Department of Mechanical Engineering, IIT Bombay

ME 374 Manufacturing Processes Lab

Metal Forming
LaboratoryIn-charge: Prof.
P.P. Date

Compression test on Universal Testing Machine

Aim- To determine flow stress(σ), strength coefficient(k) and strain hardening exponent(n) in compression test.

Equipment- UTM, cylindrical samples on Al, Vernier caliper.

Theory-

FLOW-STRESS DETERMINATION

The forming stress, or pressure, in a particular metalworking process invariably consist of three terms:

$$p = \bar{\sigma}_0 g(f) h(c)$$

where $\bar{\sigma}_0$ = the flow resistance of the material for the appropriate stress state, i.e., uniaxial, plane strain, etc. It is a function of strain, temperature, and strain rate.

$g(f)$ = an expression for the friction at the tool-workpiece interface.

$h(c)$ = a function of the geometry of the tooling and the geometry of the deformation. This term may or may not include a contribution from redundant deformation.

It is obvious from the above relationship that if we are to make accurate predictions of forming loads and stresses, we need accurate values of flow resistance (flow stress). The experimental problems in measuring the flow curve under metalworking conditions are more severe than in the usual stress-strain test determined for structural or mechanical design applications. Since metalworking processes involve large plastic strains, it is desirable to measure the flow curve out

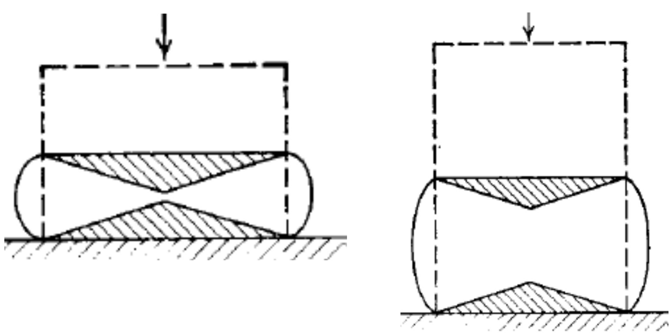
to a true strain of 2.0 to 4.0. In addition, many of these processes involve high strain rates ($\dot{\varepsilon} \approx 100\ s^{-1}$), which may not be obtained easily with ordinary test facilities. Further, many metalworking processes are carried out at elevated temperatures where the flow stress is strongly strain-rate sensitive but nearly independent of strain. Thus, tests for determining flow stress must be carried out under controlled conditions of temperature and constant true-strain rate.[1]

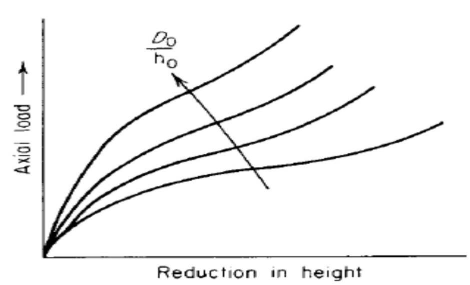
The true-stress–true-strain curve determined from the *tension test* is of limited usefulness because necking limits uniform deformation to true strains less than 0.5 (see Sec. 8-3). This is particularly severe in hot-working, where the low rate of strain hardening allows necking to occur at $\varepsilon \approx 0.1$. The formation of a necked region in the tension specimen introduces a complex stress state and locally raises the strain rate.

The *compression* of a short cylinder between anvils is a much better test for measuring the flow stress in metalworking applications. There is no problem with necking and the test can be carried out to strains in excess of 2.0 if the material is ductile. However, the friction between the specimen and anvils can lead to difficulties unless it is controlled. In the *homogeneous upset test* a cylinder of diameter D_0 and initial height h_0 would be compressed in height to h and spread out in diameter to D according to the law of constancy of volume:

$$D_0^2 h_0 = D^2 h$$

During deformation, as the metal spreads over the compression anvils to increase its diameter, frictional forces will oppose the outward flow of metal. This frictional resistance occurs in that part of the specimen in contact with the anvils, while the metal at specimen midheight can flow outward undisturbed. This leads to a *barreled* specimen profile, and internally a region of undeformed metal is created near the anvil surfaces (Fig. 1). As these cone-shaped zones approach and overlap, they cause an increase in force for a given increment of deformation and the load-deformation curve bends upward (Fig. 2). For a fixed diameter,





a shorter specimen will require a greater axial force to produce the same percentage reduction in height because of the relatively larger undeformed region (Fig. 15-11). Thus, one way to minimize the barreling and nonuniform deformation is to use a low value of D_0/h_0. However, there is a practical limit of $D_0/h_0 \approx 0.5$, for below this value the specimen buckles instead of barreling. The true flow stress in compression without friction can be obtained[1] by plotting load versus D_0/h_0 for several values of reduction and extrapolating each curve to $D_0/h_0 = 0$.

Compression test carried out on a hydraulic press is basically an example of open die Cold forging (Upsetting) where downward motion of the ram squeezes the work piece. The chief mode of deformation here is compression accompanied by considerable spreading / Barreling in the lateral directions.

The compression test of a short cylinder between anvils is a better option of measuring the flow stress in metal working applications as there is no problem of necking and test can be carried out to strains in excess of 2 if the material is ductile. However, the friction between the specimen and anvils can lead to difficulties unless it is controlled. In this experiment, a cylinder of diameter D_0 and height h_0 would be compressed in height to h and spread out in dia. to D. According to law of volume constancy in metal forming, $D_0^2 h_0 = D^2 h$

During deformation, as the metal spreads over the compression anvils to increase its diameter, frictional forces will oppose the outward flow of metal. This resistance occurs in that part of the specimen in contact with anvils, where the metal at the specimen mid-height can flow outward undisturbed. This leads to a barreled specimen profile and internally a region of undeformed metal is created near the anvil surfaces.

Procedure:

1. Measure the dimensions of test piece is measured at 3 different places along its height/length to determine the average c/s area.

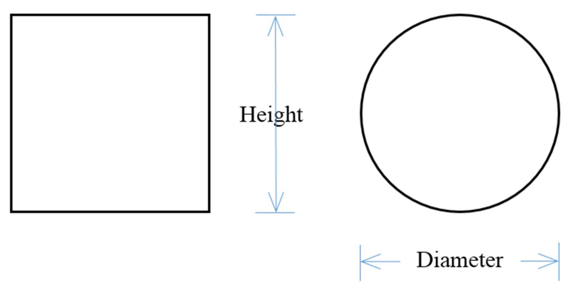


Fig. 2: Specimen for compression test

2. Ends of the specimen should be plane. For that the ends are faced & deburred (chamfered).
3. The specimen is placed centrally between the two compression plates, such that the load axis of the machine aligns with the axis of the cylinder to the extent possible.
4. Load is applied on the specimen by moving the movable head.
5. The load and the corresponding cross head travel are measured at different intervals.
6. Load is applied until the specimen deforms to 60% of initial height.

<u>Contents of Lab Report:</u>

<u>BATCH NO:DATE:</u>

NAME:

ROLL NO.:

AIM:

APPARATUS/EQUIPMENT USED:

THEORY: Write the theory related to test details with working formulas

EXPERIMENTAL PROCEDURE:

OBSERVATIONS:

Sample details: Specimen dimensions, Material and prior processing condition

Initial specimen dimensions:

a) Height, H_0 b) Diameter, D_0(mm)

Table 1: Load reduction output

Load, P (N)	Reduction, y(mm)

Final specimen dimensions:

a) Height, h_f b) Diameter, D_f (mm)

CALCULATION TABLES:

Useful formulae : Height $h=H_0-y$,

Diameter $d = D_0 \times \sqrt{\frac{H_0}{h}}$,

Strain $\varepsilon = ln(h/H_0)$,

Stress σ =P/A,

*σ = Y(1+ μ/3*d/h), where Y is the flow stress in the absence of friction, i.e., as in uniaxial tension.*

Usable formulae: strain $\epsilon = \ln\left(\frac{H_0-y}{H_0}\right)$ and Stress σ =P/A,

*σ = Y(1+ μ/3*d/h), where Y is the flow stress in the absence of friction, i.e., as in uniaxial tension.*

Analytical Method

In this method we need to find the value of K and n of power law. And also find the value of μ.
Using $Y=K\varepsilon^n$ and $\sigma=Y(1+(\mu/3)*(d/h))$

We divide the curve between true stress (σ) and true strain (ε) into several sets of 3 points each, which are sufficiently close to each other and μ can be assumed to be constant.

For first set of points, $\sigma_1=K\varepsilon_1(1+(\mu/3)*(d_1/h_1))$, $\sigma_2=K\varepsilon_2{}^n(1+(\mu/3)(d_2/h2))$ and $\sigma_3=K\varepsilon_3{}^n(1+(\mu/3)(d_3/h_3))$

We have three equations as above, and three unknowns namely K,n, μ. These equations can be solved for the several sets of values and the variation of K, n, μ can be found out over different values of stress-strains.

Table 2:

Force, *P* (kN)	Position, *y* (mm)	Height, *h* (mm)	*D*	*D/h*	A	True strain, ε	True stress, σ_o *at* $D_o/h_o = 0$ (Mpa)	ln(ε)	ln(σ_o)	*n*	σ_{avg}	μ

Table 3:

μ_{max1}		μ_{max2}		μ_{max3}		μ_{max4}		μ_{max5}		μ_{max6}		μ_{max7}		μ_{max8}	
ε	σ	ε	σ	ε	σ	ε	σ	ε	σ	ε	σ	ε	σ	ε	σ

Graphs To be Plotted -

1. Load (T) Vs Ram travel (R) (7 Curves for 7 samples in 1 Graph)
2. True Stress (σ) vs. True Strain (Є) - (7 Curves for 7 samples in 1 Graph to get 10-12 readings of strain values and corresponding 7 sample's values of σ)
3. True stress (σ) Vs D_0/h_0 for a given value of Є, thus giving 10-12 iso-strain curves (To be extrapolated by drawing tangents to them upto Y axis for $D_0/h_0 = 0$, to get σ_0 for the given value of Є)
4. $(\sigma_0)_i$ Vs $Є_i$
5. Log. Plot : ln $(\sigma_0)_i$ vs. ln $Є_i$ (To Find k and n)
6. μ vs. h (5 Curves for 5 samples in 1 Graph)

Conclusions-