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Computer-aided Simulation to Investigate Material Flow in Combined-radial Extrusion

Dr. Payman Abhari

Ph.D., Associate Professor,

Department of Metal Forming,

Donbass State Engineering Academy,

Kramatorsk, Donetsk,

Ukraine

ABSTRACT

In this present paper, the combined-radial extrusion process at room temperature is considered. Computer-aided simulations by the rigid-plastic finite element program such as QForm 2D in two different schemes of combined-radial extrusion process, viz, single-ended and double-ended have been used. The die schemes, die geometry parameters, axisymmetric billet dimensions and power mode parameters to investigate forming characteristics such as deformation patterns (gridlines distortion), distributions of effective strain and stress and comparisons of load–stroke curve in these processes by using various relationships have been applied. Based on the simulation results, it is concluded that the maximum forming load will be occur in single-ended process and the best strain-stress distributions will be appear in double-ended process.

Key Words: *Combined-radial extrusion, Finite element simulation, Forming load, Material flow, Stress-strain state.*

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1. INTRODUCTION

Extrusion process with cold, warm and hot forming was introduced as a variant of metal forming processes having industrial applications for producing different parts with various shapes. In extrusion process modelling is used to predict material flow, strain and stress distributions, forces exerted on tools and potential sources of effects and failures. Extrusion process at room temperature is type of cold forging process. However with increase of the market demand on reduction of the production cost, cold forging has been gradually applied in manufacturing industries. It has competitive advantages such as good surface finish, improved mechanical properties and dimensional accuracy of the formed products. There are principal types of extrusion process such as forward, backward, radial, and combined. In this process, the billet is located in the die cavity and is squeezed by one and more rams. The billet is compressed between punches and dies and die cavity fills with the billet material. The numerical method such as finite element method is one of the most powerful tools of computer-aided engineering (CAE) to solve and simulate various problems in design and manufacturing, especially in the extrusion processes. Recently, some commercial CAE softwares are now available for analysis and being utilized for process verification and modification as well as for design improvement [1-4].

2. METHOD OF ANALYSIS

The rigid-plastic finite element method (FEM) as software QForm 2D has been applied to investigate the different forming characteristics and parameters in combined-radial extrusion.

2. PURPOSE OF INVESTIGATION

In this study, based on the finite element simulations, forming characteristics such as patterns (gridlines distortion), distributions of effective strain and stress at several stages of processes with different forming parameters in two various schemes of combined-radial extrusion processes, viz, single-ended and double-ended. Comparisons of load–stroke curves between various processes by using this theoretical simulation method have been defined [5, 6].

4. COMBINED-RADIAL EXTRUSION PROCESS

The die schemes, die geometry parameters, axisymmetric billet dimensions and the formed part for single-ended and double-ended combined-radial extrusion processes are shown in Figure. 1. The die geometry parameters, billet dimensions and power mode parameters are as follows: R_0=R_3-R_1 – the radius of billet (R_0 = 4.21mm), R_1=internal radius of die (R_1 =7.5), R_2= external radius of die (R_2 =16.71), L_1 – the billet height (L_1= 25mm), L_2 – the formed part height (L_2= 17.972mm), h – the flange height (h=3.513mm), r – the die tip radius (r=0.5mm), S – punch stroke, 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).

5. MATERIAL PROPERTY

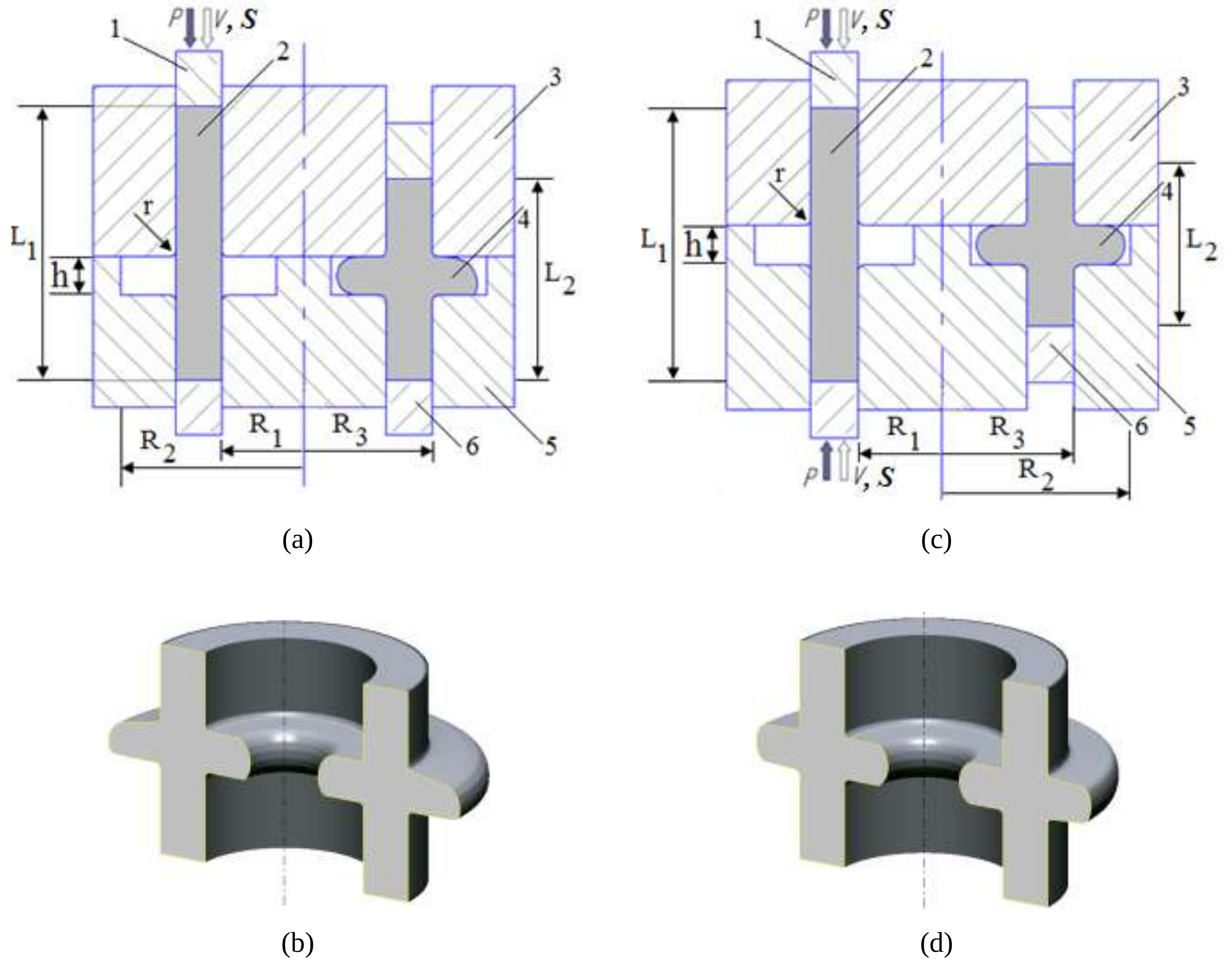
In this study, the material used for the simulation is AA 6060 aluminum alloy. The relationship between flow stress and effective strain for AA 6060 aluminum alloy can be approximated by [7, 8]:

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

6. ANALYSIS OF COMBINED-RADIAL EXTRUSION PROCESS

In the design of combined-radial extrusion process axisymmetric tubular billet and some tool parts such as upper die, lower die and some movable punches have been applied. The finite element software is used a direct iteration and Newton-Raphson methods to solve the nonlinear equations Rigid-plastic finite element simulations using Qform software are performed. During the processes simulations, it is seemed that the billet is rigid-plastic body and various tool parts are all rigid bodies. In the extrusion processes, axisymmetric tubular billet and tooling temperatures are room temperature. The material flow behavior and the influence of various factors involved in processes were explored. During the extrusion process, movable punch applies force on billet material and the material is extruded radials to form the formed part in dies cavity. The analyses are carried out in two stages. The simulation results such as deformation patterns (gridlines distortion), distributions of effective strain and stress in single-ended (Fig. 2-1) and double-ended (Fig. 2-2) combined-radial extrusion processes with relationships S/R_0 =1.669 and h/R_0 =0.834 are shown in the first stage. The influence of punch strokes on the punch loads during the extrusion processes are investigated in the second stage. In Figure 2, it can be seen that the effective strain and stress of the billet were symmetrical distributed in the processes. The maximum effective strain and stress are calculated as follows: ε_{max} =3.6, σ_{max} =220MPa in single-ended (Fig. 2-1) and ε_{max} =1.3,

σ_{max} =200MPa in double-ended (Fig. 2-2) processes with relationships S/R_0 =1.669 and h/R_0 =0.834. The variation of punch load with punch displacement (stroke) and comparison of load–stroke curves between theses processes by using various relationships have been determined (Fig. 3). As shown in this figure stiff rising of forming loads were commonly observed according to increase of the punch stroke along the any stage of the deformation. The predicted maximum forming loads of the punch in punch stroke (7.0mm) are the following (Fig. 3): P_{max}=105kN in single-ended and P_{max}=95kN in double-ended processes in the final stage of forming S/R_0 =1.669. Comparison of load–stroke curves in the figure 3 is shown that difference between maximum forming loads is less than 10%. 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.



1, 6 – punches, 2 – billet, 3 – upper die, 4 – formed part, 5 – lower die

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

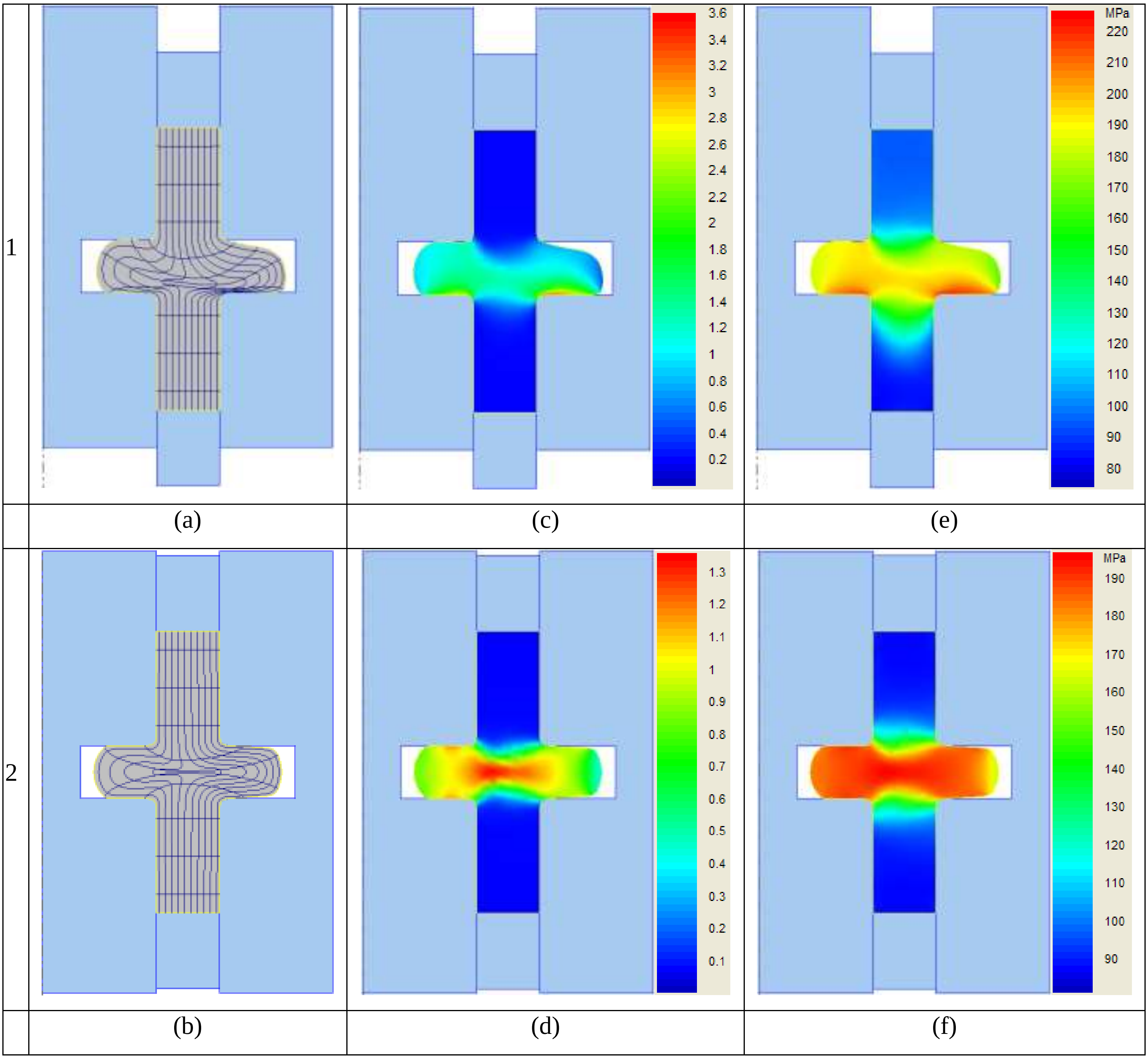


Figure 2. Gridlines distortion (a, b); distributions of effective strain (c, d); distributions of effective stress, MPa (e, f) in single-ended (1) and double-ended (2) combined-radial extrusion processes with a relationship S/R_0 =1.669

7. CONCLUSION

In this paper, the influence of design parameters such as billet dimensions, dies geometries and power modes for investigating the material flow, stress-strain state and variation of punch load in combined-radial extrusion processes with single-ended and double-ended using two dimensional finite element (FE) simulations as QForm have been explored. Deformation patterns (gridlines distortion), distributions of effective strain and stress in cold extrusion processes have been investigated. Based on FE simulation results, the formability of the double-ended extrusion is better than that of the single-ended extrusion in terms of strain-stress distributions and forming load. Comparison of load–stroke curves have been shown that difference between maximum forming loads is less than 10%.

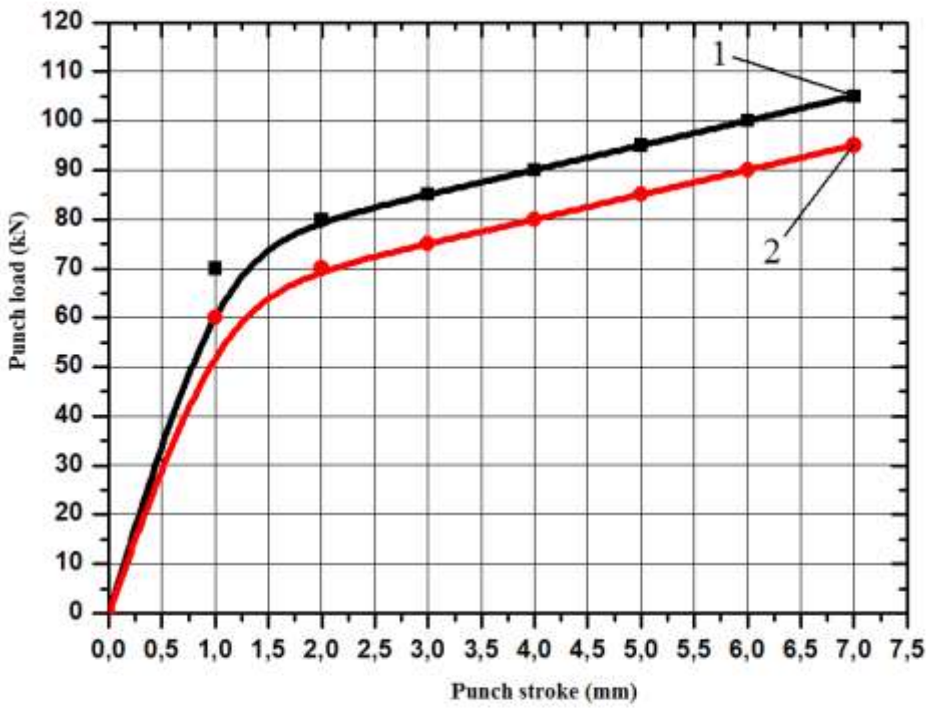


Figure 3. The punch load vs. the punch stroke in single-ended (1) and double-ended (2) combined-radial extrusion processes with a relationship h/R_0 =0.834

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