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Analysis of the Parameters Affecting Warping In Radial Forging Process

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Abstract: Radial forging is a process in which one or two punches move axially causing a radial flow into a die cavity by means of which a flange is formed. During forging, warping, in which the lower face of thin flange rises from the die face may occur. To better understand the effect of parameters affecting the warping in radial forging a Finite Element analysis was used to simulate the process with isotropic elastic-plastic material model. Parameters such as die corner Radius (r) or shape and ring gap Height (H), on the warping, were investigated and results were compared with experimental work. It has been shown that increasing ring gap height and die corner radius will lead to warping reduction. Also it has been shown that special profile such as chamfered die, tapered ring gap, cosine profile and polynomial function may be used to reduce the warping.

Key words: Radial forging process; finite element method; warping; special profile

INTRODUCTION

Radial forging is regarded as one of the most important metal forming processes. In radial extrusion or radial forging process the direction of applied force is perpendicular to the direction of flow of material. In other words, by applying a force in axial direction, material flows in radial direction. In this process one or two punches move axially causing a radial flow into a die cavity by means of which a flange is formed[1]. Due to non-homogeneous strain distribution and friction, warping may occur in area 1 and area 2 according to Fig1. This phenomenon can produce unsuitable parts, controlling this process is useful in preformed parts.

One of the important issues in radial forging is whether components can be produced with or without preform[2]. The other important issues are, homogeneous material deformation, optimization of forces and consumed energies, optimization of tool wear and controlling the material microstructure. M. Arentoft[1] studied different strain-hardening behaviors that are used in a commercially-available finite-element code, and verified finite-element simulations with metal forming experiments. Y. Qin[3] investigated, the production of thick-walled tubular components, they conducted finite element and experimenta analysis to study the of the polymers that were used as the pressurizing medium and examined process design and component quality. A performing procedure was developed by Y. Qin[4] in which the process range of injection forging of solid components can be extended to flange thickness/billet-diameter ratios of 1.4-1.5 using machined preforms and 1.50-1.64 using preformed billets. The proposed

Performance l

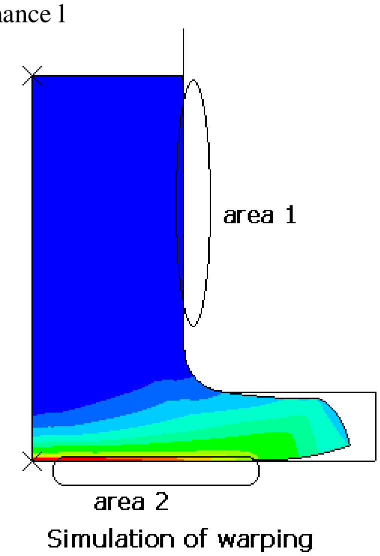

Fig. 1: Warping Effect

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preform enabled the forming of several flange-typed components without folds. T. Altinbalik[5] study on spline type parts. B.D. KO[6] studied radial extrusion and analyzed it by simulation work, he has shown that die geometry has significant influence on the material flow in to ring flange. Y. Ma[7] has shown that, applications of the processing technology could significantly reduce the cost of manufacturing thick-walled tubular components with hollow secondary elements, such as flanges with tooth geometries. S.H. siang[8] used the finite deformation theory to develop a large rigid-plastic deformation finite element program which could simulate the radial forging Process of work-hardening materials. R. Balendra[9] worked on radial forging forming limits based on energy/pressure requirements. R. Balendra[10] classified Flow-dependent forming defects were identified for the injection forging of solid billets with reference to several process configurations with a view to defining the process range of injection forging. Y.S. Lee[11] analyzed forming force on the radial-forward extrusion. Pressure losses in the injection chamber and lubrication techniques with reference to the extrusion of solid and tubular components by injection forging were studied by Y. Qin[12]. Reduction of warping phenomenon was studied by S. Hsiang[13]. M. Sabeghi[14] analyzed the effective parameters on the radial forging process by a 2D finite element method.

This paper will focus on parameters affecting warping. Using FEM simulation with elastic-plastic material model, different parameters such as die corner radius and ring gap height which can affect the warping were studied.

FEM SIMULATION

Principally, there are three different finite-element formulations employed to simulate metal forming: the rigid–plastic model, the elasto-plastic model and the visco-plastic model[15], however, each of these methods have some limitations, In this study FEM method was used to simulate the process with elasto-plastic material model. This model is commonly used for metal plasticity calculations and has a particularly simple form. Because of this simplicity the algebraic equations associated with integrating the model are easily developed in terms of a single variable, and the material stiffness matrix can be written explicitly. The material used for this study was Al6061, for which stress-strain curve and friction factor of lubricant were obtained using ring test compression[13]. The stress-strain relation has been simplified to:

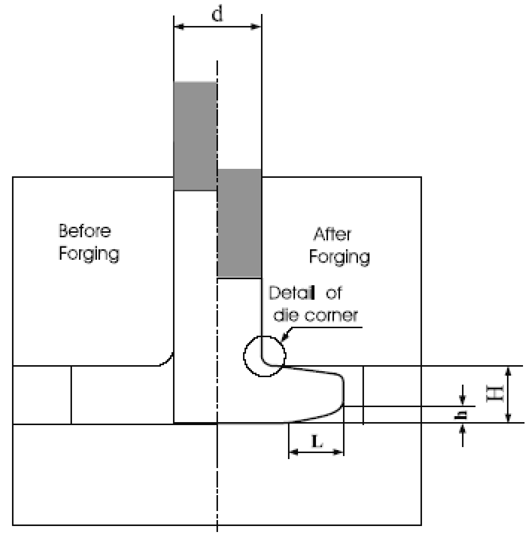

Fig. 2: Die geometry and flange dimension[13].

$$\sigma = 201(\bar{\varepsilon})^{0.121}\ \mathrm{MPa} \quad (1)$$

Which is similar to Ludvik relation and this material is independent from strain rate[16]. Kinematics contact method was used to handle the contact and friction between the work piece and the die, also between the work piece and the punch applied. Friction in the contact surfaces was simulated by the tangential force of the contact elements. Coulomb friction model was applied since in the radial forging process the work piece slides continuously between the die and the punch.

$$F_s \leq -\mu F_n \quad (2)$$

Where:

μ = The coefficient of friction.
F_s = Sliding force.
F_n = Normal force.

The die geometry and flange dimension of radial forging are shown in Fig. 2. A 2D element with four node bilinear ax-symmetric quadrilateral with the explicit method was used for simulation. For dies, rigid analysis was selected and the billet assumed to have Isotropic behavior.

The punch speed was 0.2 m s^{-1}; generally, clearance is about 0.1mm. Temperature effects were neglected.

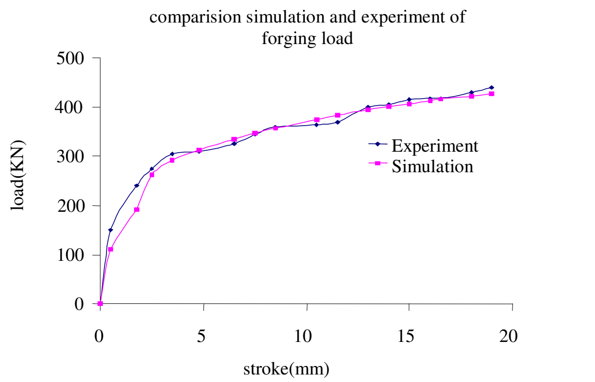

Fig. 3: Comparison between experimental[13] and finite element results

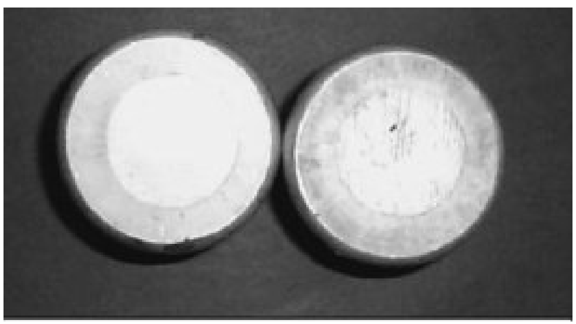

Fig. 4: Effects of die corner radius on warping[8]

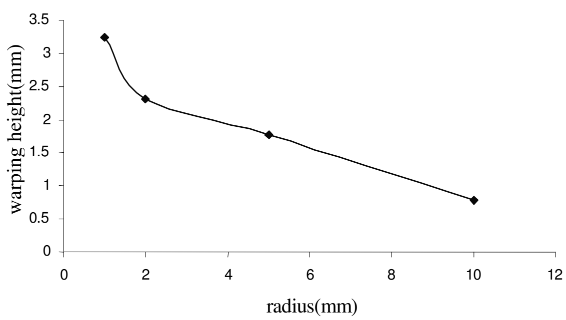

Fig. 5: Effects of die corner radius on warping (ring gap height H = 8 mm)

RESUTS AND DISCUSSION

In order to confirm the accuracy of modeling a comparison has been made with the experimental data[13] in Fig. 3. A 11 mm ring gap and friction factor of 0.18[13] was selected for analysis. As it can be seen a good agreement between experimental and numerical results has been achieved (error <6%). After confirming

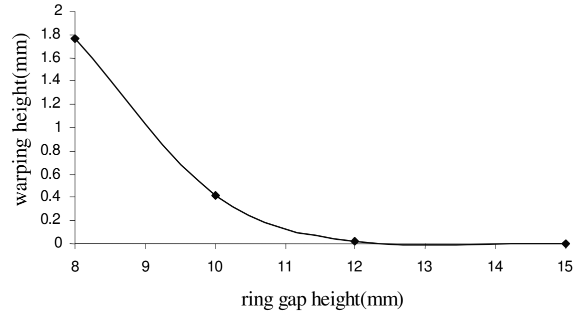

Fig. 6: Effect of rig gap Height (H) on warping

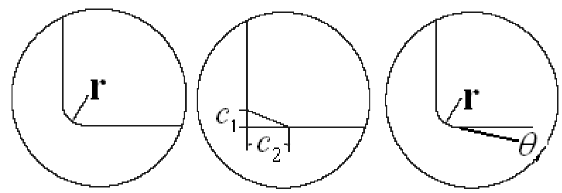

Fig. 7: Corner details

the validity of FE analysis, factor affecting warping were studied.

Die corner radius (R) of flange: Experimental work has shown that as the die corner radius decreases the warping effect increases[8] as shown in Fig. 4. the results from the simulation also shows the same trend, this also confirms the validation of the model. Figure 5 shows the die corner Radius (r) of flange against warping, as it is evident the sharper the corner the more warping effect. Under 2mm radius warping becomes noticeable, this is because, die corner radius affects the flow of materials. As the die corner radius reduces the effective strain distortion gets worse and warping occurs.

Ring gap Height (H): Effects of ring gap height on warping are shown in Fig. 6. When the height of gap is larger the effective strain distribution is homogeneous and flow of material is easier and so by increasing ring gap Height (H) the warping became smaller.

Chamfer effect on warping: Chamfer can be utilized for reducing the effect of warping. Two parameters define each chamfer c_1 and c_2 which is shown in Fig. 7.

Consider first c_2 as constant, effects of changing the values of c_1 for different ring gap Height (H) are shown in Fig 8. The result show that, for each value of ring gap Height (H) there is a specific value for c_1, at

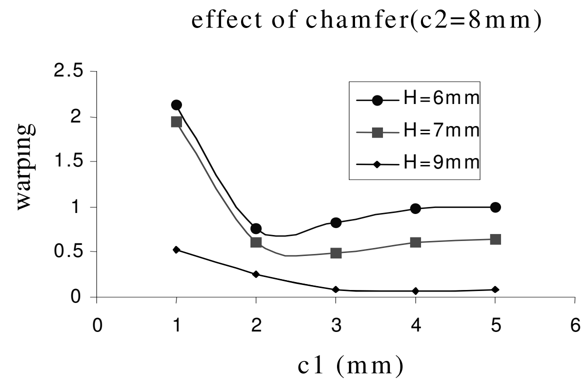

Fig. 8: Effect of c_1 on warping

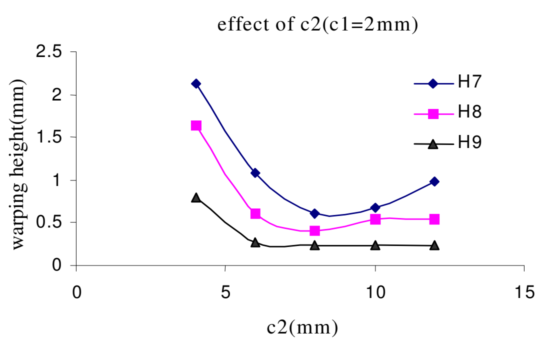

Fig. 9: Effect of c_2 on warping

which warping will be reduced considerably. The greater ring gap height, the greater value for c_1.

Now consider c_1 as a constant. As it is shown in Fig 9 result shown a similar trend.

Fillet radius effect for different ring gap Height (H) on warping is shown in Fig. 10, as it can be seen, almost in all cases studied, fillet radius has an adverse effect on warping.

Tapered ring gap effect on warping: As it is shown in Fig. 11, increasing the value of θ (see Fig. 7) will cause reduction of warping. Results show that, higher values of ring gap height (H) needs greater value of ɵ, in order warping to be contained.

Advanced profile application: Effect of different advanced profiles on warping were investigated. Figure 11 shows these profiles schematically, their formulations are as follows:

$$z = (r_2, r_2+l)$$

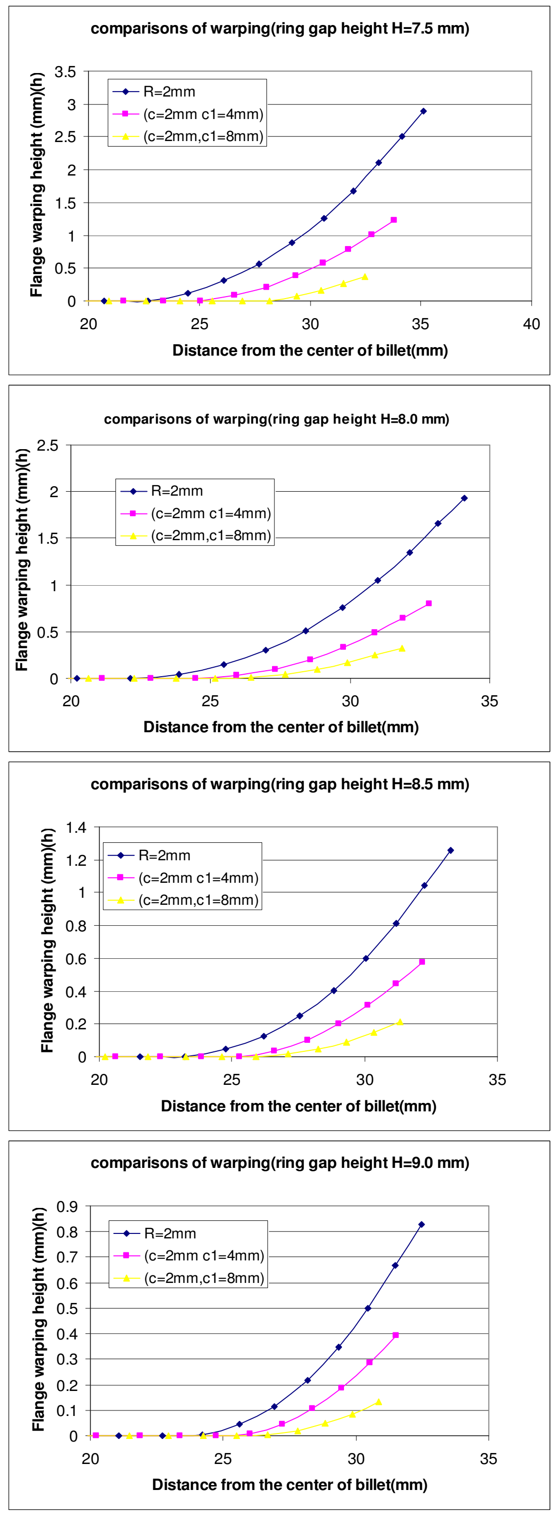

Fig. 10: Application of chamfer and Fillet radius on warping

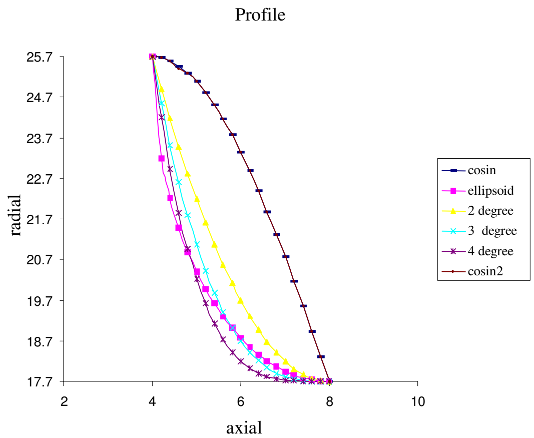

Fig. 11: Profile geometry

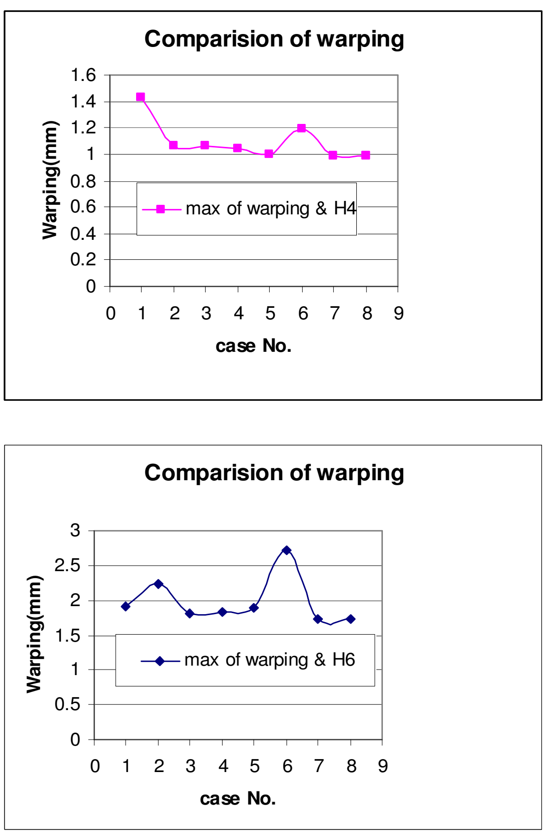

Fig. 12: Effect of advanced profile on warping

Table 1: Case number

Case4	Case3	Case2	Case1	Case No
3degree	2degree	ellipse	Cosin1	profile
Case8	Case7	Case6	Case5	Case No
6degree	Cosin2	Cir.=6	4degree	profile

$$rz_{cos} = r_1 + d\cos(\pi\frac{(z-r_2)}{2l})$$

$$rz_{eli} = r_1 + d - \sqrt{(d^2(1-(\frac{z-r_2-l}{l})^2)}$$

$$rz_2 = r_1 + d(\frac{(z-r_2-l)}{l})^2$$

$$rz_3 = r_1 - d(\frac{(z-r_2-l)}{l})^3$$

$$rz_4 = r_1 + d(\frac{(z-r_2-l)}{l})^4$$

$$rz_6 = r_1 + d(\frac{(z-r_2-l)}{l})^6$$

Where:

r_1 = Initial diameter.
r_2 = Ring gap height.
l = Axial length.
d = Radial length.

Table 1 gives the list of different profile and Figure 11, shows the effect of these profiles on warping, as it is evident applying advanced profiles will lead to an increase of warping in comparison with general fillet.

Figure 12 show the combined effect of fillet radius and advanced profile on warping, it is clear that fillet radius increases the warping effect, and it is recommended that when designing radial forge dies adding fillet radius be avoided.

CONCLUSIONS

Based on the above results and subsequent discussions, the following conclusions are drawn:

- Increasing ring gap height, die corner radius lead to warping reduction.

- Applying different chamfers, tapered ring gap will cause reduction in warping phenomenon, however in this case, forming force is increased.
- Chamfer can be used for reducing the effect of warping; this is a good tool in the hands of designer for designing dies with least warping effect.
- Applying advanced profiles will increase warping effect in comparison with general fillet. However, four degree polynomial has the most effect on warping reduction.
- It is recommended that when designing radial forge dies minimum fillet radius should be used.

REFERENCES

1. Arentoft, M., H. Bjerregaard, C.B. Andersen and T. Wanheim, 1998. The influence of the constitutive behaviors of materials on the formability in radial extrusion of tubular components: Journal of Materials Processing Technology 75: 122-126.2.
2. Slagter, W., 2001. Forging Simulation Tool Based on Breakthrough Technology: 2nd International Conference on Design and Production of Dies and Molds,
3. Qin, Y., Y. Ma and R. Balendra, 2004. Pressurising materials and process design considerations of the pressure-assisted injection forging of thick-walled tubular components: Journal of Materials Processing Technology 150: 30-39.
4. Qin, Y., R. Balendra, 2004. An approach for the forming of large-thickness-flange components by injection forging: Journal of Materials Processing Technology 145: 153-162.
5. Altinbalik, T. and Y. Can, 2005. An experimental study of lateral extrusion of splines: Materials and Design 121: 112-120. They study on splines type parts.
6. KO, B.D., D.J. Kim, S.H. Lee and B.B. Hwang, 2001. The influence of die geometry on radial extrusion processes: Journal of Materials Processing Technology 113: 109-114.
7. Ma, Y., Y. Qin and R. Balendra, 2005. Forming of hollow gear-shafts with pressure-assisted injection forging (PAIF): Journal of Materials Processing Technology 167: 294-301.
8. Hsiang, S. and H. Ho, 2004. Investigation of the influence of various process parameters on the radial forging processes by the finite element method (FEM): Int J Adv Manuf Technol 23: 627-635.
9. Balendra, R. and Y. Qin, 2004. Injection forging, engineering and research: Journal of Materials Processing Technology 145: 189-206.
10. Balendra, R. and Y. Qin, 2000. Identification and classification of flow-dependent defects in the injection forging of solid billets: Journal of Materials Processing Technology 106: 199-203.
11. Lee, Y.S., S.K. Hwang and Y.S. Chang, 2001. The forming characteristics of radial-forward extrusion: Journal of Materials Processing Technology 113: 136-140
12. Qin, Y. and R. Balendra, 2003. Optimization of the lubrication for the extrusion of solid and tubular components by injection forging: Journal of Materials Processing Technology 135: 219–227.
13. Hsiang, S. and H. Ho, 2005. A Study on the Warping Problems of Thin Flange under the Radial Forging Processes by FEM and Experiments", Int J Adv Manuf Technol 26: 47-55.
14. Sabeghi, M. and F. Djavanroodi, 2005. Analysis of the effective parameters on the radial extrude (radial forging) process by a 2D finite element method (FEM): Tehran International Congress on Manufacturing Engineering (TICME2005) December 12-15, Tehran, Iran.
15. ABAQUSE user manual version 6.4
16. Jang, D.Y. and J.H. Liou, 1998. Study of stress development in axi-symmetric products processed by radial forging using a 3-D non-linear finite-element method: Journal of Materials Processing Technology 74: 74-82.