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Research on Continuous Extrusion Method for Forming Thin-Walled Cup-Shaped Details †

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Abstract: Backward extrusion is a suitable method for forming thin-walled cup-shaped details. However, the deformation force is very large, making it difficult to choose equipment and ensure the durability of the die. The continuous extrusion method is improved from the traditional backward extrusion method to overcome the main disadvantages in the deformation process. The die structure in continuous extrusion is improved, including three main parts: fixed punch, primary punch and die. The use of a smaller size original workpiece that is deformed in the fixed punch and flows into the die cavity is the cause of the significant reduction in the deformation force. The result obtained is that the deform of the workpiece is uniform and 200 % larger according to the product height, and the deformation force is reduced by less than 50% compared to the traditional backward extrusion method. Therefore, continuous extrusion method is highly applicable in the production of products in industry and national defense.

Keywords: backward extrusion; continuous extrusion; deformation; deformation force; cup-shaped details

1. Introduction

Extrusion is a metalworking process by pressure in which the workpiece under the action of the punch is deformed through the die hole, creating products with cross-sectional profiles ranging from simple to complex. In which backward extrusion is a suitable method for forming thin-walled cup-shaped details [1, 2]. Hae Yong Cho et al. carried out process design for forward and reverse presses to shape the axially symmetric part [3]. The shape of the initial workpiece was studied as one of the most important factors determining the complex product forming process. The resulting responses include forming loads, defect-free geometrical filling of the mold, and a proper distribution of tension in the final product. The design process was conducted through numerical simulation of the cold forging operation using Deform commercial finite element software. Namburi, Kali Prasad Varma et al. [4] reported the research results on the influence of process and tool parameters on the cold- extrusion process. Deform 3D software is applied to simulate the deformation process. The selected input process parameters include the die angle, the coefficient of friction and the speed of the punch. Taguchi experimental planning method and ANOVA analysis were used to optimize the deformation force of the cold- extrusion process. H. Long has developed a finite element (FE) analysis procedure to predict component size deviations in different stages of cold extrusion [5]. The effect of elastic-plastic deformation and temperature variation of workpiece and tool on dimensional error of a cold cup extrusion is investigated. The law of influence of process and material parameters on dimensional errors of formed components are useful recommendations for the

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design process of forming technology. M. Bakhshi-Jooybari et al. [6] have shown that the deformation load is reduced by about 10% in backward rod extrusion by optimizing the profile of the die. The FEM, ABAQUS software and a computer program are applied to optimize the angle of the conical die under the same conditions. The effect of different friction on die stress during the backward extrusion process was also investigated by Yong Shun Yang et al. [7]. Research results confirm that friction affects not only the degree of plastic deformation but also the energy consumed for the deformation process. As friction decreases, the plastic deformation of the material increases. Conversely, when friction increases, the unit pressure on the punch and the stress applied to the die wall increase. That makes it difficult to ensure the durability of the extrusion die. Rotating backward extrusion (RBE) is an improved method from the traditional backward extrusion method. It is one of new severe plastic deformation technology with the aim of refining the fine grain in the microstructure of the alloy. The number of revolutions of the punch significantly increases the degree and range of grain refinement of alloy AA7075 [8]. The results obtained the microstructure with ultrafine grains (UFGs) of studied alloy. However, the main disadvantage of this method is that the die structure is complex and the control of the rotational speed of the punch in accordance with the plastic deformation of the alloy is also difficult.

According to the research literature, there is always an uneven deformation along the height of the cup-shaped part during traditional backward extrusion process. This statement is made from simulation results and experimental evaluation. Besides, the deformation force in backward extrusion is often very large, making it difficult to choose equipment and experimental process. The continuous extrusion method is improved from the traditional backward extrusion method to overcome the main disadvantages in the deformation process. The die structure in continuous extrusion is improved, including three main parts: fixed punch, primary punch and die. The use of a smaller size original workpiece that is deformed in the fixed punch and flows into the die cavity is the cause of the significant reduction in the deformation force. The result obtained is that the deform of the workpiece is uniform and 200% larger according to the product height, and the deformation force is reduced by less than 1/2 compared to the traditional backward extrusion method. Therefore, continuous extrusion method is highly applicable in the production of products in industry and national defense.

2. Materials and Research Methods

The die structure in continuous extrusion is improved, including three main parts: fixed punch, movable punch and die. The geometrical models of the traditional backward extrusion method and the continuous extrusion method are presented in Figure 1. In the traditional backward extrusion, the initial workpiece is placed in the cavity of the die, and the punch moves down to create pressure. The workpiece is compressed and flows through the gap between the punch and the die to produce a thin-walled cup-shaped product (Figure 1a). In the continuous extrusion (Figure 1b), the initial workpiece is smaller in size than the old backward extrusion method. The size of the initial workpiece is equal to the inner diameter of the fixed punch. The size of the outside diameter of the fixed punch is equal to the size of the punch diameter of the old backward extrusion method. Deformation occurs when the movable punch moves down to create pressure. The material is plastically deformed and flows into the gap between the fixed punch and the die. First, the workpiece material flows in the horizontal direction creating the bottom of the product. Then, the workpiece material flows upward in the axial direction of the workpiece to form the wall of the product. The difference between the continuous extrusion method and the traditional backward extrusion method includes the die structure, the initial workpiece size and the stroke of the movable punch.

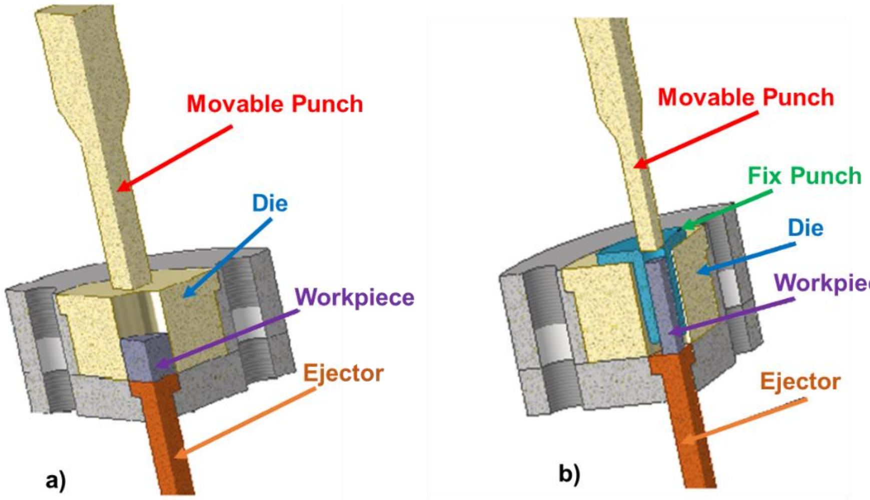

Figure 1. Geometrical models of the traditional backward extrusion method (a) and the continuous extrusion method (b).

Commercial software Deform 3D is used to simulate the deformation process including traditional backward and continuous extrusion processes. The initial workpiece material is Ck10 steel according to DIN 17210. The relationship between stress and strain as performed by tensile test [9]. By determining the true stress and true strain from the engineering stress - strain diagram, it is possible to determine the material behavior of Ck10 steel when cold forming is shown in Equation 1 [9]. The hardening plastic material model determined by Equation 1 [9] is used for material model of simulation problems on Deform 3D software.

$$\sigma = K.\varepsilon^{n} = 740.\varepsilon^{0.216} \quad (1)$$

where σ is the effective flow stress (MPa), K is is the strain hardening coefficient (MPa), ε is the effective strain, n is the strain hardening exponent.

The initial workpiece for traditional backward extrusion process is machined in diameter and length of 30 mm and 10mm, respectively. The initial workpiece for continuous extrusion process has diameter and length of 15 mm and 40 mm, respectively. The product has a bottom thickness of 6.5 mm and a wall thickness of 4 mm.The initial workpieces are meshed with 30000 elements. All the die parts have been considered as rigid bodies. The movement speed of the movable punch set in the simulation problem for both cases is 15 mm/s. Extrusion temperature is room temperature at 20^{0}C. During the deformation process, there is always contact between the tool and the workpiece, causing friction, which has a direct impact on the technological parameters of the process, product quality, and tool life and energy consumption. In simulation problems, the friction factor selected as 0.08 [10].

3. Results and Discussion

The distributions of the effective stress in the workpiece formed by both traditional backward extrusion and continuous extrusion were shown in Figure 2, respectively. The distribution of stress states of the two extrusion options is different: In the continuous extrusion method, the stress is evenly distributed over the positions of the workpiece, reaching about over 596 MPa; the largest is 672 MPa and the smallest is 56.5 MPa. Less stress occurs at the contact between the punch top and the workpiece due to contact friction. In the traditional backward extrusion, the stress is unevenly distributed, forming 3 stress zones. The largest in the radius of the punch 672 MPa due to the change of the workpiece cross-section. The part of the workpiece in contact with the bottom of the die has a smaller stress of over 500 MPa, while the upper part of the workpiece has the smallest stress because it is not subjected to the compressive stress of the punch top.

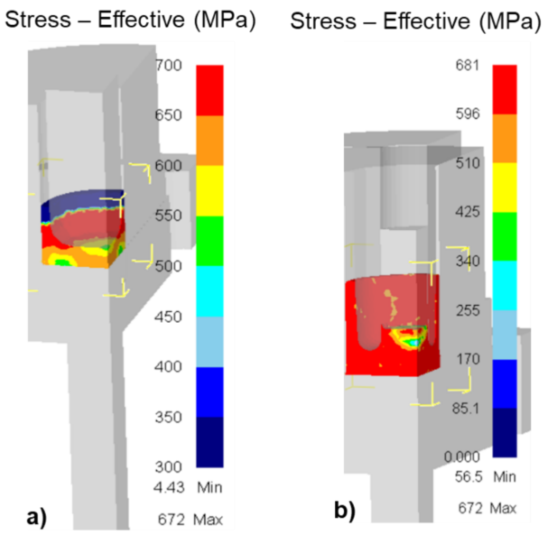

Figure 2. Distribution of state of stress in traditional backward extrusion (a) and continuous extrusion (b).

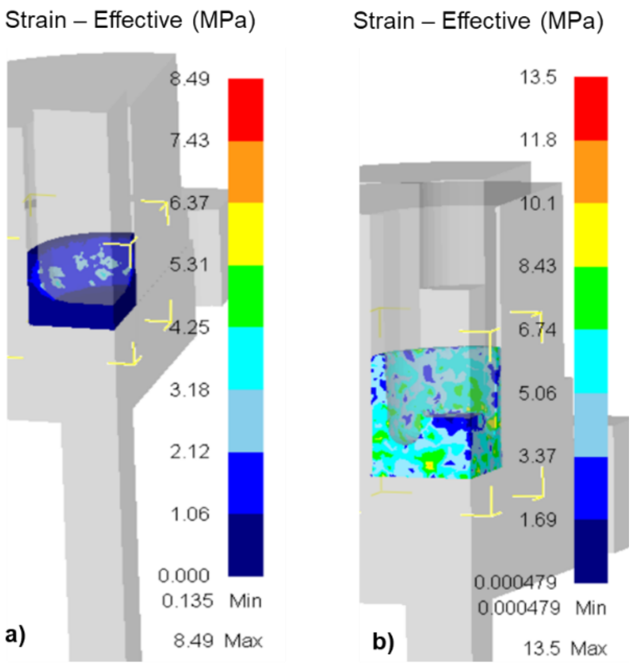

Figure 3. Distribution of state of strain in traditional backward extrusion (a) and continuous extrusion (b).

The distributions of the effective strain in the workpiece formed by both traditional backward extrusion and continuous extrusion were shown in Figure 3, respectively. It can be seen that the effective strain at the positions of the workpiece in both methods is different. The maximum effective strain of the continuous extrusion method is about 150 % greater than that of the traditional backward extrusion method. In the traditional backward extrusion method (Figure 3a), the effective strain was divided into two distinct regions, the largest being in the radius of the punch. The part wall and the bottom part have the same and minimum effective strain. In the continuous extrusion method, the strain of the workpiece is the most uniform and stable (Figure 3b). The wall part of the workpiece has a more uniform effective strain than the traditional backward extrusion method because the part metal area is flowed in the horizontal direction creating the bottom of the product before flowing upward in the axial direction of the workpiece to form the wall of the product.

The deformation force of traditional backward extrusion method and continuous extrusion method obtained from FE method has been compared as shown in Figure 4. Based on obtained simulation results, the required deformation force to forming a cup-shaped detail with traditional backward extrusion was equal to 28.5 tons, while the required deformation force to forming the same product using continuous extrusion was equal to 14 tons. Thus, one outstanding advantage of the continuous melting method is that the required deformation force has been significantly reduced (about 50%) compared to the traditional method. This is a favorable factor for the selection of equipment as well as the design process of product forming technology.

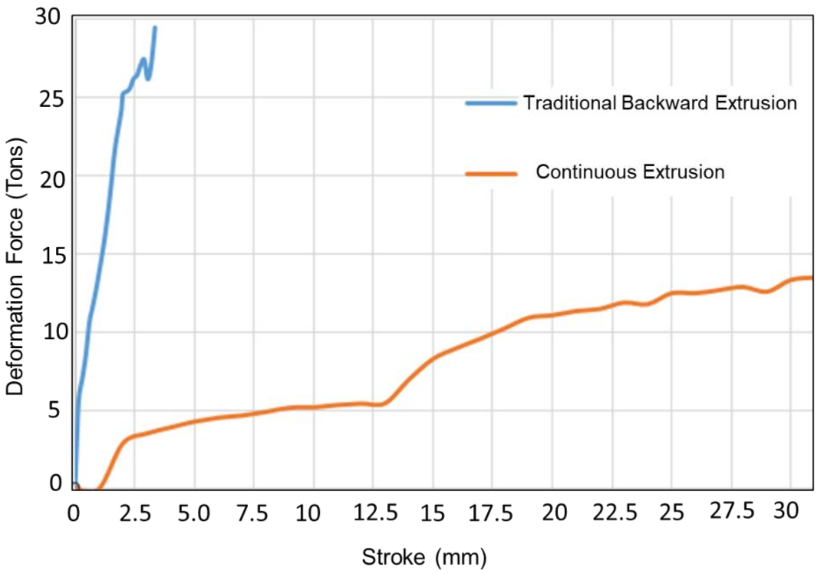

Figure 4. The force-stroke graph for both traditional backward extrusion method and continuous extrusion method.

This article result deserves to be noted compared to previous publications on solutions to reduce the required force for forming by plastic deformation. Hung et al. [11] reported on the solution to reduce the deformation force by applying the ultrasonic vibration on double backward extrusion of aluminum alloy. As a result, the required force was reduced by about 20 %. As was mentioned earlier with using of the novel method of continuous extrusion, the deformation force can be reduced about 50 %. Uyyuru et al. [12] reported that by completely eliminating friction during forming it was possible to reduce the required force by about 25%. Meanwhile, with the selection of the suitable coefficient of friction for the forming process, it is possible to reduce the required deformation force by about 50%. The comparison of the results of this work with those of previous publications shows the advantages and applicability of this method in production practice.

4. Conclusion

In this work, continuous extrusion method is studied through simulation problems using Deform 3D software. Although this method is differences from the traditional backward extrusion, including the die structure, the initial workpiece and the stroke of the movable punch. But those are the same factors that lead to the remarkable results in terms of reduction of required deformation force and increase of workpiece strain. The required deformation force of the continuous extrusion method is significantly reduced by about 50 % compared to the traditional method. The deformation on the bottom and the wall of product is uniform and increased by about 200 % compared to the traditional backward extrusion method. The process of experimenting and evaluating the effect of process and tool parameters on the deformability and mechanical and microstructure characteristics of the product will be future work.

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