A STUDY AND ANALYSIS OF THE EVOLUTION OF TEMPERATURE IN ALUMINIUM BILLETS FOR TUBE EXTRUSION

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ABSTRACT

The tube extrusion is done by using the same set up with the addition of the mandrel and the various Load verses Displacement graphs were plotted. The effect of the velocity is seen that as the velocity increases the load increases and at less speed the load is low. The surface finish of the extruded tube is different for the die angle. The finish of the 60-degree tube is showing the cracks on the surface. Blue plasticine and yellow plasticine is used for experiment but blue plasticine is poor as compared to yellow plasticine such as strength of tube and cracks are generated but yellow plasticine is performed same condition very well. No cracks, hard and loose tubes are produced.

The Load Vs Displacement graphs for the tube extrusion with the Die (60°) and with three speeds (1, 2, 3 mm/min). In these graphs the three series are shown which shows the three reading for one set of die and speed of the tube is done and the graph between the load Vs displacement is plotted for the tube. In tube the same pattern of the load and the die. The load increases as the speed increases and the load decreases as the die angle increases. The comparative table is prepared for the Tube and the simulated results. By this the percentage error for the tube extrusion experiment and the FE simulation. It has been observed that the simulation & experimental results is 673.11 & 613.32 respectively. The Finite element simulation percent error of the tube experiment and the tube simulation is 1.91%. This error as compare to previous result is very less and we have seen the difference of temperature is very important for Extrusion process because temperature is low than extruded material is very hard and brittle and temperature is high than extruded material is very soft and loose. In this reason cracks is generated on tube like hair and line cracks. It has been observed that the standard temperature is required for extrusion.

The effect of die angle on tube extrusion processes using experiment. The extrusion experiments are carried out by using die of 60° die angle with variable die landing and at the three different speeds. Blue and yellow colors plasticine is used. Extrusion load increases with increase in ram velocity irrespective of die angle and material. Simulation study reveals a good match between experimental and numerical load stroke curves. Safe and finished tube is generated after maintaining temperature. It shows that simulation can be effectively used for the analysis of real material like aluminum extrusion process. The designed die was further adopted for computer simulation using MSC.MARC software (based on FE Method) to assess stress, strain and strain rate distributions and load requirements. Effects of single die angle at various ram speeds are...
critically examined. The expectation of this study would provide a new insight into the design of manufacturing process. Aluminium simulation is very critical because simulation is very costly for original material.

**Keywords:** Extrusion, Plasticine, Die angle, MSC.Marc software.

1.1 Introduction

Extrusion is the process of confining the metal in a closed cavity and then allowing it to flow from only one opening so that the metal will take the shape of the opening. The operation is identical to the squeezing of toothpaste out of the toothpaste tube. A typical extrusion process is presented in Fig. 1.1. The equipment consists of a cylinder or container into which the heated metal billet is loaded. On one end of the container, the die plate with the necessary opening is fixed. From the other end, a plunger or ram compresses the metal billet against the container walls and the die plate, thus forcing it to flow through the die opening, acquiring the shape of the opening. The extruded metal is then carried by the metal handling system as it comes out of the die. A dummy block which is a steel disc of about 40 mm (0.50 to 0.75 of diameter) thick with a diameter slightly less than the container is kept between the hot billet and the ram to protect it from the heat and pressure.

![Fig. 1.1. Extrusion setup](image)

1.1.1 Extrusion defects

Depending on material condition and on process variables, extruded products can develop several types of defects that can significantly affect their strength and product quality. Some defects are visible to the naked eye; others can be detected only by some special techniques. There are three principal extrusion defects: surface cracking, pipe, and internal cracking. All defects are generated by temperature variation. Its tendency for center cracking:

- Increases with increasing die angle;
- Increases with increasing amount of impurities; and
- Decreases with increasing extrusion ratio and friction.

![Fig. 1.7: Extrusion constant k for various metals at different temperatures](image)

1.2 Literature review

This thesis consists of an introduction and the following appended papers:

LI Feng et al (2009) reduced defects caused by non-homogeneous metal flow in conventional extrusion, a die with guiding angle was designed to improve the metal flow behaviour. The characteristic quantities such as the second invariant of the deviator stress $J^2$ and Lode’s coefficient $\mu$ were employed for the division of deformation area. The results show that when the metal is extruded with the guiding angle, no metal flow interface forms at the container’s bottom, the dead zone completely disappears, the deformation types of the metal in the plastic deformation area change from three types to one type of tension, and the homogeneity of the deformation as well as metal flow are greatly improved. The non-homogeneous metal flow at the final stage of extrusion is improved, reducing the shrinkage hole at
the axis end. The radial stress of the furthest point from the axis is transformed from tensile stress to compressive stress and the axial stress, and decreased from 70.8 to 34.8 MPa. Therefore, the surface cracks caused by additional stress are greatly reduced.

K. K. Pathak et al (2010) gave experimental verification of a proposed extrusion die profile design approach, which aims to satisfy microstructural criteria at maximum production speed and minimum left out material in the die cavity, is presented. The design problem is formulated as a nonlinear programming problem, which is solved using genetic algorithm (GA). Selection of the processing parameters is carried out using dynamic material modelling (DMM). Microstructural study reveals considerable grain refinement in the extruded tube.

Ashish Saxena et al (2012) an attempt has been made to study the effect of die landing on rod extrusion processes using experiment. The extrusion experiments are carried out by using three dies of different die landing and at the three different speeds. A blue color plasticine is used. The experimentation results show that as the die land height increases the load also increases the designed die was further adopted for computer simulation using MSC. Super forge software (based on FV Method) to asses stress, strain and strain rate distributions and load requirements. Using these results, effects of die landings at various ram speeds are critically examined. The expectation of this study would provide a new insight into the design of manufacturing process.

1.3 TUBES EXTRUSION EXPERIMENTAL SETUP

The experiment the computer controlled testing machine having load cell capacity of 100 kg as shown in Fig 1.3. This is the electric control machine in this controlling of the speed can be done and the load verses displacement graphs can be obtained directly from it. By making the fixtures for the extrusion process the machine is operated and the load curves are obtained.

Tube extrusion is the extrusion of seamless tubes over a mandrel. The extrusion of tubes through a welding chamber die is, therefore classified under the section extrusion. The direct extrusion of the tube is performed in the experiment. The yellow & blue coloured plasticine material is used for tube. The mandrel of diameter 6mm is used. The same three different die angled dies were used. The extruded tube arrangement. The tube is extruded and the load/displacement graphs were plotted. Material modeling of the plasticine is carried out using power law equation given below:

\[ \sigma = k \varepsilon^n \]

Where \( k = \) strength co-efficient,
\( n = \) strength exponent.

The extrusion of steel has regularly gone down. Seamless tubes are exchanged by welded tubes, which can be generated at a much minimum cost of all steel tubes that are generated in the world, about 30% are seamless of these, and less than 10% are extruded.

![Fig 1.2: Tube extrusion](image)

Tube extrusion is to manufacture uniform products with minimal dimensional edition. The hole in the extrudate is not centered along the centerline of the billet outer diameter. Some amount of eccentricity is always produced when tubes are manufactured but the temperature variations of the extrudate can be low. It was proposed that the major causes of eccentricity in stainless steel tubing are billet temperature, billet preparation, equipment misalignment and improper lubrication. Best quality of the die is also essential to achieve tubes with tight good surface quality. The tube extrusion is done by using the same set up with the
addition of the mandrel and the various Loads verses displacement graphs were plotted. The same effect as that on rod is seen the die angle increases the load decreases. The effect of the velocity is seen that as the velocity increases the load increases and at less speed the load is low. The surface finish of the extruded roads is different for the die angles.

![Image 1](image1.jpg)

Figure 1.3 (a) Computer controlled testing machine

1.4 EXTRUSION EXPERIMENTS OF TUBE

The setup of the extrusion process at the time of experiment is shown in the Fig. 1.3(b).

![Image 2](image2.jpg)

Figure 1.3 (b) Extruded tube after Extrusion

1.5 EXPERIMENTAL SETUP FOR EXTRUSION

(We are using in this experiment plasticine material because real material is very costly as compare to plasticine)The experiment the computer controlled testing machine having load cell capacity of 100 kg as shown in fig 1.3(a) & (b). This is the electric control machine in this controlling of the speed can be done and the load verses displacement graphs can be obtained directly from it. By making the fixtures for the extrusion process the machine is operated and the load curves are obtained.

1.5.1 DIE FABRICATION (FOR EXPERIMENT PURPOSE)

Die angle 60 degrees. The cylinder and the die arrangement are made for the machine. A setup has been made to do direct extrusion of the model material, yellow & blue colour Plasticine. The extrusion experiment setup consist of a cylindrical container of external diameter 50 mm and internal diameter 40 mm of made of Steel alloy using machining process which produces an excellent surface finish to produce smooth extruded surfaces. The dies were made from Aluminum material. The die angle 60 degree is shown in fig 1.4. The top and the front view of the die & container are shown in fig.1.5. Mandrel is made for the tube extrusion fig. 1.6.

![Image 3](image3.jpg)

Figure 1.4 Die angles 60°

![Image 4](image4.jpg)

Figure 1.5: Die with container

![Image 5](image5.jpg)

Figure 1.6: Mandrel for Tube Extrusion

![Image 6](image6.jpg)

Figure 1.7: Tube Extrusion
1.6 PREPARATION FOR BLUE, GREEN & YELLOW PLASTICINE

The plasticine is prepared for the experiment. The billet of the material is prepared of the desired shape of the diameter 40mm and the height of the desired die.

Fig. 1.8: Extrusion picture of tube by Blue plasticine

1.7 GEOMETRICAL PARAMETERS

The dimensions of the die and the container are as follows:
1. Inner Diameter of the Cylinder = 40 mm
2. Outer Diameter of Cylinder = 60 mm
3. Height of the container = 72.5 mm
4. Die 60 Degree Diameter = 40 mm
5. Die 60 Degree Height = 28 mm
6. Mandrel diameter = 8 mm
7. Extrusion ratio for all the dies is same i.e. 8/3 (Billet / Rod)

1.8 MATERIAL PARAMETERS

In this the three materials or three color of plasticine are used blue & Yellow. The simulation is run for the tube with the yellow plasticine only. The properties of the material that is used in the simulation are the \( k = \) strength co-efficient, \( n = \) strength exponent. The values are put in equation 3.1 and solved.

The value is:
\( k = 0.130 \) MPa
\( n = 0.091 \)

1.9 FE SIMULATION

Finite element analysis of the extrusion is done in order to compare the effect of load on the die angle with the experimental data. For the simulation of the tube the yellow color tube, die angle 60 degree is taken. The material properties of the green plasticine is take treating green and the yellow as same. The simulation tube is done by using the MSC. Marc software. In this by using equation 1.9, the simulation is run. Due to symmetric condition only a half specimens are modeled. Four nodded quadrilateral elements are used for FE modeling. The displacement boundary conditions are applied through the movement of the ram. The number of nodes in tube 442, the number of elements in tube and rod are 435. The meshed view of the model of tube which is simulated on the 60-degree die is shown in Fig. 1.9. The simulated deformed tube showing the von misses stress is shown in Fig. 1.10. The tube with plastic strain is shown in Fig. 1.11.
Fig. 1.12: Meshed view of the tube extrusion

Fig. 1.13: simulation of tube extrusion

Fig. 1.14: Simulation of extruded tube
With the von misses stress

Fig. 1.15: FEM simulation with Plastic Strain

Fig. 1.16: Effective plastic strain

Fig. 1.17: FE models included in the process flow simulations

Figure 1.18: Effective Strains

Figure 1.19: Effective Stress

Figure 1.20: Simulations using 3D and 2D.

1.10 PROCESS FLOW EXTRUSION SIMULATIONS

The most common approach in extrusion simulations is to use a uniform billet temperature as initial condition in the extrusion model. This means that the initial
stages of heating and transport are ignored in the modeling. The initial billet temperature has a major effect on the force that is required for extrusion. The importance of billet temperature for the prediction of extrusion force is also concluded. It is clear that the initial billet temperature, and possible temperature gradients, must be known with good accuracy in order to obtain accurate simulation results.

1.11 RESULTS & DISCUSSION

The tube extrusion is done by using the same set up with the addition of the mandrel and the various Load verses Displacement graphs were plotted. The effect of the velocity is seen that as the velocity increases the load increases and at less speed the load is low. The surface finish of the extruded tube is different for the die angle. The finish of the 60-degree tube is showing the cracks on the surface. Blue plasticine and yellow plasticine is used for experiment but blue plasticine is poor as compare to yellow plasticine such as strength of tube and cracks are generated but yellow plasticine is performed same condition very well. No cracks, hard

<table>
<thead>
<tr>
<th>Die angle (degree)</th>
<th>Load (N)</th>
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</thead>
<tbody>
<tr>
<td>V = 1 mm/min</td>
<td>V = 2 mm/min</td>
</tr>
<tr>
<td>60</td>
<td>343.44</td>
</tr>
</tbody>
</table>

and loose tubes are produced.

The Load Vs Displacement graphs for the tube extrusion with the Die (60°) and with three speeds (1, 2, 3 mm/min) are shown in Fig. 1.9 to Fig. 1.19. In these graphs & material flow figures flow, the three series are shown which shows the three reading for one set of die and speed of the tube is done and the graph between the load Vs displacement is plotted for the tube as shown in Fig.1.9 to Fig.1.19. The Extruded Tube shown in Fig.1.7 and the tubes extruded by the three different speeds as shown in Fig.1.7. The section view of the tube. In tube also the same pattern of the load and the die. The load increases as the speed increases and the load decreases as the die angle increases. The comparative table is prepared for the Tube and the simulated results as shown in Table.1.3. By this the percentage error for the tube extrusion experiment and the FE simulation. It has been observed that the simulation & experimental results is 673.11 & 613.32 respectively. The Finite element simulation percent error of the tube experiment and the tube simulation is 1.91%.this error as compare to previous result is very less and we have seen the difference of temperature is very important for Extrusion process because temperature is low than extruded material is very hard and brittle and temperature is high than extruded material is very soft and loose. In this reason cracks is generated on tube like hair and line cracks. It has been observed that the standard temperature is required for extrusion because in this work we have seen error is reduced due to room temperature. Temperature is responsible for extruded tube quality and surface finishing.

Table.1.1: Average load on blue plasticine

<table>
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<tr>
<th>Table.1.2: Average load on yellow plasticine</th>
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Table 1.3: Comparison of Experimental & Simulation results

<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Experimental Load (N)</th>
<th>Simulation Load (N)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube</td>
<td>673.11</td>
<td>613.32</td>
<td>1.91</td>
</tr>
</tbody>
</table>
Fig. 1.21: Tubes with speed 1, 2 & 3 mm/min

Fig. 1.22: Yellow color extruded tube

Fig. 1.23: Load/Displacement Graph for 60 Degree blue material 1mm/min speed

Fig. 1.24: Load/Displacement Graph for 60 Degree blue material 2mm/min speed

Fig. 1.25: Load/Displacement Graph for 60 Degree blue material 3mm/min speed

Fig. 1.26: Load/Displacement Graph for 60 Degree yellow material 1mm/min speed

Fig. 1.27: Load/Displacement Graph for 60 degree yellow material 2mm/min speed

Fig. 1.28: Load/Displacement Graph for 60 Degree yellow material 3mm/min speed

Fig. 1.29: Simulated Graph between Load/Displacement for rod

Finite element modeling analysis and design of extrusion and other metal forming processes is constantly increasing. Computer models that with adequate accuracy can describe the material behavior during extrusion can be very useful for product and process development. The process development in industrial extrusion today is to a great extent based on trial and error. This often involves full size experiments which are expensive, time consuming and interfere with
the production. It would be of great value if these experiments could be performed in a computer. It depends on the material and surface roughness of the contacting bodies as well as lubrication conditions, together with temperature and pressure. It is also a very important factor in forming processes, since it affect the material flow, the forces and the tool wear. The physics behind friction and the numerical representation of the same is a continuous topic of research. In the simulation of metal forming processes, friction is often included by simple models such as the Coulomb friction model or the constant shear friction model. These two models are briefly described below. A variety of more complex friction models exist, however, the problem is often the lack of input data to these models. It is very difficult to investigate the friction, and the factors affecting friction, experimentally, since the billet-tool interface often is under high pressure and temperature. Billet and tool temperatures, friction coefficient and heat transfer coefficient, were included in the analysis. The design of experiments for the numerical experiments was created by fractional factorial design. The relationship between the model parameters and the responses was analyzed by a calculation of two different regression models: one linear polynomial model and one model that include interaction terms. Additional simulations were carried out to validate the regression models. The results showed that the initial billet temperature is the parameter that has the strongest impact on the extrusion force within the parameter ranges studied in this work. The second-most influential factor on the initial peak force was the friction coefficient between the billet and the container. The goodness of prediction and goodness of fit were excellent for both regression models.

1.12 CONCLUSION

The tube extrusion is done by using the same set up with the addition of the mandrel and the various Load verses Displacement graphs were plotted. The effect of the velocity is seen that as the velocity increases the load increases and at less speed the load is low. The surface finish of the extruded tube is different for the die angle. The finish of the 60-degree tube is showing the cracks on the surface. Blue plasticine and yellow plasticine is used for experiment but blue plasticine is poor as compare to yellow plasticine such as strength of tube and cracks are generated but yellow plasticine is performed same condition very well. No cracks, hard and loose tubes are produced. The Load Vs Displacement graphs for the tube extrusion with the Die (60°) and with three speeds (1, 2, 3 mm/min). In these graphs the three series are shown which shows the three reading for one set of die and speed of the tube is done and the graph between the load Vs displacement is plotted for the tube. In tube also the same pattern of the load and the die. The load increases as the speed increases and the load decreases as the die angle increases. The comparative table is prepared for the Tube and the simulated results. By this the percentage error for the tube extrusion experiment and the FE simulation. It has been observed that the simulation & experimental results is 673.11 & 6133.2 respectively. The Finite element simulation percent error of the tube experiment and the tube simulation is 1.91%.this error as compare to previous result is very less and we have seen the difference of temperature is very important for Extrusion process because temperature is low than extruded material is very hard and brittle and temperature is high than extruded material is very soft and loose. In this reason cracks is generated on tube like hair and line cracks. It has been observed that the standard temperature is required for extrusion.
In this study an attempt has been made to study the effect of die angle on tube extrusion processes using experiment. The extrusion experiments are carried out by using die of 60\(^{0}\) die angle with variable die landing and at the three different speeds. Blue and yellow colors plasticine is used. Extrusion load increases with increase in ram velocity irrespective of die angle and material. Simulation study reveals a good match between experimental and numerical load stroke curves. Safe and finished tube is generated after maintaining temperature. It shows that simulation can be effectively used for the analysis of real material like stainless steel extrusion process. The designed die was further adopted for computer simulation using MSC.MARC software (based on FE Method) to assess stress, strain and strain rate distributions and load requirements. Effects of single die angle at various ram speeds are critically examined. The expectation of this study would provide a new insight into the design of manufacturing process.

The equipment consists of a cylinder or container into which the heated is one of the most potential and useful working processes and has a metal billet is loaded. On one end of the container, the die with the necessary opening is fixed. From the other end, a plunger or a ram compress the metal billet against the container wall and the die plate, thus forcing it to flow through the die opening, acquiring the shape of the opening. Stainless steel simulation is very critical because simulation is very costly for original material. In this work we have seen error is reduced due to room temperature. Temperature is responsible for extruded tube quality and surface finishing.

1.13 FUTURE WORK

The following subjects are recommended for future research:

- Simulation and experiments should be carried out in order to ensure that the axisymmetric FE models have adequate accuracy for all tube dimensions.
- This experimental work is related to extrusion simulation using Plasticine. The same may be extended to real material like Aluminum.
- Evolution of an exact three-dimensional extrusion model which runs in fair computational time. A model could be of great use for parameter studies of eccentricity.

REFERENCES


