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3D SIMULATION OF THE COLD EXTRUSION PROCESS OF NON-SYMMETRIC SECTION OF TELLURIUM-LEAD

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Abstract

In this paper, making use of the ABAQUS software, an extrusion simulation is made with Tellurium-lead alloy. In this respect, two kinds of die land and their effects on extrusion force are investigated. The results are compared with available experimental ones in some references. The results show that a straight-line product is achieved by adding die lands to the die (with two statements), which increases the extrusion load and the deformation of the metal significantly. Also is investigated that the amount of force increase in the second state decreased in comparison with the first state.

Key Word: Simulation, Cold Extrusion, Non-symmetric Section, Finite Element Method, Metal Forming

Introduction

Extrusion is one of the most important metal forming processes due to its high productivity, lower cost and the fact that it increases the physical properties of the materials. In the metal forming industry, many kinds of non-symmetric rods are produced by the extrusion process. For example, the extrusion from a round billet into a bar with various cross-sectional shapes such as 'T', 'L', 'U', 'I', etc., by using aluminum alloys, steel, super alloys and titanium alloys is widely used. However, the process itself is difficult to analyze due to complex die shapes and the rotational velocity component that can lead to unpredictable metal flow behaviors during extrusion. Metal flow does not remain in a radial plane passing pattern along the longitudinal axis of the die and this behavior results in unusual stress and strain distribution in the deforming material. The complexity grows even further when determining the optimum location of the exit section of the extrusion die, particularly in the three-dimensional (3-D) extrusion of shaped sections. Therefore, attempts to obtain the optimum die configuration are still done mostly by applying intuitive and empirical methods. Some analytical methods for

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predicting the metal flow in order to obtain the optimum die configurations for various cross-sectional shapes have been proposed by some researchers. The survey literature of the related work to the problem was earlier reviewed by Chitkara and Celik [1]. Most of the research work that has been done thus far, being very specific to certain cross-sections, considers the exit section to be not only symmetric but also situated symmetrically along one of the planar axes of the die [2–7]. There is, to the authors' knowledge, no research work so far that has either been presented or done on the non-symmetric shaped sections or has considered the effect of their positioning except that of Kiuchi *et al*. [5] who applied general theoretical analysis to only the symmetric T-sections and, to some extent, on the L sections. Chitkara and Celik [8] recently investigated the extrusion of non-symmetric T-shaped sections in their early report. Investigating the extrusion of non-symmetric shaped sections and the effects of their positioning, however, is a useful area because non-symmetric sections are widely used and the positioning of the exit section not only affects the required extrusion pressure but varies considerably both the curvature and the soundness of the extruded product. In the previous paper [9] it was suggested that off-centric positioning may be advantageous under certain conditions to obtain smaller extrusion pressures. Besides, in some cases a curved extruded product may be required that would, thus, necessitate a correct positioning of the exit section with respect to the entry section. Again, where horizontal extrusion machines are used even for centric extrusion, the extruded product may also come out bent due to the increased frictional resistance at the bottom part of the die. In practice, most of the times, a straight-line product is achieved by adding die lands to the die, which significantly increases the extrusion load and the deformation of the metal. However, this may also be achieved by using correct positioning to obtain a straight-line extruded product.

Process modeling

In this paper, as the section is non-symmetric, the product deviates after exiting the die in a straight-line direction and the deviation rate is shown in Chitkara's experimental trial, Fig. 1. There are different methods to reduce this deviation. Replacing the geometrical center of the output cross-section in the proportion of the input is one of the most popular ways, but this method does not produce results in all cases. As an alternative solution, die land, which is common in the extrusion industry and generally makes a straight-line and high quality product, can be used. In the simulation, the output deviation from the extrusion die confirms the practical results which are shown in Fig. 2.

Today's, extrusion pressure is calculable at many different ways. There are many charts and relations for this case in the literature. Finite elements method is one of the most important ways in simulation processes, which can calculate the extrusion pressure with reasonable accuracy. In this paper, the simulation is done with the ABAQUS software and the extrusion force is evaluated for a state that no die land is added to the die. In this simulation, tellurium-lead alloy is used with the hard strain, shown in Eq. (1).

$$\bar{\sigma} = 34.595(1+16.5\dot{\bar{\varepsilon}})^{0.0512} \times \bar{\varepsilon}^{0.221} \quad (Mpa) \tag{1}$$

Fig. 1. Deviation of product after exiting the die [10]

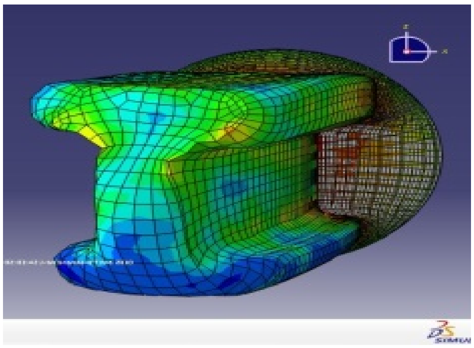

Fig. 2. Deviation of product in simulation

The dimensions are fixed in the whole analyses. The reduction area is 68.8% and the dimensions are similar to Fig. 3.

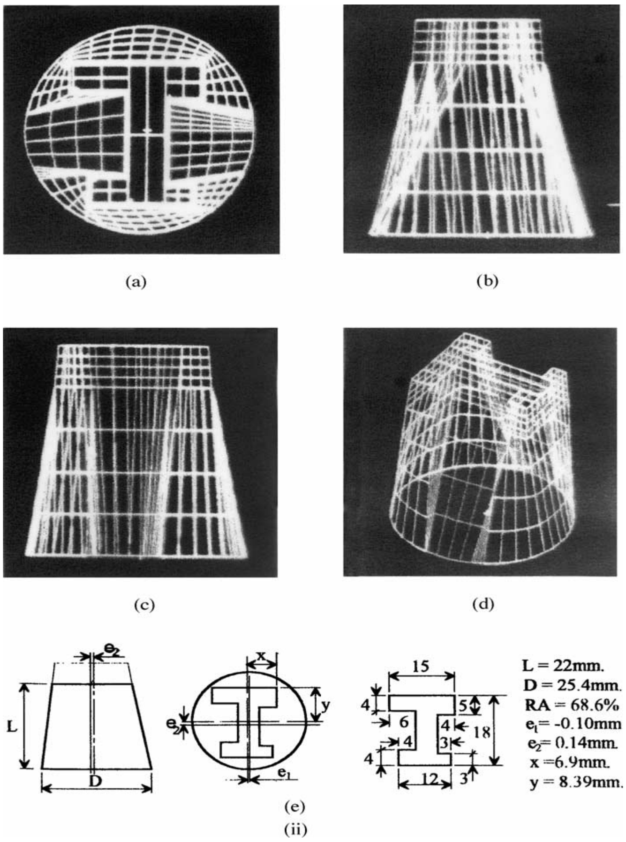

Fig. 3. Dimension of die [10]

This force is calculated for both totally dry frictions with a 0.4 coefficient, and lubricant friction with a 0.2 coefficient and the results for this simulation are compared with Chitkara's experiment.

Then, the amount of force increase and the quality of the output product in being straight-line are considered by adding two kinds of die land to the die. Fig. 4 shows the extrusion force produced from Chitkara's experiment. The results of the simulation are shown in Fig. 5. It can be seen that there is a good conformity between the experimental results and the simulation results. Table 1 shows the amount of differences between forces in the experimental results and the simulation results. The amounts of the increase in the force are 2% and 4.8% (respectively for lubrication and dry friction states) which can be considered insignificant because of the errors which take place in the finite elements method. Fig.1 depicts the extent of product deviation after exiting the die for the friction coefficient of 0.2.

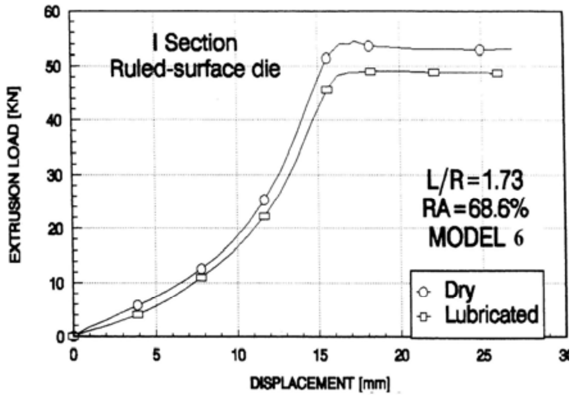

Fig. 4. Results of Chitkara's simulation [10]

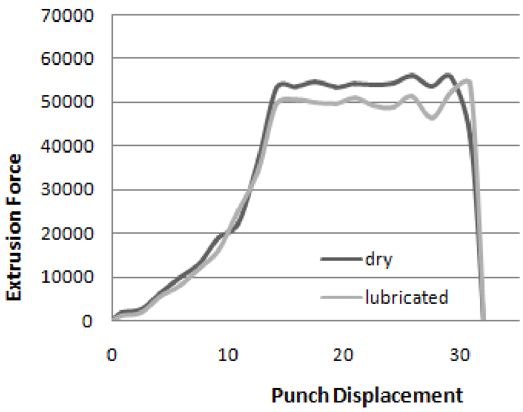

Fig. 5. Results of simulation

Table 1 Comparison extrusion force between simulation and Chitkara's experiment

Friction coefficient	Simulation's result	Chitkara's experiment	Rate of increase
Lubricated = 0.2	50000 N	49000 N	2 %
Dry = 0.4	54500 N	52000 N	4.80 %

Firstly, a die land of 18.5 mm of length is added to the output section of the die and the subsequent effects on the increase of the extrusion force and product straightness is examined. The rate of product straightness, after using this special die land, in relation with the vector perpendicular to the output of the die surface is shown in Fig. 6. The corner of the die, which possesses the highest deviation through the output direction of the product, stretches outward in the figure and is considered to be the index for the amount of product deviation because there is not any contact surface defined between the die land and the product in that zone and the slightest deviation causes an interference between the elements of the die and the product. For this reason, this corner, if any deviation takes place, is used for observation.

The extent of force increase with die land in two conditions, lubrication and a friction coefficient of 0.2 and dry friction with a friction coefficient of 0.4 is shown in Figures 7 and 8, respectively. A comparison can be made with the condition where no die land exists. The amount of extrusion force increase is shown in Table 2 for both conditions, with and without die land.

As shown in Table 2, compared to the state where no die land exists, the extrusion force increased from 21.68% to 35.8% (respectively for the two conditions of lubrication and dry friction). This increase is due to an increase in the length of the frictional surface between the die and the die land and multiple plastic deformations in the whole product when exiting the die. However, this force can be reduced by enhancing the die land to the parts of the die where the product possesses a higher deviation outward the surface center. As shown in Fig. 2, in the x-z surface, after exiting the die, the product deviates downward (in the z direction) and to some extent to the left side and moves further away from the vector perpendicular to the surface. This deviation can be reduced by enhancing the die land to these parts, which can in turn decrease the amount of the extrusion force.

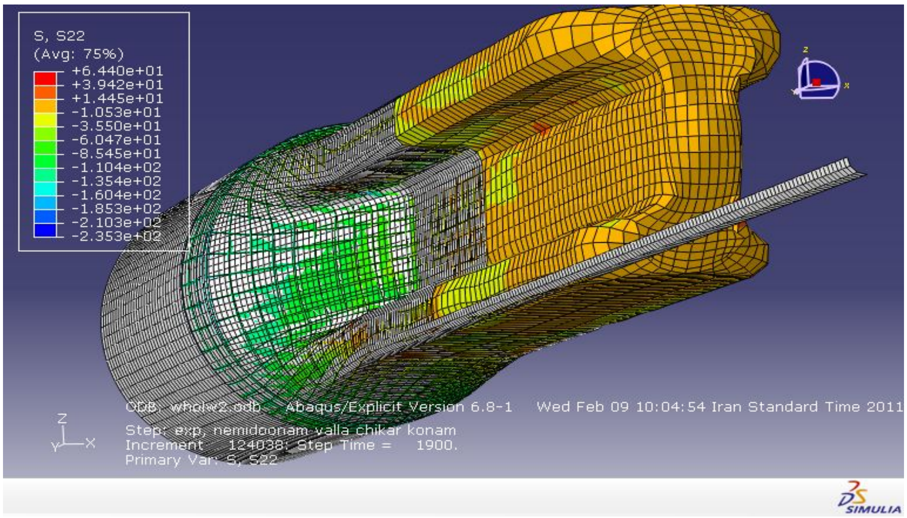

Fig. 6. Exit product without deviation, with stretching whole die land

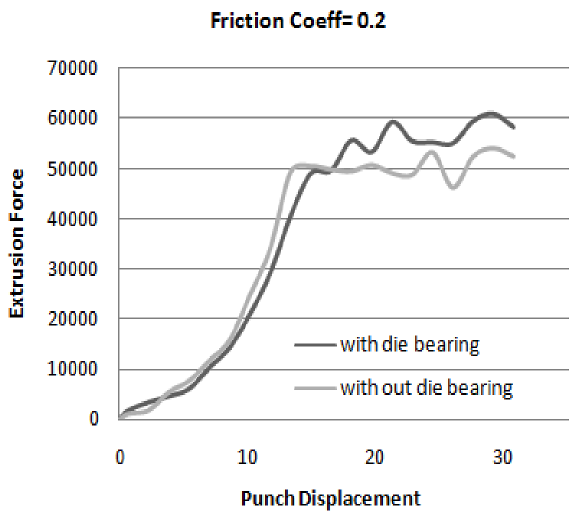

Fig. 7. Comparison extrusion force with and without die land in simulation

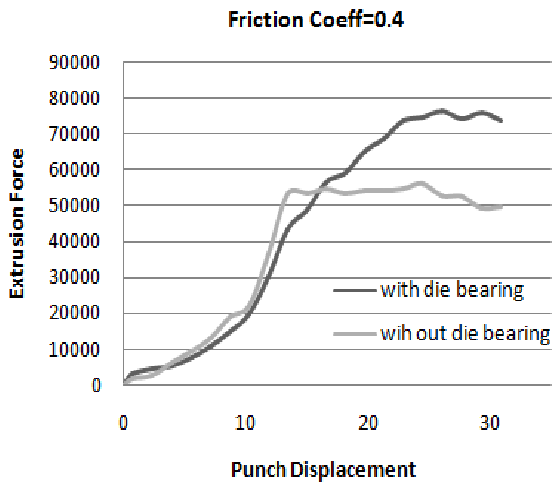

Fig. 8. Comparison extrusion force with and without die land in simulation

Table 2 Rate of increase extrusion force with die land

Friction coefficient	Without die land	With die land	Rate of increase
Lubricated = 0.2	50000 N	60841 N	22%
Dry = 0.4	54500 N	74030 N	35.80%

The new die land which is designed based on the new dimensions is shown in Fig. 9. This die land reduces the energy and the fatigue of the achieved product and, therefore, increases the quality of the product. As shown in Fig. 10, the output product in this case is in a straight-line and smooth condition after exiting the die. The die length is increased as much as 20.5 mm in the bottom (through z) and 19.5 mm in the left side (through x). These values were achieved after optimizing the length and conducting the simulation.

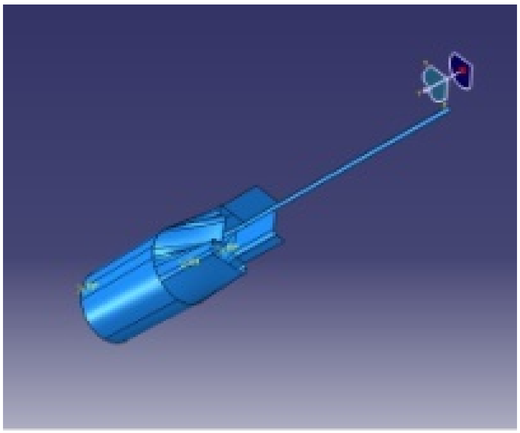

Fig. 9. Die with die land in simulation

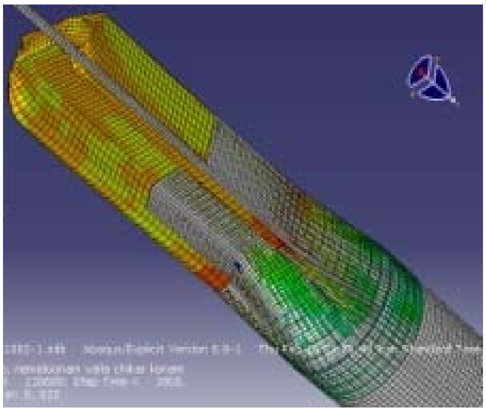

Fig. 10. Straightly product by using die land in simulation

The amounts of force increase in the lubricating state with a 0.2 frictional coefficient and the full drying state with a 0.4 frictional coefficient are depicted in Figures 11 and 12, respectively. In this case it is possible to compare the amount of the extrusion force increase with the previous position (without die land). It can be observed that the force increase dropped dramatically in proportion to the previous position.

This issue is fully obvious in Fig. 12. The amount of extrusion force increase in the proportion to the state of the die without die land is shown in Table 3. As shown in Table 3 the amount of force increase in the second state decreased in comparison with the first state, in a way that in the lubricating state about 8% and in the dry frictional state about 10% reduction of the extrusion force is observed. This is due to omitting some parts of the die that are not of use in reducing die deviation after exit. This die land just create a bigger resistant force against the mandrel as a result of friction because of its contact with billet surface. This issue is of great importance in industrial situations where optimizing the forces and energy, increasing the production speed, and achieving a final product with less fatigue is considered.

Table 3. Rate of increase extrusion force with new die land

Friction coefficient	**Without die land**	**With new die land**	**Rate of increase**
Lubricated = 0.2	50000 N	58523 N	13%
Dry = 0.4	54500 N	68212 N	25.15%

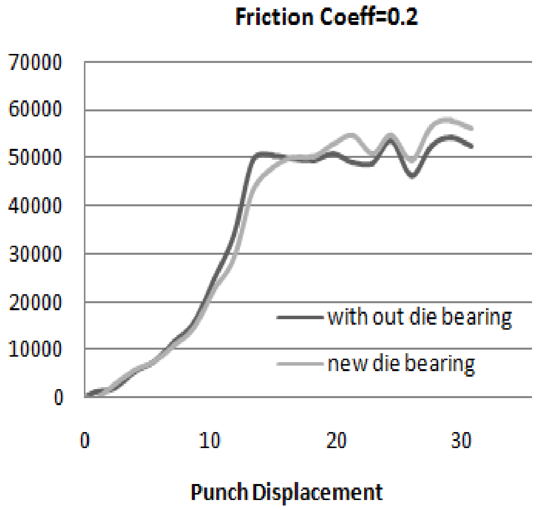

Fig. 11. Rate of increase extrusion force with die land

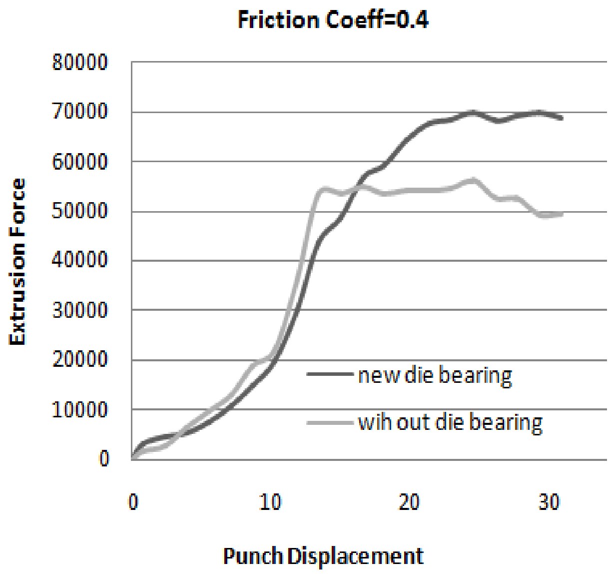

Fig. 12. Rate of increase extrusion force with die land

Consequently, in the whole analysis, the amount of the kinetic energy was less than 2%, of the input energy, which satisfies the quasi-statically condition in this project. Fig. 13 shows this issue perfectly.

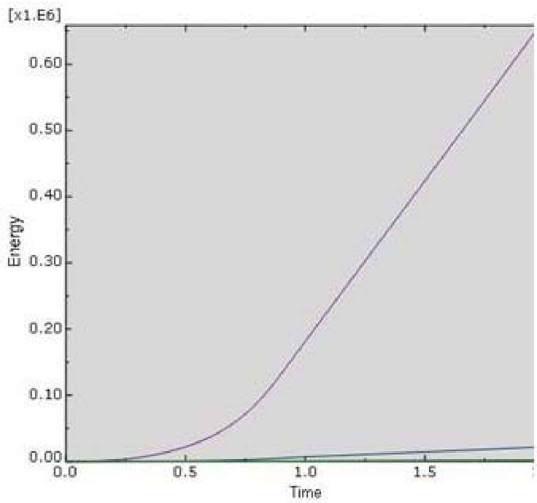

Fig. 13. Comparison between kinetic energy and internal energy in simulation

Conclusions

The values of the forces achieved from the simulation results are higher than the values of the forces achieved from Chitkara's experiment to the extent of 2% and 4.8% (respectively for lubrication and dry friction states). Possible reasons are errors in solving the finite elements method and in the approximations done in problem solving. Additionally, unstable testing situations can be of the other causes of this difference.

The products deviation is to be eliminated. One of the ways for eliminating this deviation and achieving a straight-line and smooth product is adding a die land to the output section of the die. The length of this die land is to be considered so as to cause no extra work in the process. The existence of this die land causes all parts of the product to have the same velocity in the moment of exit and this exit occurs with the product being perpendicular to the surface of the output section of the die.

In a condition where the die land is stretched through the whole cross section area of the die, the product exits the die in a smooth and straight-line condition. However, the extrusion force increases dramatically to 21.68% and 35.8% (respectively for lubrication and dry friction states). Although this application leads to the desired product, a much higher extrusion force is also inevitable. This is basically due to the increase in the length of the friction surface and also to the plastic deformation in the moment the product exits the die.

As mentioned before, the aim is to minimize the extrusion force in order to make energy consumption cost effective. For this purpose, by using the new die land, stretching only in the parts where the output product possesses a higher deviation in comparison with the vector perpendicular to the surface of the die, the extrusion force can be controlled. As resulted from the table. 3, in this condition, the increase in the extrusion force is up to 13.04% and 25.15% (respectively for lubrication and dry friction states). This reduction is due to the existence of less frictional surfaces through the deformation process. Using this method, the extrusion force reduces to about 8% and 10% compared to the previous state.

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