Lecture -2 (TMF)
Strain rate, degree of deformation, FLD etc.

by
Prof. Santosh Kumar
Department of Mechanical Engineering
Institute of Technology, B.H.U. Varanasi 221005
e-mail: santosh.kumar.mec@itbhu.ac.in
Effect of Strain Rate

\[ \bar{Y}_f = C \dot{\varepsilon}^m \]

\( \dot{\varepsilon} \) strain rate

The strain rate is strongly affected by the temperature.

\[ Y_f = A \varepsilon^n \dot{\varepsilon}^m \]

\( A \) = a strength coefficient
If a deformation is carried out in the time $t$, this results in an average strain rate of:

$$w_m = \frac{\varphi}{t}$$

where:
- $w_m$ in $\%$/s, mean strain rate
- $\varphi$ in $\%$, degree of deformation
- $t$ in s, deformation time

It may, however, also be determined by the ram / slide velocity and the initial height of the workpiece.

$$\dot{\varphi} = \frac{v}{h_0}$$

where:
- $\varphi$ in $s^{-1}$, strain rate
- $v$ in $m/s$, velocity of the ram / slide
- $h_0$ in s, height of the blank.
Flow stress curve - cold forming

$k_{str} = f(\varphi_p)$  \( a = f(\varphi_p) \) in \( \text{Nmm/mm}^3 \)

specific strain energy

Material: Ck15  soft annealed

\( a \) \hspace{2cm} \( k_{str} \)

\[
\begin{array}{c|c|c}
\text{[Nmm]} & \text{[mm}^3] & \text{[N]} & \text{[mm}^2] \\
\hline
1000 & 1000 & 800 & 800 \\
600 & 600 & 400 & 400 \\
200 & 200 & 0 & 0 \\
\end{array}
\]

\( \varphi_p \) [\%]
Deformability

This means the ability of a material to be deformed. It depends upon:

**Chemical composition**

In steels, for example, the cold deformability depends on the C content, the components of the alloy (Ni, Cr, Va, Mo, Mn) and the phosphor content. The higher the C content, the P content and the alloy components, the lower is the deformability.

**Crystalline structure**

Here, the grain size and above all the pearlitic structure are important. Steels should be as fine-grained as possible, since in steels with small to medium grain size, the crystallites are easier to displace on the crystallite slip planes.

**Heat treatment**

An equally-distributed structure is achieved by normalizing (above Ac3) and fast cooling. The resulting hardness is cancelled out by subsequent soft annealing (around Ac1). Note: only soft annealed material can be cold formed.
In some cases, analysis is based not on the instantaneous flow stress, but on an average value over the strain-stress curve from the beginning of strain to the final (maximum) value that occurs during deformation:

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

Stress-strain curve indicating location of average stress \( \bar{Y}_f \) in relation to yield strength \( Y \) and final stress \( Y_f \).

The mean flow stress is defined as

\[ \bar{Y}_f = \frac{K \varepsilon_f^n}{1+n} \]

Here \( \varepsilon_f \) is the maximum strain value during deformation.
Degree of deformation and principal strain

Bulk forming process

The measure of the extent of a deformation is the degree of deformation. The calculation is generally made from the relation between an indefinitely small measurement difference, \(dx\), and an existing measurement \(x\). By integrating it into the limits \(x_0\) to \(x_1\) this produces

\[
\varphi_x = \int_{x_0}^{x_1} \frac{dx}{x} = \ln \frac{x_1}{x_0}.
\]

when it is presumed that the volume of the body to be deformed remains constant during forming.

\[
V = l_0 \cdot w_0 \cdot h_0 = l_1 \cdot w_1 \cdot h_1.
\]
According to which value changes the most during forming, a difference is made between

Cuboid before forming with the measurements \( h_0, w_0, l_0 \) and after forming with the measurements \( h_1, w_1, l_1 \)
Degree of upsetting \[ \varphi_1 = \ln \frac{h_1}{h_0} \]

Degree of lateral flow \[ \varphi_2 = \ln \frac{W_1}{W_0} \]

Degree of elongation. \[ \varphi_3 = \ln \frac{l_1}{l_0} \]

If the change of cross section or the change of wall thickness are dominant values, \( \varphi \) can also be determined from these values:

in the case of a change in wall thickness \[ \varphi = \ln \frac{s_1}{s_0} \]

in the case of a change of cross section \[ \varphi = \ln \frac{A_1}{A_0} \].
The sum of the three deformations in the three main directions (length, width, height) is equal to 0. What is lost in the height is gained in width and length.

\[ \varphi_1 + \varphi_2 + \varphi_3 = 0 \]

This means one of these three deformations is equal to the negative sum of the two others.

For example, \( \varphi_1 = -(\varphi_2 + \varphi_3) \).

This, the greatest deformation, is known as the principal strain, \( \varphi_p \).

It characterises the manufacturing process and enters into the calculation of force and work.

It is how the extent of a deformation is measured.

The degree of deformation that a material can withstand, i.e. how great its deformability is, can be taken from tables of standard values showing permissible deformation \( \varphi_{p\text{perm}} \).

The workpiece can only be produced in a single pass if actual deformation during its production is equal to or less than \( \varphi_{p\text{perm}} \). Otherwise, several passes are required with intermediate annealing (soft annealing).
METALLURGY deals with material science that studies the physical and chemical behavior of metallic elements, their intermetallic compounds, and their mixtures, called alloys. The common engineering metals are:

Aluminum, chromium, copper, iron, magnesium, nickel, titanium and zinc. The most alloys are: iron-carbon alloy systems as Steels and cast Irons including Ductile iron, Stainless steel or Galvanized steel etc. Aluminum alloys and magnesium alloys are used for applications where strength and lightness are required. Copper-nickel alloys (such as Monel), Nickel-based super alloys like Inconel are used in high temperature applications such as turbochargers, pressure vessel, and heat exchangers. For extremely high temperatures.

In MANUFACTURING, Metallurgy is concerned with the production of metallic components for use in consumer or engineering products. This involves the production of alloys, the shaping, the heat treatment and the surface treatment of the product. The task of the metallurgist is to achieve balance between material properties such as cost, weight, strength, toughness, hardness, corrosion, fatigue resistance, and performance in temperature extremes.
Surface treatment

If the blanks (sections of wire or rods) were simply inserted into the molding die and then pressed, the die would be made useless after only a few units. Galling would occur in the die because of cold welding between the work piece and the die. As a result, burrs would form on the die which would make the pressed parts unusable. For this reason, the blanks must be carefully prepared before pressing. This preparation, which is summed up as “surface treatment”, includes pickling, phosphating, lubricating etc.
A FORMING LIMIT DIAGRAM OR CURVE, is basically used in sheet metal forming for predicting forming behavior of a sheet metal. The diagram attempts to provide a graphical description of material failure tests, such as a punched dome test.

In order to determine whether a given region has failed, a mechanical test is performed. The mechanical test is performed by placing a circular mark on the workpiece prior to deformation, and then measuring the post-deformation ellipse that is generated from the action on this circle. By repeating the mechanical test to generate a range of stress states, the formability limit diagram can be generated as a line at which failure is onset.
The course contents

**Part A:**
INTRODUCTION TO TECHNOLOGY OF METAL FORMING
(30 -Lectures)

**Part B:**
OTHER FORMING PROCESSES
(10 -Lectures)
Part A: INTRODUCTION TO TECHNOLOGY OF METAL FORMING


Effects of Temperature, strain rate, microstructure & friction in Metal working

Tribology in Metal Forming, Metal Working Lubricants, Metallurgical aspects of metal forming

Post forming heat treatment & defects in Metal working, Forming Limit Diagram
Forging

• Introduction and classification of forging, Forging Operations, Forging Processes, Miscellaneous Forging Operations

• Design of Forging Dies, Drop Forging Die Design, Upset Forging Die Design

• Forgeability, Forging Temperature, Forging Defects, Forging Equipment

• Strip Forging (Open-Die Plane Strain Forging), Upsetting Under Axial Symmetry

• Closed Die Forging with Overlapping Dies, Closed Die Press Forging with axial Symmetry and Overlapping dies, Forces in Impression Die Forging
• Rolling
  • Introduction and classification of rolling

• Strip Rolling and Entry Conditions, Work of Deformation and Roll Separating Force

• Limit of Rolling, Temperature Variation during Metal Rolling, Forces on the Rolls, Forces on the Rolls of Four High Mills, Simplified Analysis and Torque, calculations and Defects in Rolling

• Sheet Metal Forming Processes

• Sheet Metal Dies and defects in sheet metal forming
Wire Drawing and Extrusion Processes

Introduction and classification

Zero Friction Case, Wire Drawing with Friction, Wire Extruding with Friction, Hot Extrusion

Strip Drawing with Friction, Strip Extruding with Friction, Reduction in Strip Drawing, Tube Drawing with a Stationary Mandrel.

Tube Drawing with a Moving Mandrel, Drawing and Extruding Through Stationary Tools of Circular Profile, Practice in Drawing of metals, Hydrostatic Extrusion, Practice in Extrusion of metals, Defects in Drawing and Extrusion, Drawing and Extrusion Equipment and practices.
Part B: OTHER FORMING PROCESSES

- **Tube Sinking and Ironing**
  - Introduction and classification, Tube Sinking, Equilibrium Equations for Shells of Rotational Symmetry, Tube Sinking with a Conical Die, Tube Reducing with a Conical Die, Nosing with a Die of Circular Contour, Tube Ironing

- **Unconventional Forming Processes**

Miscellaneous Topics

- Introduction to: Visco-plasticity, Deformation Theory of Plasticity, Thermo-plasticity, Theory of Machining, Dynamic Plasticity, Micro forming processes
- Common materials/ alloys for forming by different processes, Super plasticity
List of Books and Reference Books:

1. Metal Forming: Application of Limit Analysis by B. Avitzur (Marcel Dekker Inc. NY 1980)
2. Plasticity Theory: by A. Mendelson (Macmillan Pub. 1968)
13. Technology of Metal forming Processes by Surender Kumar (PHI pub. ND 2008)
14. Metal forming Processes published by HMT Limited, Marketing division Bangalore
You can now test yourself and prepare to evaluate for the understanding of this Lecture by answering questions.

Thank you all for your patience

Please do not forget to give your valuable feedback/suggestion to improve