Manufacturing Technology

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What is manufacturing?

- To make or process a raw material into a finished product, especially by means of a large-scale industrial operation

Processes are.

- Primary process.
- Secondary process.

Primary vs. Secondary Manufacturing

Primary processes convert raw materials into standard stock

bauxite ore → aluminum

petroleum → polyester resin

Tree → Wood

Secondary processes convert standard stock into usable parts

aluminum rod → fuel valve

polyester resin → medical tubing

lumber → furniture

Products often made of many parts

- Iron & aluminum ingots
- Plastic resin pellets
- Uncured rubber
- Copper wire
- Nylon thread

CAR

Secondary Manufacturing Processes

- Casting and Molding
- Forming
- Machining / Material Removal
- Assembling / Joining
- Finishing

Secondary Processes

- **Forming** processes use a shaping device and pressure to cause a material to take on a new shape and size

- **Machining** processes remove material to produce a desired shape and surface

Manufacturing Work Flow

- Custom
- Batch
- Continuous

Custom manufacturing

- **Limited number of products built to customer specifications.**
- **Requires highly skilled labor**.

Batch manufacturing

- Parts made in lots of 10 – 1,000
- **General-purpose machinery** (table saw, vertical mill) is used, often run by hand
- Setup times *per part* decreases as batches get larg

“Continuous” manufacturing

- **Same product made repeatedly by dedicated machinery** (custom built machine – NOT CUSTOM built product)
- Automation becomes more cost-effective
- Some processes still require batch staging
- Tooling and setup are large initial

PRODUCTION TECHNOLOGY
Manufacturing Processes

Contents

1. Metal forming.
2. Metal Machining.

1. Overview of Metal Forming

Definition of Forming

Forming is a fabrication process for solid substances by controlled plastic deformation in order to obtain alterations of:

- the form,
- the material properties,
- the surface properties.

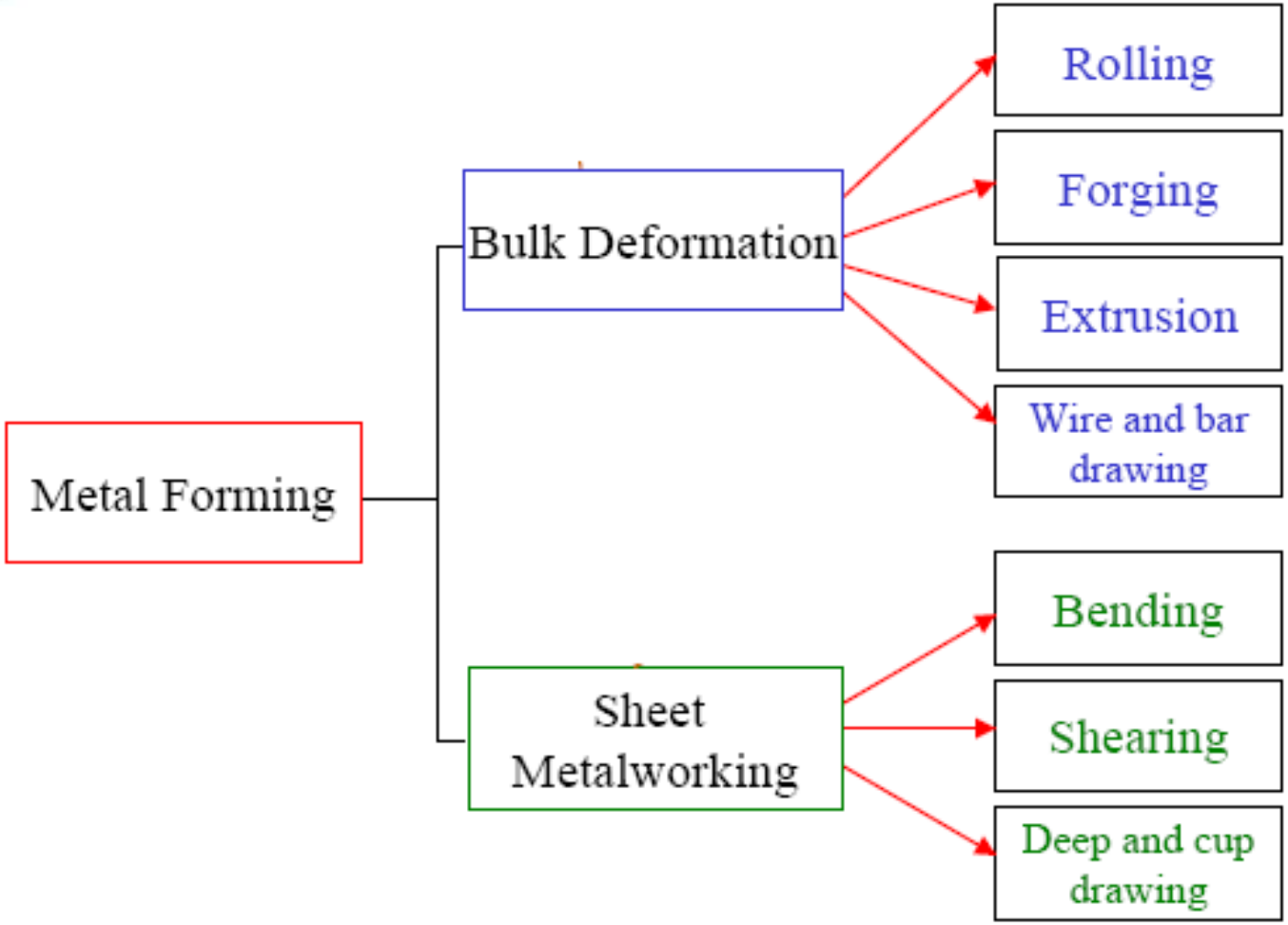
FUNDAMENTALS OF METAL FORMING

1. Overview of Metal Forming
2. Material Behavior in Metal Forming
3. Temperature in Metal Forming
4. Strain Rate Sensitivity
5. Friction and Lubrication in Metal Forming

Terms for Classifying Forming Processes

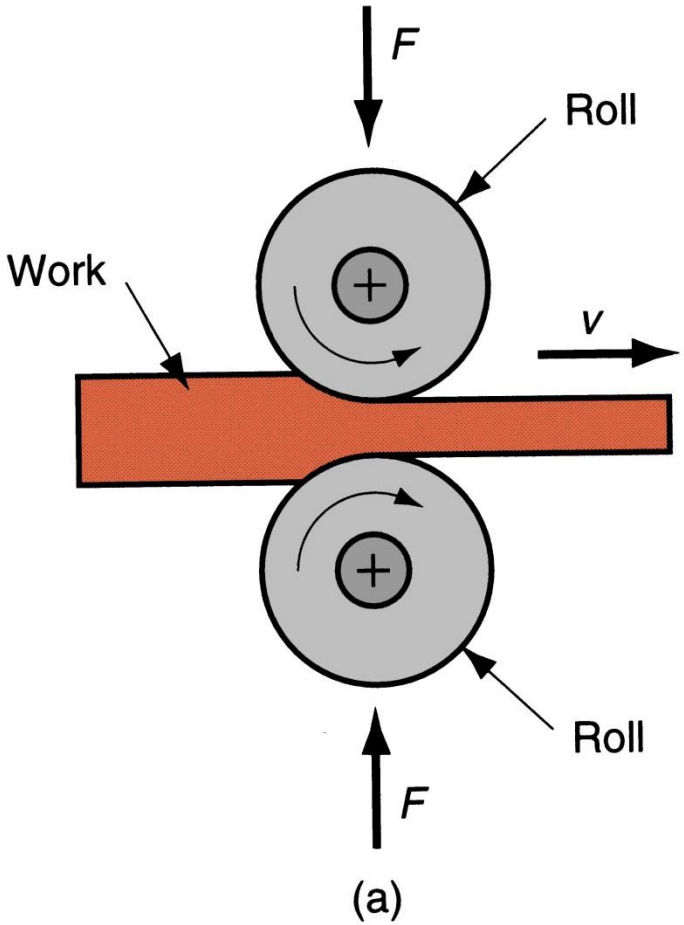
- Classification by Type of Raw Material
- Classification by State of Stress
- Classification by Forming Temperature
- Classification by Methods of Induction of Forces into the Work-Piece

Forming Processes

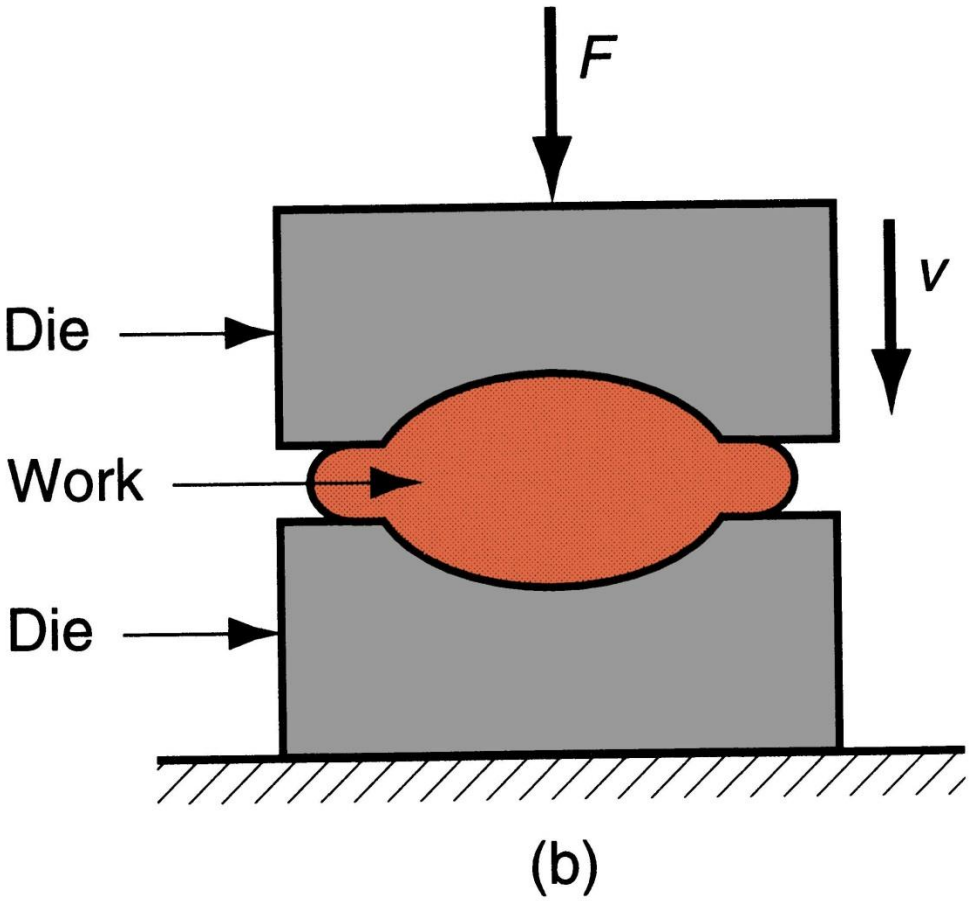


1-Bulk Deformation Processes

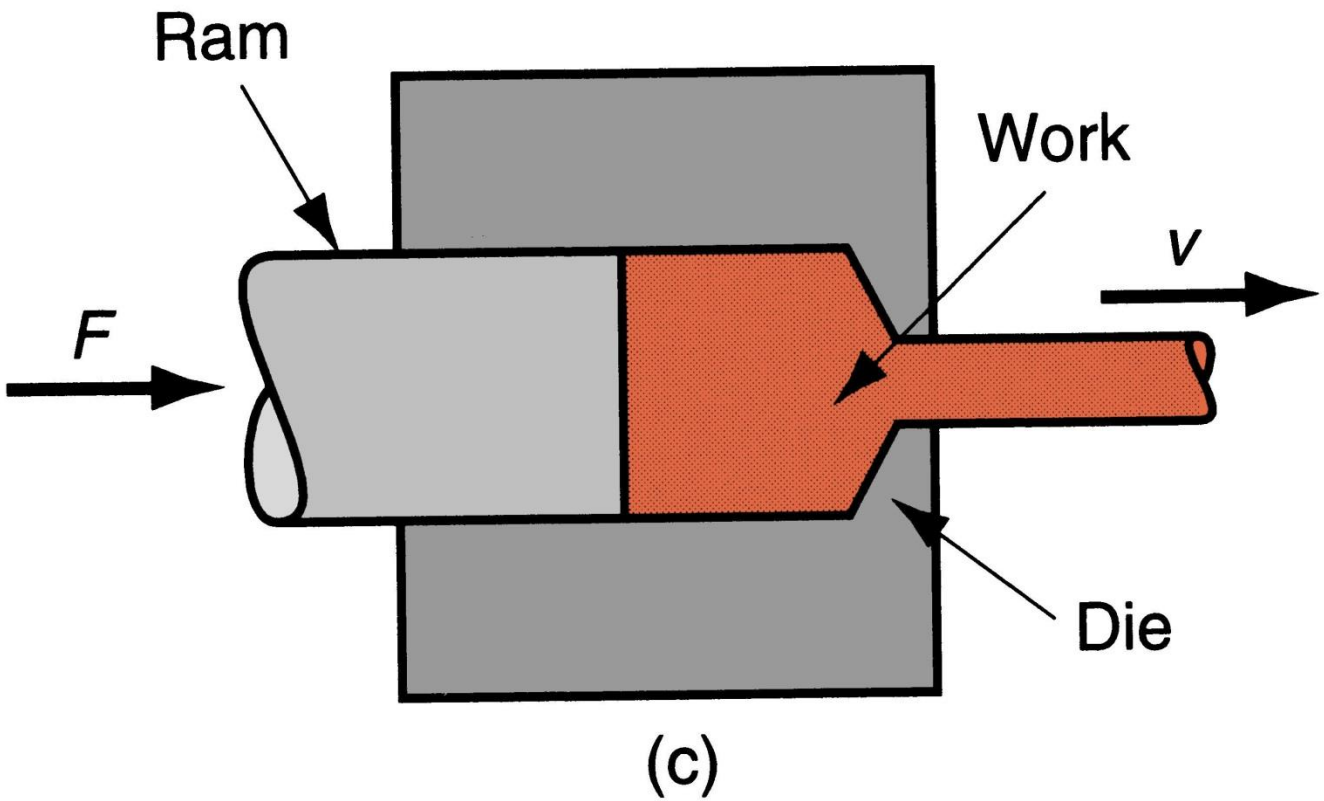
- Characterized by significant deformations and massive shape changes
- "Bulk" refers to workparts with relatively low surface area-to-volume ratios
- Starting work shapes include cylindrical billets and rectangular bars



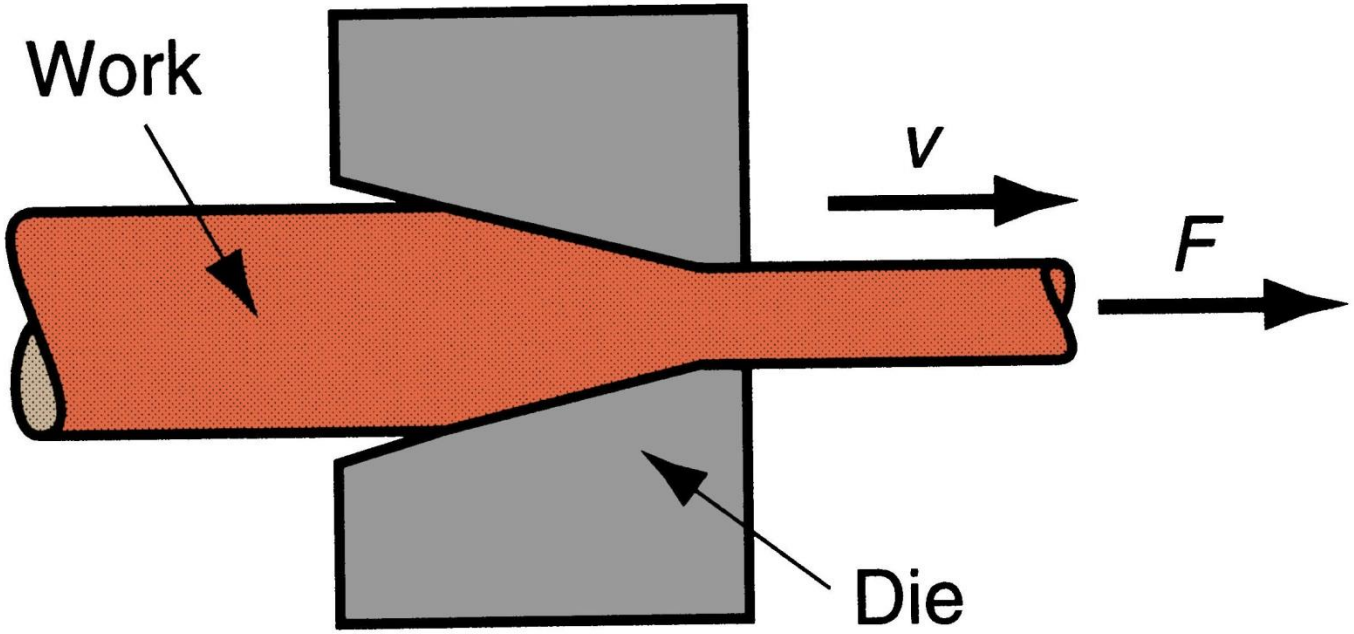
Basic bulk deformation processes: (a) rolling



Basic bulk deformation processes: (b) forging



Basic bulk deformation processes: (c) extrusion



(d)

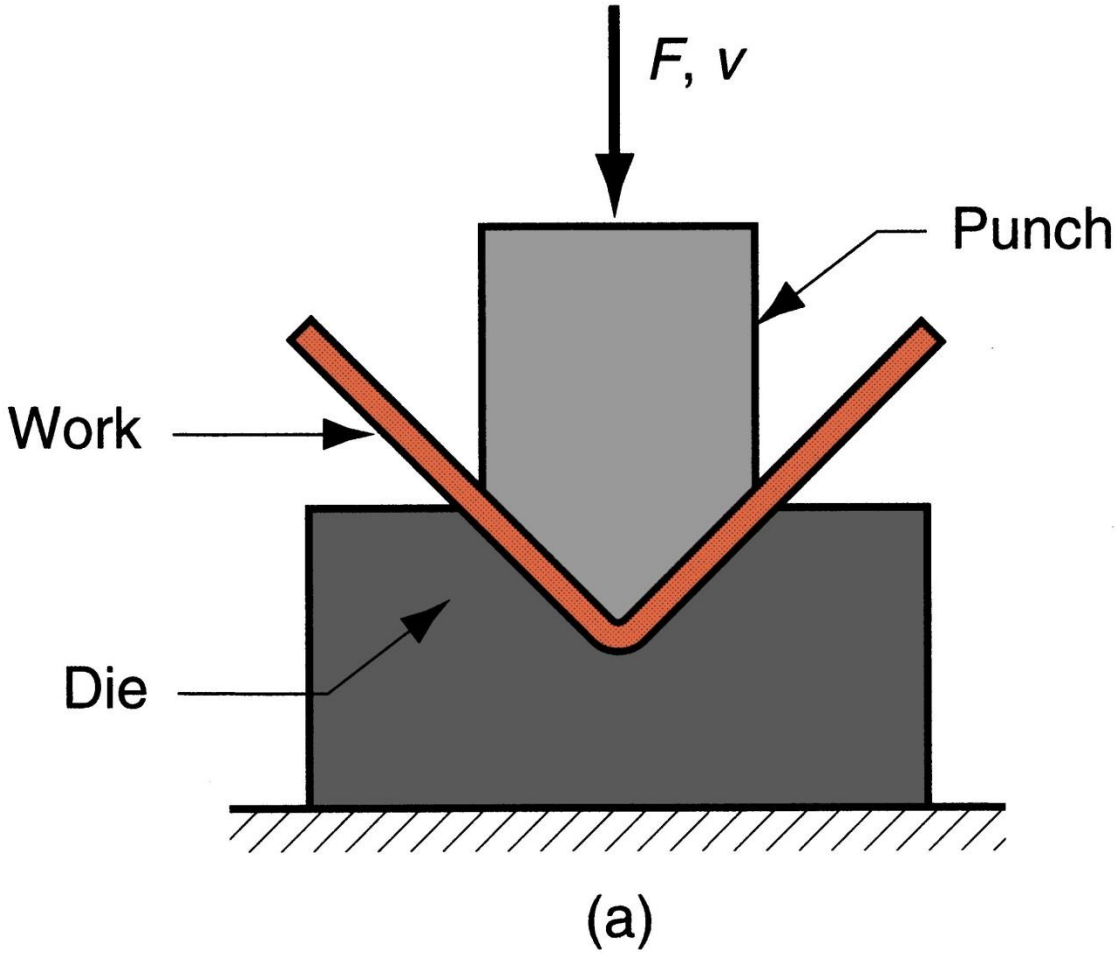
Basic bulk deformation processes: (d) drawing

Sheet Metalworking

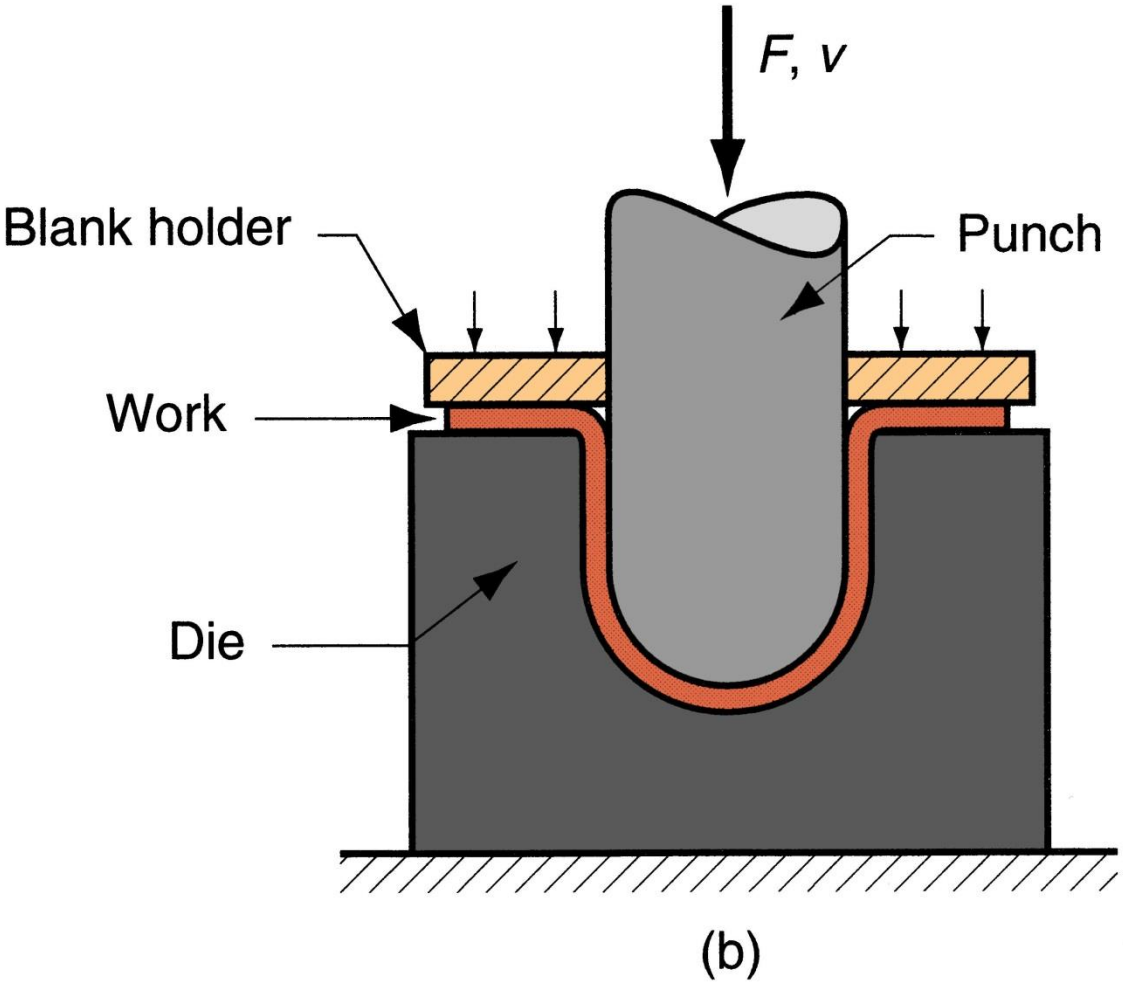
- Forming and related operations performed on metal sheets and strips
- High surface area-to-volume ratio of starting metal, which distinguishes these from bulk deformation
- Often called *press working* because presses perform these operations

  Parts are called *stampings*

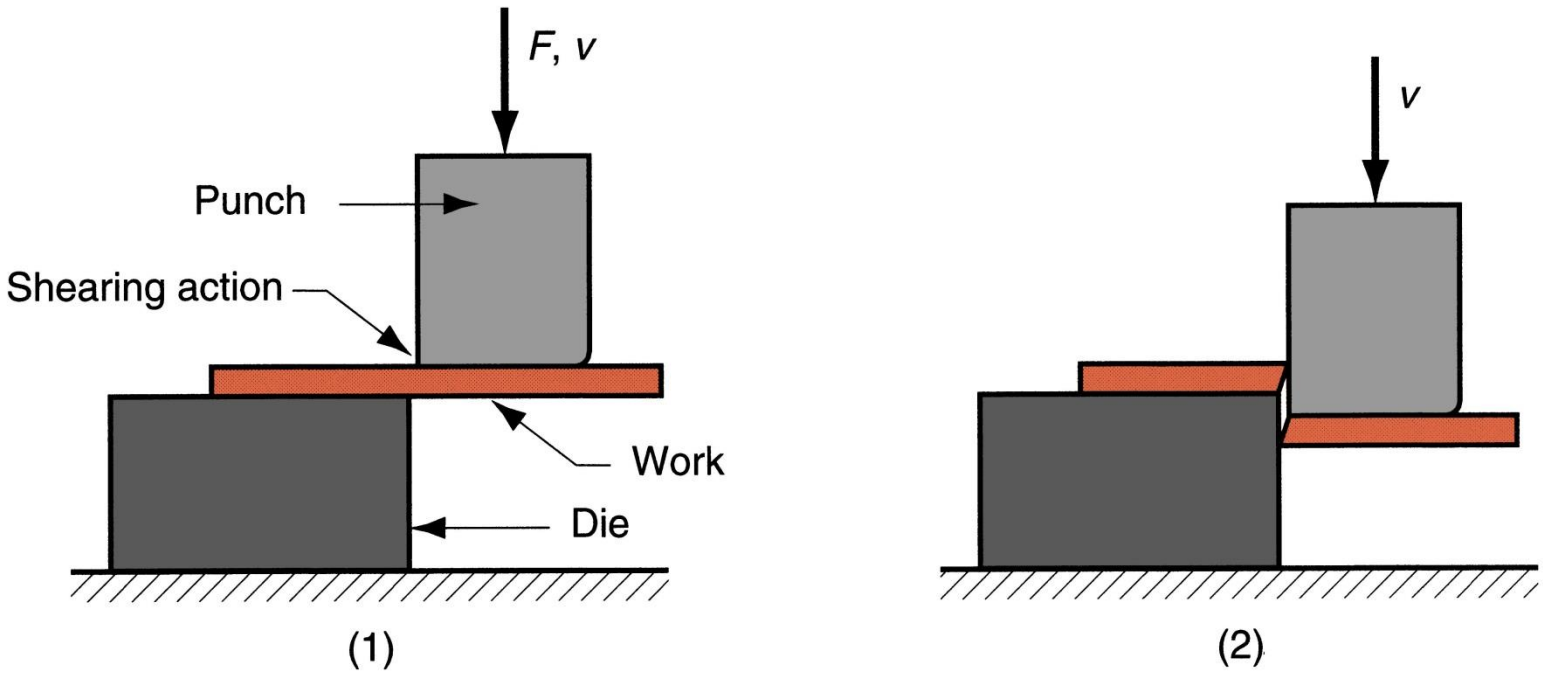
  Usual tooling: *punch* and *die*



Basic sheet metalworking operations: (a) bending



Basic sheet metalworking operations: (b) drawing



- Basic sheet metalworking operations: (c) shearing

Metal Forming

Large group of manufacturing processes in which plastic deformation is used to change the shape of metal workpieces

- The tool, usually called a *die*, applies stresses that exceed yield strength of metal
- The metal takes a shape determined by the geometry of the die

Stresses in Metal Forming

- Stresses to plastically deform the metal are usually *compressive*

  Examples: rolling, forging, extrusion
- However, some forming processes

  Stretch the metal (*tensile* stresses)

  Others bend the metal (*tensile* and *compressive*)

  Still others apply *shear* stresses

Material Properties in Metal Forming

- Desirable material properties:

  Low *yield strength* and high *ductility*

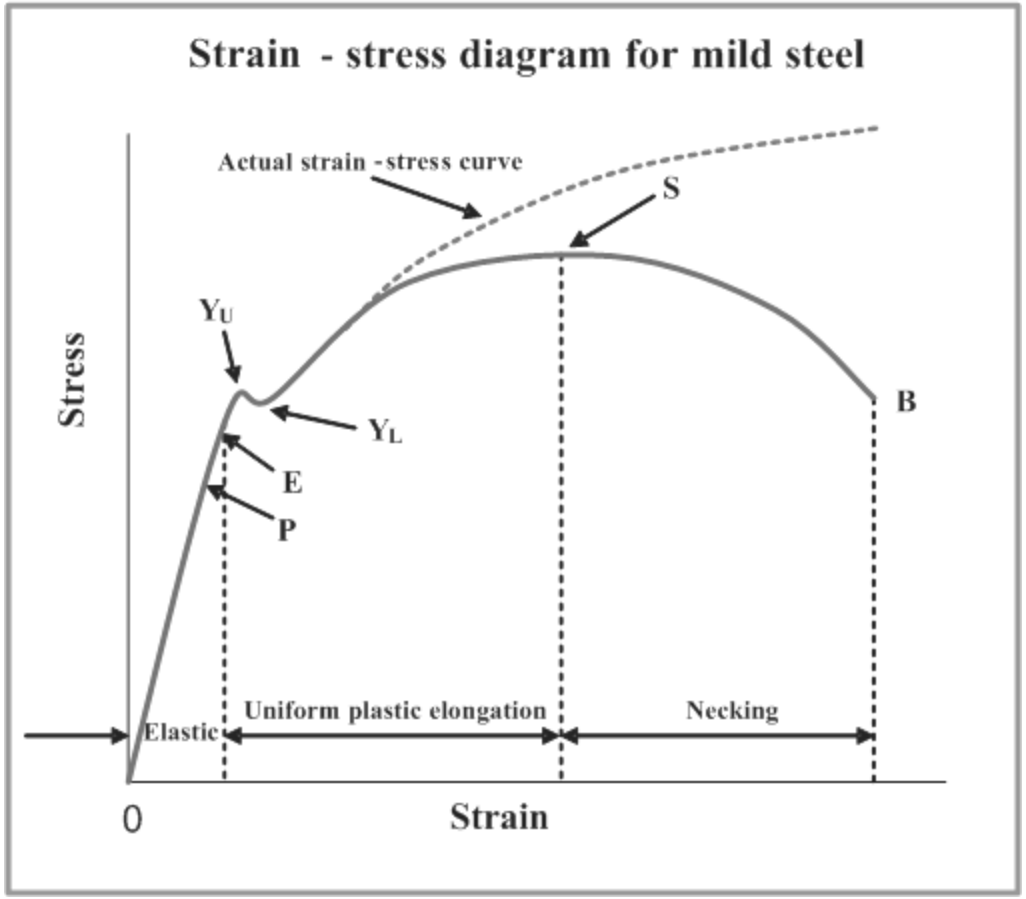
- These properties are affected by t*emperature* :

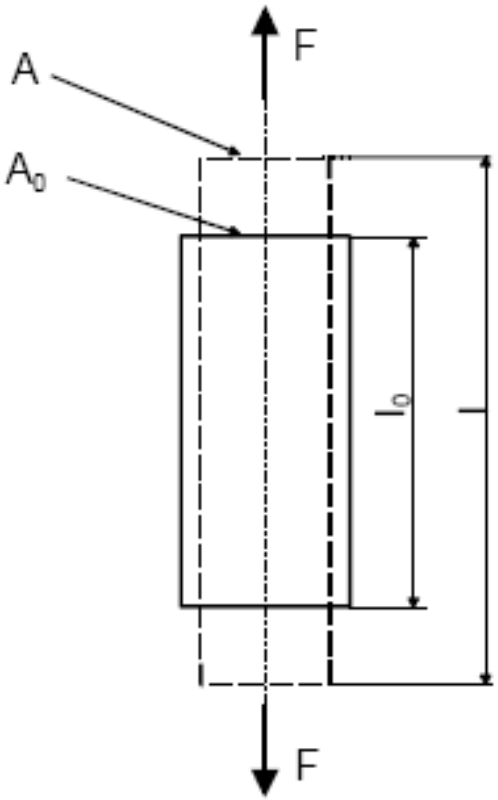
  Ductility increases and yield strength decreases when work temperature is raised

- Other factors:

  Strain rate and friction

Material Behavior in Metal Forming

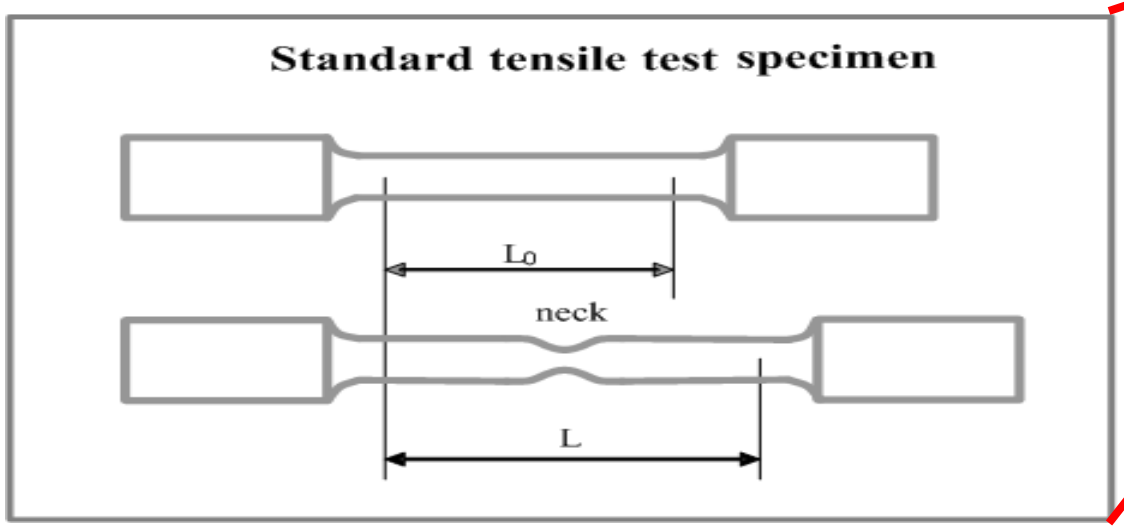




Tensile Testing Machine

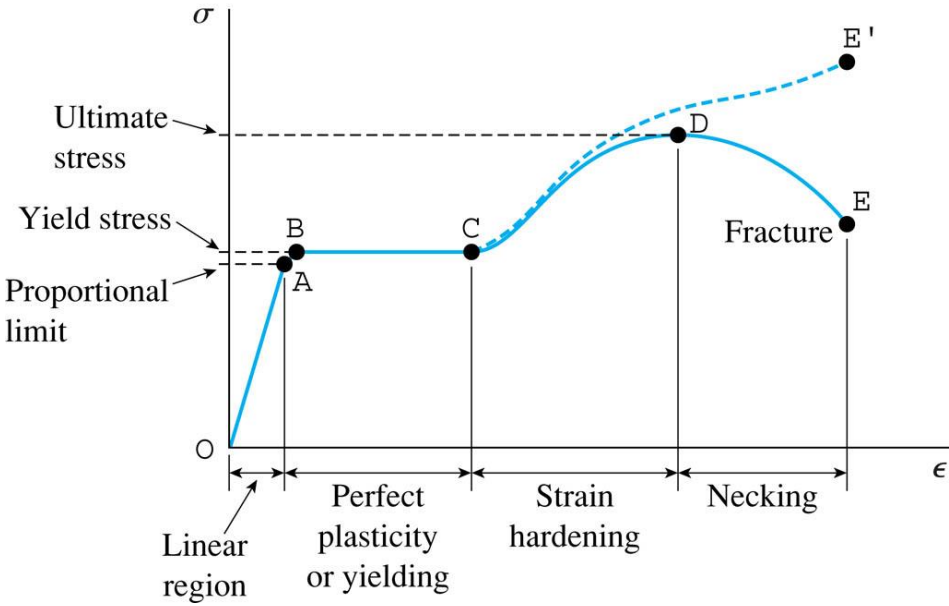
Mechanical properties of materials

- In order to understand the mechanical behaviour of materials we need to perform experimental testing in the lab
- A tensile test machine is a typical equipment of a mechanical testing lab
- ASTM (American Society for Testing and Materials)



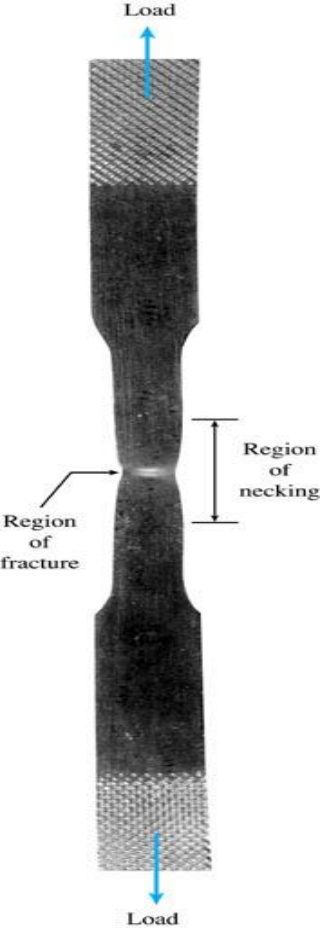
Stress (σ) – strain (ε) diagrams

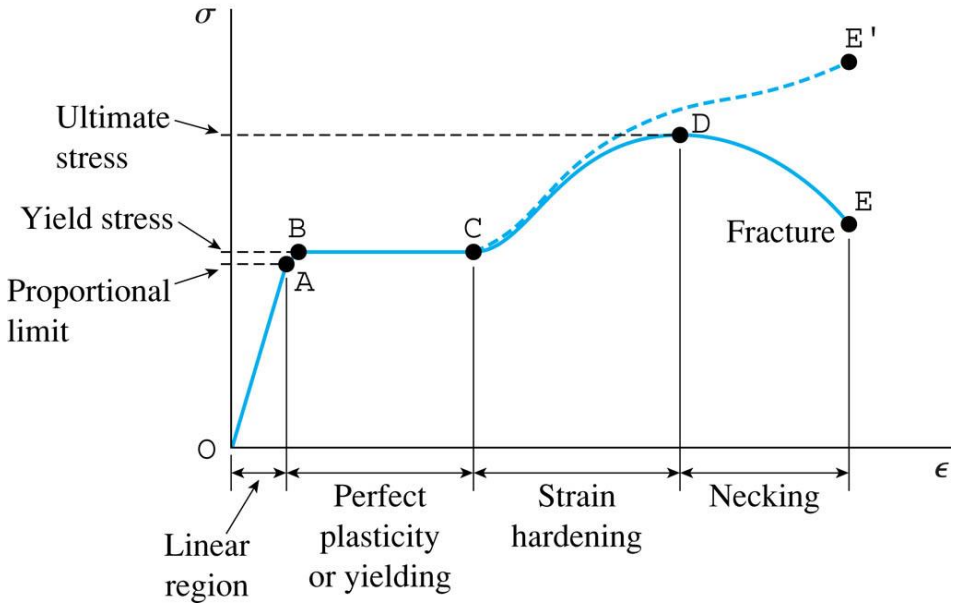
- Nominal stress and strain (in the calculations we use the <u>initial</u> cross-sectional area A)
- True stress (in the calculations we use the cross-sectional area A when <u>failure occurs</u>)
- True strain if we use a strain gauge
- Stress-strain diagrams contain important information about mechanical properties and behaviour



Stress-strain diagram for a typical structural steel in tension (not to scale)

Stress (σ) – strain (ε) diagrams





Stress-strain diagram for a typical structural steel in tension (not to scale)

OA: Initial region which is linear and proportional

Slope of OA is called modulus of elasticity

BC: Considerable elongation occurs with no noticeable increase in stress (yielding)

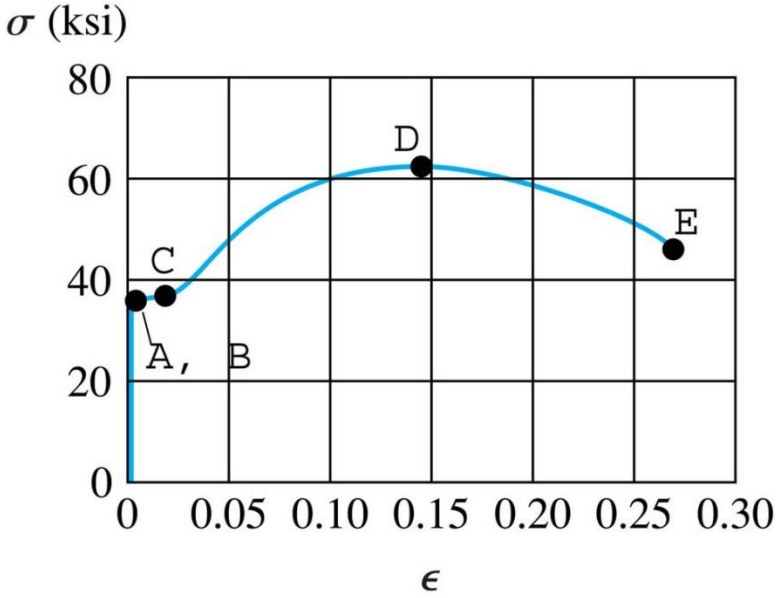
CD: Strain hardening – changes in crystalline structure (increased resistance to further deformation)

DE: Further stretching leads to reduction in the applied load and fracture

OABCE': True stress-strain curve

Stress (σ) – strain (ε) diagrams

- The strains from zero to point A are so small as compared to the strains from point A to E and can not be seen (it is a vertical line…)
- Metals, such as structural steel, that undergo permanent large strains before failure are <u>ductile</u>
- Ductile materials absorb large amounts of strain energy
- Ductile materials: aluminium, copper, magnesium, lead, molybdenum, nickel, brass, nylon, teflon



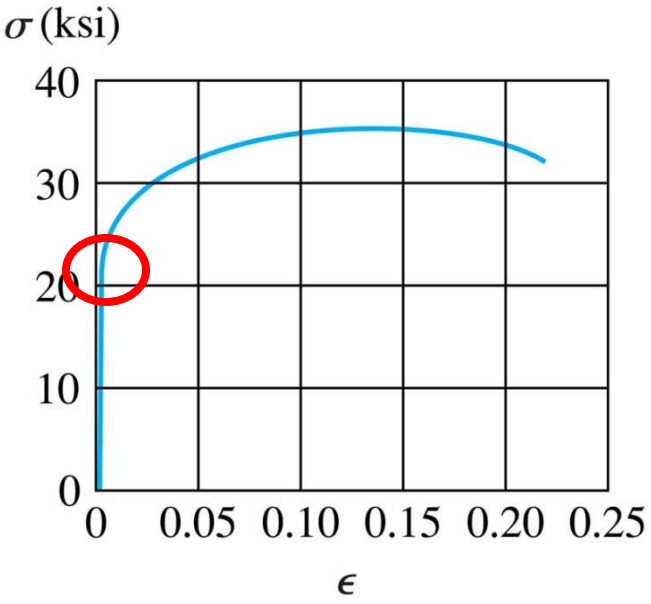
Stress-strain diagram for a typical structural steel in tension (drawn to scale)

Aluminium alloys

•Although ductile…aluminium alloys typically do not have a clearly definable yield point…

•However, they have an initial linear region with a recognizable proportional limit

• Structural alloys have proportional limits in the range of 70-410 MPa and ultimate stresses in the range of 140-550 MPa

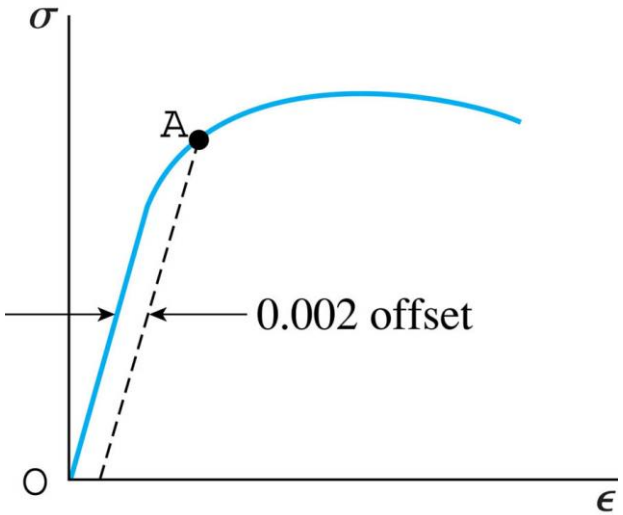


Typical stress-strain diagram for an aluminum alloy.

Offset method

- When the yield point is not obvious, like in the previous case, and undergoes large strains, an arbitrary yield stress can be determined by the offset method

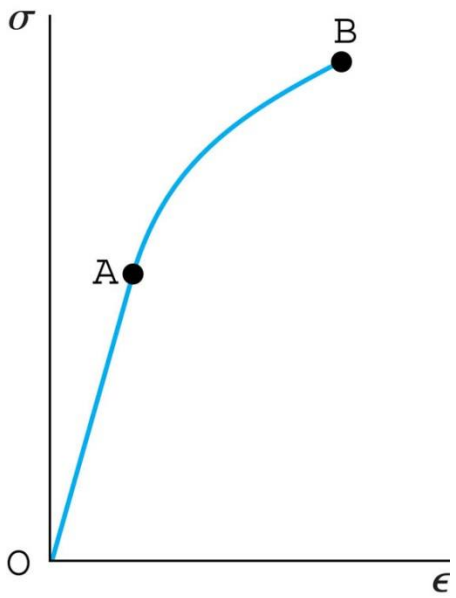
- The intersection of the offset line and the stress-strain curve (point A) defines the yield stress



Arbitrary yield stress determined by the offset method

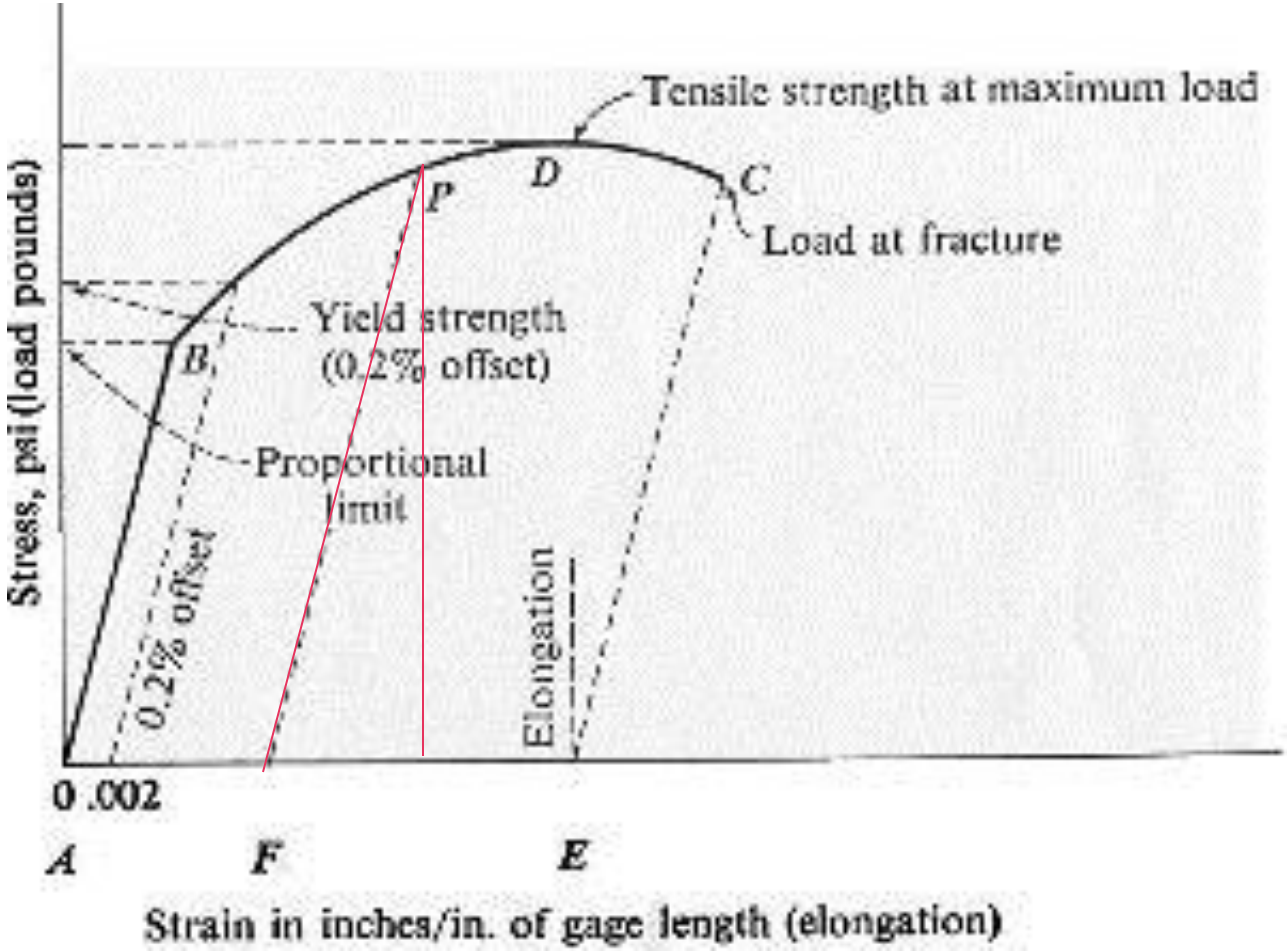
Brittle materials

- Brittle materials fail at relatively low strains and little elongation after the proportional limit
- Brittle materials: concrete, marble, glass, ceramics and metallic alloys
- The reduction in the cross-sectional area until fracture (point B) is insignificant and the fracture stress (point B) is the same as the ultimate stress



Typical stress-strain diagram for a brittle material showing the proportional limit (point *A*) and fracture stress (point *B*)

Stress Strain diagram – materials



- Plastic region of stress-strain curve is primary interest because material is plastically deformed
- In plastic region, metal's behavior is expressed by the flow curve:

$$Y_f = K\,\varepsilon^n$$

where Y_f = flow stress, K = strength coefficient; and n = strain hardening exponent

strain

$$\varepsilon t = \int_{l_o}^{l} \frac{dl}{l} = \ln \frac{l}{l_o} = \ln(1 + \varepsilon e)$$

Flow Stress

- For most metals at room temperature, strength increases when deformed due to strain hardening
- *Flow stress* = instantaneous value of stress required to continue deforming the material

$$Y_f = K\,\varepsilon^n$$

where Y_f = flow stress, K = strength coefficient; and n = strain hardening exponent

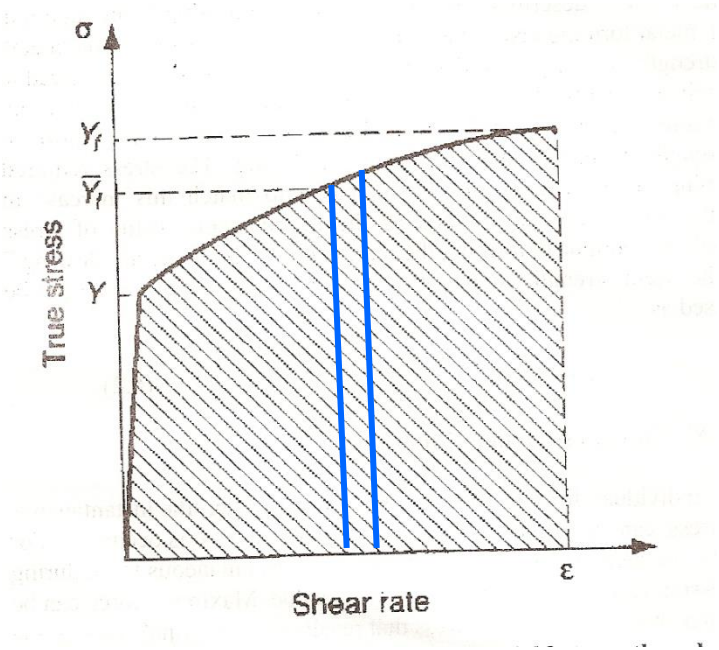
Average Flow Stress

Determined by integrating the flow curve equation between zero and the final strain value defining the range of interest

$$\bar{Y}_f = \frac{\int_0^{\varepsilon} Y_f \, d\varepsilon}{\varepsilon} = \frac{\int_0^{\varepsilon} K\varepsilon^n \, d\varepsilon}{\varepsilon}$$

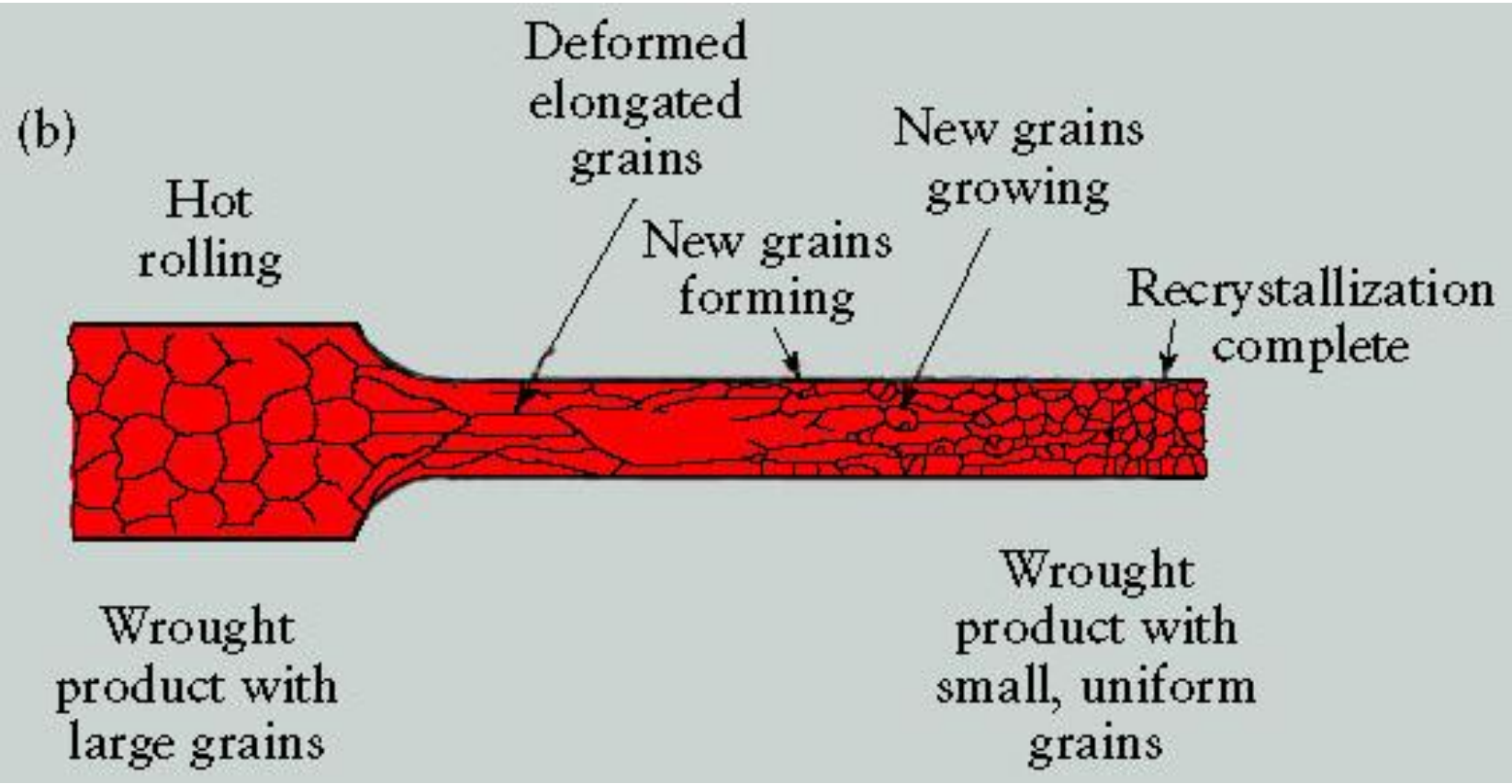
$$\bar{Y}_f = \frac{K\varepsilon^{n+1}}{\varepsilon(n+1)} = \frac{K\varepsilon^{n+1-1}}{n+1}$$

$$\bar{Y}_f = \frac{K\varepsilon^n}{1+n}$$

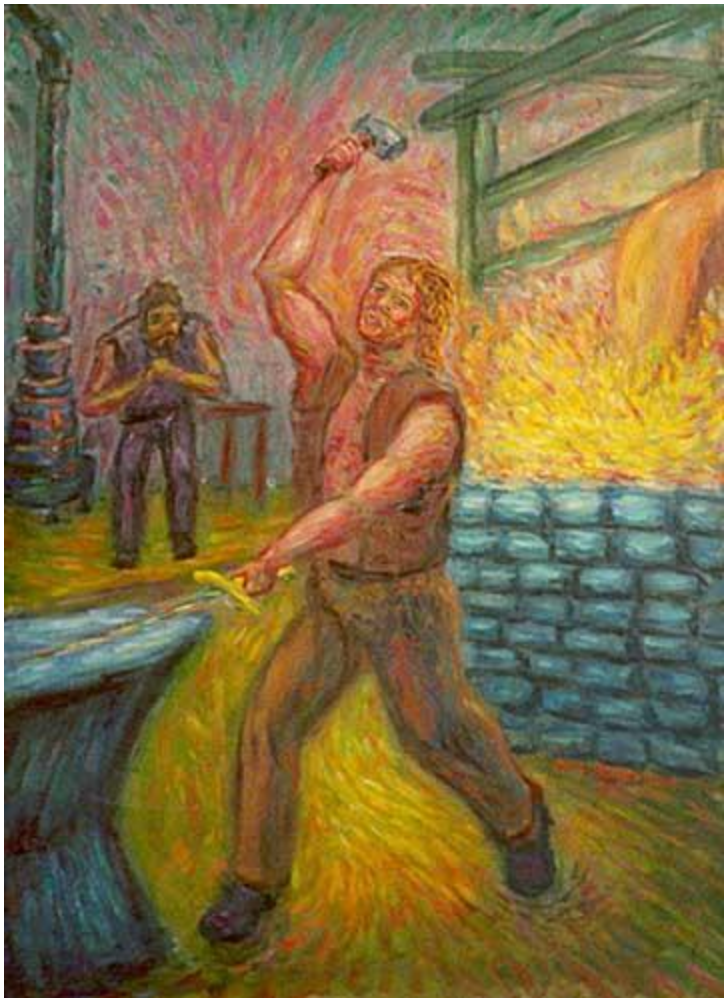


where $\bar{Y}_f$ = average flow stress; and ε = maximum strain during deformation process

Hot Forming


(b)
Hot rolling
Deformed elongated grains
New grains forming
New grains growing
Recrystallization complete
Wrought product with large grains
Wrought product with small, uniform grains

Hot Working:



Temperature in Metal Forming

- For any metal, *K* and *n* in the flow curve depend on temperature
- Both strength and strain hardening are reduced at higher temperatures
- In addition, ductility is increased at higher temperatures

Temperature in Metal Forming

- Any deformation operation can be accomplished with lower forces and power at **elevated temperature**
- **At elevated temperature**

$$n = 0$$

$$\bar{Y}_f = Y_f = K$$

- Three temperature ranges in metal forming:

  Cold working

  Warm working

  Hot working

Cold Working

- Performed at room temperature(below RC temperature.)
- Many cold forming processes are important mass production operations
- Minimum or no machining usually required

Warm Working

- Performed at temperatures above room temperature but below recrystallization temperature
- Warm working: T/T_m from 0.3 to 0.5, where T_m = melting point (tm+273) for metal

Hot Working

- Deformation at temperatures above *recrystallization temperature*
- In practice, hot working usually performed somewhat above $0.5T_m$
- Metal continues to soften as temperature increases above $0.5T_m$, enhancing advantage of hot working above this level

Advantages of Cold Forming vs. Hot Working

- Better accuracy, closer tolerances
- Better surface finish
- Strain hardening increases strength and hardness
- No heating of work required
- Grain flow during deformation can cause desirable directional properties in product

Disadvantages of Cold Forming

- Higher forces and power required
- Surfaces of starting workpiece must be free of scale and dirt
- In some operations, metal must be annealed to allow further deformation
- In other cases, metal is simply not ductile enough to be cold worked

Advantages of Warm Working

- Lower forces and power than in cold working
- More intricate work geometries possible
- Need for annealing may be reduced or eliminated

What is Strain Rate?

- Strain rate in forming is directly related to speed of deformation *v*
- Deformation speed *v* = velocity of the ram or other movement of the equipment

Strain rate is defined:

$$\dot{\varepsilon} = \frac{v}{h}$$

where $\dot{\varepsilon}$ = true strain rate; and *h* = instantaneous height of workpiece being deformed

Strain Rate Sensitivity Equation

$$Y_f = C\dot{\varepsilon}^m$$

where

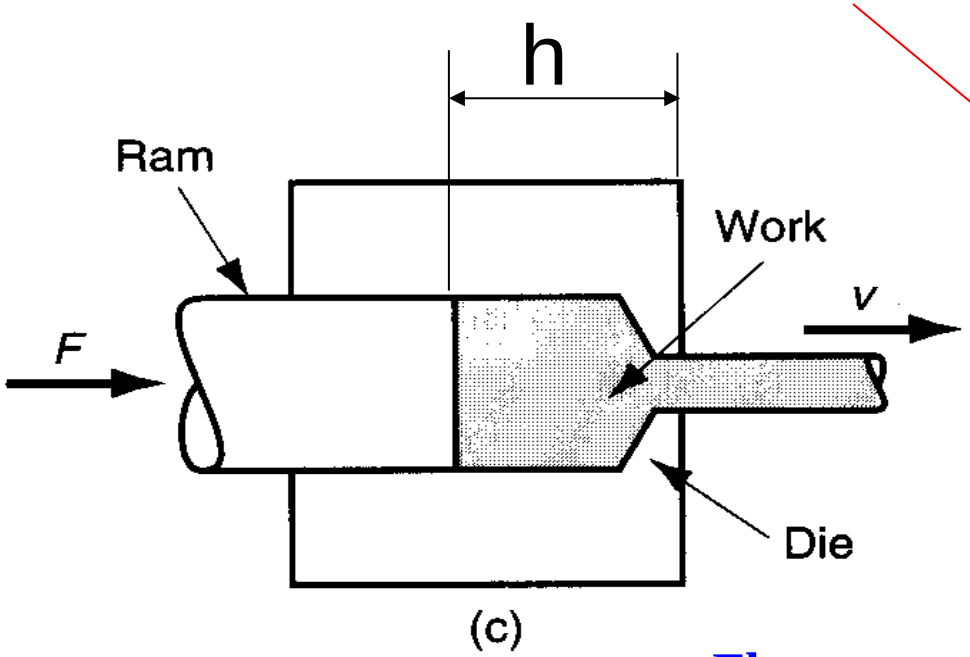
C = strength constant (similar but not equal to strength coefficient in flow curve equation), and

m = strain-rate sensitivity exponent

- **Strain rate (related to elevated temperatures)**

  Rate at which metal is strained in a forming process

  - In the hot forming or warm forming, the strain rate can affect the flow stress



Strain Rate

Speed of deformation (could be equal to velocity of ram)

Instantaneous height of work-piece being deformed

$$\dot{\varepsilon} = v / h$$

Flow stress

$$Y_f = C\dot{\varepsilon}^m$$

$$Y_f = C\dot{\varepsilon}^m$$

Strength coefficient but not the same as K

where

C → strength constant

m → strain-rate sensitivity exponent

$$\mathrm{Y_f} = K\varepsilon^n$$

and m are determined by the following figure which is generated from the experiment

Effect of Strain Rate on Flow Stress

- Flow stress is a function of temperature
- At hot working temperatures, flow stress also depends on strain rate
- As strain rate increases, resistance to deformation increases
- This effect is known as *strain-rate sensitivity*

Effect of Strain Rate

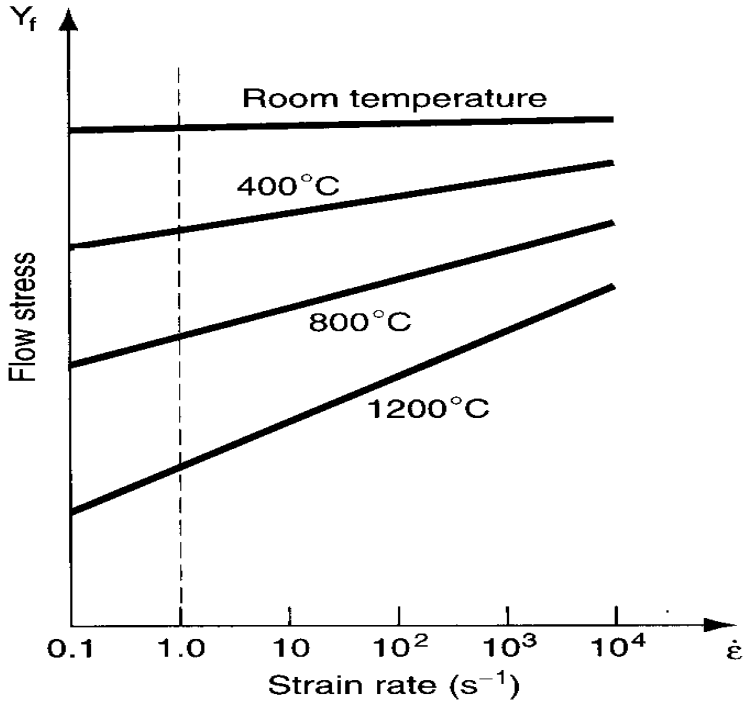
$$\bar{Y}_f = C\dot{\varepsilon}^m$$

$\dot{\varepsilon}$ strain rate

The strain rate is strongly affected by the temperature

$$Y_f = C\ \dot{\varepsilon}^m$$

C = a strength coefficient



Friction in Metal Forming

- In most metal forming processes, friction is undesirable:

  Forces and power are increased

  Wears tooling faster

  Metal flow is retarded
- Friction and tool wear are more severe in hot working

Lubrication in Metal Forming

- Metal working lubricants are applied to tool-work interface in many forming operations to reduce harmful effects of friction
- Benefits:

  Reduced sticking, forces, power, tool wear

  Better surface finish

  Removes heat from the tooling

Considerations in Choosing a Lubricant

- Type of forming process (rolling, forging, sheet metal drawing, etc.)
- Hot working or cold working
- Work material
- Chemical reactivity with tool and work metals
- Ease of application
- Cost

Metal Forming Laws

$$Y_f = K\varepsilon^n = C\dot{\varepsilon}^m$$

$$\varepsilon = \int_{l_o}^{l} \frac{dl}{l} = \ln \frac{l}{l_o}$$

$$\dot{\varepsilon} = \frac{v}{h}$$

$$\overline{Y}_f = \frac{K\varepsilon^n}{1+n}$$

Example (1)

A metal has a flow curve with parameters: *K = 850 MPa and strain hardening exponent n = 0.30.* A tensile specimen of the metal with gage length = 100 mm is stretched to a length = 157 mm. Determine the flow stress at the new length and the average flow stress that the metal has been subjected to during the deformation.

Solution

$$\varepsilon = \ln(157/100) = \ln 1.57 = 0.451$$

Flow stress $Y_f = 850(0.451)^{0.30} = \mathbf{669.4\ MPa.}$

Average flow stress $\overline{Y}_f = 850(0.451)^{0.30}/1.30 = \mathbf{514.9\ MPa.}$

Example (2)

For a certain metal. K = 700 MPa and n = 0.27. Determine the average flow stress that the metal experiences if it's subjected to a stress that is equal to its strength coefficient K.

Solution

$$Y_f = K = 700 = K\varepsilon^{n} = 700\varepsilon^{.27}$$

$$\varepsilon = 1$$

$$\overline{Y}_f = 700(1.0)^{.27}/1.27 = 700/1.27 = \mathbf{551.2\ MPa}$$

Example (3) The gage length of a tensile test specimen = 150 mm. It is subjected to a tensile test in which the grips holding the end of the test specimen are moved with a relative velocity = 0.1 m/s. Construct a plot of the strain rate as a function of length as the specimen is pulled to a length = 200 mm.

Solution

The following values are calculated for the plot:

At L = 150 mm, $\dot{\varepsilon}$ = 0.1/0.15 = 0.667 s-1

At L = 160 mm, $\dot{\varepsilon}$ = 0.1/0.16 = 0.625 s-1

At L = 170 mm, $\dot{\varepsilon}$ = 0.1/0.17 = 0.588 s-1

At L = 180 mm, $\dot{\varepsilon}$ = 0.1/0.18 = 0.555 s-1

At L = 190 mm, $\dot{\varepsilon}$ = 0.1/0.19 = 0.526 s-1

At L = 200 mm, $\dot{\varepsilon}$ = 0.1/0.20 = 0.500 s-1