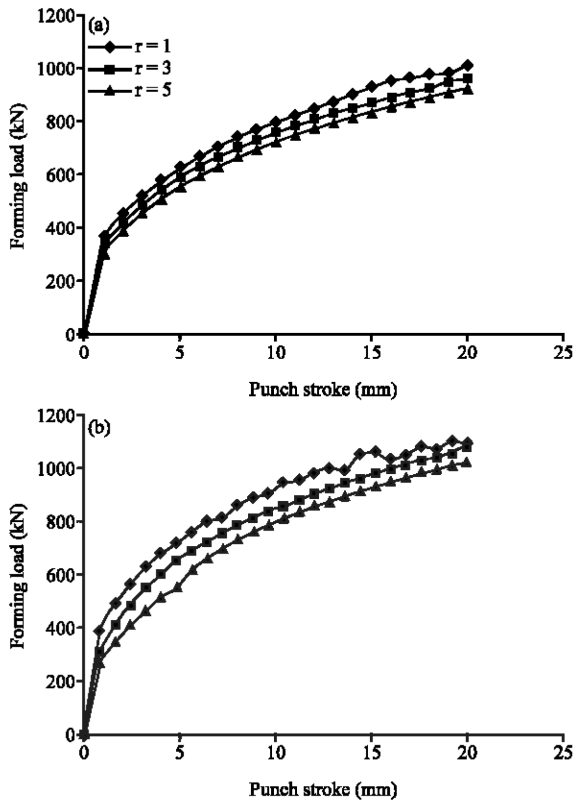

Fig. 9: (a) Effect of die corner radius on forming load in case I (s/d = 0.25, m = 0.1, d = 32) and (b) In case II (s/d = 0.25, m = 0.1, d = 32)

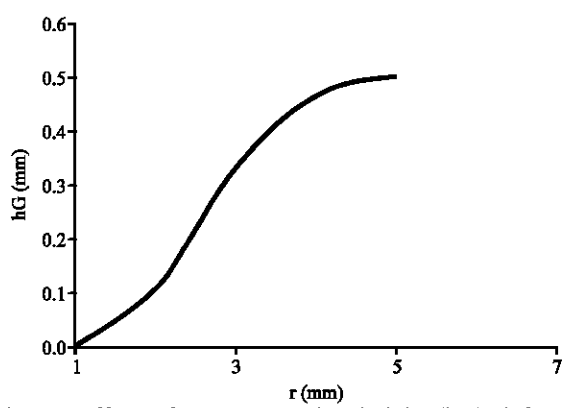

Fig. 10: Effect of r on separation height (hG) defect in case I

case I, II, as shown in these figures, forming load decrease about 16% with increasing die corner from 1 to 5 mm, when punch stroke is 20 mm. This could be explained by the fact that at higher die corner radius, there is lower constraint when material goes to flow. In case II, at the similar conditions, the forming load approximately

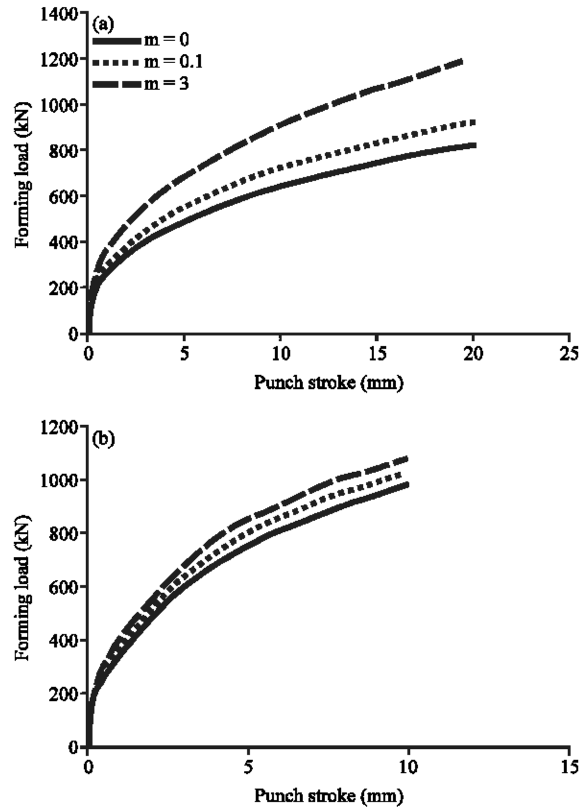

Fig. 11: (a) Effect of friction coefficient on forming load in case I (s/d = 0.25, r = 5, d = 32) and (b) In case II (s/d = 0.25, r = 5, d = 32)

decrease 13% such as shown, the forming load in each stroke in case II is about 7.2% higher than case I. According to Fig. 4, 5, 9a and b and comparison the forming load at similar punch stroke, between two cases, at different (s/d) it can concluded that effect of (s/d) is higher than r.

Figure 10 shows that the better material flow (lower hG) in case I could be obtained for lower r. The result could be explained by effect of contact surface augmentation at higher die corner radius.

Influence of friction coefficient in case I and case II: In the study of friction coefficient effect, the forming load obtained from simulations work when the conditions is similar to other study items (s/d = 0.25, r = 5, d = 32 mm) at different friction coefficient m = 0, 0.1 and 0.2 represented by curves in Fig. 11a and b. The results show that the friction coefficient in case I have significant effect in comparison with required forming load in case II. It can be concluded that lowers material flow in case I, with higher m, is due to high resistance of lower die surface.

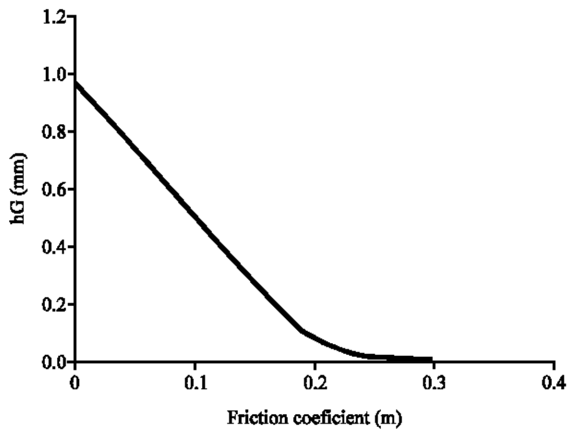

Fig. 12: Effect of m on separation height (hG) defect in case I

Also the friction coefficient has significant effect on separation height hG. This parameter decrease with increasing m up to 0.2, for m = 0.2, separation height hG tends to zero. Figure 12 shows that the friction coefficient has significant effect on material flow in case I. The friction coefficient hasn't important effect on material flow in case II.

CONCLUSION

The model validation was performed via comparing the forming load required, obtained numerically and experimentally. The results obtained from simulation work were reported in two cases.

Case I : Forcing a cylindrical billet against a flat die
Case II : Forcing the same billet by moving both the upper and the lower dies in opposite directions

The following conclusion is obtained:

- Load required to deformation for same (s/d), in case I is lower than that case II
- Increasing (s/d) cause to decreasing the forming load in each two cases
- Thelower separation height (hG) was obtained at higher (s/d) in case I (hG value tend to zero at s/d = 0.5)
- Flange angle (α_f) increase by increasing (s/d) and better material flow can be obtained with the lower (s/d)
- Forming load decrease by increasing die corner radius (r) in two cases
- Effect of (s/d) on forming load is higher than die corner radius (r) in two cases
- Better material flow (lower hG) in case I could be obtained for lower r. The result could be explained by effect of contact surface augmentation at higher die corner radius
- Forming load increase by increasing friction coefficient (m) but the friction coefficient in case I have significant effect in comparison with required forming load in case II
- Separation height defect in case I, (hG) decrease with increasing friction coefficient (m), but it hasn't important effect on material flow in case II

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