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Study of the effects of die shape geometry on deformation in radial forging process without mandrel

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1. INTRODUCTION

Radial forging is a hot or cold forging process utilizes two or more radially moving anvils, or dies, for producing solid or tubular components with constant varying cross sections along their length. This process is usually used for reducing the diameters of ingots and bars, forging of stepped shafts and axels, forging of guns and rifle barrels, and production of tubular components with and without internal profiles [1].

Using slab method analysis, Lahoti and Altan [2] analyzed the mechanics of radial forging process. Domblesky et al [3] presented a finite element model and obtained strain, strain rate and temperature distribution in radial forging. Jang and Liou [4] also modeled radial forging by finite element method to obtain residual stresses.

All of these studies have been based on two basic assumptions; 1) A mandrel is used and 2) the die inlet section forms a perfect conical surface. Usually a mandrel is used inside a tubular workpiece to create internal profile and/or size the internal diameter, but the process can also be performed without a mandrel when workpiece geometry does not allow it or internal surface quality is not critical. When no mandrel is used, the required load, energy and die wear rate are all reduced and the cost of mandrel which is usually significant is saved. The amount of die angle which limits the radial forging process is increased and the process is feasible with larger die angles. To our knowledge, a study of deformation when no mandrel is used has not been presented in the literature. This will be discussed in this paper.

Among parameters affecting the deformation pattern and quality of the forged product, the die shape is very important. Generally, the die shape is made of two sections, the inlet section which forms a conical surface and the die land which is perfectly cylindrical, as shown in Fig. 1. The die angle remains constant along the workpiece axis.

In the present study, slab method analysis has been used to analyze radial forging of tubes with circular die shapes and without mandrel. When a variable cross section tubular part has a fillet connecting tow sections, the shape of the die in inlet section should have the same fillet to produce that fillet in part. Because circular die shapes have some advantages, which are discussed in this paper, can be used for every part. Instead of perfect cone in inlet section, first concave and convex surfaces and then combination of these two shapes are proposed, as shown in Fig. 2. The material is assumed to be perfectly rigid-plastic.

2. ANALYSIS OF FORGING

When mandrel is used, there are three distinct regions of deformation: (1) sinking zone, (2) forging zone, (3) sizing zone [2]. But without mandrel, the forging zone will not exist. Using slab method, the equations was written for each shape. The obtained equations are nonlinear, so they were solved numerically by Runge-Kutta method.

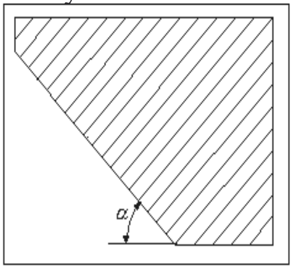

Fig. 1. conic die shape

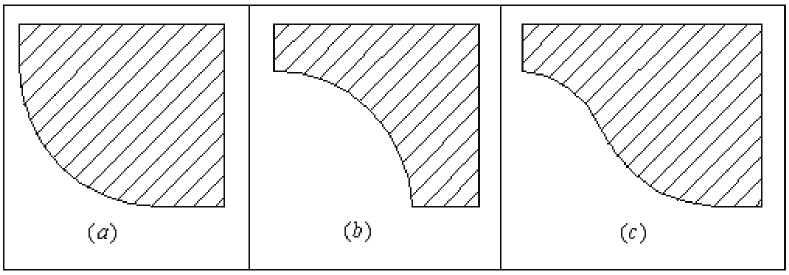

Fig. 2. Circular die shapes, (a) convex, (b) concave, (c) hybrid

2.1. Sinking zone

The analysis in this section is based on the assumption that the thickness of the tube does not change significantly in the sinking zone. This assumption was justified by performing experiments on tubes, which showed that when the diameter over thickness ratio of the tube is less than 10, the thickness of the tube remains almost constant during the process

The stress analysis of sinking zone was first given by Sachs and Baldwin [5]. Referring to Fig. 3 and neglecting the small quantity $d\sigma_z.dz$, equilibrium of forces acting on the element in axial direction gives:

$$d(\sigma_1.A) - 2\pi.R.(p_u.\tan\alpha + m.k).\frac{dz}{\cos\alpha} = 0 \tag{1}$$

The equilibrium of the forces acting on the element in the radial direction yields the normal pressure p_u on the hammer die:

$$p_u = -\sigma_3.\frac{t.\cos\alpha}{R} \tag{2}$$

In sinking zone, the radial pressure on die is small in comparison with the principal longitudinal and circumferential stresses, and therefore the approximate yield condition is given by:

$$\sigma_1 - \sigma_3 = \overline{\sigma}\,. \tag{3}$$

The corresponding radial pressure in the sinking zone is:

$$p = \frac{t}{R}.(\overline{\sigma} - \sigma_1).(\cos\alpha)^2 \tag{4}$$

2.2. Sizing zone

Referring to Fig. 4, considering the equilibrium of forces acting on an element in axial direction gives:

$$A.d\sigma_z - mk.2\pi.R_2.dz = 0 \tag{5}$$

The equilibrium of the forces acting on the element in the radial direction yields equation (2), but here σ_3 is σ_θ. In the sizing zone circumferential stress is the smallest and axial stress is positive and the largest stress, so the approximate yield condition is given by:

$$\sigma_z - \sigma_\theta = \overline{\sigma} \tag{6}$$

Substituting equations (2), (6) into equation (5) and solving it, the radial pressure distribution is obtained.

2.3. Convex surface in sinking zone (Fig. 3a)

The following geometrical relations are given in Fig. 5:

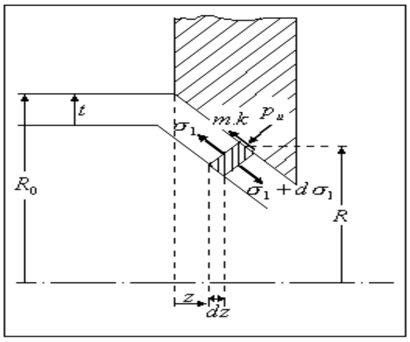

Fig. 3.Analysis of stresses in sinking zone

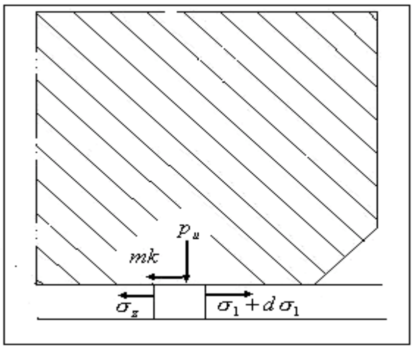

Fig. 4. Analysis of stresses in sizing zone

$$z = L_1 - R_d.\sin\alpha \longrightarrow dz = -R_d.\cos\alpha.d\alpha \qquad (7)$$

$$R = R_1 + R_d.(1-\cos\alpha) \longrightarrow dR = R_d.\sin\alpha.d\alpha \qquad (8)$$

$$A = \pi.t(2R - t.\cos\alpha) \longrightarrow dA = \pi.t.(2dR + t.\sin\alpha.d\alpha) \qquad (9)$$

Substituting these relations into equations (1) for the sinking zone gives:

$$(2R - t.\cos\alpha)d\sigma_1 + (\sigma_1.t.\sin\alpha + \frac{2R_d.m.\bar{\sigma}}{\sqrt{3}.t}.R + 2R_d.\bar{\sigma}.\sin\alpha)d\alpha = 0 \qquad (10)$$

For the sizing zone the equation (5) is valid.

The equation for concave and hybrid die shapes is similarly obtained.

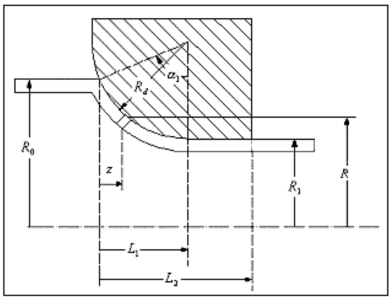

Fig. 5. Convex circular shape

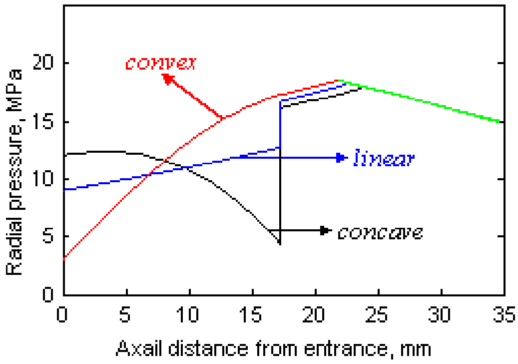

Fig. 6. Effect of die shape in pressure distribution

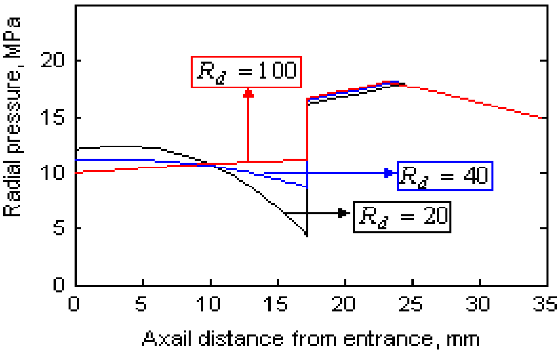

Fig. 7. Effect of increasing die radius in ($R_d = 20$, α=30 deg, $\bar{\sigma} = 120$ MPa concave surface (α=30 deg, t=5 mm, t=5 mm, R_0 =50 mm, R_1 =40 mm) R_0 =50 mm, R_1 =40mm, $\bar{\sigma} = 120$ MPa)

3. RESULTS

Considering Fig. 6 reveals that the radial pressure in each point depends on the die angle in that point and for circular shapes, it can be higher or lower than the pressure at the corresponding point for linear shape. Fig. 7 illustrates the effect of die radius on pressure distribution in concave surface die shape. It can be seen that the pressure distribution in sinking zone is greatly affected when the die radius changes and for some larger radii becomes almost constant along the forging axis (Fig. 7 when R_d =100 mm). In fact, when the radius is large, the pressure profile becomes closer to that of linear profile, forming a conical shape. It is clearly observed by comparing Figs. 6 and 7.

Fig. 8 shows that when the entrance and exit angle changes, pressure on the die can be higher or lower than linear shape in the entire length of sinking zone. Moreover, in curve number (1) the neutral plane has been moved toward the preform and the radial load increased, but in the curve number (2) the neutral plane has been moved toward the part and the radial load increased. This means that when the hybrid shape is used, it is possible to obtain better pressure distributions in the constant length of sinking zone by changing the die angle. On the other hand, when case number (1) is used, the neutral plane moves toward the preform and the amount of material flowing forward is increased, and the radial load is also increased. This can be an important observation, because if linear shape is used instead of case (1) to get the same material flowing forward, smaller die angle or longer length in sinking zone is required which results in longer dies.

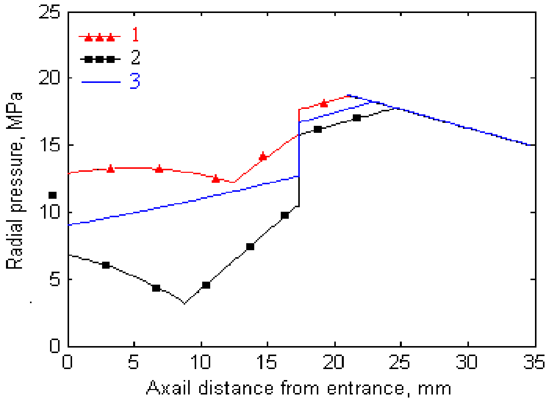

Fig. 8. The effect of die angle in hybrid die shape on pressure distribution

4. CONCLUSIONS

In this study slab method was used to analyze the radial forging of tubes without mandrel. The results of this study indicate that:

1- When the outer diameter of tube is large relative to its thickness, the thickness remains constant during radial forging.
2- Using convex circular surface in sinking zone moves neutral plane toward the preform.
3- Using hybrid surface in sinking zone gives more control on the process and can make the process more cost-effective.

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