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Application of Numerical Simulation to Investigate Material Flow in Hollow Radial Extrusion

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ABSTRACT

In this paper, the radial extrusion process with mandrel is considered. The numerical simulation results by the rigid-plastic finite element method (FEM) to investigate the forming characteristics in two different schemes of radial extrusion process with mandrel as single-ended and double-ended have been determined. Based on the finite element simulations using two-dimensional QForm software, deformation patterns (gridlines distortion), distributions of effective strain and stress, the variations of relative punch pressure with punch stroke and also to predict and avoid folding defect with different forming parameters in single-ended and double-ended processes have been investigated.

Keywords: Finite Element Method, Folding Defect, Material Flow, Numerical Simulation, Radial Extrusion

I. INTRODUCTION

In the metal forming processes, extrusion process is on of the most important processing methods in the manufacturing industry for producing different parts with various shapes such as flanges, branches and other geometric forms. Recently, the numerical simulation techniques using the rigid-plastic finite element method (FEM) have been successfully applied to investigate the forming characteristics of various metal forming processes especially in extrusion methods. In the extrusion process, the billet retained in an extrusion chamber is extruded into a die cavity. By this process can be produced axisymmetric and non-axisymmetric parts. There are principal types of extrusion process such as forward, backward, radial, lateral and combined. The radial extrusion process with mandrel, a tubular billet is extruded simultaneously by punch movement into the radial direction to fill die cavity. Defects occurring as folding defect during this process sometimes are caused. It is very important and necessary to control material flow during the process to avoid the formation of folding defect [1-10].

II. Method of Analysis

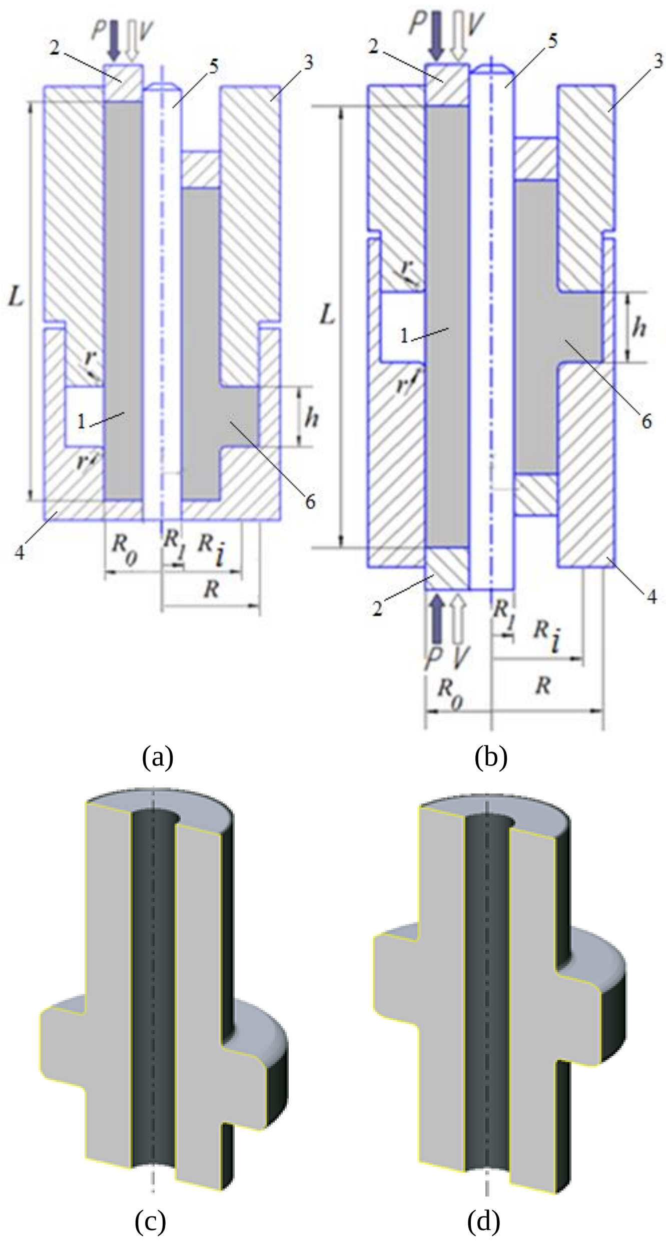
In the present study, rigid plastic finite element simulations using QForm 2D software to analyse material behavior and stress-strain state are performed.

III. Purpose of Investigation

In this paper, based on the finite element simulations, forming characteristics such as deformation patterns (gridlines distortion), distributions of effective strain and stress in two different schemes of radial extrusion process with mandrel, viz, single-ended and double-ended during the forming process with different forming parameters, and also to predict and avoid folding defect in theses processes have been investigated. The relative punch pressure–stroke and upper die velocity with relative flange height in single-ended and double-ended processes are shown.

IV. Radial Extrusion Process with Mandrel

The die schemes, die geometry parameters, axisymmetric tubular billet dimensions and the formed part for single-ended and double-ended radial extrusion processes are shown in Fig. 1. The die geometry parameters, tubular billet dimensions and power mode parameters are as follows: R_0 – the outer radius of tubular billet (R_0 = 27mm), R_1 – the inner radius of tubular billet or the radius of mandrel (R_1 = 9mm), R – the outer radius of flange or formed part (R = 45mm), R_i – the intermediate flange radius, L – the billet height (L= 100mm), h – the flange height (h=11.7mm), t = R_0-R_1, h/t – the relative flange height, r – the die tip radius (r=2mm), V – punch velocity (V=1mm/s), P – punch load, , The friction factors between the billet and tools are constant (Zibel's law, μ=0.08).



1 – tubular billet, 2 – punch, 3 – upper die, 4 – lower die, 5 – mandrel, 6 – formed part

Figure 1. Die scheme of single-ended radial extrusion process with mandrel (a) and formed part (c); die scheme of double-ended radial extrusion process with mandrel (b) and formed part (d)

V. Material Property

In this study, the material used for the simulation is AA 6060 aluminum alloy. The relationship between flow stress and effective strain for AA 6060 aluminum alloy can be approximated by:

$$\bar{\sigma} = 191.55\,\bar{\varepsilon}^{0.202}\ (MPa) \quad (1)$$

VI. Analysis of Radial Extrusion Process with Mandrel

The accurate design of radial extrusion process with mandrel, axisymmetric tubular billet and some tool parts such as upper die, lower die, mandrel and some movable punches have been applied. Simulations based on the finite-element (FE) method are considered. The finite element software is used a direct iteration and Newton-Raphson methods to solve the nonlinear equations. During the simulations by commercial software for plastic deformation as QForm2D, it is seemed that the tubular billet is rigid-plastic body and various tool parts are all rigid bodies. In the radial extrusion processes with mandrel, tubular billet and tooling temperatures are room temperature. Deformation patterns (gridlines distortion), distributions of effective strain and stress in single-ended (Fig. 2) and double-ended (Fig. 3) radial extrusion processes with mandrel using relationship h/t=0.65 are shown. It is observed in these figures that the maximum amounts will be in a relationship R_i/t=2.5. In Fig. 2 and 3, it can be seen that the effective strain and stress of the workpiece were symmetrical distributed in the processes. The maximum effective strain and stress are calculated as follows: ε_{max} =4.5, σ_{max} =220MPa in single-ended (Fig. 2) and ε_{max} =2.4, σ_{max} =200MPa in double-ended (Fig. 3) processes. The relative pressure on the punch with punches travel as determined by finite element simulation in theses processes. Fig. 4 shows comparisons of the relative punch pressure vs. the relative punch stroke between single-ended and double-ended processes with relationship h/t =0.65. In Fig. 4, it is observed that the maximum relative punch pressure in single-ended and double-ended processes were 5.25 and 5.0 respectively. Thus it was construed that formability of the double-ended forming is better than that of the single-ended forming in terms of strain-stress distributions and forming load. The material flow behavior and the influence of various factors involved in radial extrusion processes with mandrel were explored. In this process study to predict and avoid defect as a folding defect is very important and necessary to create hollow parts. A finite element simulation is developed to study the defect formation mechanism. During the radial extrusion processes with mandrel a defect as a folding defect appears on the material flow when value of relationship h/t will be more than 1.45 in single-ended and 1.6 in double-ended. In Fig. 5, it can be seen that a folding defect has been appeared with relationship h/t =1.8 in single-ended and double-ended radial extrusion processes with mandrel. Based on the revealed folding defect, it is therefore necessary to design a kinematical mechanism by using finite element simulation to avoid defect as a folding defect.

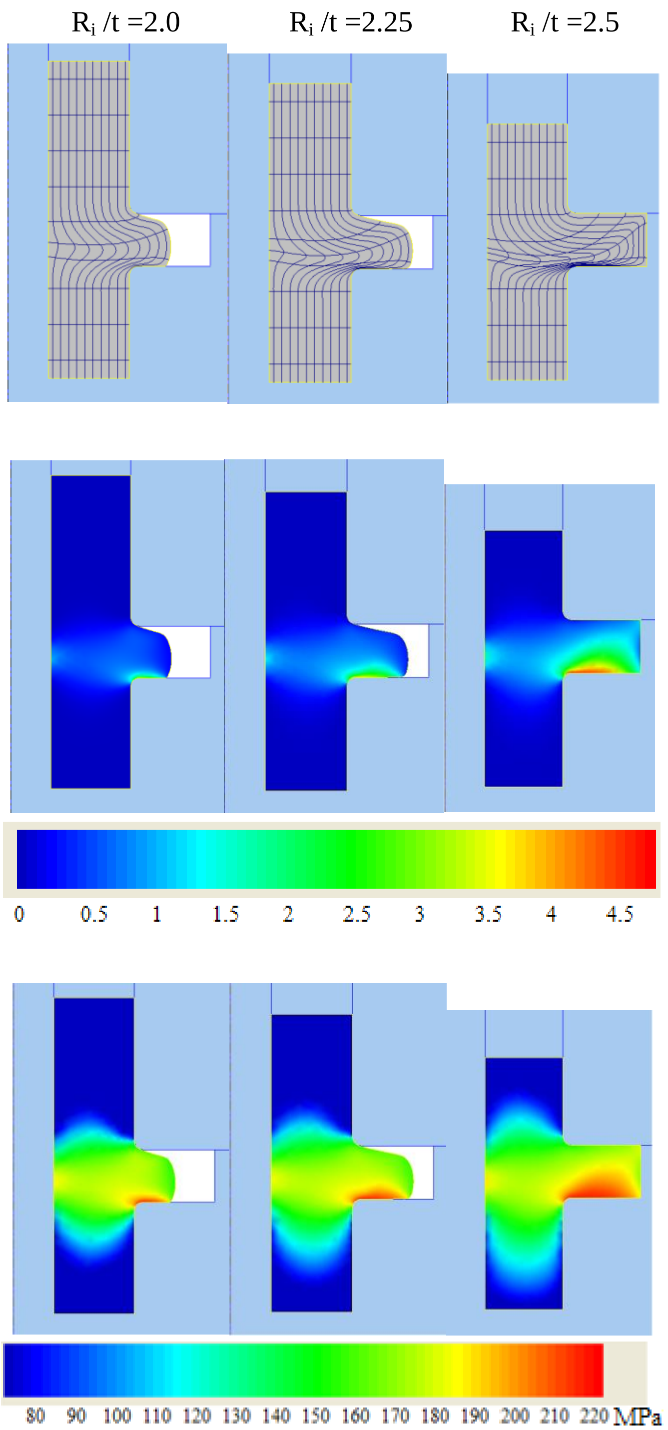


Figure 2. Deformation patterns or gridlines distortion (a); distributions of effective strain (b); distributions of effective stress (c) with different stages R_i/t in single-ended radial extrusion process with mandrel

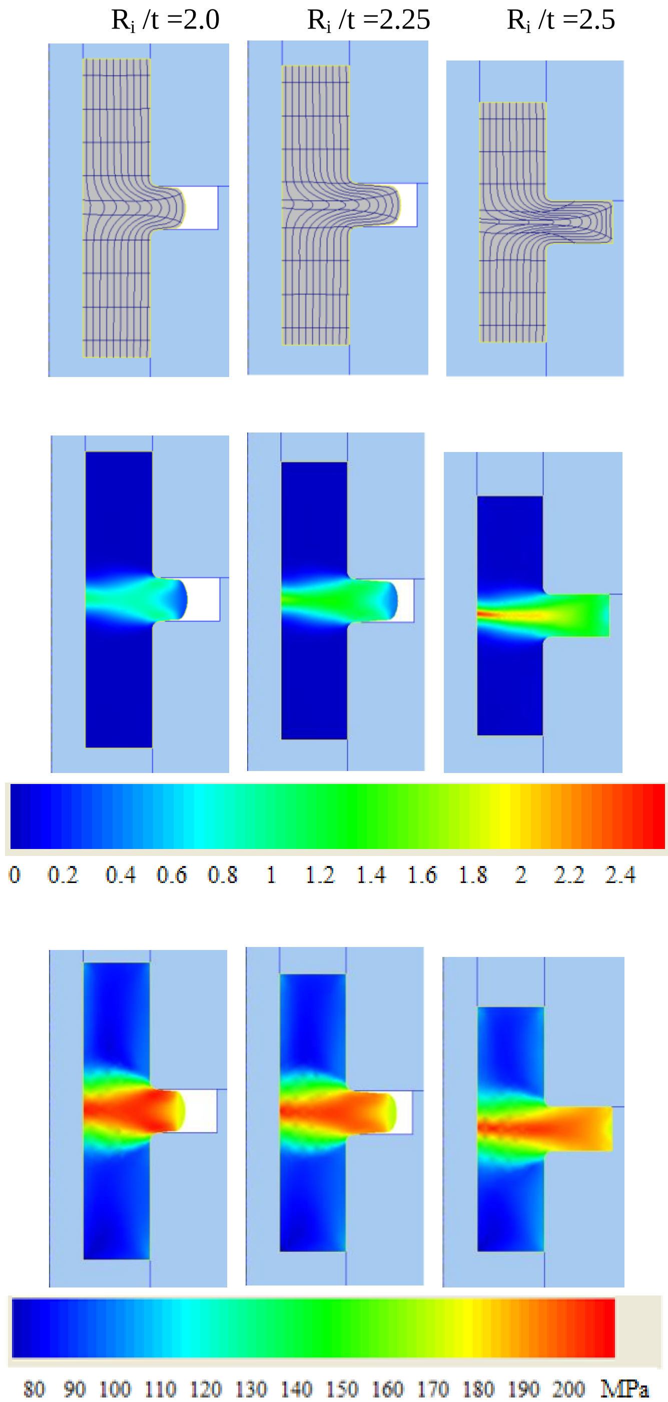


Figure 3. Deformation patterns or gridlines distortion (a); distributions of effective strain (b); distributions of effective stress (c) with different stages R_i/t in double-ended radial extrusion process with mandrel

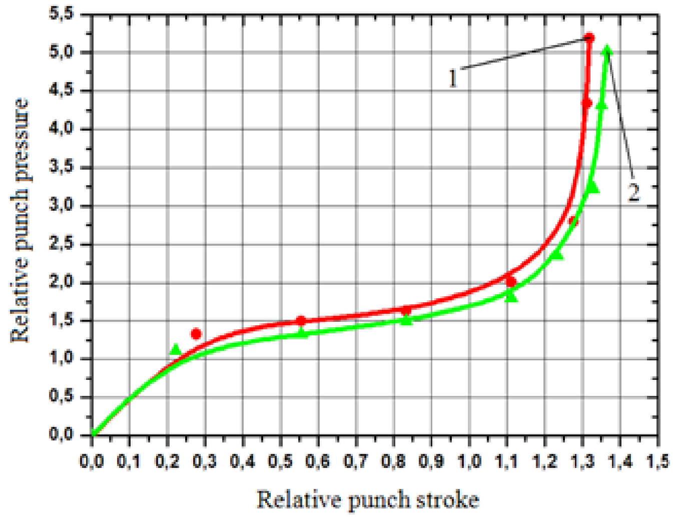
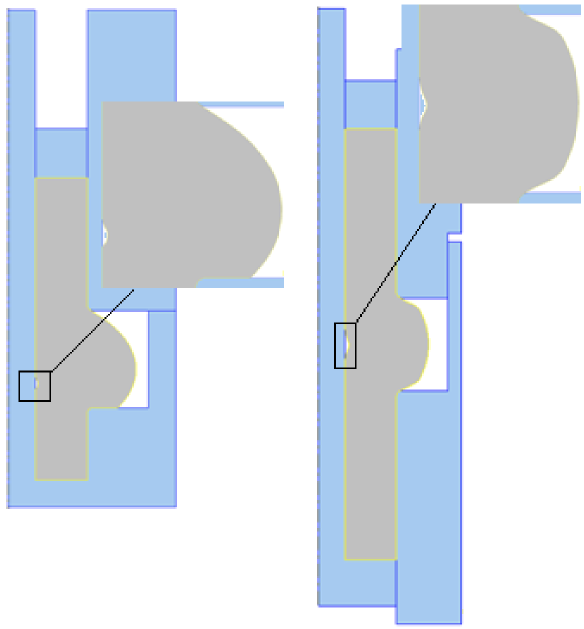


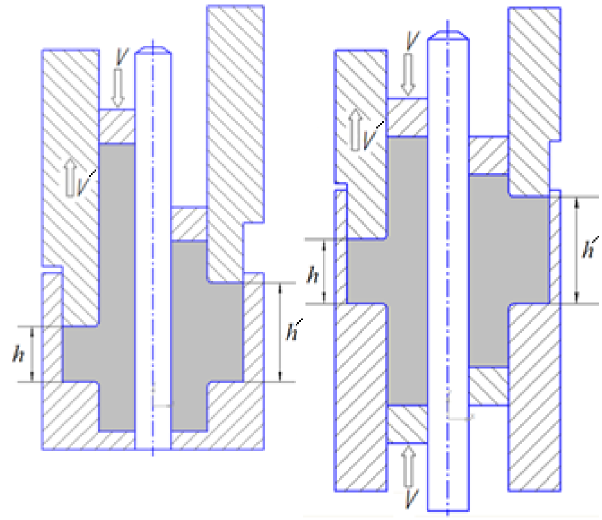
Figure 4. The relative punch pressure vs. the relative punch stroke in single-ended (1) and double-ended (2) radial extrusion processes with mandrel



(a) (b)

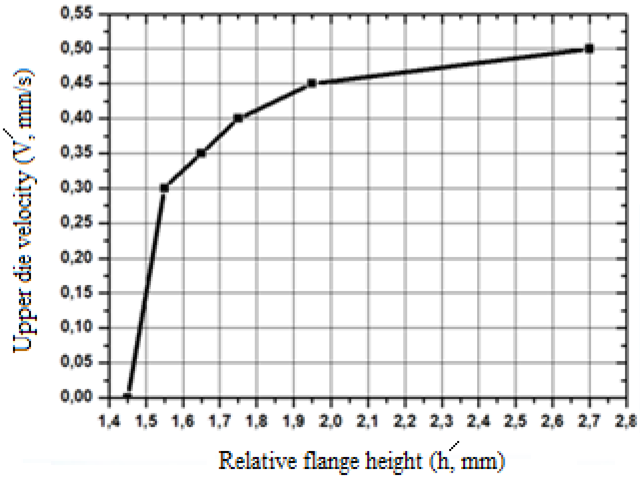
Figure 5. Folding defect in single-ended (a) and double-ended (b) radial extrusion processes with mandrel

In this investigation in order to avoid folding defect and to make new material flow and to create a hollow parts without folding defect has been used a movable upper die in die schemes. Fig.6 presents kinematic die schemes of single-ended and double-ended processes with the movable punch and the movable upper die. Fig. 7 (a, b), show the upper die velocity vs. the relative flange height in theses processes. It is observed in these figures that with different upper die velocities ($V^{/}$) can be created hollow parts with different flange height when the punch moves with a constant velocity (V=1mm/s).

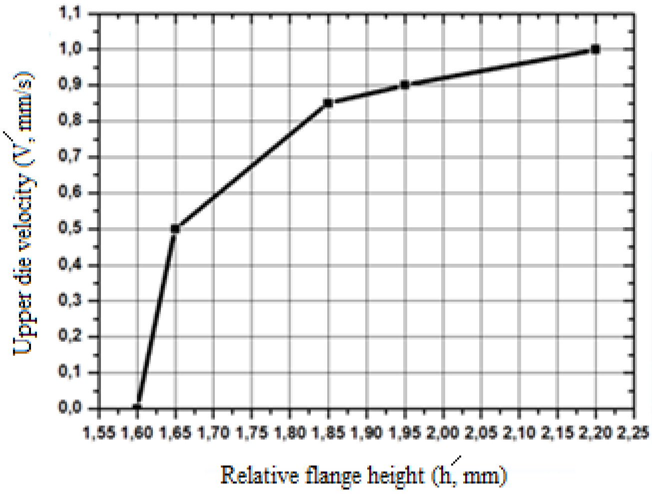


(a) (b)

Figure 6. Kinematic die schemes of single-ended (a) and double-ended (b) radial extrusion processes with mandrel



(a)



(b)

Figure 7. The upper die velocity vs. the relative flange height in single-ended (a) and double-ended (b) radial extrusion processes with mandrel

VII. CONCLUSION

In the present study, the cold radial extrusion processes with mandrel as single-ended and double-ended using two-dimensional finite element simulations such as QForm have been considered. The die geometry parameters, tubular billet dimensions and power mode parameters have been used. Deformation patterns (gridlines distortion), distributions of effective strain and stress, variations of relative punch pressure and material behavior by kinematical mechanism to avoid folding defect in single-ended and double-ended processes have been investigated. Based on simulation results, the formability of the double-ended forming is better than that of the single-ended forming in terms of strain-stress distributions and forming load.

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