Metal Forming Laboratory
Experiment No. 03: Extrusion

- ## Aim of the Experiment:

  - To extrude a cylindrical cup by backward extrusion.
  - To determine the load variation with the thickness of the bottom of the cup.

- ## Equipment & Specimen Required:

  - Extruding punch and dies
  - Compression testing machine
  - LVDT
  - Load cell
  - Vernier caliper
  - Lead specimen

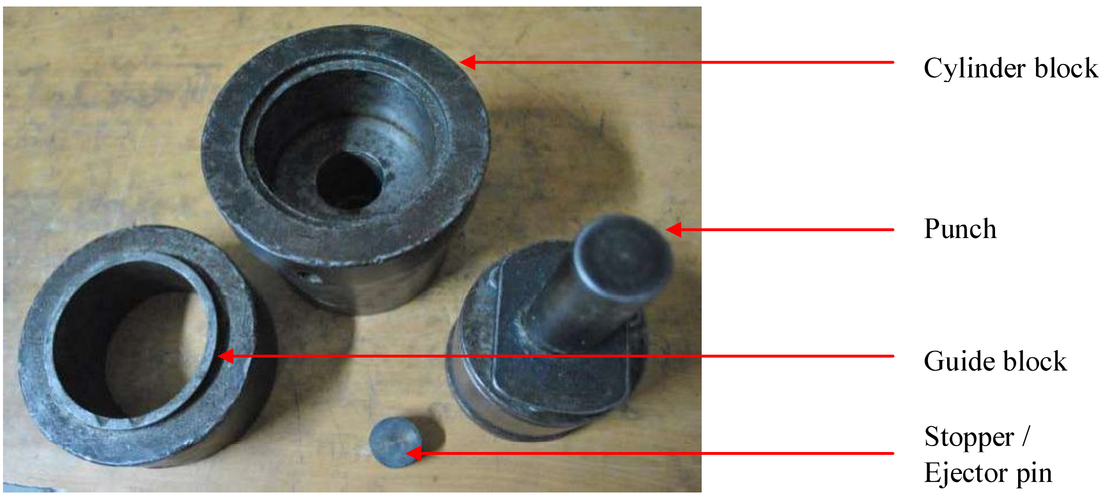


Fig. 1 Extruding punch and dies

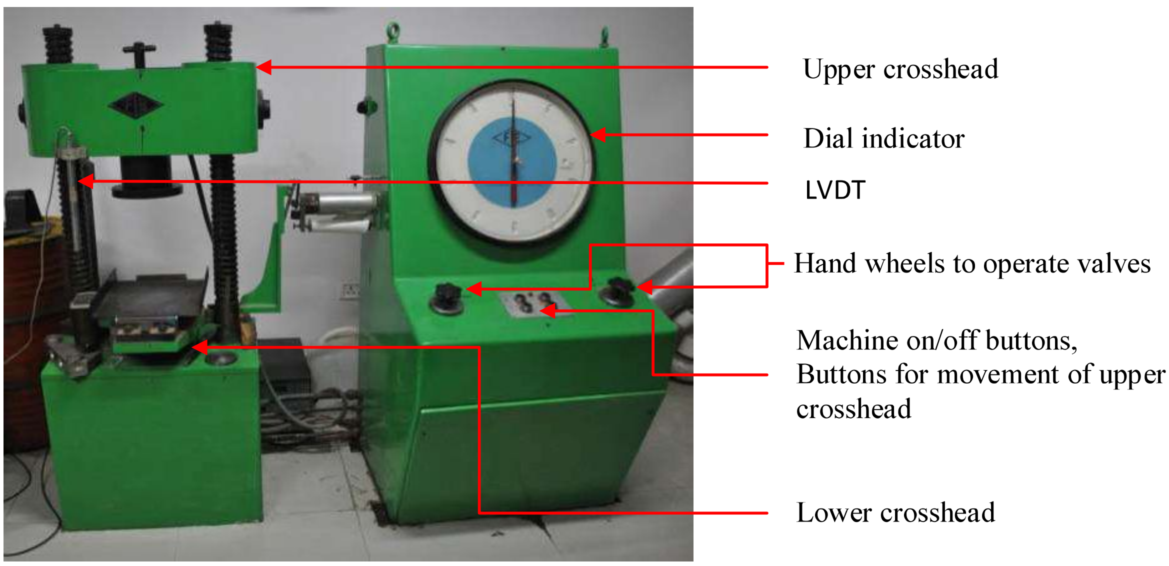


Fig. 2 Compression testing machine

- **Theory:**

Extrusion is a plastic deformation process in which a block of metal (billet) is forced to flow by compressing through the die opening of a smaller cross-sectional area than that of the original billet. The different types of extrusion processes are:

In **direct** or **forward extrusion,** metal flows in the same direction as that of the ram. Because of the relative motion between the heated billet and the chamber walls, friction is severe and is reduced by using lubricant. (See Fig. 3)

In **indirect** or **backward extrusion,** metal flows in the opposite direction as that of the ram. It is more efficient since it reduces friction losses considerably. The process, however, is not used extensively because it restricts the length of the extruded component. (See Fig. 4)

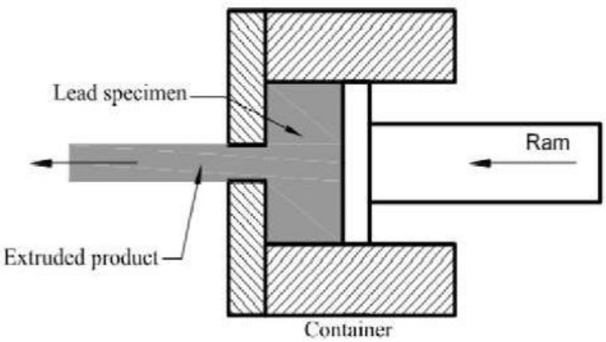


Fig. 3 Direct extrusion

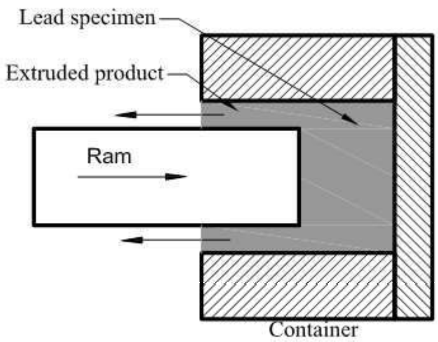


Fig. 4 Indirect extrusion

Extrusion may be hot extrusion or cold extrusion depending on the recrystallization temperature of the material to be extruded. If the extrusion is carried out above the recrystallization temp of the material, it is called **hot extrusion;** and if it is carried out below the recrystallization temperature of the material, it is called **cold extrusion**.

The force required for extrusion can be calculated approximately by equating specific internal strain energy to the external work per unit volume of the material extruded under the assumption of no losses. For details see Appendix I.

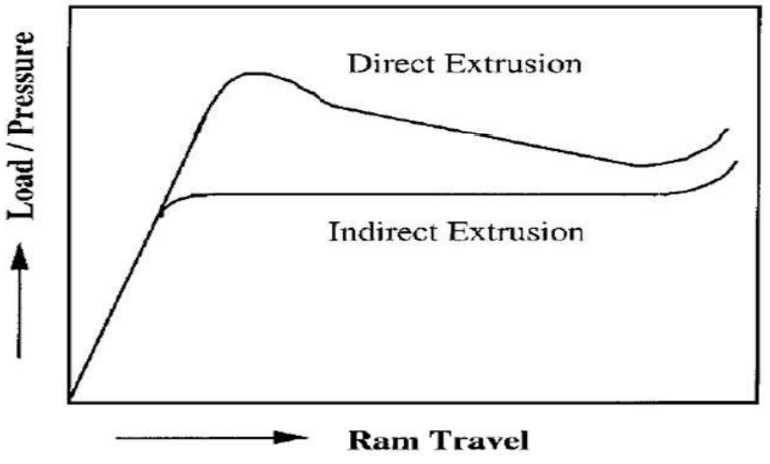


Fig. 5 Variation of force with ram displacement
(Source: www.wikipedia.org)

- ## Compression Testing Machine:

The Extrusion operation is carried out on Compression testing machine. The machine is divided into two sub assemblies. One assembly consists of hydraulic oil container, few valves to operate the machine, a motor which sucks oil from oil container & deliver it with high pressure to high pressure oil chamber (at another assembly) & circular scale which gives load readings. Another assembly consist of upper & lower crosshead, high pressure oil chamber, oil pipe lines & base. The upper crosshead can be moved by electric motor, just operating valves (at first assembly); whereas the lower crosshead is moved by high pressurised oil. With this assembly there is an attachment to attach LVDT as shown in the Fig. 2.

The circular scale which gives load readings has two pointers, one is black coloured & another is red coloured. Red coloured pointer is just over the black coloured pointer & contains a retainer at its end & in front of black coloured pointer. So when the high pressure oil is allowed to flow into the second sub assembly the black coloured pointer is moved & it also moves the red coloured pointer till the load is increasing. When load starts decreasing black coloured pointer comes back but red coloured pointer remains at its final position. This facilitates in reading the maximum load value.

- ## Linear Variable Differential Transformer (LVDT):

The linear variable differential transformer (LVDT) is a type of electrical transformer used for measuring linear displacement. LVDT consists of a cylindrical former where it is surrounded by one primary winding in the centre of the former and the two secondary windings at the sides. The numbers of turns in both the secondary winding are equal, but they are opposite to each other, i.e., if the left secondary winding is in the clockwise direction, the right secondary windings will be in the anti-clockwise direction, hence the net output voltages will be the difference in voltages between the two secondary coil. An alternating current drives the primary and causes a voltage to be induced in each secondary proportional to the length of the core linking to the secondary. The frequency is usually in the range 1 to 10 kHz.

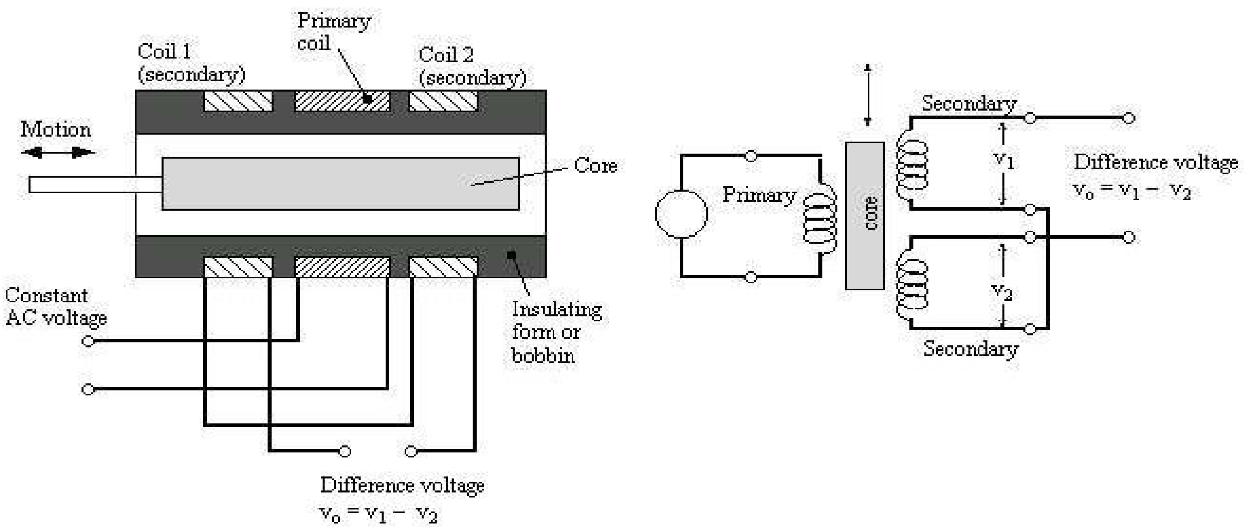


Fig. 6 Principle of LVDT
(Source: www.instrumentationandcontrollers.blogspot.in)

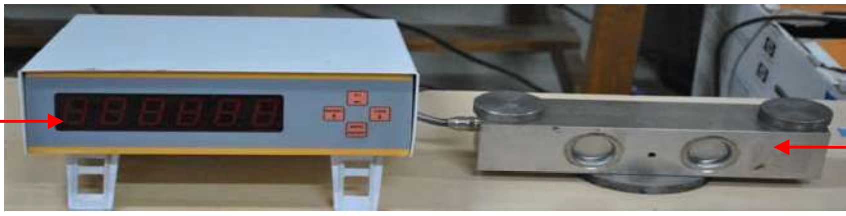
When the core is in its central position i.e. equidistant from the two secondary coils, equal voltages are induced in the two secondary windings and the output voltage is zero. As the core moves, the primary's linkage to the two secondary windings changes and causes the induced voltages to change. The phase of the output voltage determines the direction of the displacement (up or down) and amplitude indicates the amount of displacement.

- **Load Cell:**

A load cell is a transducer that is used to convert a force into electrical signal. There are many types of load cells available like strain gauge load cell, hydraulic load cell, piezoelectric load cell, capacitive load cell etc. Strain gauge load cells are the most common.

A strain gauge load cell usually consists of four strain gauges in a Wheatstone bridge configuration. Through a mechanical arrangement, the force being sensed deforms strain gauge and strain gauge measures the deformation (strain) as an electrical signal, because the strain changes the effective electrical resistance of the wire. The electrical signal output is typically in the order of a few millivolts and requires amplification by an instrumentation amplifier before it can be used. The output of the transducer is plugged into an algorithm to calculate the force applied to the transducer.

Display



Load cell

Fig. 7 Load cell

- **Experimental Procedure:**

1. Measure the height and diameter of the specimen.
2. Give some lubricant coating (if available) over the punch wall and inside wall of die block for easy removal of the component after extrusion.
3. Place the specimen in the die block and put the punch over it.
4. Place the die punch set up in between the two jaws of the compression testing machine. Care must be taken to place the set up coaxial with the machine central axis.
5. Reset the load cell and LVDT readings to zero.
6. Now give the load by the rotating the right hand wheel gradually and take the load readings up to 15 mm of punch displacement at an interval of 0.2 mm.
7. When the punch displacement reaches 15 mm, stop the machine, rotate the left hand wheel to release the load and take the total set up out of the machine to remove the extruded cup.

- **Observations:**

Table 1

Sl. No.	Punch displacement (mm)	Load (kg)

- **Results & Discussions:**

  - Graph to be plotted between the thicknesses of the bottom of the cup and load values.
  - Discussions to be made on the observed defects (if any) on the extruded cup.

  Some of the possible defects are:

  - Non uniform thickness of the cup.
  - Non uniform height of the cup.
  - Scratches on the surfaces of the extruded cup.
  - Cracks on the surfaces.

- **Conclusions:**

  Comment on:

    - Trends of the graph plotted.
    - Quality of the extruded cup.

- **Questions:**

  1. What material properties control extrusion?
  2. Differentiate between hot working and cold working?

- **References:**

  1. Metal Forming Handbook, Schuler, L. 671.02, SCH/M.
  2. Theory of Plastic Deformation and Metal Working, Masterov, V. And Berkovsky, V.
  3. Mechanical Metallurgy, Dieter, George E. 669, DIE/M.

- **Appendix I**

The force required for extrusion can be calculated approximately by equating specific internal strain energy to the external work per unit volume of the material extruded under the assumption of no losses

$$L \times p_{av} = V_m \times \int_0^{\bar{\varepsilon}} \sigma . d\varepsilon$$

where the integral represents the area under true stress-strain curve of the material. Now

$$\sigma = k\varepsilon^n$$

Hence,

$$\frac{L \times p_{av}}{V_m} = \int_0^{\bar{\varepsilon}} \sigma . d\varepsilon = \int_0^{\bar{\varepsilon}} K\varepsilon^n d\varepsilon = \frac{k\bar{\varepsilon}^{n+1}}{n+1} = \frac{\bar{\sigma} . \bar{\varepsilon}}{n+1}$$

Effective strain $\bar{\varepsilon}$ is calculated as

$$\bar{\varepsilon} = ln\left(\frac{l_2}{l_1}\right) = ln\left(\frac{D_d^2}{D_d^2 - D_p^2}\right) = ln\left(\frac{A_0}{A_1}\right)$$

Where
$k =$ Strength coefficient, n = strain harden ability coefficient, $\sigma =$ true stress, $\varepsilon =$ natural strain, p_{av} = average load on punch, V_m = material volume, D_d = die diameter, D_p = punch diameter.

The value of p_{av} thus, obtained underestimates the pressure because shearing work and friction has been neglected in this expression. The error may be of the order of 40 to 50 %. The extrusion pressure changes considerably when, the bottom of the cup becomes thin. The extent of redundant work can be studied by the split specimens where a uniform gridline is scribed before the extrusion operation is carried out.