ANALYTICAL STUDIES ON ROD EXTRUSION TO EVALUATE HOT EXTRUSION PROCESS USING PLASTICINES & GENERATION OF COUNTER MAP FOR MATERIAL CHARACTERIZATION USING ANALYTICAL & EXPERIMENTAL VERIFICATION

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Abstract

In this study, Analytical studies on rod extrusion to evaluate hot extrusion process using plasticines. Generation of counter map for material characterization using analytical result, Experimental verification of contour map.

In this study an attempt has been made to study the effect of die angle on rod & tube extrusion processes using experiment. The extrusion experiments are carried out by using dies of 30^0 die angle at the three different speeds. The die is of semi angle 30 degree. The cylinder and the die arrangement are made for the machine. A setup has been made to do direct extrusion of the model material, Plasticine, (Red and Green color). 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 die is made from Aluminum material.

A contour map has been generated for determination of material parameters using Surfer Software Surfer is a grid based graphics programmer.

The proposed contour map is validated using extrusion experiments. Since flow properties of plasticine material matches with hot deformation of metal, the proposed method can be very suitable for studying the thermal behavior of hot deformation.

Key words: *Modeling Material, Flow Parameter, Methodologies, Material Characterization, Sufer software, Extrusion Dies, Red & Green plasticine, manufacturing process, Die angles, Rod, Aluminum.*

1.1 **Introduction**

Extrusion-Extrusion is the process of confining the metal in a closed cavity and then allowing it to flow from only one opening (die) so that the metal will take the shape of the opening. The operation is identical to the squeezing of tooth paste out of the tooth paste tube. The paste inside the tooth paste has no shape, when the tooth paste tube is squeezed the paste flows out of the circular opening taking the shape of the opening.Because they have sufficient ductility, aluminum, copper, magnesium, and their alloys and steels and stainless steels are extruded with relative ease into numerous shapes. Other metals such as titanium and refractory metals can be extruded, but only with some difficulty and considerable die wear.

Extrusion ratios, R, usually range from about 10 to 100. They may be higher for special applications (400) or lower for less ductile materials, although they usually need to be at least 4 to work the material plastically

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through the bulk of the work piece. Extruded products are usually less than 7.5 m (25 ft) long, because of the difficulty in handling greater lengths, but they can be as long as 30 m (100 ft).

Circumscribed-circle diameters for aluminum range from 6 mm to 1 m (0.25 in. to 40 in.); most are within 0.25 m (10 in.). Because of the higher forces required, the maximum CCD for steel is usually limited to 0.15 m (6 in.).

Ram speeds may range up to 0.5 m/s (100 ft/min). Generally, lower speeds are preferred for aluminum, magnesium, and copper, higher speeds for steels, titanium" and refractory alloys.

Most extruded products, particularly those with small cross-sections, require straightening and twisting. These operations are accomplished by stretching the extruded product, usually in a hydraulic stretcher equipped with jaws. Dimensional tolerances in extrusion are usually in the range of ±0.25 mm-2.5 mm (±0.01 in.-O.1 in.), and they increase with increasing cross-section.

The presence of a die angle causes a small portion of the end of the billet to remain in the chamber after the operation has been completed. This portion, called scrap or the butt *end, is* subsequently removed by cutting *off* the extrusion at the die exit. Alternatively, another billet or a graphite block may be placed in the chamber to extrude the piece remaining from the-previous extrusion.

Fig.1.1: Typical extrusion setup

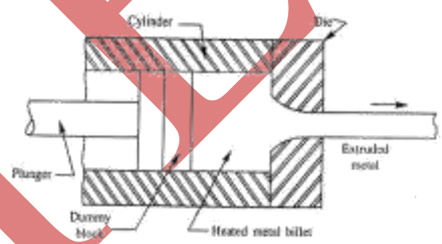

Fig. 1.2: Forward hot extrusion process

1.2 Basic of Study

Experimental study on hot extrusion is very difficult. It is because of controlling of Processing parameters are very complex. Properties of modeling materials like plasticine have many similarities with hot metal. In this regard, extrusion with plasticine can be helpful in studying the hot extrusion process. This motivation has led to carry out proposed study.

1.2 Literature Review

There are huge amount of research activity on the topic covering, different aspects of extrusion. Some of the prominent literatures on extrusion are especially using plasticine described below

Kim K.J. et al (2008) reported investigation into the improvement of welding strength in three-dimensional extrusion of tubes using porthole dies. A modified porthole die for tube extrusion has been developed in order to obtain larger welding pressure than that of conventional porthole dies, and the effect of the improved porthole die on welding pressure has been investigated by performing the finite element analysis on aluminum tube extrusion. The comparison of welding strength of tubes extruded by the modified porthole die with that of tubes made by a conventional porthole die on an expanding test has shown that the tubes from the modified die have been improved in welding strength.

Eckerson K et al. (2010) conducted the compression tests to determine the strain, strain rate, and temperature

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sensitivities of Van Aken plasticine at elevated temperatures. A true stress–true strain relationship is presented in the form of the Norton–Hoff viscoplastic

Model. The plasticine is most sensitive to the deformation rate and temperature. At low strains, the material hardens with increasing strain, but strain hardening is negligible above a logarithmic strain of approximately 30 percent. The shear friction factor for a plasticine– metal interface with and without lubrication is estimated using ring compression tests. Without lubrication, the shear friction factor approaches 1.0; however, lubrication with Vase line considerably reduces friction. In addition to the mechanical properties of the plasticine.

1.3 Methodology

The various steps involved in this study to obtained hot extrusion parameters using plasticine are as follows-

Step 1: Selection of geometrical material and frictional parameter like μ=Friction co-efficient, k=Strength co-efficient and n=Strain rate hardening.

Step 2: Analytical formulation and generation of data bank with the help of Hoffman and sach theory and available variable data's and software development.

Step 3: Development of counter map with the help of surfer grid based graphics program Software generated data

Step 4: Rod extrusion experiment using plasticines.

Step 5: Validation of contour map with experimental results.

1.4 Analysis of Rod Extrusion

Rod extrusion is the process in which the extruded product is the rod and the set up of direct rod extrusion is shown in Fig1.2.In this Study the rods of two different colored plasticine material were extruded. It was extruded by 30^0 die angles. The two different speeds were taken as 1 and 2 mm/min. The extrusion ratio is kept constant. The Load/Displacement graph were plotted for the cases and studied.

General Governing Equations

We know that,

Extrusion ratio= Initial cross sectional area of the billet / Final cross sectional area after Extrusion

Or $R = A_o / A_f$ ……….. (1.1)

Metal working deformation frequently is expressed as reduction in cross-sectional area.

The frictional reduction area is,

$r = A_o - A_f / A_o$

Or

$r = 1 - A_f / A_o$

Or

$A_f / A_o = 1 - r$

Or $1/R = 1 - r$

Or $R = 1/(1-r)$ ………………(1.2)

For the large deformation R is a more descriptive parameter because there is (Constancy of mass flow rate through die = the velocity of extruded product is the ram velocity * R)

But the extrusion pressure is directly related to the natural logarithm of the extrusion ratio.

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Then, Extrusion Pressure $P = k.A_o \ln (A_o/A_f)$ ……………… (1.3)

(Where k = Strength co-efficient)

1.5 Slab Analysis

A simple approach to determining die pressure P_d is to use a **SLAB ANALYSIS** to account for fraction on extruding through a conical die (for a 180^0 flat die it is assumed that the material shears internally to form an effective cone angle of 2α= 90)

Sach (O. Hoffman and G.Sachs) "Introduction to the theory of plasticity for engineers" performed this analysis for coulomb sliding friction.

The solution is directly analogous to that for wiredrawing through a conical die is,

$$P_d=\sigma_{xb} \qquad \text{……………………………….(1.4)}$$

Or

$$P_d= \sigma_o(1+B/B)(1-R^B) \qquad \text{……………………(1.5)}$$

(Where, B=μCotα

α= Semi die angle

R=Extrusion ratio

$R= A_o /A_f$

But $\sigma =k.\varepsilon^n$ ………………………..(1.6)

Then $\sigma_o =k.(6V\ln R/D_b)^n$ ……………………….(1.7)

(Where, V=Velocity of material par tool interface D_b = Billet diameter and n= Strain rate hardening exponent

So that equation 4.5, becomes

$$P_d = k.(6V\ln R/D_b)^n (1 +\mu Cot\alpha /\mu Cot\alpha)(1- R^{\mu Cot \alpha}) \qquad \text{………………... (1.8)}$$

But Total extrusion force

$P_e =P_d +P_f$

{Where, P_f =Frictional force $P_f = (4 \tau_i L /D_b)$ ……………. ….(1.9)

Then, ……………..(1.10)

And we also know that,

Total extrusion load (P)

$$P=P_e.A$$

Or $P=\{(P_d +4\sigma_oL/3^{1/2}D_b).(\pi D_b^2/4)\}$ ....(1.12)

Or $P=[\{k.(6V\ln R/D_b)^n (1+\mu Cot\alpha /\mu Cot\alpha)(1-R^{\mu Cot \alpha})+$

$(4L/3^{1/2}D_b)k.(6V\ln R /D_b)^n\}(\pi D_b^2/4)]$ ....(1.13)

$P=k.(6V\ln R/D_b)^n[(1+\mu Cot\alpha/\mu Cot\alpha)(1-R^{\mu Cot \alpha})+$

$(4L/3^{1/2}D_b)](\pi D_b^2/4)]$

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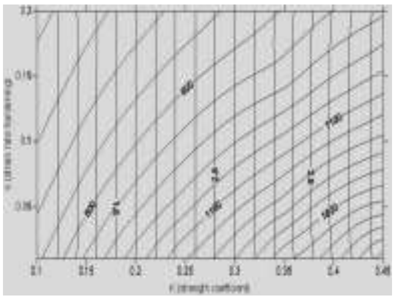

Fig.1.3 Contour map

1.6 Extrusion Analysis

We have taken the following values of the variables,

V = 1 mm/minute

Or V = 1 / 60 mm/second

Or V = 0.0167 mm/second

D_b = 40 mm

D_e = 15 mm

$R = D_e^{\,2} / D_b^{\,2} = 40^{\,2} / 15^{\,2} = 7.11$

$\alpha = 30^0$

L = 22 mm

Following material and frictional parameters are considered in this study. Considering these values, total 150 cases are framed.

Table 1.1: Material and friction parameters

K	0.1	0.15	0.2	0.25	0.35	0.45
n	0.01	0.05	0.1	0.15	0.2	
μ	0.1	0.15	0.2	0.25	0.3	

Putting the value of V, D_b, D_e, R, α and L, Eq. 4.14 can be written as,

$$P=k(0.0049136)^n * 1256\ [(1 + 1.732\mu / 1.732\mu)(1 - R^{1.732\mu}) + 1.2702] \qquad ....(1.15)$$

To calculate the extrusion load using Eq.1.15, software in C++ has been developed.

S.No.	k (bulk modulus)	n (Strain hardening exponent)	μ (friction coefficient)	P (extrusion load) N	k/μ
1	0.1	0.01	0.1	477.88	1
2	0.1	0.01	0.15	535.36	0.6666667
3	0.1	0.01	0.2	601.89	0.5
4	0.1	0.01	0.25	679	0.4

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5	0.1	0.01	0.3	768.49	0.3333333
6	0.1	0.05	0.1	386.35	1
7	0.1	0.05	0.15	432.81	0.6666667
8	0.1	0.05	0.2	486.6	0.5
9	0.1	0.05	0.25	548.95	0.4
10	0.1	0.05	0.3	621.29	0.3333333
11	0.1	0.1	0.1	296.18	1
12	0.1	0.1	0.15	331.79	0.6666667
13	0.1	0.1	0.2	375.03	0.5
14	0.1	0.1	0.25	420.82	0.4
15	0.1	0.1	0.3	476.28	0.3333333
16	0.1	0.15	0.1	227.04	1
17	0.1	0.15	0.15	254.35	0.6666667
18	0.1	0.15	0.2	285.96	0.5
19	0.1	0.15	0.25	322.6	0.4
20	0.1	0.15	0.3	365.12	0.3333333
21	0.1	0.2	0.1	174.05	1
22	0.1	0.2	0.15	194.99	0.6666667
23	0.1	0.2	0.2	219.22	0.5
24	0.1	0.2	0.25	247.31	0.4
25	0.1	0.2	0.3	279.9	0.3333333
26	0.15	0.01	0.1	716.83	1.5
27	0.15	0.01	0.15	803.05	1
28	0.15	0.01	0.2	902.85	0.75

Using these data, a contour map has been generated for determination of material parameters using Surfer Software.

1.7 Software Surfer

Surfer (Ref.12) is a grid based graphics programmer. **Surfer** interpolates irregularly spaced XYZ data into a regularly spaced grid. The grid is then used to produce different types of maps including contour, vector, wire frame, image, shaded relief, and surface maps. maps can be displayed and enhanced in surfer by the addition of boundary information, posting, data point, combining several maps, adding drawing, and annotating with test.

1.8 Generation of Contour Map

With the help of surfer software we have plotted and superimposed counter maps which have various wire drawing lines shown in Fig 1.1

X axis denotes the Strength Co-efficient (k)

Y axis denotes the Strain Rate Hardening (n)

Solid contour line denoted the ratio of Strain Rate Hardening and Friction Co-Efficient (n/µ)

Dashed contour line denotes the extrusion Load in Newton

The proposed contour map is validated using extrusion experiments

1.9 Experimental Setup

For the experiment the computer controlled testing machine having load cell capacity of 100 kg as shown in Fig 5.2. 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.

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Fig. 1.4: Computer controlled Testing machine with the extrusion process fixtures

1.10 Die Design

The die is of semi angle 30 degree. The cylinder and the die arrangement are made for the machine. A setup has been made to do direct extrusion of the model material, Plasticine, (Red and Green color). 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 die is made from Aluminum material. The side view and top view of the 30 degree die is shown in Fig 1.3 and 1.4 respectively. The side view of the extrusion setup cylinder and side view of the extrusion setup cylinder with die is shown in Fig. 1.5 and 1.6 respectively. Extruded green and red plasticine for 30 degree die angle shown in Fig. 1.7 & 1.8 Respectively.

Fig.1.3 side view of the dies 30 degree

Fig. 1.4 Top view of the dies 30 degree

Fig.1.5: Side view of the extrusion setup cylinder

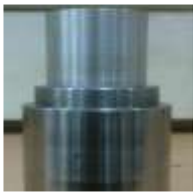

Fig.1.6: Side view of the extrusion setup cylinder with die

Fig. 1.7: Extruded rod of Green plasticine from 30 degree dies

Fig. 1.8: Extruded rod of Red plasticine from 30 degree dies

1.11 Results & Discussion

Results of experimental & analytical formulation are described under following heads:

Generation of variable data from experimental results and counter map

Green plasticine-From experimental result load/displacement graph (three series) we have taken average load for 1 & 2 mm/min velocity this is shown in Fig. 1.9,and these load and velocity tabulated in Table 1.9. It can be observed that extrusion load increases with increase in ram velocity.

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(a) (b)

Fig. 1.9: Load/Displacement Graph for 30 degree green material 1 & 2 mm/min speed

Table.1.3: Average load on Green plasticine for 30^0 die angle

Velocity (mm/min)	Load (N)
1	650
2	683.84

Using these data,

$$P_{1} / P_{2} = (V_{1} / V_{2})^{n}$$

$$(0.65 / 0.683) = (1/2)^{n}$$

$$n \ln(1/2) = \ln(0.65/0.683)$$

$$n \ln(0.5) = \ln(0.9516)$$

$$n (0.69314) = \ln(0.04961)$$

$$n = 0.04961/0.69314$$

$$n = 0.0715$$

Using this value of n and extrusion load as 650 N

A value of k and (k/μ) is obtained by counter map as follows:

$$k = 0.19$$

$$k/\mu = 1.9$$

Hence $\mu = 0.1$

Using these values of (n, k, μ) in the equation given below:

$$\mathbf{P = k(0.0049136)^{n} * 1256 \,[(1 + 1.732\mu / 1.732\mu)(1 - R^{1.732\mu}) + 1.2702]}$$

We get the extrusion load as

P= 648.41 N

It can be observed that contour map predicted load is quite close to the experimental one.

Red plasticine-From experimental result load/displacement graph (three series) we have taken average load for 1 & 2 mm/min velocity this is shown in Fig. 1.10 and tabulated in Table 1.3

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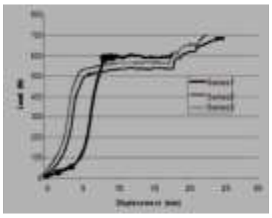
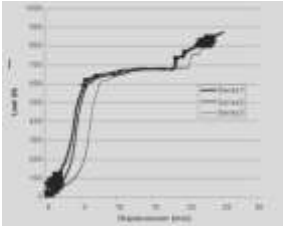

Fig. 1.10: Load/Displacement Graph for 30 degree green material 1& 2 mm/min speed

Table.1.4: Average load on Red plasticine for 30^0 die angle

Velocity (mm/min)	Load (N)
1	567.88
2	568.73

It can be observed that extrusion load is not affected by extrusion speed.

Using these data

$P_{1\,/}\,P_2 = (V_{1\,/}\,V_2)^n$

$(0.567/0.568)=(1/2)^n$

n ln(1/2)=ln(0.65/0.683)

n ln(0.5)=ln(0.99823)

n(0.69314)=(0.001762)

n=0.001762/0.69314

n=0.00254

Using this value of n and extrusion load as 567.88 N

A value of k and (k/µ) is obtained by counter map as follows:

k = 0.12

k/µ = 1.2

Hence µ = 0.

Using these values of (n, k, µ) in the equation given below:

$P=k(0.0049136)^n * 1256\ [(1 + 1.732\mu / 1.732\mu)(\ 1 - R^{1.732\mu}\ )+1.2702]$

We get the extrusion load as

P= 598.58 N

It can be observed that contour map predicted load is quite close to the experimental one.

1.12 Validation of Contour Map with Experiment:-

The analytical and experimental extrusion loads for green and red plasticines are given in Table 1.3 and 1.4.

Table.1.5: Comparison of Experimental & Analytical results for green plasticine

S.No.	n (MPa)	K	µ	Load experimental (N)	Load Analytical (N)	% error
1	0.0715	0.19	0.1	650	648.41	0.245

Table.1.6: Comparison of Experimental & Analytical results red plasticine

S.No.	n (MPa)	K	μ	Load experimental (N)	Load Analytical (N)	% error
1	0.00225	0.12	0.1	567.88	598.58	5.12

It can be observed that contour map predict quite accurate results as compared to the experimental text. Hence such map may play important role in mechanical characterization of modeling material like plasticine.

1.13 Hot Deformation of metal

In hot deformation of metal, the choices of process parameter such as temperature, stress, strain, strain rate, micro structure evaluation and plastic stability affect product quality in terms of final shape and mechanical properties. The constitutive relationship among deformation parameters, derived from data of mechanical tests, are used to model manufacturing process and to produce behavior maps, which are a useful representation of stress- temperature domains for certain deformation mechanisms.

A new method of modeling material behavior which accounts for the dynamic metallurgical process occurring during hot deformation presented. The approach in this method is to consider the real metal and evaluate the load from the **Power Law Equation and Sach Theory** relating the bulk modulus, strain rate hardening and fraction co-efficient. The dynamic behavior of material is useful in obtaining a unique combination of temperature and strain rate hardening.

Thermodynamics of Hot Deformation Process-Hot working is defined as deformation under conditions of temperature and strain rate such that recovery processes take place simultaneously with the deformation. In hot working the strain hardening and distorted grain structure produced by deformation are very rapidly eliminated by the formation new strain free grains as the result of recrystallization. Very large deformations are possible in hot working because the recovery process keep pace with the deformation. Hot working occurs at an essentially constant flow stress and because the flow stress decreases with increasing **temperature.** For most commercial alloy a hot working operation must be carried out at a relatively high temperature in order that a rapid rate of recrystallization is obtained. However lead and tin recrystallize rapidly at room temperature after large deformations. So that the working of their metals at room temperature constitutes hot working. Similarly working Tungsten at 1100 degree Celsius in the hot working range for steel, constitutes cold working because this high melting metal has a recrystallization temperature above this working temperature

$$\mathbf{T_d = U_p / \rho c}$$

Where, ρ = the work of plastic deformation per unit volume

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P = Density of work piece

C = Specific heat of the work piece

Temperature increases due to friction is,

$$T_f = \mu.p.v.A.\Delta t / \rho.c.V$$

Where, μ = Fraction co-efficient at material

P = Stress normal to interface

v = velocity at the material

A = Surface area at the material

Δt = Time interval of consideration

V = Volume subjected to the temperature rise.

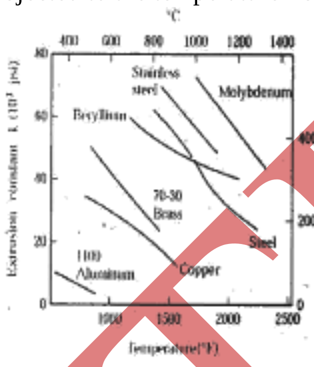

Fig. 1.11: Extrusion constant (Bulk modulus) k for various metals at different temperatures

Material Parameter-

We have taken the following values of the variables,

V = 1 mm/minute

Or V = 1 / 60 mm/second

Or V = 0.0167 mm/second

D_b = 40 mm

D_e = 15 mm

$R = D_e^{\,2} / D_b^{\,2} = 40^2 / 15^2 = 7.11$

$\alpha = 30^0$

L = 22 mm

Following material and frictional parameters are considered in this study. Considering these values, total 150 cases are framed

Table 1.7: Material and friction parameters

K	50	75	100	125	150	200
n	0.01	0.05	0.1	0.15	0.2	
μ	0.1	0.15	0.2	0.25	0.3	

Putting the value of V, D_b, D_e, R, α and L, Eq. 4.14 can be written as,

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$$P= k(0.0049136)^{n} *1256 [(1 + 1.732\mu / 1.732\mu)(1 – R^{1.732\mu})+1.2702] \quad ....(1.1)$$

To calculate the extrusion load using Eq.7.1, software in C++ has been developed.

With the help of surfer software we have plotted and superimposed counter maps which have various wire drawing lines shown in Fig 5.1

X axis denotes the Strength Co-efficient (k)

Y axis denotes the Strain Rate Hardening (n)

Solid contour line denoted the ratio of Strain Rate Hardening and Friction Co-Efficient (n/μ)

Dashed contour line denotes the extrusion Load in K N

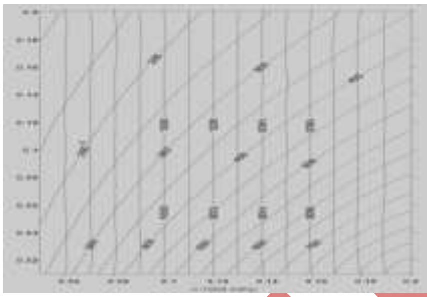

Fig.1.12 Contour map

1.14 Conclusions-

Since flow properties of plasticine material matches with hot deformation of metal, the proposed method can be very suitable for studying the thermal behavior of hot deformation.

Proposed methodology of counter map has been found to be very suitable for characterization of plasticine material. The developed C++ software for hot extrusion analysis is found to be very effective. Using proposed methodology costly experimental method may be avoided. The proposed approach is fast and economical.

1.15 Future Scope-

(1) FEM of the extrusion process can be carried out considering different lubricating medium.

(2) Experimental validation on the real material can be carried out to study the thermal behavior of the hot deformation processes.

(3) In this study only circular cross section has been considered. The same study may be attempted considering different sections.

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