Development of a novel method for the backward extrusion

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In this study, a new method of backward extrusion using small diameter billet is proposed. In this new process, the die setup consists of three main parts of the fix-punch, the moveable punch and the matrix. The fix-punch has been used to decrease the cross section of applied billet and finally reducing the total force of the process. To investigate the capability of this process, experimental and finite element (FE) methods were used. The results showed that the first advantageous of the new process is that the load is reduced to about less than a quarter in comparison with the conventional backward extrusion process. This higher reduction in the required force is due to reduce of the cross section of the initial billet. EF results showed that while needing lower loads, the applied plastic strain through the processed sample is about two times higher than that in the sample processed via conventional backward extrusion. This is the second advantageous of the process. Eventually, the most important advantage of the novel method of backward extrusion are the lower process force, imposing higher effective strain and a better strain homogeneity through the tube length. This new process is also very promising for producing ultra fine grained (UFG) samples because the higher level of shear strains.

1. Introduction

Nowadays, the extrusion process has an important role in the manufacturing industries. Backward extrusion has been conventionally used for the production of hollow-shape symmetric and cylindrical products [1]. Bae and Yang analyzed the backward extrusion process of internally elliptic shaped tubes from round billets with using of upper bound method [2]. Shen et al. have proposed a method for estimating the value of shear friction factor using of a backward extrusion-type forging [3,4]. Lee et al. examined the extrusion of hexagonal shaped wrench bolts using of upper bound method [5]. Cho et al. studied the process design of a forward and backward extruded axisymmetric part [6]. Fereshteh-Saniee et al. have performed several tests with different lubricants and friction conditions to find out the friction modeling of different bulk forming processes [7]. Bakhshi-Jooybari et al. have worked on reducing the deformation load in backward rod extrusion to optimize the die profile by both numerical and experimental approach [8]. Uyyuru and Valberg examined the material flow over the punch head in backward extrusion process by finite element simulation and physical modeling [9]. Saboori et al. have examined the extrusion energy of the two optimal conical and curved die in the forward and backward extrusion using of both finite element method and experimental investigation [10]. Kim et al. evaluated the effects of lubricants in backward extrusion of large aspect ratio rectangular aluminum case [11,12]. The effects of geometrical parameters such as die corner radius and gap height, as well as process condition such as friction on the radial-backward extrusion process were examined by Farhounmand and Ebrahimi [13]. Fatemi-Varzaneh and Zarei-Hanzaki proposed a novel severe plastic deformation process based on an accumulative back extrusion process [14]. Abrinia and Orangi analyzed the backward extrusion process of internally arbitrary-shaped tubes from circular billet using of finite element method. They examined tubes with elliptical, rectangular and circular shape [15]. Fatemi-Varzaneh and Orangi have studied the strain distribution and deformation behavior during accumulative back extrusion process on AZ31 magnesium alloy [16]. Orange et al. have carried out the analysis of backward extrusion process of aluminum tubes which have internally and externally shaped section using of finite element method [17]. Javanmard et al. have analyzed the backward extrusion process for circular shape hollow components from round billets by a computational method based on the natural element method [18]. Alhosseini et al. described a new process based on a cyclic forward–backward extrusion for producing ultrafine grains materials. They applied this new process to AA1050 aluminum alloy [19].
In the new backward extrusion, as shown in Fig. 2, small diameter pressed and flowed through the gap between punch and matrix. The extrusion process, the billet has been initially placed in the matrix metal ingot was melted and casted, then was extruded using of the fix-punch, the moveable punch and the matrix. Schematic illustrations of the conventional and new backward extrusion process. For the elimination of these limitations, a new backward extrusion process is proposed. To study the capability of this new process, experimental and finite element analysis were used.

2. Principle of the new backward extrusion process

In the new process, the die setup consists of three main parts of the fix-punch, the moveable punch and the matrix. Schematic illustrations of the conventional and new backward extrusion methods are shown in Figs. 1 and 2. In the conventional backward extrusion process, the billet has been initially placed in the matrix and then with the pressure of the punch, the material is compressed and flowed through the gap between punch and matrix. In the new backward extrusion, as shown in Fig. 2, small diameter billet is put in a cylindrical hole named billet chamber in the fix-punch. Then the moveable punch is pressed the billet into the gap between fix-punch and the matrix. So the compressed material is flowed through the gap between fix-punch and the matrix. The inner radius of fix-punch helped to material easily flowed through chamber of the billet and internal die. Also, the outer radius of fix-punch and radius of the matrix have been improved the material flow in the process.

3. Experimental and FE procedure

High-purity lead was used in the experiments. As-received lead metal ingot was melted and casted, then was extruded using of direct extrusion process to achieve a cylindrical sample with a distinct diameter. The diameter and length of the billet were 20 mm and 170 mm, respectively. The inner and outer radius of fix-punch, the radius of the matrix and the height of the edge for produced die selected as 7.5 mm, 10 mm, 10 mm and 5 mm, respectively. The length, outer diameter and thickness of the final product were designed to be 85, 63 and 3 mm, respectively. Compression test according to ASTM: E9-09 standard has been performed to obtain the mechanical properties. The physical and mechanical properties of the material were reported in Table 1. The main parts of the die setup including matrix, fix-punch, moveable punch, guide shafts and the holder plate of guide shafts were shown in Fig. 3(a). Different parts of the die were hardened to 50 HRC. The test has been carried out using of an INSTRON hydraulic press. The experiment was performed at 1 mm/s plunger speed at room temperature. Brinell hardness test with 30 kg force was used for hardness measurements according to the ASTM: E10-12 standard. The experimental setup including assembled die on the press was shown in Fig. 3(b).

The DEFORM 3D-6.1 software has been used for FE simulation. The material model was defined as elastic–plastic. The data of true stress–strain based on the results of compression test has been entered to the FE software. All the die parts have been considered as rigid bodies. The billet has been defined as deformable object during all analyses. The dimensions of all objects in the simulation perfectly matched with experimental ones in order to validate the results of the simulation. Tetrahedral element type was used, and the mesh sensitivity test has been carried out. Suitable mesh number reported as 25000. The friction type selected as shear. Because of the nature of the process, the friction factor (m) selected as 0.2 [7]. The type of simulation was Lagrangian Incremental. The global re-meshing was chosen and the type of interference depth selected as relative and its value considered as 0.7. The Conjugate-Gradient has been chosen as the solver of simulation.

4. Results and discussion

The unprocessed initial billet and processed sample which is a closed-end tube were shown in Fig. 4(a and b), respectively. As shown, a 20 mm diameter billet was changed to 63 mm diameter cup shaped sound sample successfully via new backward extrusion process. It seems that most of the materials such as aluminum, copper and magnesium. and their alloys which can be processed via conventional method may be processed by the new method. Though, this statement needs experimental evidence; it is promising that the new process could be applied to a wide range of metallic materials.

The process force of conventional and novel method of backward extrusion obtained from FE method has been compared as shown in Table 2. Based on obtained results, the required force to produce a particular product with conventional backward extrusion was equal to 264.6 kN, while the required force to produce the same product using novel backward extrusion was equal to 61.1 kN. Consequently in the novel backward extrusion process the required force to produce a particular product was less than a quarter in comparison with conventional backward extrusion.

Hung and Chiang [23] investigated the influence of ultrasonic-vibration on Double Backward extrusion of aluminum alloy. In this method, the ultrasonic energy applied to the punch die and then the punch die deformed material. They reported that the required load for conventional method was 14.3 kN while it is 11.5 kN by imposing the ultrasonic energy to the punch. So by using of ultrasonic vibration, the extrusion force will be decreased about 20%. As was mentioned earlier with using of the novel method of backward extrusion, the extrusion load can be reduced about 75%. Uyyuru
and Valberg [9] showed that even by eliminating the friction in the process of backward extrusion the total forming load just decreased only 25% while, in the novel method of backward extrusion even by considering the reasonable value for the friction coefficient that can be obtained by routine lubrication of die, the total forming load of the process has been decreased about 75%. This is an important advantageous of this new method.

The distributions of the effective strain in the samples prepared by both conventional and novel methods of backward extrusion were shown in Fig. 5(a and b), respectively. Effective strain contours show that the new method could apply larger strain compared to the conventional method. Quantitative values of the effective strain through the thickness at the final sample produced by both conventional and new process have been shown in Fig. 6. As shown the mean value of plastic strain in the sample processed via new process is about 3 while it is about 1.5 in the sample processed via conventional process. This means that the new process could apply higher plastic strain compared to the traditional method. This is other advantageous of this novel backward extrusion process.

Table 1
The mechanical and physical properties of the material used in the experiments.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Density (kg/m³)</th>
<th>Young’s modulus (E) (GPa)</th>
<th>Poisson’s ratio</th>
<th>Yield strength (MPa)</th>
<th>Ultimate strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>11,350</td>
<td>14</td>
<td>0.42</td>
<td>14.5</td>
<td>25</td>
</tr>
</tbody>
</table>

Fig. 2. A schematic view of the new method of backward extrusion.

Fig. 3. (a) The main parts of die and (b) the assembly view of die.
As was obtained from the graph, with moving toward the outside of the part, the effective strain in the new process has been rapidly increased specifically at near of the exterior area of the part. But in the conventional method, the maximum effective strain obtained at the inner surface of the part. The difference between the effective strain of conventional and new method was very high. The difference is more sensible at the exterior area of the part than that at the interior. It can be deduced from results that the effective strain of the new method of backward extrusion through the thickness of the part was at least two times of the effective strain at any point of thickness in part that has been made from the conventional method of backward extrusion and at outside of the part, the strain effective in the novel process through the thickness was about three times in comparison with the same point of part that has been made from conventional method. The microstructure and formation of small sized grains were corresponded to the amount of effective strain [24]. The higher plastic strain cause to decrease the grain size of the microstructure and consequently enhance the mechanical properties [14,20]. So, this new method is promising for producing ultra fine grained samples with higher strength compared to the conventional technique. The hardness of the processed sample was increased to about 19 HB from the initial value of 7.4 HB in the unprocessed billet. This shows a significant improvement in mechanical property of the processed sample by new backward extrusion process.

In the recent years, several novel severe plastic deformation methods have been proposed to impose higher effective strain to the material in order to increase the hardness and improve the mechanical properties of the final product. Alihosseini et al. [19] reported after only one cycle of cyclic forward–backward extrusion (CFBE), hardness has been increased from the initial value of 25 Hv to around 47–52 Hv (about 100% improvement). Fatemi-Varzaneh and Zarei-Hanzaki [14] processed wrought magnesium alloy by ABE method. Based on the researches, the ABE technique is capable of imposing an equivalent strain about 4–5 after one pass. This range of equivalent strain was very close to the range of equivalent strain applied by the novel method of backward extrusion. Based on the results of microhardness test, after two passes the hardness has been increased about 53% and 34%, at 180 °C and 380 °C respectively. Alihosseini et al. [25] processed AA1050 by accumulative back extrusion method and then investigated the microstructural evolutions and microhardness of samples that subjected to one, two and three passes of ABE. Based on the researches, in the ABE process the most increase in the hardness value has been obtained after the first pass. They reported that the microhardness was increased from 31 Hv to 67 Hv after 3 passes of ABE. So the hardness increased about 116%.

As was mentioned earlier, the hardness in the novel method of backward extrusion has been increased from the initial value of 7.4 HB to the 19 HB. This means that the hardness has been
increased about 156% by using the novel method of backward extrusion instead of conventional method of backward extrusion. Quantitative values of the effective strain along the length of the produced tube by both conventional and new methods have been shown and compared in Fig. 7. Clearly the effective strain along the length of the produced tube by new method in the middle node of thickness at the distance of 15 mm from the bottom of the tube was 3.3 in comparison with the effective strain of 1.9 at the same point in the produced tube by conventional method. The variation range of the effective strain from the bottom to the top of the produced tube by new method was very homogeneous in comparison with the conventional method and this range equaled to value of 0.62 while the effective strain along the length of the produced tube by conventional method has been changed in a wide range. For the produced tube by conventional method, the maximum and minimum values of effective strain occurred at the distances of 35 mm and 80 mm from the bottom of the tube respectively and these values were 2.22 and 0.5 so the variation range of the effective strain along the length equaled to 1.72 that was about three times more than of the variation range of gained effective strain along the length of the tube that has been made by new method.

According to the last researches, the inhomogeneous distribution of effective plastic strain resulted to the different microstructure characterizations and the inhomogeneous obtained microstructure was related to the heterogeneous strain pattern developed during deformation [22]. The standard deviation value of effective strain data along the length of the processed tube by both conventional and novel method of backward extrusion is 0.564 and 0.195 respectively. Obviously these values show that the effective strain along the length of the produced tube by novel method of backward extrusion is more coherent than that of processed tube by conventional method of backward extrusion so the mechanical properties along the length of processed tube by novel method of backward extrusion are more homogenous than that of processed tube by conventional method of backward extrusion.

The last researches confirmed that the larger plastic strain leads to the higher fraction of dynamically recrystallized new grains and the higher hardness values, consequently [22]. So the higher plastic strain along the length of the produced tube by new method leads to the higher hardness value in comparison with the conventional method. At produced part from the conventional method of backward extrusion, the effective strain along the length of the tube has been suddenly decreased after the distance of 55 mm from the end of the tube while the changes of the effective strain along the length of the produced tube by novel method of backward extrusion were very smooth by moving from the end of the tube toward...
to the top of the tube. At the top of the produced tube by new method, the effective strain was 2.7 in comparison with the effective strain of 0.5 at the same point of produced tube by conventional method. The obtained distribution of effective strain along the length of produced tube by conventional method of backward extrusion has been confirmed by the last researches [21] in which the effective strain has been gradually decreased by moving from the bottom towards the top of the produced part and the strain pattern along the length of the final part obtained as nonuniform. The obtained load–displacement graphs from simulation and experiment of the new method of backward extrusion have been compared in Fig. 8. The maximum process force of the novel method of backward extrusion obtained as 61.1 kN and 65.6 kN by numerical and experimental method respectively. So obviously the simulation error was about 6.8%.

5. Conclusions

In this study, a new method of backward extrusion has been proposed, and the effect of this process on reducing the force of the process has been investigated by numerical method and the numerical results have been validated by experimental procedure. The results showed that the effective strain along the thickness of the part that has been produced by new method of backward extrusion was at least two times of effective strain at any point along the thickness of produced part by conventional method. The results also indicated that the distribution of the effective strain through the length of the tube prepared by new backward extrusion was very homogeneous in comparison with that prepared by the conventional backward extrusion method. Based on obtained results, the required force to produce a particular product with conventional backward extrusion was equal to 264.6 kN, while the required force to produce the same product with new backward extrusion was equal to 61.1 kN. Consequently in the novel backward extrusion process the required force to produce a particular product was less than a quarter in comparison with conventional backward extrusion. Eventually, it can be deduced from obtained results that the most important advantages of the new method were the lower process force for producing a particular part in comparison with the conventional method of backward extrusion, imposing higher effective strain at produced part than the conventional method and uniform distribution of effective strain along the length of produced part that caused to homoge-neous microstructure and properties at final part. Application of this new process to the other materials like Al, Cu, Mg and their alloys is the aim of future works.

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References