Design & Fabrication of dies for Shaped Extrusion under Cold/Hot Working Condition

[1]Manish Kumar Mishra, [2]Vijay Pitroda

[1] Sr. Asst. Prof., Bhilai Institute of Technology, Raipur, C.G. India
[2] A.E., Boiler Erection, 2 X 500 MW, MTTPP (CSPGCL), Champa, C.G. India
Email: [1]mishramanish68@yahoo.com, [2]pitrodavijay@rediffmail.com

Abstract—The present work is carried out for design and fabrication of extrusion dies for cold and hot extrusion of Lead alloy (70Pb30Sn) and Aluminum (2024) respectively. The hot extrusion experiments has been performed at temperatures 300 0C and 500 0C. Fabricated flat dies for H, L, T, two-hole product profile and conical dies of elliptical profile have been used for experimentation. A billet heating arrangement and ring type load cell with instrumentation have been fabricated to perform experiments. Experimental investigations have been made on the average pressure/ total extrusion power consumed in the cold and hot extrusion of Lead alloy (70Pb30Sn) and commercial grade Aluminum (2024) respectively. Various parameters such as reduction, friction between die-billet interfaces, ram velocity and extrusion ratio has been studied for process optimization. The total extrusion power obtained has been compared with the theoretical work using the upper bond theorem for cold extrusion of the Lead alloy. For hot extrusion of Aluminum, results are compared with commercial software Hyper-Xtrude 3.0. The theoretical results obtained compares well with the experiment results.

Keywords— Cold Working, Hot Working, Extrusion, & Dies.

I. INTRODUCTION

Extrusion is a deformation process used to produce long, straight, semi-finished metal product such as bars, solid and hollow sections, tubes and wires and strips. The principal is very simple: under a high load, a billet is squeezed under closed container through a die, to give a desired product.

Extrusion process may involve several passes through a single hole die or multiple hole die to obtain the final shape of a component. Dies of appropriate shape and sizes are then required to impart the right shape and specified tolerance in their respective passes. A welding chamber die (bridge, spider etc.) under hot condition is common for extrusion of hollow component. Square dies for single and multi-hole extrusion under hot condition have been widely used. Continuous dies such as streamlined, conical, elliptical, hyperbolic and cosine dies are becoming important for manufacture of better mechanical and metallurgical properties at lower power consumption. Extrusion through multiple hole dies, using a high capacity extrusion press is preferred for reasons of economy and high productivity.

In Extrusion process most of the work done during the plastic deformation and in overcoming friction at the die-billet interface is converted into heat. This heat results in rise of temperature of the work-material (billet) as well as tooling (die and container). However, the rise in temperature does not affect the material properties in case of cold extrusion, as it is carried out at lower temperature. But, material properties are very sensitive even to small changes in strain, strain rate and temperature, in the range at which hot extrusion is carried out.

In the present work, attempt has been made to design and fabricate some extrusion dies and to determine experimentally the average pressure/total extrusion power required for the cold/hot extrusion of commercial grade Aluminum (2024) and Lead alloys (70Pb30Sn) through flat and conical die of H, L, T, Two-hole and elliptical product shapes.

An extensive literature exists on optimal die profile design based on power minimization by using the slip line field technique, the upper bound technique and more recently by rigid plastic finite element method.

Reddy [1] carried out parametric study for third order polynomial die to study the effect of reduction ratio friction factor and strain hardening or the optimal die length and die pressure distribution.

Reddy et al. [2] proposed an upper bound model for axisymmetric extrusion with strain hardening effects and compared streamlined (third order, fourth order polynomial and cosine), elliptical, hyperbolic and conical die profiles. Based on the consideration of total extrusion power (under optimal conditions) they concluded that third order and the cosine dies are the best amongst the profile as increasing the order of the die profile (fourth and higher order) does not contribute significantly to the optimum power and optimum die length. They also found that the conical die consumes maximum power.

Balaji et al. [3] used the finite element method to propose a general methodology for optimal die design in which the die geometry and the plastic boundaries also appear as variables, but the material is assumed to be perfectly plastic.

Joun and Hwang [4] developed an iterative optimization scheme along with penalty rigid viscoplastic finite element formulation for optimal design in metal forming and applied it for obtaining optimal die profiles for axisymmetric extrusion under various process conditions and for strain rate sensitive materials.

The extrusion of aluminium sections with high demands on decorative surface appearance requires a high degree of control of the thermo-mechanical conditions in connection to their effect on metallurgical properties [5]. There has been a considerable interest in the investigation on the effects of die geometry and other extrusion parameters on the structure flow patterns, extrusion pressure and mechanical properties of the shaped sections [6 & 7]. In recent years however, attention has been given to the study of the mechanics of extrusion of such simple shapes such as circular, tubular, square and rectangular section. In a study, both the deformation modes and the internal patterns of the deformed specimens were examined in detail as to ascertain the metal flow in the production of shaped sections such as I and T sections [8].

In a related investigation to determine the effects of section shape (circular, square and rectangular) with various lengths to breadth ratio on extrusion load, it was found that the frictional load in container and the deformation load followed an exponential relationship with the extrusion speed. Also, the frictional load was found to be virtually independent of the section shape [9].

II. DESIGN AND FABRICATION OF DIES

This heading is concerned with design and fabrication of an extrusion dies (H, L, T, Two-hole and Elliptical product shapes) suitable for 25.09 mm billet used for cold/hot extrusion. Correct choice of steel for the stresses developed is of particular importance.

A. Review of Previous Fabrication Work

Biswajit [10] has been fabricated extrusion tooling (3 piece container and die set assembly) for extrusion of axi-symmetric shape suitable for 25.09 mm billet of Al (2024) and Lead alloy under cold working condition. The tooling is, without doubt, the key to the economical extrusion of rod, tube and, in particular, sections. Figure 2.1 shows three piece container fabricated by Mr. Biswajit. The extrusion tooling (Figure 2.2) involves container and die set. The functions of individual tool of die set can be seen in the Biswajit [10].

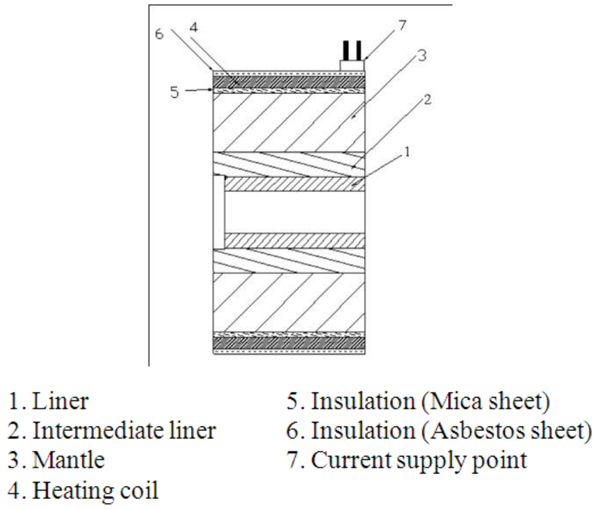


Figure 1 : Photograph of Dies and Die backers

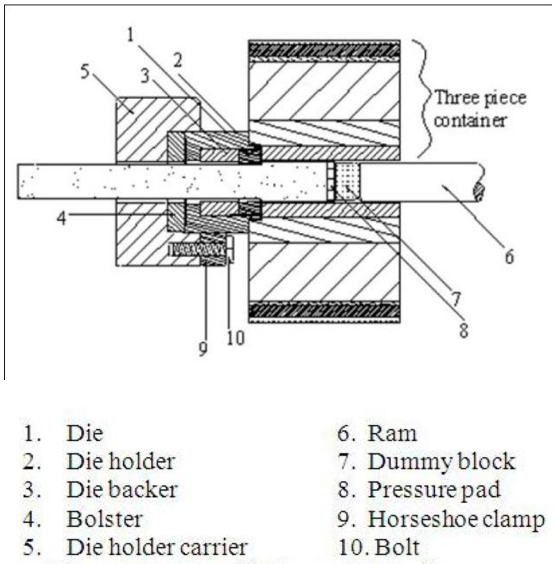


Figure 2 : Assembled extrusion tooling

Figure 3 : Photograph of Dies and Die backers

B. Die Design

In extrusion process, geometry of the die constitutes an important aspect of die design. The die geometry determines the extent of redundant work done during the deformation. Redundancy is a measure of the extra work required beyond the minimum value, to achieve the desired reduction of the Work piece, for a friction-less homogeneous compression process.

The optimal die profile can be obtained in two ways. In a more general approach, the die profile f (z) is expressed as a function of several parameters. For example, it can be expressed as a polynomial in z with multiplying constants as the parameters. The optimal values of these parameters are then obtained by optimizing the extrusion power using a suitable optimizing scheme.

Following six factors are considered in the design and construction of a die.

(1) The flow pattern.

(2) Maximum specific pressure.

(3) Geometrical shape of the section.

(4) Wall thickness and tongue sizes.

(5) Shape of the bearing surfaces (die lands).

(6) The tolerances of the section.

C. Dimensioning of Die According to Stress Criteria

The ratio of the length of tongue L_t to its width b_t is critical for the deflection.

$$i = \frac{L_t}{b_t}$$

This classic and very simple method of calculation is still used today but the simple expression can only give approximate results. In critical cases the shear and bending stresses in the die have to be calculated: the necessary steps are given below [17].

(1) Pressure on the die:

Specific pressure $P = \frac{F}{A_o}$

(2) Bending:

Bending moment M_b =Q.e

(3) Shearing :

Shearing stress $\tau = \frac{Q}{b_t . L_D}$

Equivalent stress from bending and shearing:

Reference stress

$$\sigma_R = \sqrt{\sigma^2 + (1.73\tau)^2} \cong \sqrt{\sigma^2 + 3\tau^2}$$

(According to the strain energy hypotheses) $\sigma_R < \sigma_o$

D. Fabrication Of Billet Heating Arrangement And Load Cell

1) Design of Ring type Load cell

In case of extrusion only vertical force is acting (i.e. ram force). The maximum limit of applied force is 500 kN. For the purpose of the design of the ring type load cell assuming the vertical component act directly above the ring then the ring will be subject to a vertical force of 500 kN. From equation below strain at position 1,2,3,4 is given by

$$e_{1,2,3,4} = \frac{1.09 F_V r}{E w t^2}$$

If the maximum strain to which the strain gauge can be subjected to is 0.00092. For load cell to be sensitive without a further loss in the stiffness the strain developed is as high as possible. Then we have,

$$strain / deflection \; \alpha \; \frac{t}{r^2}$$

This shows that in order to $strain / deflection$ high a decrease in r will give more pronounced effect then an increase in thickness of the ring but we cannot decrease r to a certain limit as a smaller r will provide lesser space for strain gauge to be fixed in flat. Also makes more difficult for the strain gauges to be fixed on the inside.

2) Fabrication of load cell

Ring type load cell is made from mild steel ring of outer diameter 290 mm and inner diameter 110 mm and width 45 mm. First ring is turned to outer diameter 277 mm and inner diameter 128 mm. After turning, grinding operation is carried out to get desired surface finish and dimension as outer diameter 276 mm and inner diameter 127 mm. After this operation facing operation is done to get desired width of ring i.e. 34 mm. Two web of diameter 34 mm and length of 50 mm is welded diametrically opposite such that axis is passing through center of the ring.

3) Deflection sensing device

Although there are many devices which could be used to measure the elastic deflection due to the application of force required for extrusion such as dial indicator, optical lever device, piezeo electric crystals, air gauges etc. One of the most attractive elements for use in force measurement is strain gauge.

Almost all strain measurement system can be broken down into the components as shown in figure below:

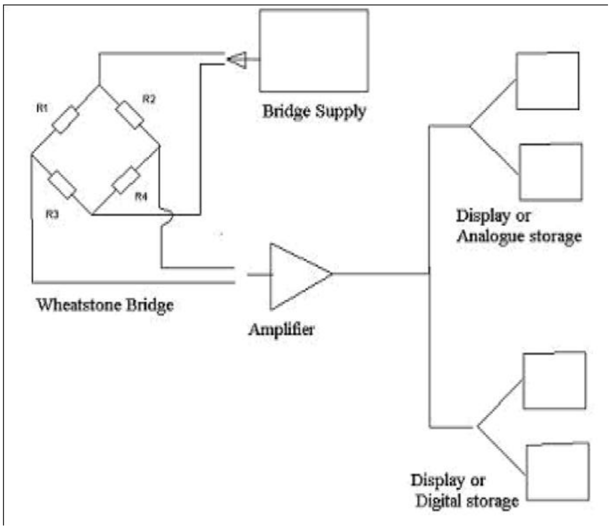
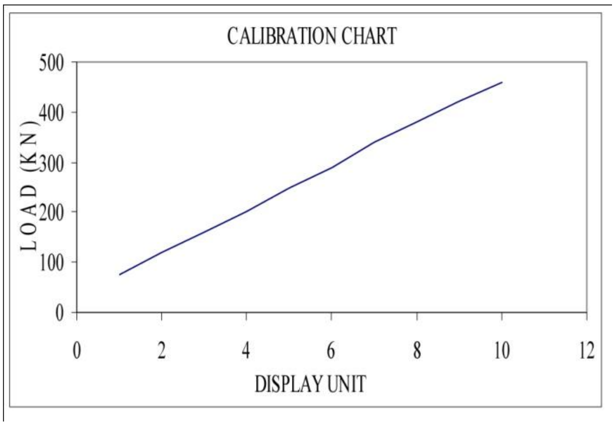


Figure 4 : Strain measurement system

4) Calibration of Ring type load cell

Load cell is calibrated for vertical force on compression testing machine shown in figure 3.10. The calibration chart is given in Appendix B. Calibration curve should be straight line. But in our case it is slightly curve. The reason behind that during calibration dynamic load is applied, due to which difficulty in taking reading of applied load and output of strain measurement system. Calibration curve is shown below. From this curve we can calculate force corresponding to display unit.



5) Billet Heating Arrangement

Generally low frequency induction furnace and the continuous gas furnace is used for billet heating .The induction furnace is most technically efficient unit for billet heating available, but a temperature difference is developed between the surface and interior of the billet. With induction heating, the billet can be subjected to higher energy input with very short heating times. Production requirements are the minimum radial temperature difference at the maximum rate of heating, although, even with induction heating, there is a definite temperature profile.

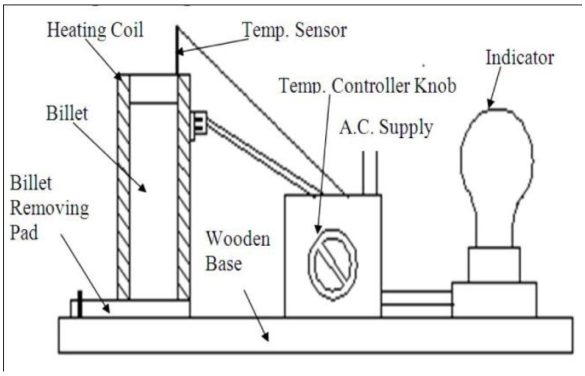


Figure 5 : Line diagram of Billet Heating Arrangement

III. EXPERIMENTATION - EQUIPMENT DESCRIPTION AND EXTRUSION PROCEDURES

Extrusion tests have been conducted on a 200 Ton Hydraulic digital compression testing machine. The extrusion set up is shown in the fig.4.1. For each extrusion test, the container walls, die, pressure pad, dummy block, ram and the specimen were first cleaned with sodium hydroxide solution to degrease the components. The container walls, die, pressure pad, dummy block, ram and the specimen are lubricated with mobil oil mixed with graphite powder (20%) for aluminium billet and lead alloy billet extrusion test. The die is carefully placed in the recess of the die holder, to ensure that the die is symmetrically placed with respect to the recess.

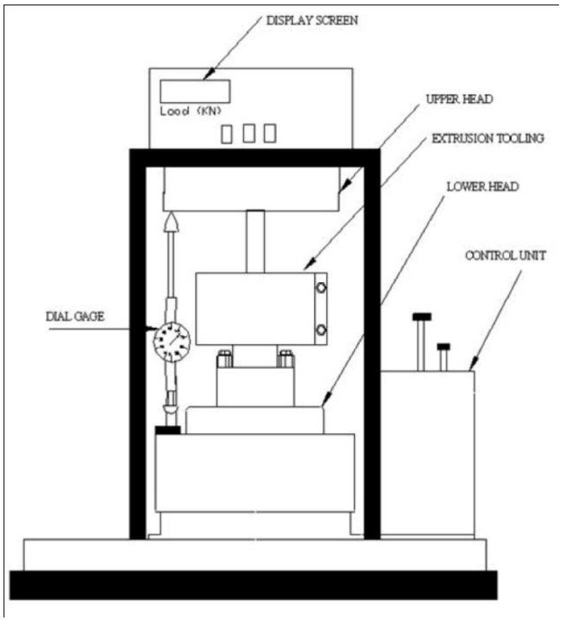


Figure 6 Line diagram of Experimental set up

Extrusion tests are conducted at an average ram speed, since speed is not constant. Extrusion tests have been continued at an average ram speed till the desired length of product is extruded. After this apparatus is removed from the compression testing machine, dismantled and the extruded product finally removed.

IV. RESULTS

For hot extrusion of commercial grade aluminium (2024), total extrusion power is compared with power obtained from HyperXtrude 3.0 solver.

Table 4.1: Extrusion pressure and power obtained from the experiment (lead alloy)

Die	Experimental Average Pressure (MPa)	Experimental Power (Watts)
Flat Die- L Shape	16.38	0.972
Flat Die- T Shape	16.58	1.049
Flat Die - H shape	33.19	2.117
Flat Die- Multi Hole	27.96	1.603
Conical Die- Elliptical Shape %r=40.97	20.63	0.704

Table 4.2: Comparisons between power obtained from the experiment and theoretical power obtained using upper bound analysis (Kumar. et. al [16]) (lead alloy)

Die	Experimental Power (Watts)	Theoretical Power (Watts)
Flat Die- L Shape	0.972	1.049
Flat Die - T Shape	1.049	1.183
Flat Die - H shape	2.117	2.188
Conical Die - Elliptical Shape (%r=40.97)	0.704	0.740

Followings are some of the curves plotted for various results obtained:

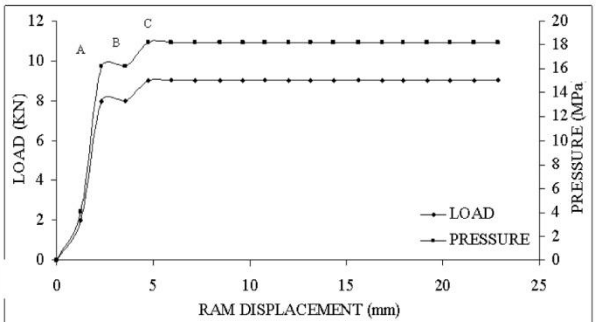


FIGURE : LOAD AND PRESSURE Vs RAM DISPLACEMENT CURVE
(Lead Alloy ,Flat Die - L Shape, %r = 54.88, Vo = 0.120 mm/s)

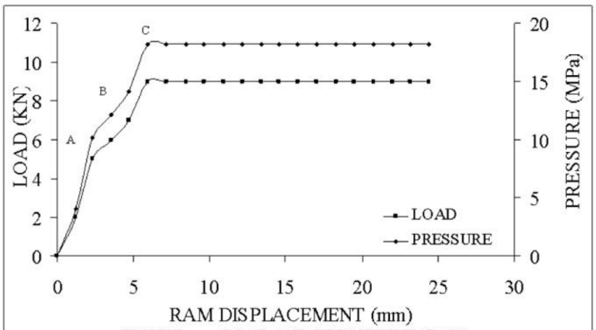


FIGURE : LOAD AND PRESSURE Vs RAM DISPLACEMENT CURVE
(Lead Alloy, Flat Die -T Shape, %r = 51, Vo = 0.128 mm/s)

V. CONCLUSIONS

On the basis of the experimentation, on designed and fabricated dies, instrumentation of extrusion set up and on the fabricated billet heating arrangement following conclusions are derived:

- The designed and fabricated dies give satisfactory result.
- The designed and fabricated load cell is used for measurement of applied force.
- Billet heating arrangement along with the temperature controller is used for billet heating in the range of 25 0C to 500 0C. The heated billet shows good result on extrusion run.
- The products have been found better surface finish without any defect such as surface crack, central
- burst etc.
- It is observed that as the complexity of section increases extrusion power also increases.

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