Manufacturing Processes

Chapter One:

An Introduction

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What is Manufacturing??

- The word *manufacturing* is centuries old and derived from two Latin words *manus* (hand) and *factus* (make); the combination means by hand. Hence manufacturing literally means made by hand.

- Although modern manufacturing is accomplished by automated and computer-controlled machinery the word manufacturing is still in use.

Manufacturing → technological / economically

Manufacturing Defined

- Manufacturing can be defined in two ways; ① technologically and ② economically.

- In technology, manufacturing is the application of physical and chemical processes to alter the geometry, properties, and/or appearance of a starting material to make products. Manufacturing also includes assembly of multiple parts to make products.

  عمليات التجميع

- In economy, manufacturing is the transformation of materials into items of greater value by means of one or more processing and/or assembly operations.

- The key point is that manufacturing adds value to the material either by changing its shape or properties or by combining it with other materials that have been similarly altered.

The Target of manufacturing is to add value to the initial material

Manufacturing Defined

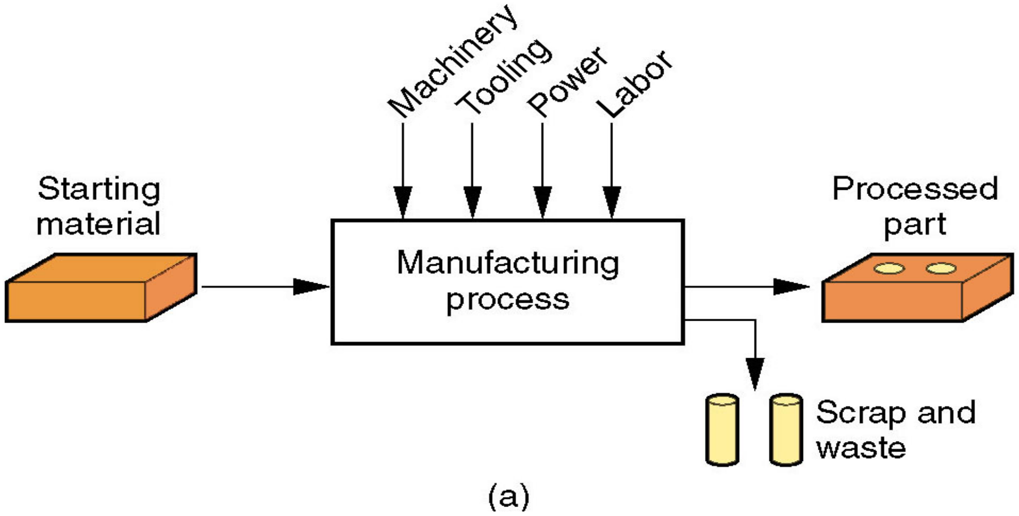


Figure 1.1 (a) Manufacturing as a technical process

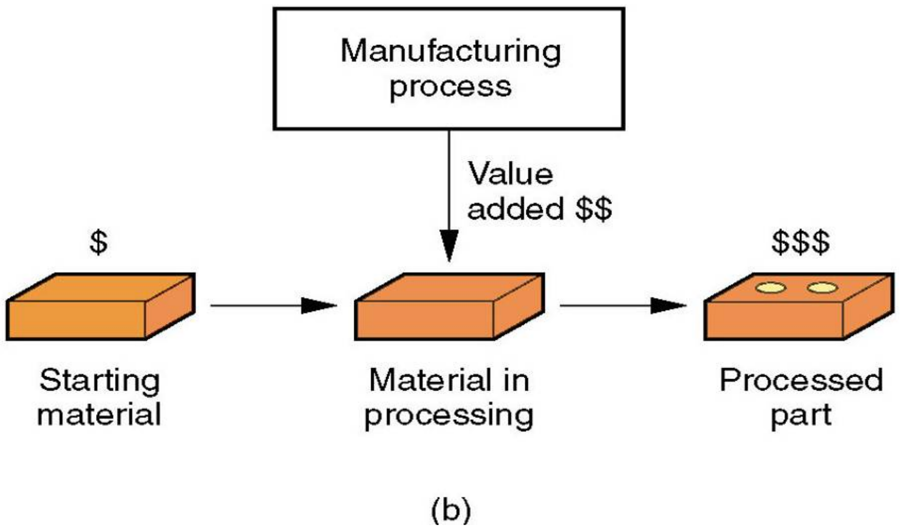
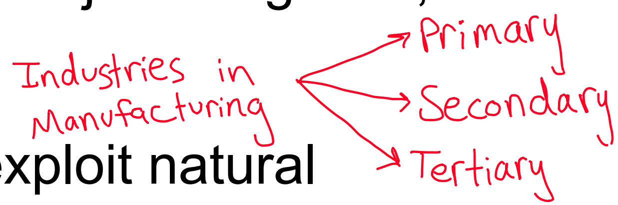


Figure 1.1 (b) Manufacturing as an economic process

Manufacturing Industries and Products

- Manufacturing is important to our lives. Yet, we do not manufacture stuff just for the sake of manufacturing. We manufacture because we want to make money!

- Industries in manufacturing is divided into three major categories; Primary, Secondary and Tertiary Industries.



1. Primary industries are those that cultivate and exploit natural resources, such as agriculture and mining.

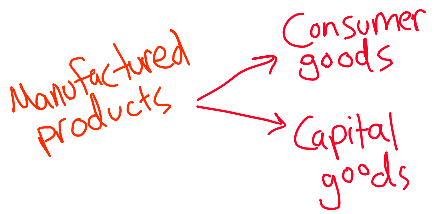
we will study the secondary in this course

2. Secondary industries are those that take the outputs of the primary industries and convert them into consumer and capital goods. (This type is of our concern because it is engaged directly in manufacturing).

3. Tertiary industries constitute the service sector of the economy.

Manufacturing Industries and Products

- Manufactured products: Final products by industries such as Aerospace, Automotive, Basic Metals, Computers, Electronics, Glass, Ceramics can be divided into two major classes:



1. Consumer goods: Products purchased directly by consumers, such as cars, PCs, TVs, etc.

2. Capital goods: Products purchased by other companies to produce goods and supply services, such as aircrafts, mainframe computers, railroad equipment, machine tools, construction equipment, etc.

Manufacturing Industries and Products

* يوجد علاقة عكسية بين ال Quantity (Q) و ال Variety (V)
(inversely proportional relationship)

- Production Quantity (*Q*) and Product Variety (*V*).

1. The quantity of products made by a factory has a great influence on the way its people, facilities and procedures are organized. Annual production can be classified into 3 ranges:

- Low production: quantities in the range 1 to 100 units/year.
- Medium production: from 100 to 10,000 units/year.
- High production: 10,000 to millions of units/year. However and depending on the kinds of products, these ranges may shift by an order of magnitude or so.

2. The product variety: since some factories specialize in high production of only one product type while other factories produce a variety of products each type being made in low or medium quantities, it is instructive to identify product variety as a parameter distinct from production quality. It is logical to consider factories with a high number of product types to have high product variety.

Manufacturing Industries and Products

- There is an inverse correlation between production quantity and product variety. The higher the production quantity the lower the product variety and vise versa.

- Manufacturing plants tend to specialize in a combination of *Q* and *V* that lies somewhere inside the diagonal band in the figure.

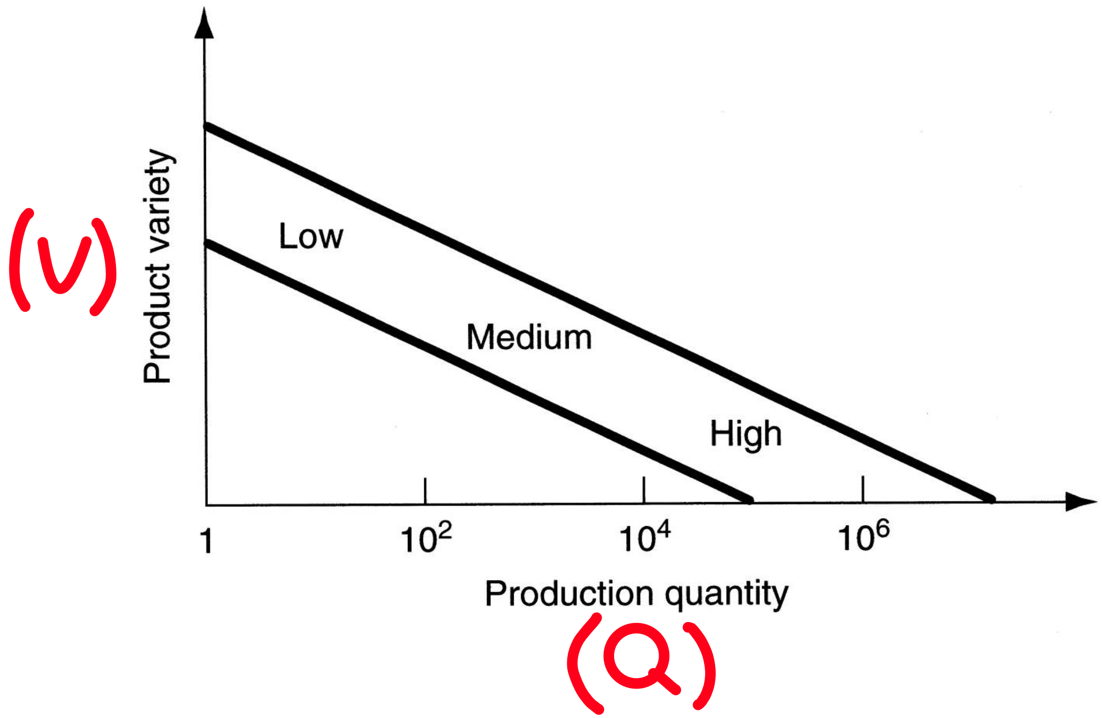


Figure 1.2 Relationship between *Q* and *V*.

Manufacturing Industries and Products

- Although *V* is a quantitative parameter, it is much less exact than *Q* because details on how much the designs differ is not captured simply by the number of different designs.

1. Soft product variety: small differences between products, e.g., between car models made on the same production line, with many common parts among models.

2. Hard product variety: products differ substantially; e.g. between a small car and a large truck, with few common parts.

Materials in Manufacturing

- Most engineering materials can be classified into one of the three basic categories: (1) Metals, (2) Ceramics and (3) Polymers.
- They have different chemistries and their mechanical and physical properties are dissimilar.
- These differences affect the manufacturing processes that can be used to produce products from them.
- In addition, there are (4) Composites: nonhomogenious mixtures of the other three basic types rather than a unique category.

Materials in Manufacturing

- The relationship of the four groups is pictured in the following figure.

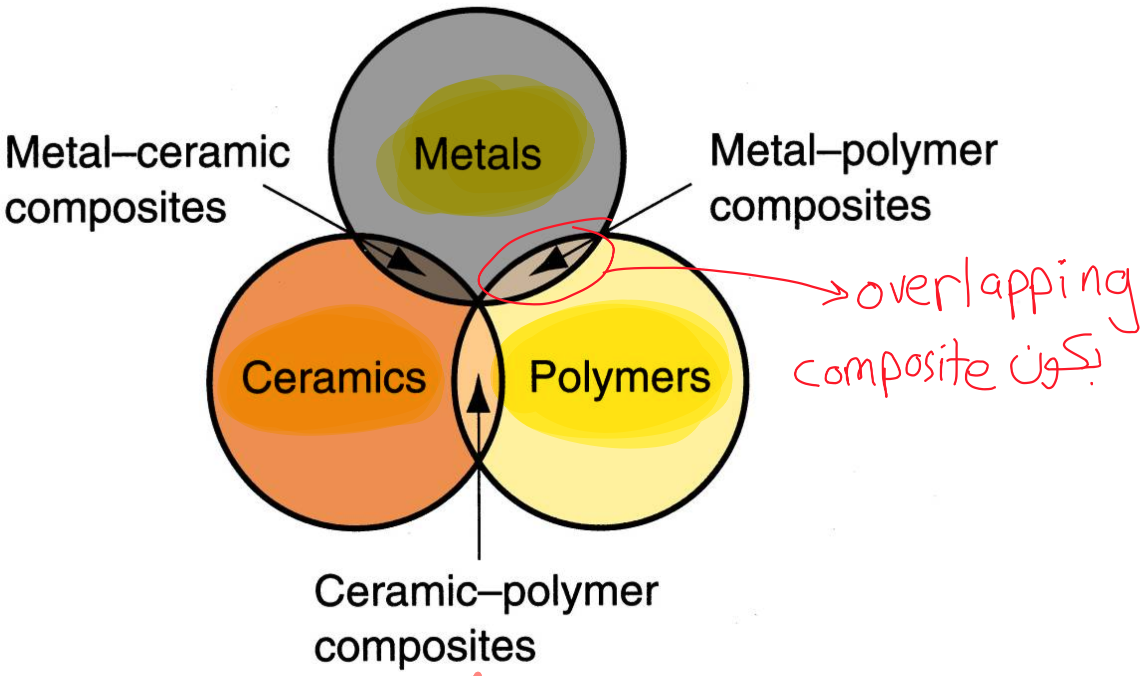


Figure 1.3 Venn diagram of three basic material types plus composites.

Metals → Ferrous, Non Ferrous

Materials in Manufacturing

[1] Metals: metals used in manufacturing are usually in the form of alloys (two or more elements, at least one of which is metallic). Metals are divided into two basic groups; ferrous and nonferrous.

سبائك

a. Ferrous metals: based on Iron (Fe) as the major alloying element. This group includes steel and cast iron.

Ferrous Metals → (Fe) Iron; +(C) → Steel; +(C) → Cast Iron (strength ↑, Harder ↑, Ductility ↓)

- More than 75% of the metal tonnage throughout the world.

- Fe has limited commercial use, but when alloyed with carbon (C), Fe has more use and greater commercial value than any other metal.

- Fe when alloyed with C forms Steel or Cast Iron.

Fe + C → Plain C-steel (carbon)

Carbon (for strengthening purpose)

★ properties of (Alloys) is better than the (General categories)

Materials in Manufacturing

- **Steel**: Is an Iron-Carbon alloy containing 0.02 to 2.11 wt. % C.

  $0.02\% < C\% < 2.11\%$

- Most important category within the ferrous metals group, due to low cost and good mechanical and physical properties.
- Its composition contains other metals such as Mg, Cr, Ni, Mo, etc, to enhance the properties of the alloy.

  Fe + C + Mo + Cr + Mg + ... → Alloyed Steel

- Used widely in construction, transportation and consumer products.

Materials in Manufacturing

Strength ↑
Harder ↑
Ductility ↓

- **Cast iron**: Iron-Carbon alloy containing ~2 to ~4 wt.% C.

$\sim 2\% < C\% < \sim 4\%$

- Used primarily in sand casting.

$0.5\% < Si\% < 3\%$

- Other elements such as Si (0.5 to 3 wt.%) is present in the alloy. Other elements are often added as well.

- Gray cast iron is the most common type of cast iron; its applications include blocks and heads for internal combustion engines, manholes covers, etc.

Materials in Manufacturing

b. Nonferrous metals: These include other metallic elements and their alloys.

- In almost all cases, the alloys are more important commercially than the pure metals.

- Some examples are Gold alloys, Titanium alloys, Copper alloys, etc.

Materials in Manufacturing

Ceramics → Metalic or semimetalic + Nonmetalic O, N, C

[2] Ceramics: A compound containing metallic (or semimetallic) and nonmetallic (O, N and C) elements.

- Traditional ceramics: Been used for thousands of years. They include: clay (consists of fine particles of hydrous aluminum silicate and other minerals used in making brick, tile and pottery); silica (the basis of nearly all glass products); and alumina and silicon carbide (abrasive materials used in grinding).
- Modern ceramics: Consists of alumina of enhanced properties. Newer ceramics include carbides, metal carbides such as tungsten and titanium carbides (used as cutting tool materials); and nitrides (e.g. titanium nitride and boron nitride, used as cutting tools and grinding abrasives).

ceramics → crystalline, amorphous

- For processing purposes, ceramics can be divided into (1) crystalline ceramics and (2) amorphous ceramics (glasses). The former are formed in various ways from powders and then sintered, while the later can be melted and cast and then formed (e.g. glass blowing).

crystallity → atoms pack together

Materials in Manufacturing

[3] Polymers: A compound formed of repeating structural units called *mers*, whose atoms share electrons to form very large molecules. They consist of carbon plus one or more other elements such as hydrogen, oxygen, nitrogen and chlorine. They are divided into three categories:

- Thermoplastic polymers: can be subjected to multiple heating and cooling cycles without altering molecular structure; e.g. polyethylene, polystyrene, polyvinylchloride and nylon.
- Thermosetting polymers: molecules chemically transform (cure) into a rigid structure upon cooling from a heated plastic condition; e.g. epoxies and amino resins.
- Elastomers: they exhibit significant elastic behavior; e.g. silicon and rubber.

Materials in Manufacturing

[4] Composites: A mixtures of the other three basic types. A composite is a material consisting of two or more phases that are processed separately and then bonded together to achieve properties superior to its constituents.

- Phase: Homogeneous mass of material, such as grains of identical unit cell structure in a solid metal.
- The usual structure of a composite material consists of particles or fibers of one phase mixed in a second phase, called the matrix.
- Composites are found in nature (wood) and they can be produced synthetically (fiber-reinforced plastic).
- Properties depend on its components, physical shapes of components, and the way they are combined to form the final material. Some composites combine high strength and light weight and are used as aircraft components, car bodies, etc. Other composites are strong and hard, and capable of maintaining these properties at high temperatures; e.g. cemented carbide cutting tools.

Manufacturing Processes

Processing operations

Assembly operations

- Manufacturing processes can be divided into two basic types:

1. Processing operations: transforms a work material from one state of completion to a more advanced state closer to the final desired product. It adds value by changing geometry, properties or appearance of the starting material.

2. Assembly operations: joins two or more components in order to create a new entity called an assembly, subassembly, etc.

Manufacturing Processes

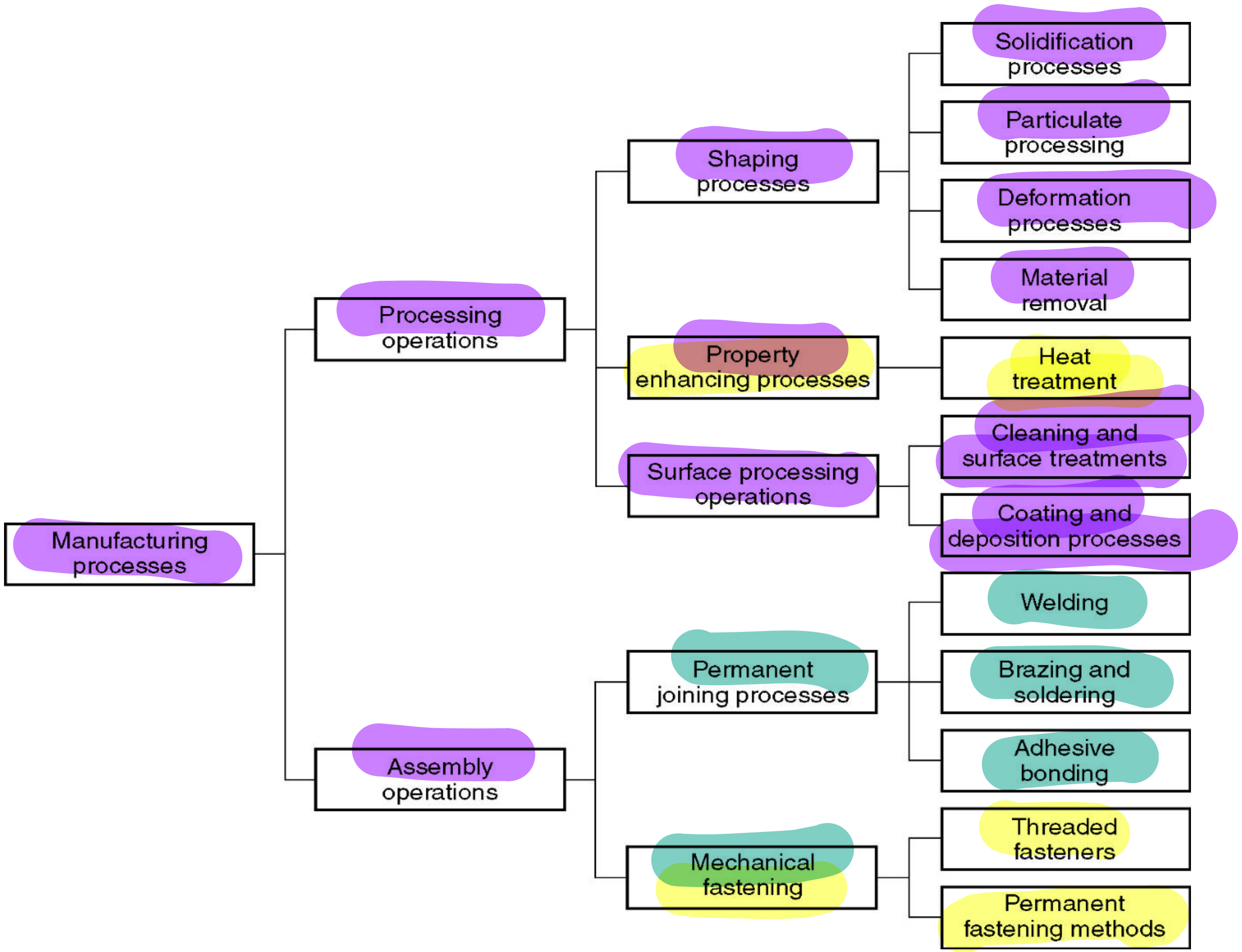


Figure 1.4 Classification of manufacturing processes

Manufacturing Processes

- Processing operations: use energy to alter a workpart's shape, physical properties or appearance in order to add value to the material. There are three categories of processing operations:

1. Shaping operations: alter the geometry of the work material by methods including casting, forging and machining.

2. Property-enhancing operations: add value to the material by improving its physical properties without changing its shape; e.g. Heat treatment.

3. Surface processing operations: performed to clean, treat, coat or deposit material onto the exterior surface of the work. Examples for coating are plating and painting.

Manufacturing Processes

- Shaping processes: change the geometry of a work material by application of heat or mechanical force or a combination of both. It can be classified into four categories:

1. Solidification processes: the starting material is a heated liquid or semifluid that cools or solidifies to form the part geometry.
2. Particulate processing: the starting material is a powder, and the powders are formed and heated into the desired geometry.
3. Deformation processes: the starting material is a ductile solid that is deformed to shape the part.
4. Material removal processes: the starting material is a solid, from which material is removed so that the resulting part has the desired geometry.

Manufacturing Processes

- Solidification process: starting material is heated sufficiently to transform it to the liquid state. With the material (metals, plastics and ceramic glasses) in the liquid state, it can be poured into a mold cavity and allowed to solidify , thus taking a solid shape that is the same as the cavity.

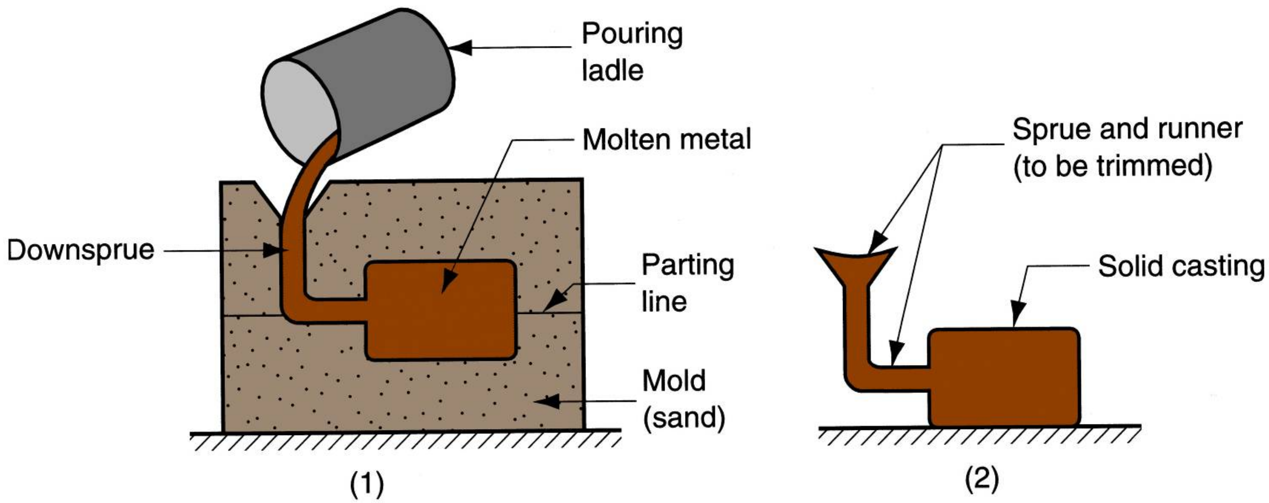


Figure 1.5 Casting (metals) and molding (plastics) processes.

Manufacturing Processes

- Particulate processing: Starting materials are powders of metals or ceramics. The powders are then pressed and sintered. The powders are first squeezed into a die cavity under a high pressure and then heated to bond the individual particles together.

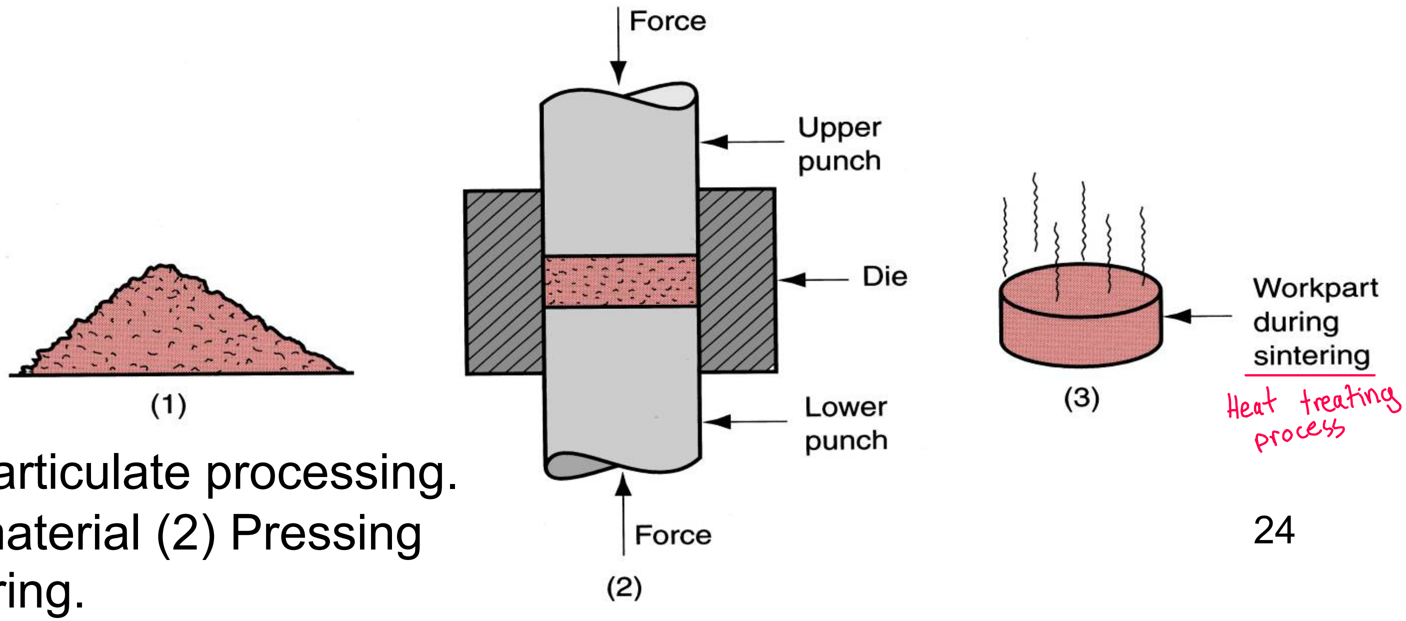


Figure 1.6 Particulate processing. (1) Starting material (2) Pressing and (3) Sintering.

Self-lubricating — Ball-bearing.

they minimized the friction ⇒ We need to get rid of the friction

By the use of lubrication (oil)

90% compaction → porosity → dipping into oil bath

→ Friction is removed

Manufacturing Processes

- Deformation processes: the starting workpart is shaped by application of forces that exceed the yield strength of the material (material must be ductile enough (accomplished by means of heating)), this process includes extrusion and forging.

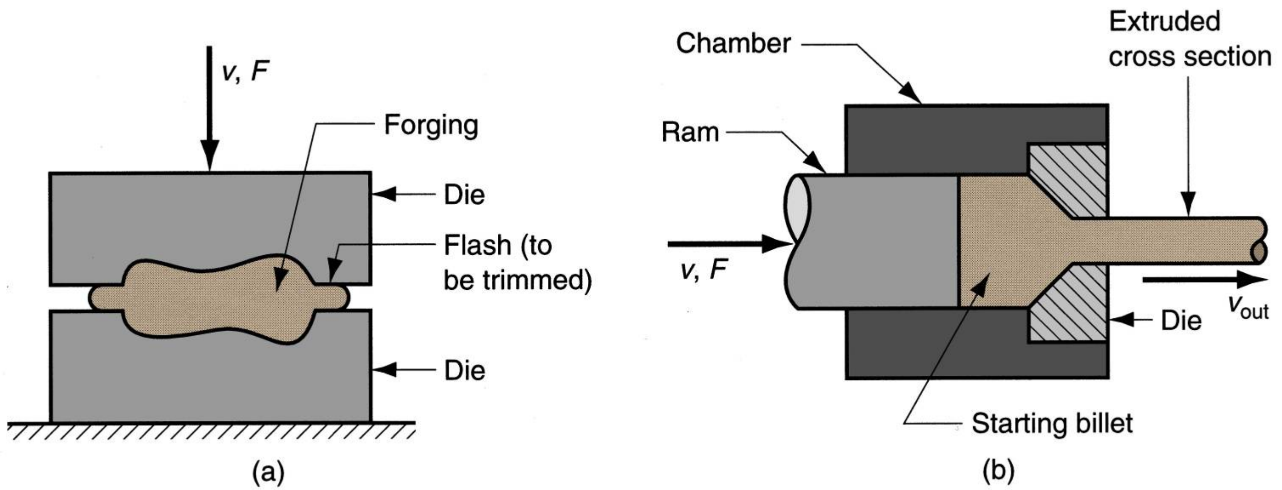


Figure 1.7 Deformation processes (a) forging (b) extrusion

Manufacturing Processes

- Material removal processes: operations that remove excess material from the starting workpart to get the desired geometry. Most common processes in this category include machining and grinding. The former includes turning, drilling and milling. Other special processes are known as nontraditional processes as they use lasers, electron beams, electric discharge, etc.

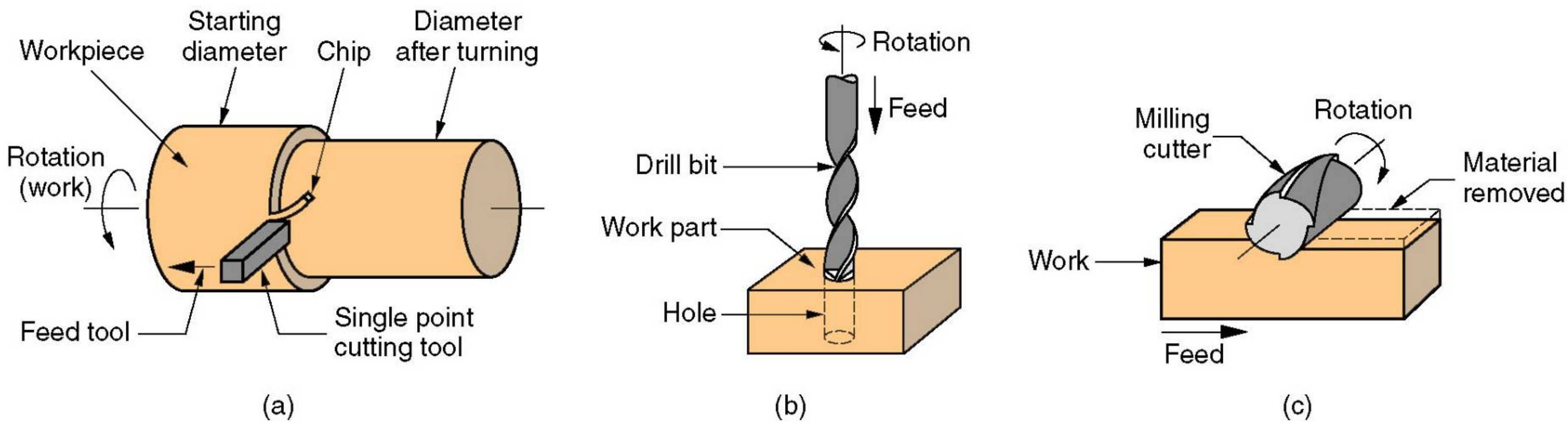


Figure 1.8 Material removal processes. (a) turning (b) drilling and (c) milling.

Manufacturing Processes

- Waste: it is desirable to minimize the waste and scrap in converting a starting workpart into a desired geometry.

- Material removal processes tend to be wasteful of material, simply by the way they work.

- Solidification processes convert close to 100% of the starting material into final product, such processes are called net shape processes, while other processes that require minimum machining to produce the final shape are called near net shape processes.

Manufacturing Processes

Chapter Three:

Mechanical Properties Of Materials

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Introduction

- Mechanical properties of a material determine its behavior when subjected to mechanical stress (examples on materials under stress are aluminum alloy from which an airplane wing is constructed and the steel in an automobile axle).

- Mechanical properties include: elastic modulus, ductility, hardness, etc.

- Two opposite objectives for the product in design and manufacturing:
  - In design: the objective for the product is to withstand stresses without significant change in geometry (dependent on elastic modulus and yield stress).
  - In manufacturing: the objective is to alter the geometry by applying stresses that exceed the yield strength of the material.

Note: it is helpful for the manufacturing engineer to appreciate the design objective and for the designer to be aware of the manufacturing objective.

Stress-Strain relationships

- There are 3 static stresses to which materials can be subjected
  - Tensile stresses: tend to stretch the material
  - Compressive stresses: tend to squeeze the material.
  - Shear stresses: tend to cause adjacent portions of the material to slide against one another.

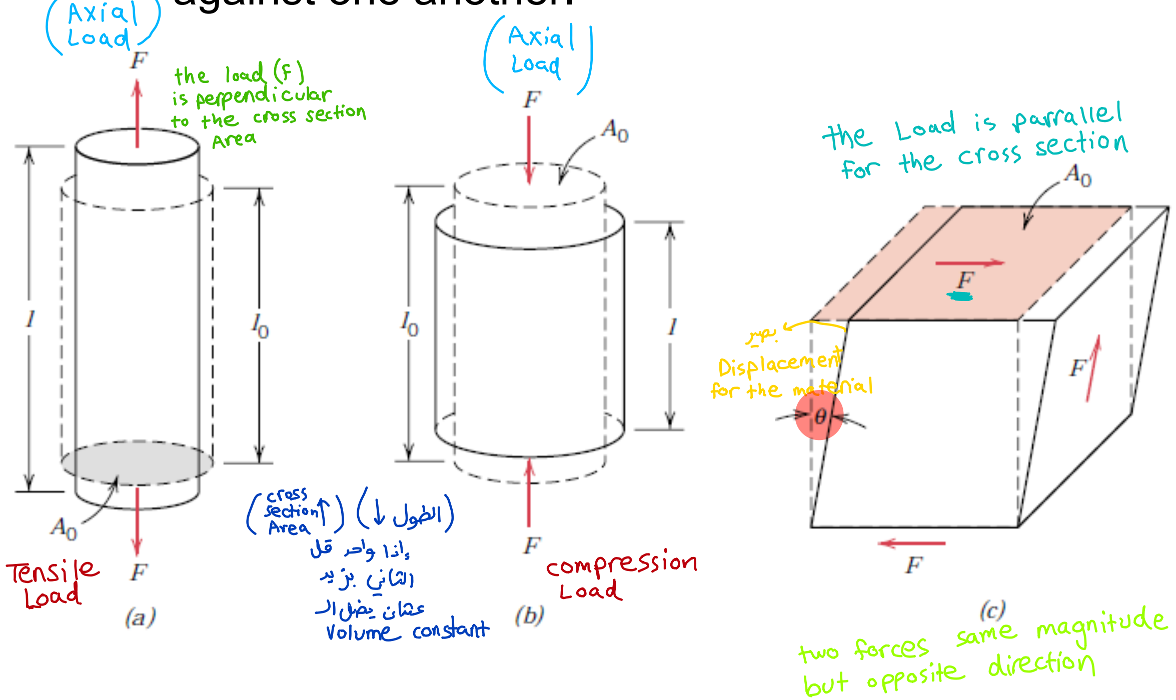


Fig. 3-1: Materials under static stresses; (a) Tensile, (b) compressive, and (c) shear ($\gamma = \tan\theta$). Dashed lines: shape before deformation.

Stress-Strain relationships; Tensile properties

- Tensile test: most common procedure for studying stress-strain relationships, particularly for metals.
- In the test, force is applied that pulls the material, tending to elongate it and reduce its diameter.
- Standards by ASTM specify the preparation of the test specimen and the test procedure.

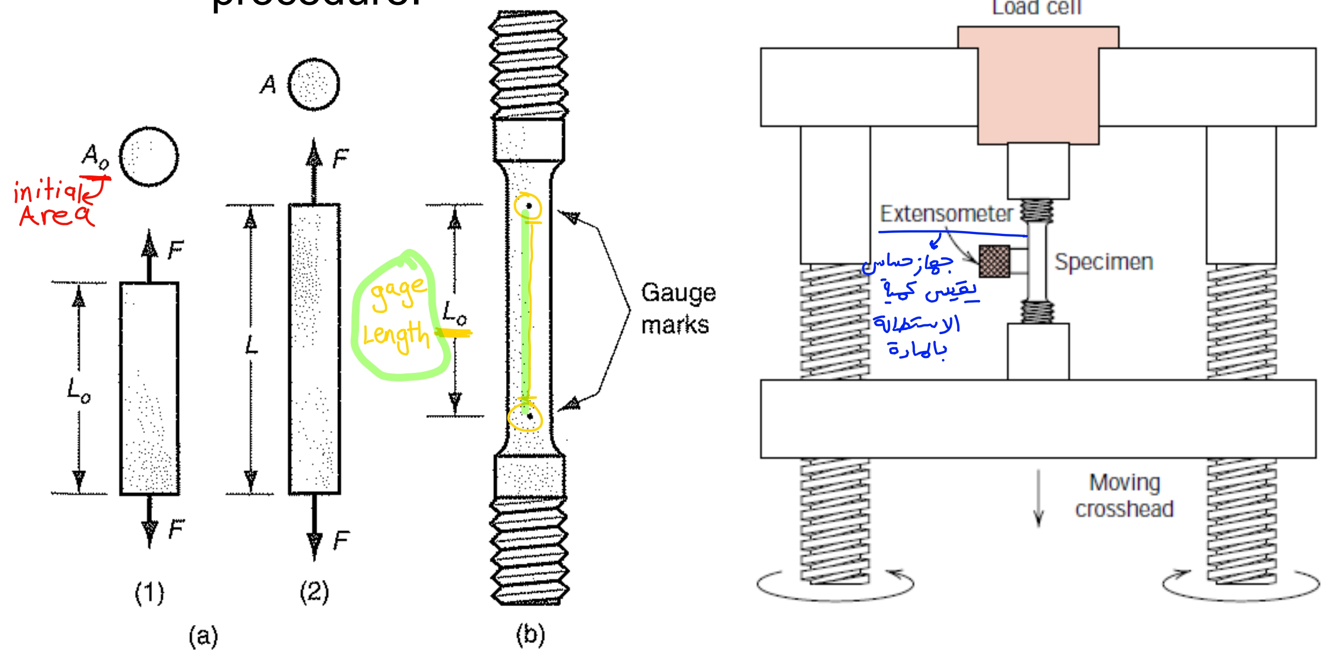
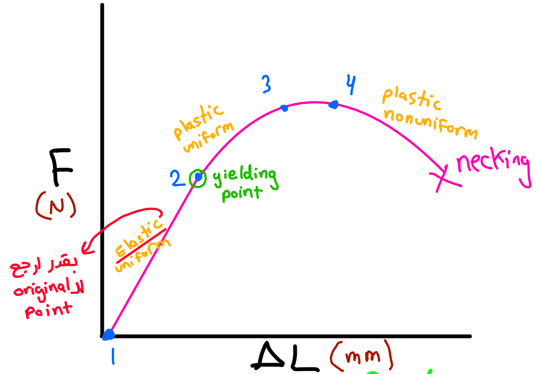
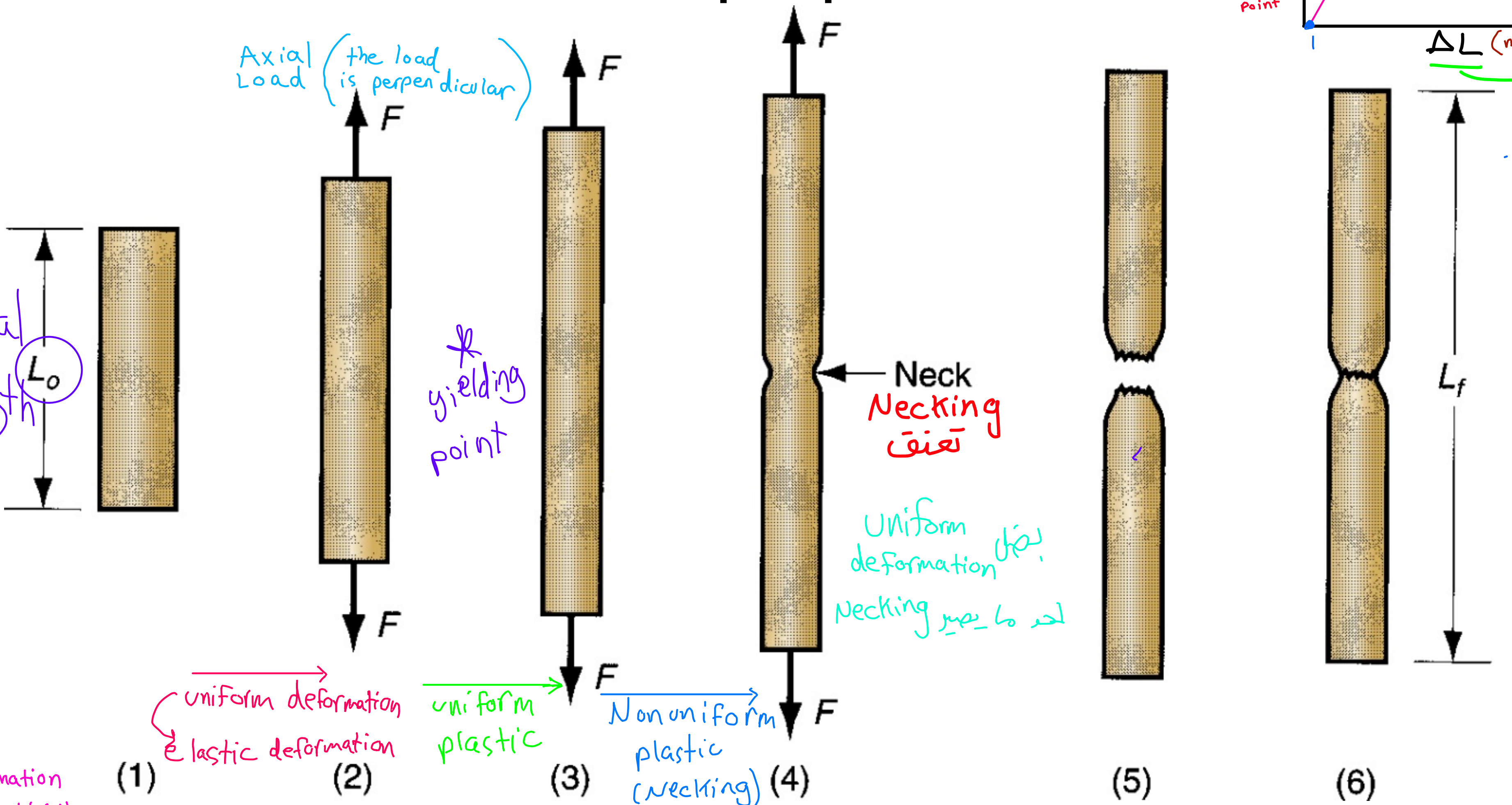


Fig. 3-2: Tensile specimen and setup of the tensile test. (A_0 & L_0: cross sectional area and length before test, length is measured between the gauge marks (gauge length)).

الزيادة في الطول يرافقها
تقليل الـ cross section للحفاظ
على نفس الـ volume

Stress-Strain relationships; Tensile properties





Uniform deformation
انخفاض الـ Area بكل الـ height → is uniform (ثابت)

Fig. 3-3: Progress of a tensile test: (1) beginning of test, no load, (2) uniform elongation and reduction of A_0, (3) Continued elongation, max. load reached, (4) necking begins and load decreases, (5) fracture, and (6) final length can be measured if pieces are put back together.

The machine gives us Load with displacment

Stress-Strain relationships; Tensile properties

- There are two different types of stress-strain curves: (1) Engineering stress-strain and (2) True stress-strain. The first is more important in design and the second is more important in manufacturing.

$\sigma = \frac{F}{A_o}$

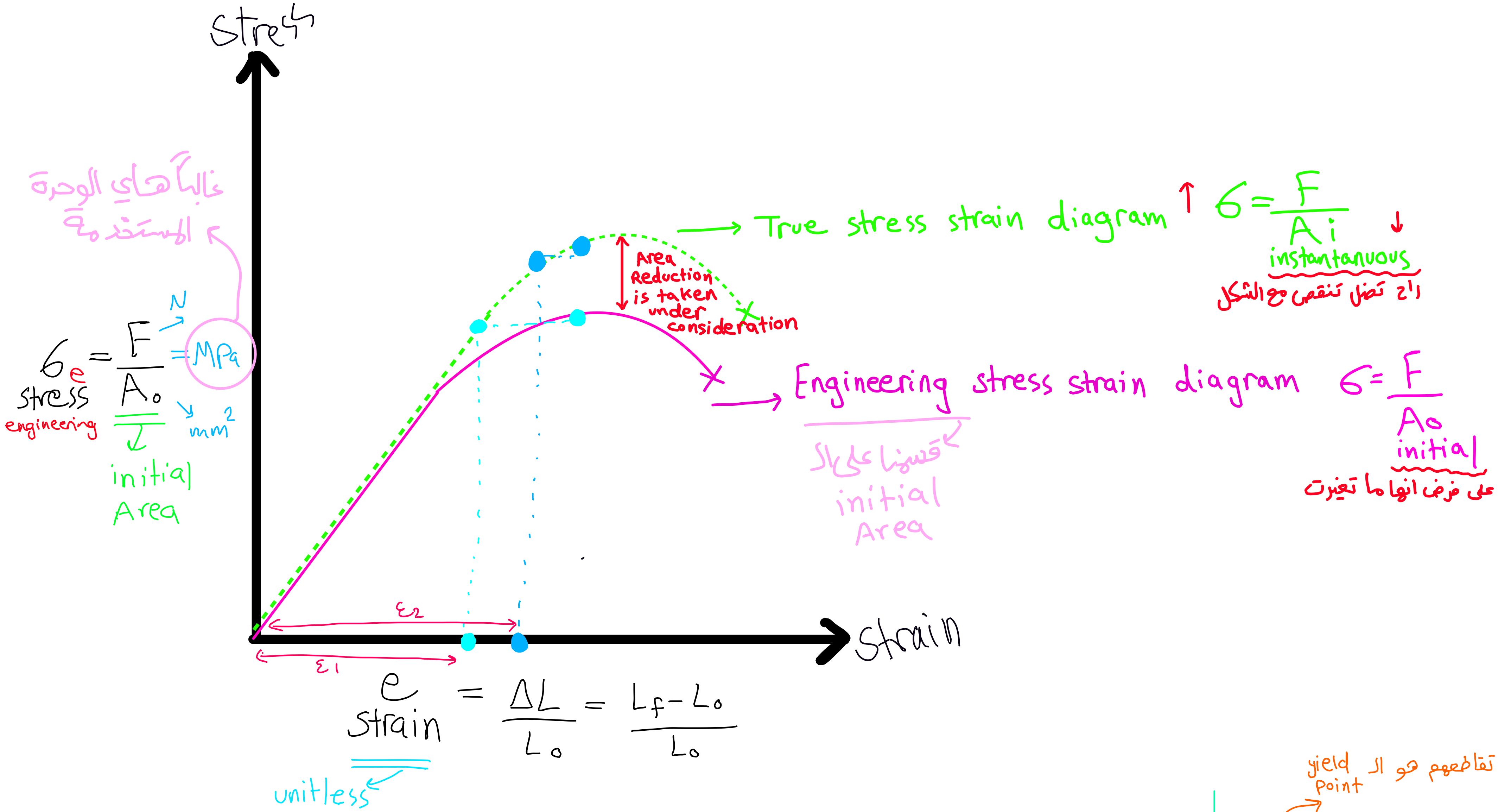
(1) Engineering Stress-Strain: stress and strain defined relative to the original area and length of the specimen.

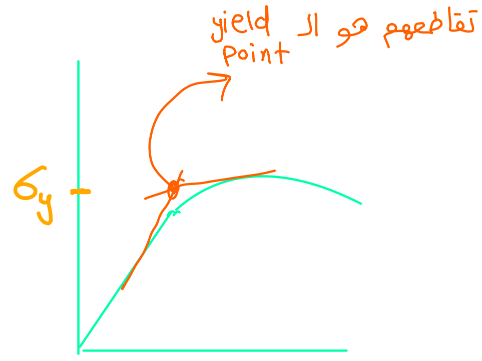
$\sigma = \frac{F}{A_i}$

– Important in design as the designer assumes that the strains experienced by any component will NOT significantly change its shape. The components are designed to withstand the anticipated stresses encountered in service.

Manufacturing Engineers → (True stress-strain diagram) because they represent the actual UTS

Design Engineers → (Engineering stress strain Diagram) For safety reasons





In Elastic Region → True, Engineering → both are exactly the same

Stress-Strain relationships; Tensile properties

- Fig. 3-4 shows an engineering stress-strain curve for a metallic specimen.

- The engineering stress at any point on the curve is defined as the force divided by the original area:

$$\sigma_e = \frac{F}{A_0}$$

where σ_e: engineering stress, MPa (n / mm^2), F = applied force, N, and A_0 is the original area of the specimen, mm^2.

- The engineering strain at any point in the test is given by:

$$e = \frac{L - L_0}{L_0}$$

where e is engineering strain, mm / mm, L = length during the elongation at any point, mm, and L_0 is the gauge length, mm.

e can be thought of as elongation per unit length.

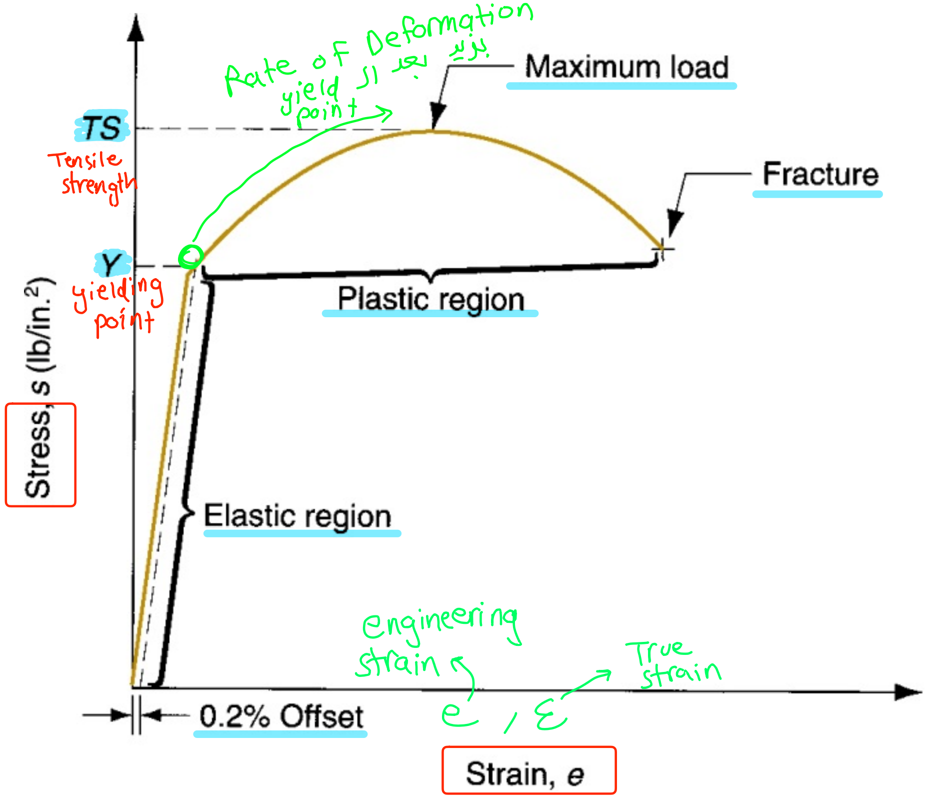


Fig. 3-4: a typical engineering stress-strain curve for a metallic specimen.

Stress-Strain relationships; Tensile properties

- The stress-strain relationship in the figure has two regions, elastic and plastic regions:

  (1) In the elastic region: the relationship is linear and the material exhibits elastic behavior by returning to its original length when the load is released. The relationship is defined by ***Hooke's law***:

$$\sigma_e = Ee$$

,where E is modulus of elasticity (MPa)

  – As stress continues to increase, a point ***Y*** is reached, this is the point where material begins to yield and called the ***yield point*** *or* ***yield strength*** (end of elastic region and transition to plastic region). Y is defined as the stress at 0.2% strain offset (***Y*** is not always clear on the figure).

Stress-Strain relationships; Tensile properties

- The stress-strain relationship in the figure has two regions, elastic and plastic regions:

  (2) In the plastic region: the relationship is no more linear and is no longer guided by Hooke's law. Further stressing will lead to further elongation in the specimen but with faster rate, leading to a dramatic change in the slope.

  – Elongation is accompanied by a uniform reduction in A_0 so as to maintain a constant volume.

  – Finally, the applied load reaches a max. value. The engineering stress calculated at this point is called the *tensile (or ultimate) tensile strength (TS or UTS), where* $TS = F_{max} / A_0$.

  in engineering stress → at maximum value → $UTS = \frac{F_{max}}{A_0}$

  – After crossing the *TS* point, stress starts to decline where ***necking*** occurs; the specimen during necking starts exhibiting localized elongation. The area at the necking narrows down significantly until failure occurs. The stress calculated just before the failure is called ***fracture stress***.

Stress-Strain relationships; Tensile properties

- ***Ductility***: the ability of a material to plastically strain without fracture. Ductility is important in both design and manufacturing. This measure can be taken as either elongation or reduction in area:

(1) Elongation and defined as:

$$EL = \frac{L_f - L_0}{L_0}$$

(2) Area reduction and defined as:

$$AR = \frac{A_0 - A_f}{A_0}$$

Stress-Strain relationships; Tensile properties

- There are two different types of stress-strain curves: (1) Engineering stress-strain and (2) True stress-strain. The first is more important in design and the second is more important in manufacturing.

  (2) True Stress-Strain: stress and strain defined relative to the instantaneous (actual) area that becomes increasingly smaller as the test proceeds.

- The true stress at any point on the curve is defined as the force divided by the instantaneous area:

$$\sigma = \frac{F}{A}$$

where σ: true stress, MPa (n / mm^2), F = applied force, N, and A is the instantaneous area resisting the load, mm^2.

Stress-Strain relationships; Tensile properties

- Similarly, the ***true strain*** is a more realistic assessment of the instantaneous elongation per unit length of the test specimen. This is done by dividing the total elongation into small increments, calculating the engineering strain for each increment of its starting length, and then adding up the strain values:

$$\varepsilon = \int_{L_0}^{L} \frac{dL}{L} = \ln \frac{L}{L_0}$$

where *L* is the instantaneous length at any moment during deformation

Stress-Strain relationships; Tensile properties

- The elastic region in the true stress-strain curve is almost similar to that of the engineering stress-strain curve (can you guess why). Hence, the elastic region in the true curve obeys Hooke's Law.

- The progressive reduction in area in the true stress-strain curve is considered in the plastic region. Hence, the stress in this region is higher as compared to that of the engineering stress-strain curve.

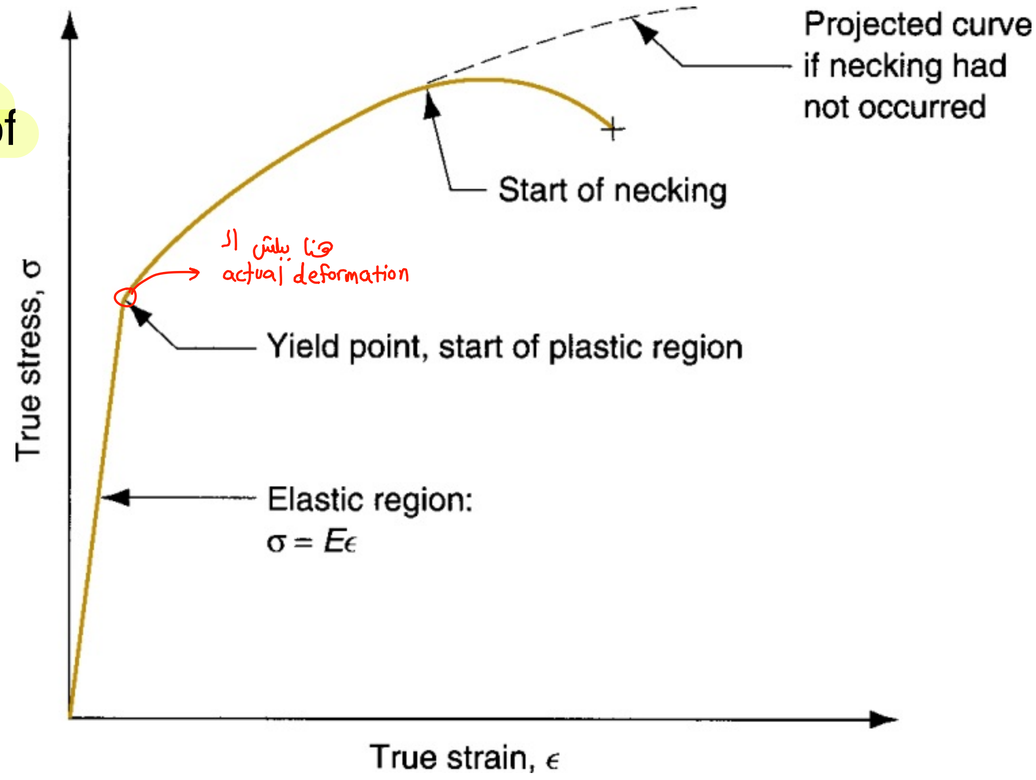


Fig. 3-5: a typical true stress-strain curve for a metallic specimen.

$$\varepsilon = \ln(1+e)$$

$$\sigma = \sigma_e(1+e)$$

True strain, eng strain, True stress, eng stress, eng strain

Stress-Strain relationships; Tensile properties

- Strain (work) hardening: a property that most metals exhibits during deformation. It means that the metal is getting stronger as strain increases (see true stress-strain curve).

- Strain hardening is important in manufacturing, especially in metal forming processes.

- With plotting the true stress and true strain of the plastic region on a log-log scale, the result would be a linear relationship as in fig. 3-6, and the relation between true stress and true strain would then be:

$$\sigma = K\varepsilon^n$$

K (strength coefficient) = σ if $\varepsilon = 1$.

n (strain hardening exponent) (slope), and related to a metal's tendency to work harden.

- Flow curve equation. It captures a good approximation of the behavior of metals in the plastic region, including their capacity for strain hardening

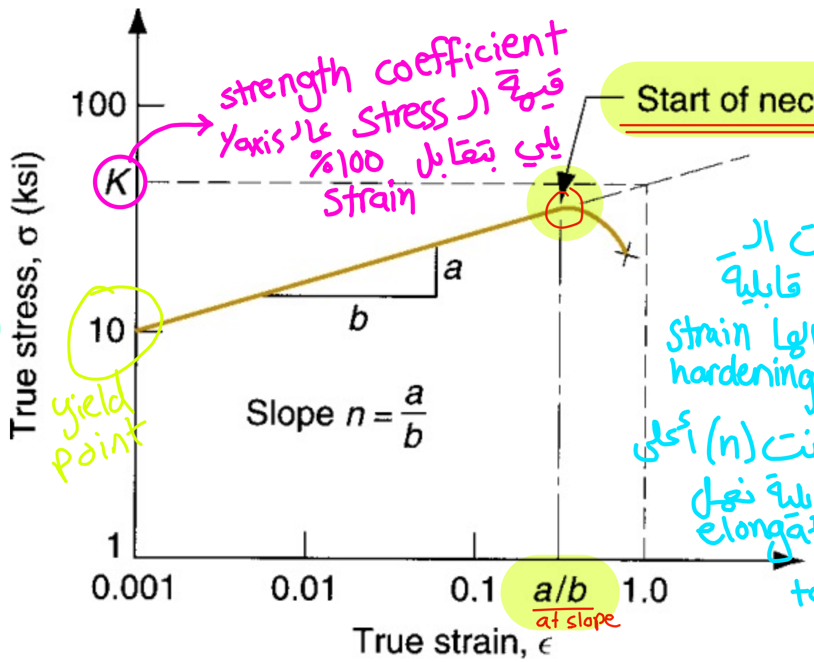


Fig. 3-6: true stress-strain curve plotted on a log-log scale.

Note: Necking is closely related to strain hardening.

Necking begins when $\varepsilon = n$. A higher n means the metal can be strained further before necking begins

Crystalline Structures

- A **crystalline** material is one in which the atoms are situated in a repeating or periodic array over large atomic distances; that is, long-range order exists, such that upon solidification, the atoms will position themselves in a repetitive three-dimensional pattern, in which each atom is bonded to its nearest-neighbor atoms (that includes all metals, many ceramics and many polymers).

Imperfections in Crystals

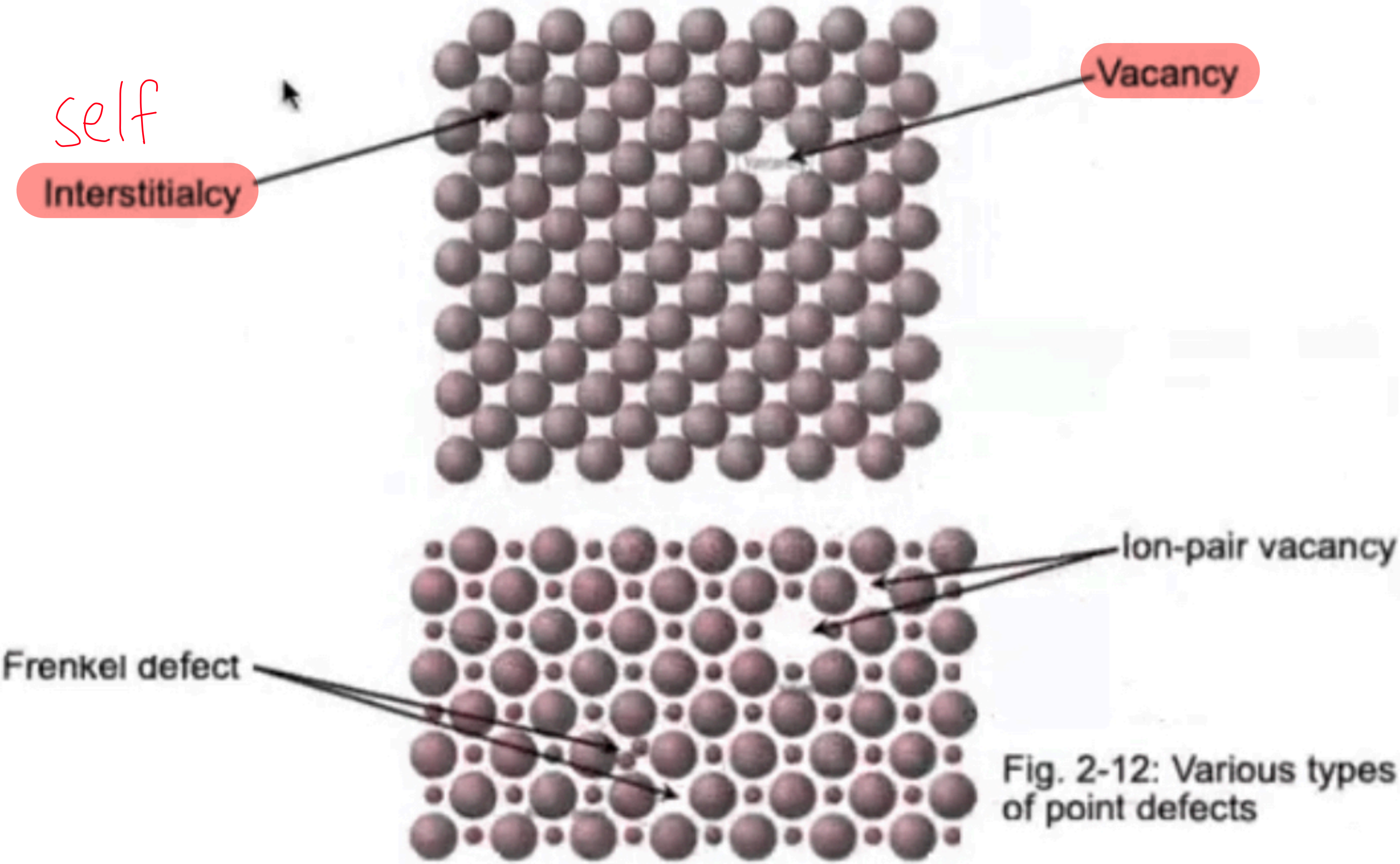


Fig. 2-12: Various types of point defects

Deformation in Metallic Crystals

- The atoms at the edge dislocation require a smaller displacement within the distorted lattice structure in order to reach a new equilibrium position. Thus, a lower energy is needed to realign the atoms into the new positions than if the lattice were missing a dislocation.

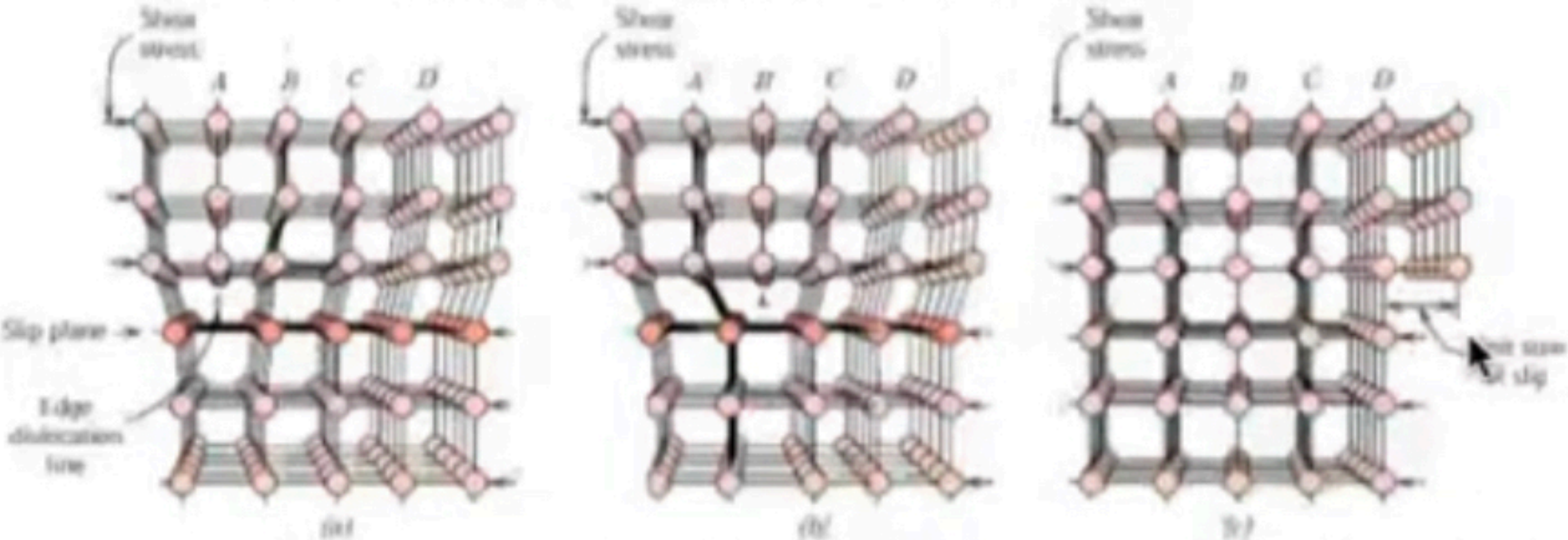
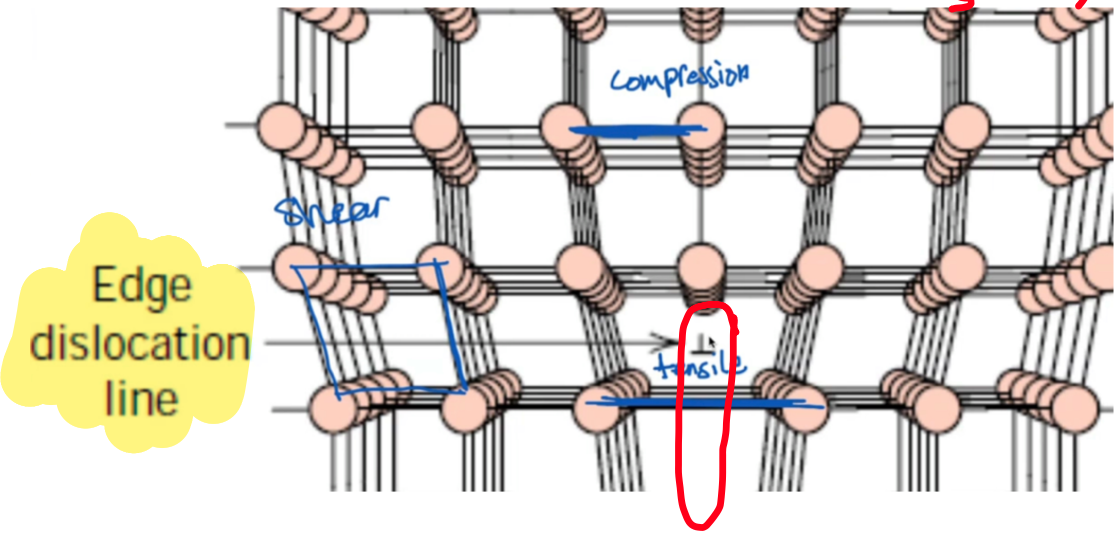
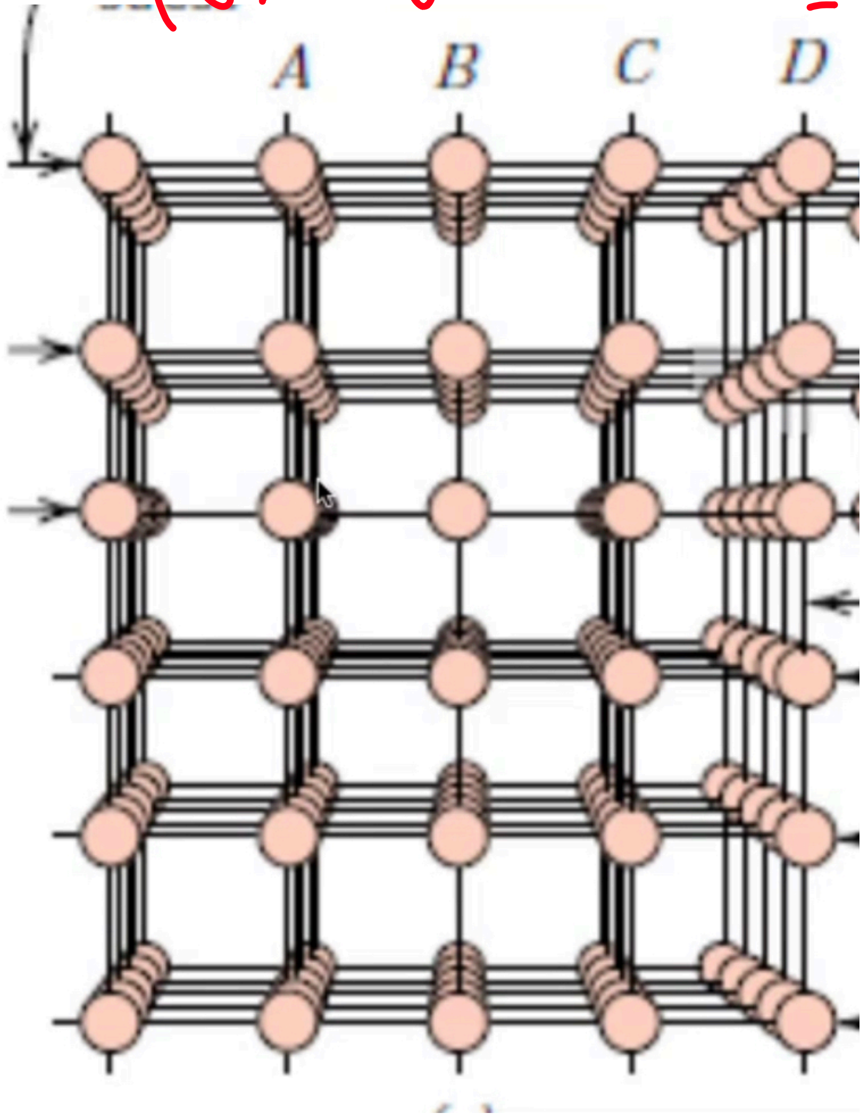


Fig. 2-17: Atomic rearrangements that accompany the motion of an edge dislocation as it moves in response to an applied shear stress. *(a)* The extra half-plane of atoms is labeled *A*. *(b)* The dislocation moves one atomic distance to the right as *A* links up to the lower portion of plane *B*; in the process, the upper portion of *B* becomes the extra half-plane. *(c)* A step forms on the surface of the crystal as the extra half-plane exits.

There is a dislocation line
(we have stresses)



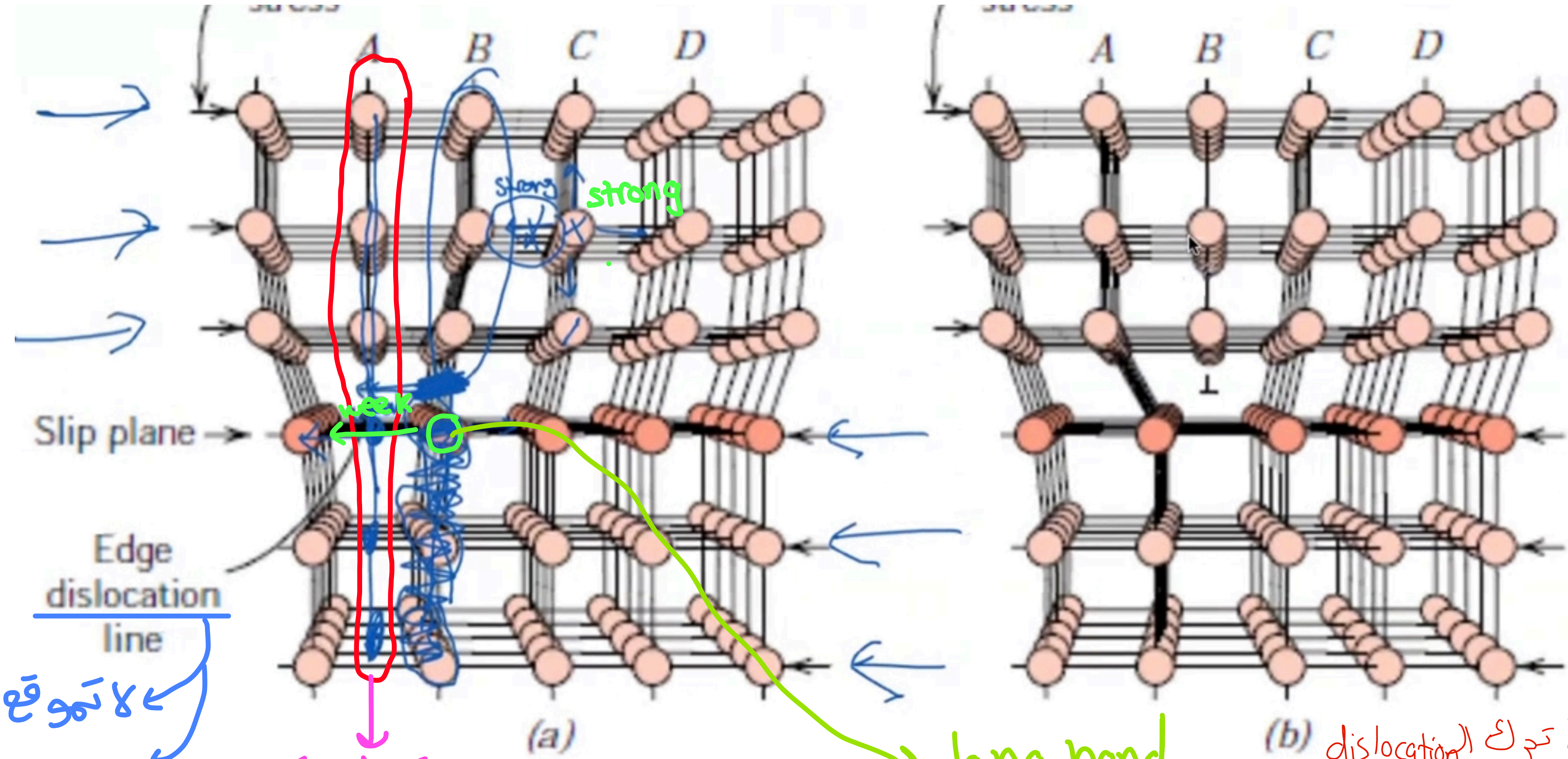
الشكل بدون dislocation
(ما في stresses مثل القبل)



(in plastic Deformation)

line Defect

كل واحد يعتبر plane لأنه ليس له thickness

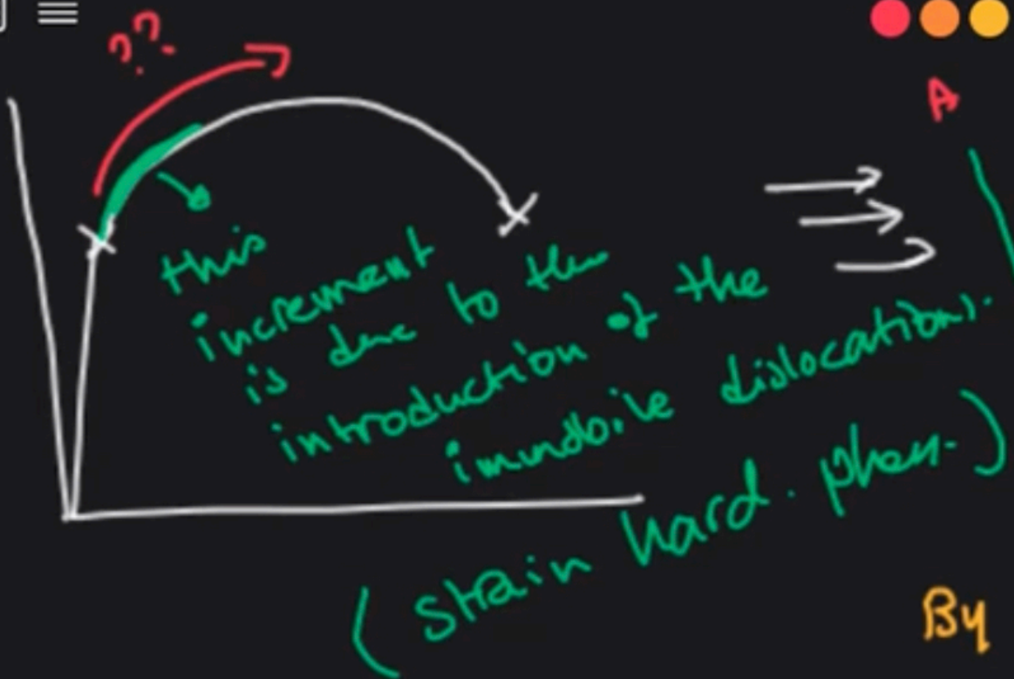


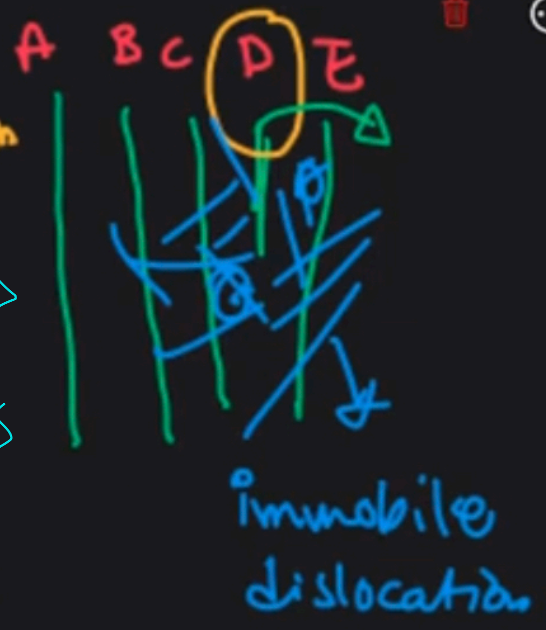
Edge dislocation line → لاتموقع → الانخلاع

بقدر اسميه
* extra half plane of atoms
or
* missing half plane of atoms

long bond so its weak bond

لما تحرك الdislocation معناه صار عندي plastic deformation بالعادة
(حركة الdislocation تدل على الplastic region)





By application of stress :

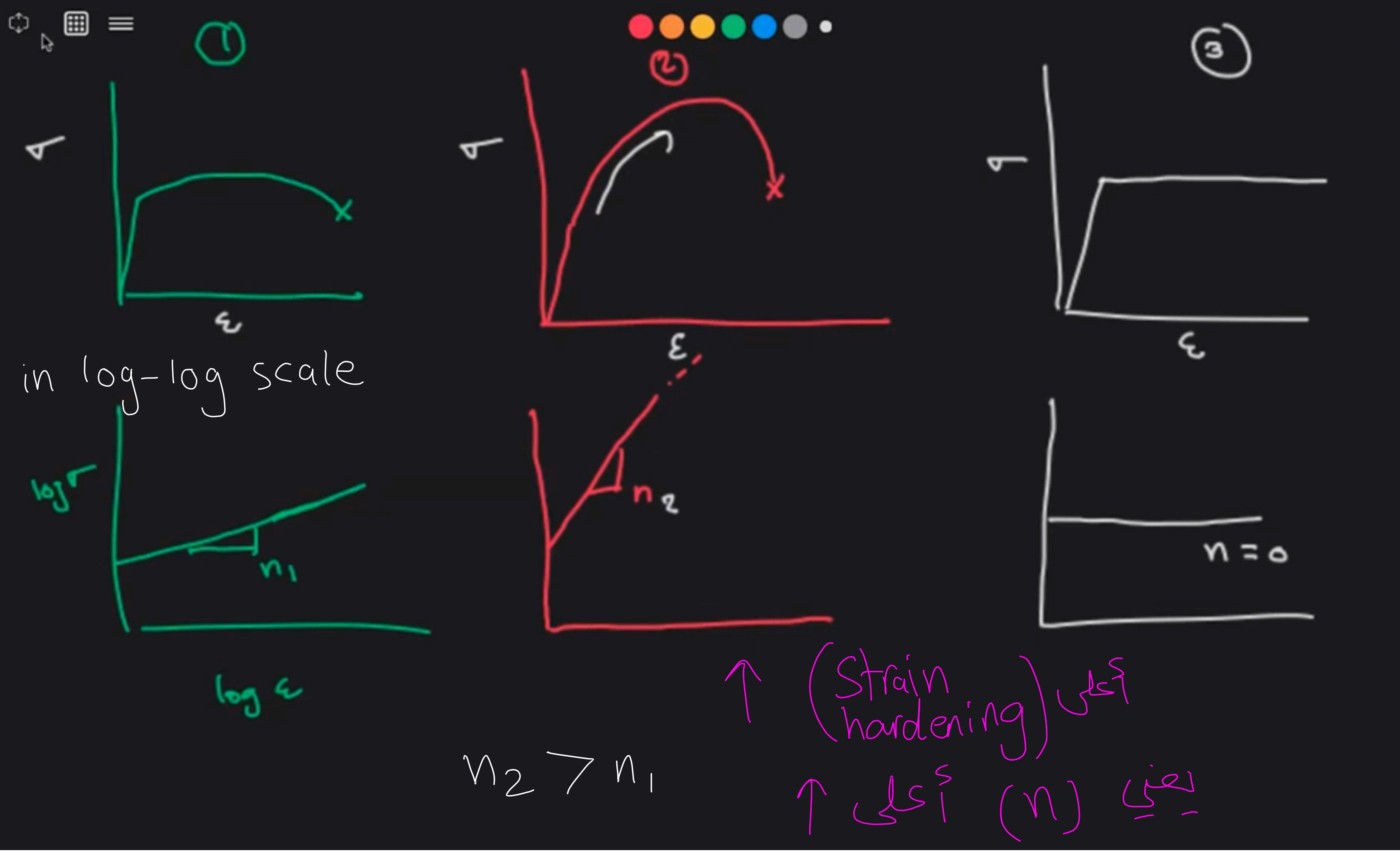
1. we move the mobile dislocation

2. we create new defects

(immobile dislocations)

they cannot move

they work as obstacles for the motion of the mobile dislocations.



1
2
3
σ
ε
in log-log scale
log σ
log ε
n1
n2
n = 0
n2 > n1
↑ (Strain hardening) أعلى
↑ أعلى (n) يعني

Stress-Strain relationships; Tensile properties

- Much information about elastic-plastic behavior is provided by the true stress-strain diagram; as Hooke's law governs the metal's behavior in the elastic region and the flow curve equation determines the behavior in the plastic region. Three basic forms of stress-strain relationship describe the behavior of nearly all metals:

(a) Perfectly elastic: the material is defined completely by its stiffness indicated by modulus of elasticity. It fractures before yielding or plastic flow; example of these materials are ceramics and thermosetting polymers. These materials are bad for forming.

(b) Elastic and perfectly plastic: as yield stress is reached, the material deforms plastically at the same stress level. Flow curve in this case $K = Y$ and $n = 0$. Happens to metals heated during straining that recrystallization occurs rather than strain hardening. For Pb, this is the situation at RT as the recrystallization temperature for Pb is below RT.

(c) Elastic and strain hardening: obeys Hooke's Law in the elastic region, and starts to flow when Y is reached. Continued deformation requires an ever-increasing stress, given by flow curve whose K is > Y and n is > 0. Most ductile materials behave this way when cold-worked.

Stress-Strain relationships; Tensile properties

- Much information about elastic-plastic behavior is provided by the true stress-strain diagram; as Hooke's law governs the metal's behavior in the elastic region and the flow curve equation determines the behavior in the plastic region. Three basic forms of stress-strain relationship describe the behavior of nearly all metals:

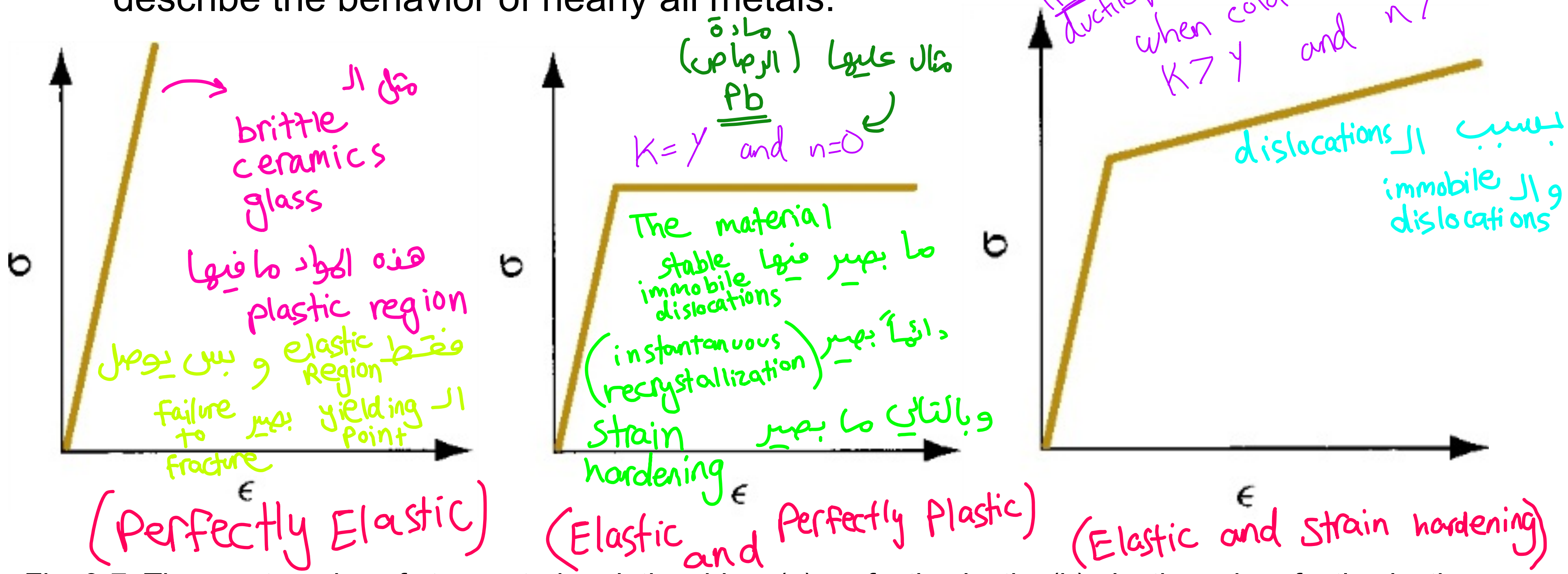


Fig. 3-7: Three categories of stress-strain relationships: (a) perfectly elastic, (b) elastic and perfectly plastic and (c) elastic and strain hardening.

Stress-Strain relationships;
Compression properties

- Compression test: a test that applies a load that squeezes a cylindrical specimen between two platens (see fig. 3-8). As the specimen is compressed, its height is reduced and its cross-sectional area is increased. The engineering stress is defined in the same way as in the tensile test; i.e.,

$$\sigma_e = \frac{F}{A_0}$$

- The engineering strain is defined as:

$$e = \frac{h - h_0}{h_0}$$

where h is the height of the specimen at any particular moment into the test in mm, and h_0 is the starting height in mm.

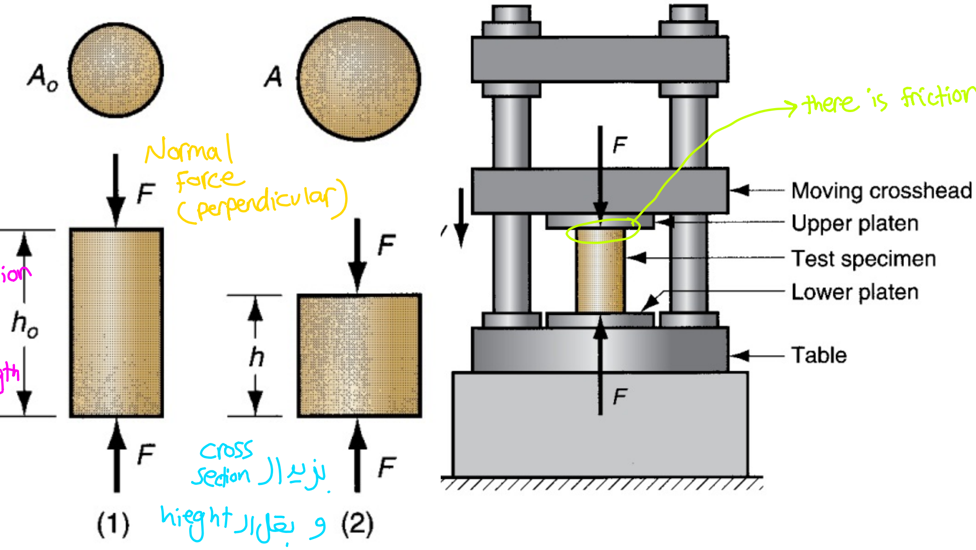


Fig. 3-8: Compression test: (a) compression force applied to test specimen in (1) and (2) resulting change in height; and (b) setup of the test.

Note that e will have a negative sign, as the height is decreased during compression. This sign is neglected.

Stress-Strain relationships; Compression properties

- Fig. 3-9 shows an engineering stress-strain curve. The curve has elastic and plastic regions as before, but the shape of the plastic region is different from its tensile test complement. Reasons:
  - Compression causes A to increase, the load increases more rapidly.
  - As the cylindrical specimen is compressed, friction at the surfaces in contact with the platens prevent the cylinder from spreading. Additional energy is consumed by friction during the test, resulting in a higher applied force.
  - This will result in ***barreling*** of the specimen; the middle of the specimen is permitted to increase in A much more than at the ends.
  - Important compression processes include forging, rolling and extrusion.

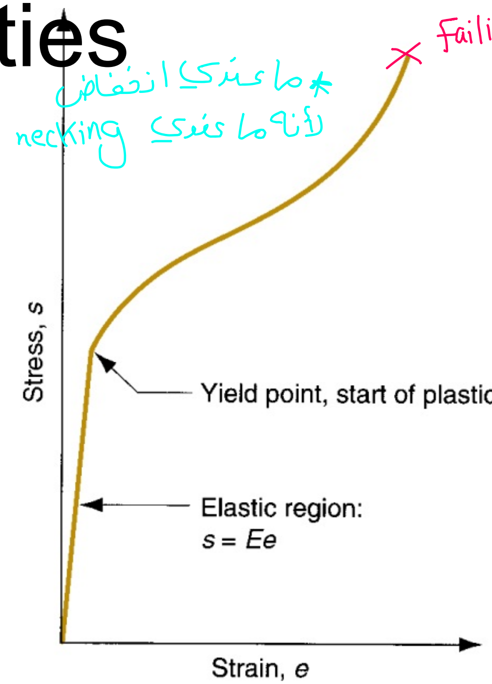


Fig. 3-9: Typical engineering stress-strain curve for a compression test.

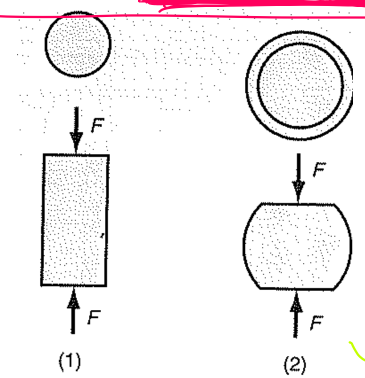


Fig. 3-10: Barreling effect. (1) before and (2) after compression.

combination of tensile and compression

Stress-Strain relationships; Bending & Testing of Brittle Materials

- Bending operations: used to form metal plates and sheets (Fig. 3-11; showing the setup of the bending test). Bending results in two stress (and strain) components; tensile in the outer half of the bent section and compressive in the inner half.

- ***Bending test*** (also known as ***flexure test***) suits brittle materials that possess elasticity the best; e.g. ceramics.

- These materials do not respond well to traditional tensile testing because of the difficulty in preparing the test specimens and possible misalignment of the press jaws that hold the specimen.

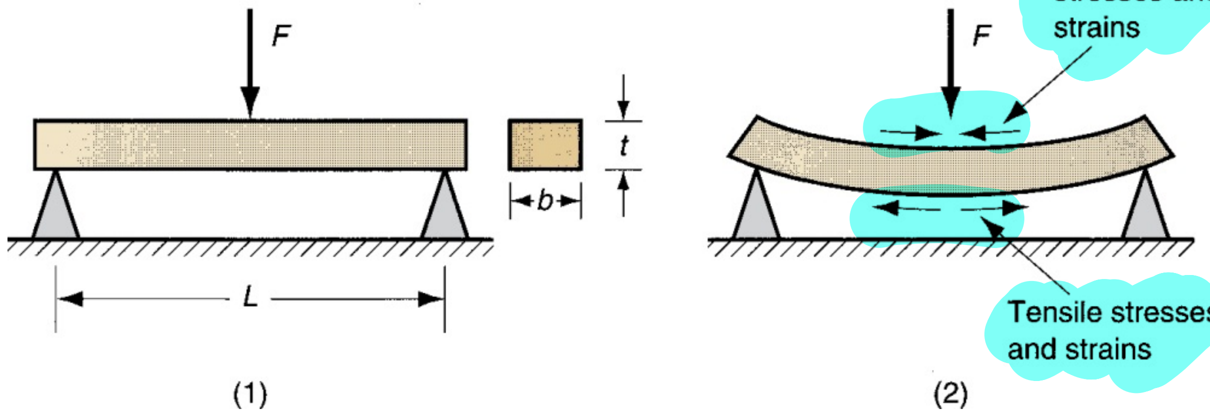


Fig. 3-11: Bending test setup and specimen: (1) initial loading, and (2) highly stressed and strained specimen

Stress-Strain relationships; Bending & Testing of Brittle Materials

- Specimen's cross-section is rectangular, positioned between supports and load is applied at its center (three-point bending test).
- The specimen bends elastically during the test until immediately before fracture (no plastic region).
- Strength value derived from this test is called ***Transverse Rupture Strength*** (*TRS*):

$$TRS = \frac{1.5FL}{bt^2}$$

where TRS is in MPa, F: the applied load at fracture in N, L: the length between supports and b and t are dimensions of the cross-section in mm (Fig. 3-11)

- Flexure test can be utilized for nonbrittle materials such as thermoplastic polymers. These materials deform rather fracture, so TRS cannot be determined. Instead, either of the two measures are used: (1) the load recorded at a given level of deflection, or (2) the deflection observed at a given load.

Stress-Strain relationships;
Shear properties

- Shear: involves the application of stresses on opposite directions on either side of an element to deflect it.

- Shear stress is defined as:

$$\tau = \frac{F}{A}$$

where τ : shear stress, MPa (n / mm^2), F = applied force, N, and A is the area over which force is applied, mm^2.

- Shear strain can be defined as:

$$\gamma = \frac{\delta}{b}$$

where γ is shear strain, mm / mm, δ = the deflection of the element, mm, and L_0 is the orthogonal distance over which the deflection occurs, mm.

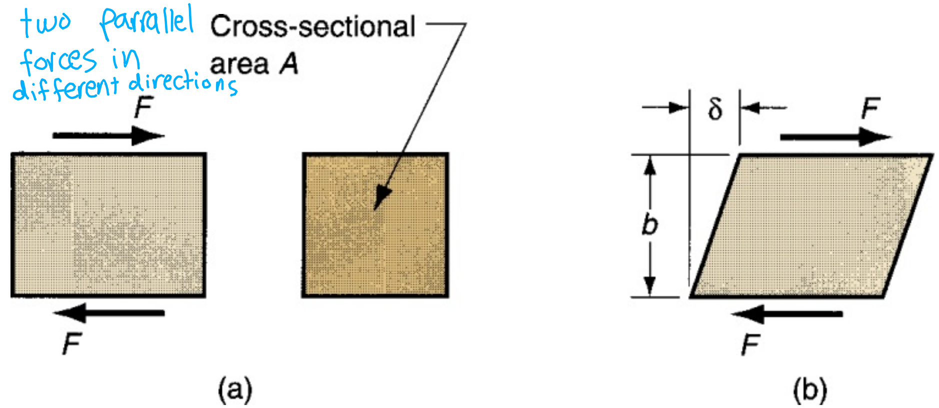


Fig. 3-12: Shear (a) stress and (b) strain.

Stress-Strain relationships; Shear properties

- Shear stresses and strains are commonly tested in a ***torsion test***.

- In torsion test: a thin-walled tubular specimen is subjected to a torque. As torque is increased, a tube deflects by twisting (shear strain for this geometry).

$$\tau = \frac{T}{2\pi R^2 t}$$

where T: is the applied torque (N-mm), R = radius of the tube measured to the neutral axis of the wall (mm), and t = wall thickness (mm).

- Shear strain :

$$\gamma = \frac{R\alpha}{L}$$

where α is the angular deflection, radians, and L is the gauge length in mm.

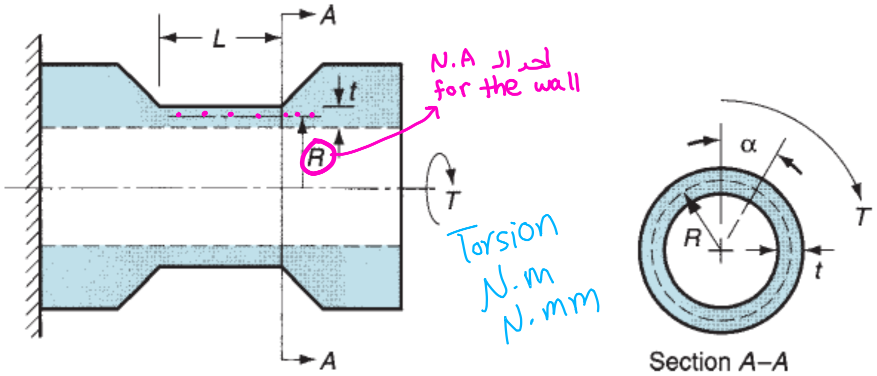


Fig. 3-13: Torsion test setup.

Stress-Strain relationships; Shear properties

- A typical shear stress-strain curve is shown in Fig. 3-14.

- In the elastic region:

Shear modulas

$$\tau = G\gamma$$

where G: is the ***Shear modulus*** or ***shear modulus of elasticity*** (MPa)

- G is related to E by the equation:

$$G = 0.4E$$

where E is the conventional elastic modulus.

- In the plastic region:

The material strain hardens to cause the applied torque to continue to increase until fracture.

Shear strength is the stress at fracture (S).

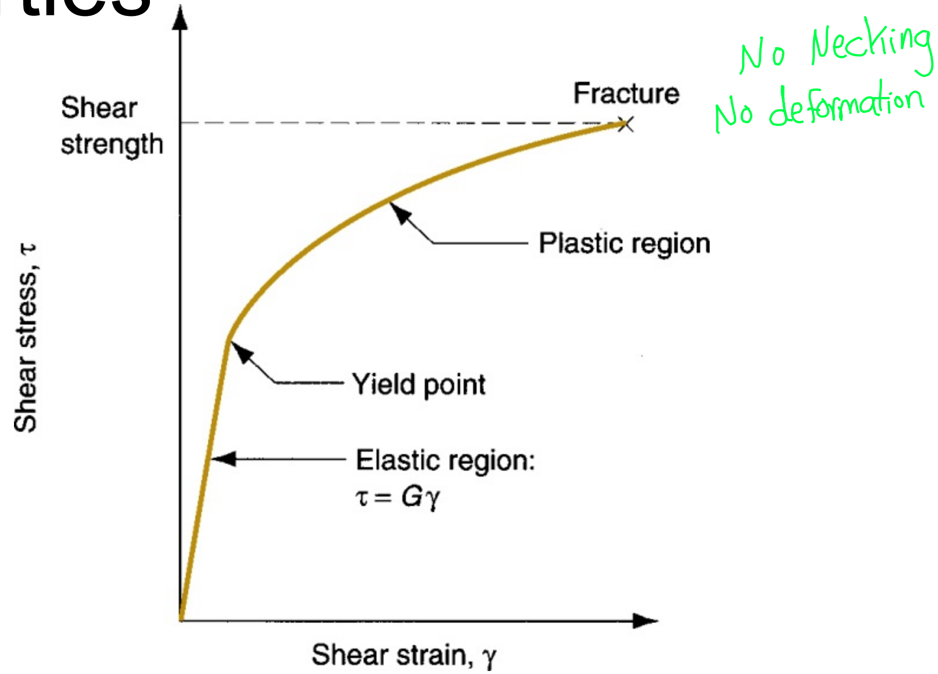


Fig. 3-14: A typical shear stress-strain curve from a torsion test.

S can be estimated from tensile test data

$$S = 0.7(TS)$$

Shear examples in industry: blanking, punching & machining

Engineering and true stress-strain curves for shear are similar. Guess why?

because the area doesn't change so they are exactly the same in shear

Effect of Temperature on Properties

- Temperature has a significant effect on nearly all properties of materials.

- **Important in design**: a designer need to know how the material properties at the operating temperatures during service.

- **Important in manufacturing**: a manufacturer need to know how the properties are affected by temperature during manufacturing.

- Generally speaking, the higher the temperature the higher the ductility and the lower the strength (better formability at high temperatures).

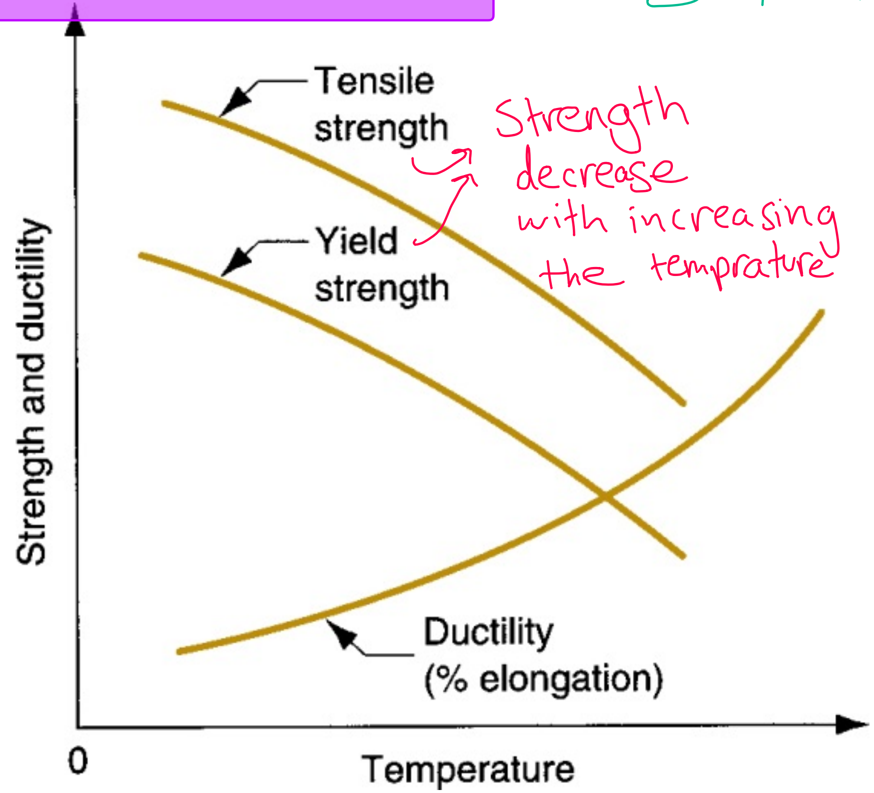


Fig. 3-18: Effect of temp. on strength & ductility

إذا برفع درجة الحرارة ال bonding between atoms بصير أضعف

Strength decrease with increasing the temprature

Tempreture ↑
Strength values ↓
Ductility ↑

Effect of Temperature on Properties (Hot Hardness)

- **Hot hardness**: is a property often used to characterize strength and hardness at elevated temperatures. It is simply the ability of a material to retain hardness (or resist softening) at elevated temperatures.

- Usually presented as a plot of hardness versus temperature.

- In steel: alloying would enhance the hot hardness.

- Ceramics: they show superior properties at elevated temperatures (that is why they are used as refractory material).

- Good hot hardness is desirable in tooling materials used in manufacturing operations.

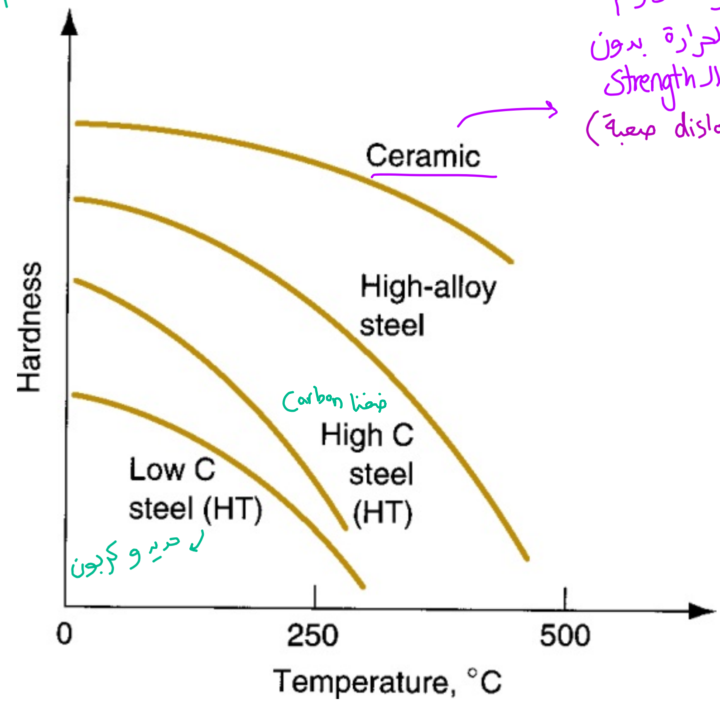


Fig. 3-19: Hardness vs. temperature for various materials.

Effect of Temperature on Properties (Recrystallization Temp.)

- **Recrystallization**: is the process in which new strain-free grains are formed. The temperature at which this process happens is called the ***Recrystallization Temperature*** (~ one half the melting temperature (0.5 $T_{melting}$)).

- If metals were deformed at room temperature, they would behave in accordance with the flow curve equation. $\sigma = K\varepsilon^n$

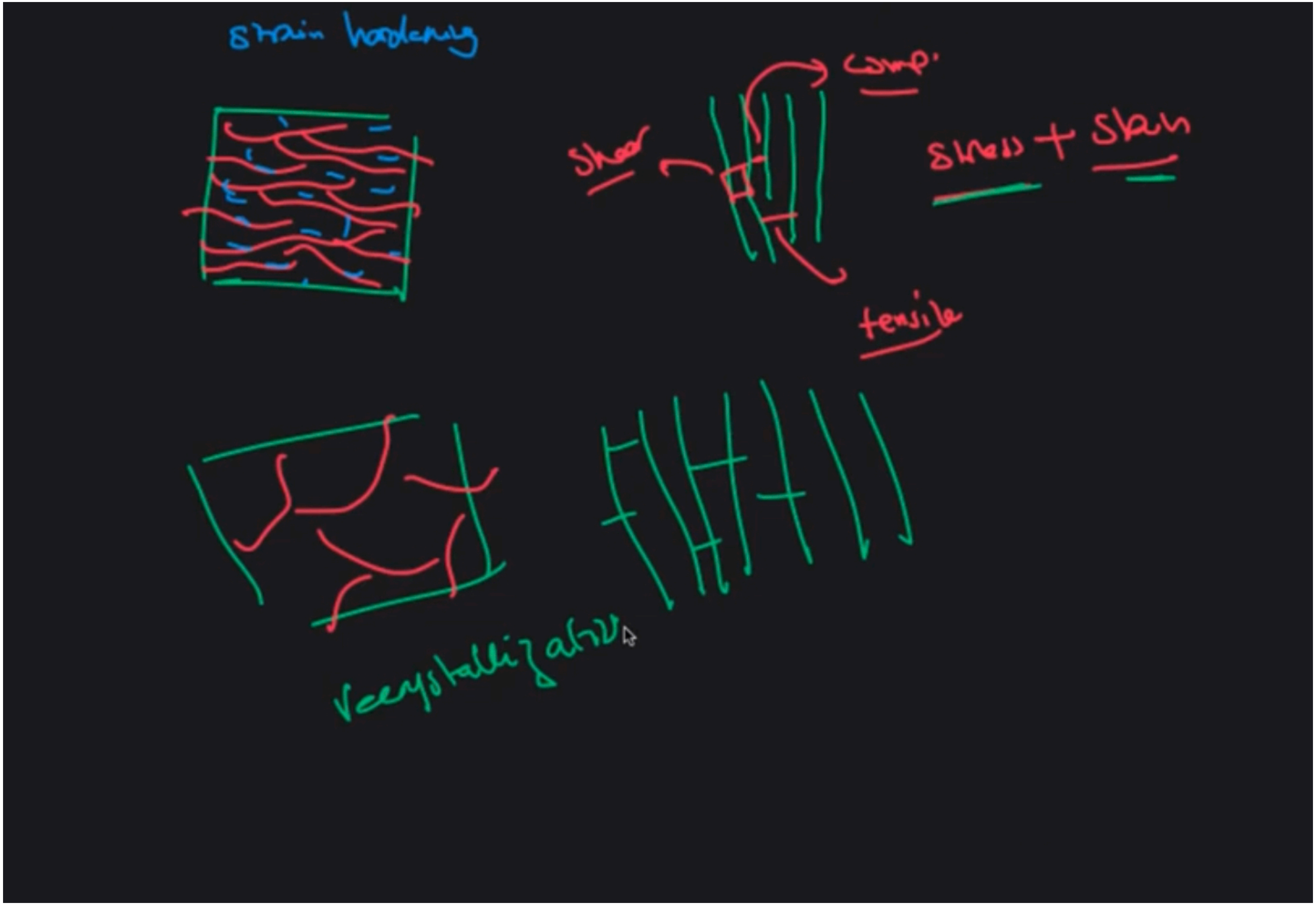
- If metals where deformed at high temperatures, say recrystallization temperature, then they would have an elastic and superplastic behavior (no strain hardening). $\sigma = K =$ Yield streng because $n=0$

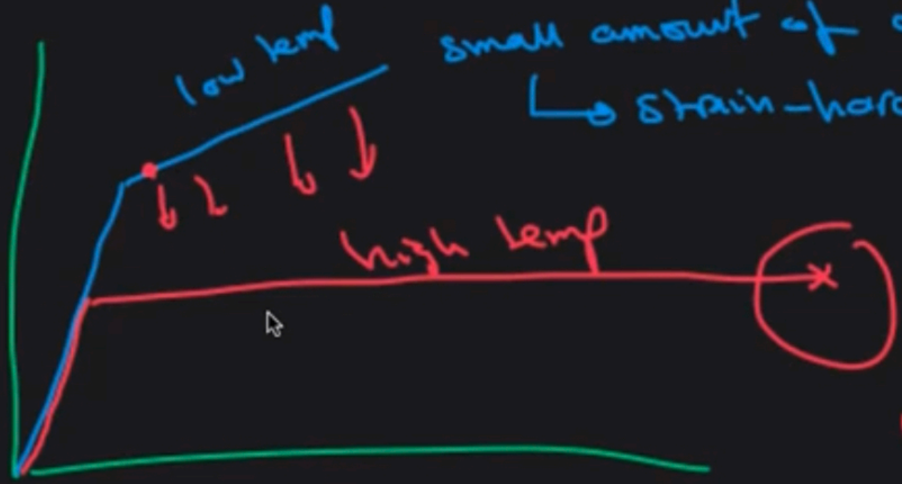
- This is due to the formation of new strain-free grains at elevated temperatures.

- Higher strain can be endured (تحملت) at recrystallization temperature. Power spent to carry out deformation is significantly reduced.

  Ductility ↑
  Strength ↓
  Stress values ↓
  بالتالي الـ power ↓ بتكون أقل
  لأن الـ strength أقل

- Metal forming at recrystallization temperature is called ***Hot Working***.


strain hardening
shear
comp.
stress + strain
tensile
recrystallization



small amount of deformation (cold-working)
→ strain-hardening

large amount of deformation
hot-working

10cm → 1 mm

10cm → 3mm hot working

3mm → 1mm cold-working
→ strengthening.

hot-working

Hardness

- ***<u>Hardness</u>***: is a measure of a material's resistance to localized plastic deformation (permanent indentation).
- High hardness: material is resistant to scratching and wear.
- Mohs scale (qualitative): ranges from 1 on the soft end for talc to 10 for diamond.
- There is a good correlation between the material's hardness and its strength.

Hardness

- Hardness tests are performed more frequently than any other mechanical test for several reasons:
  - They are simple and inexpensive—ordinarily no special specimen need to be prepared, and the testing apparatus is relatively inexpensive.
  - The test is nondestructive—the specimen is neither fractured nor excessively deformed; a small indentation is the only deformation.
  - Other mechanical properties often may be estimated from hardness data, such as tensile strength

Hardness
Rockwell Hardness Tests

- The most common method used to measure hardness because they are so simple to perform and require no special skills.
- Several indenters (steel ball, conical diamond), several loads can be utilized. Thus, suitable for almost all metal alloys, including polymers.
- Indenter (1.6 or 3.2 mm in diameter) is pressed into the specimen. Load starts at 10 kg to seat the indenter in the material, and then increased up to 150 kg. The indenter penetrates into the material. The distance penetrated (*d*) is converted to Rockwell hardness by the testing machine.

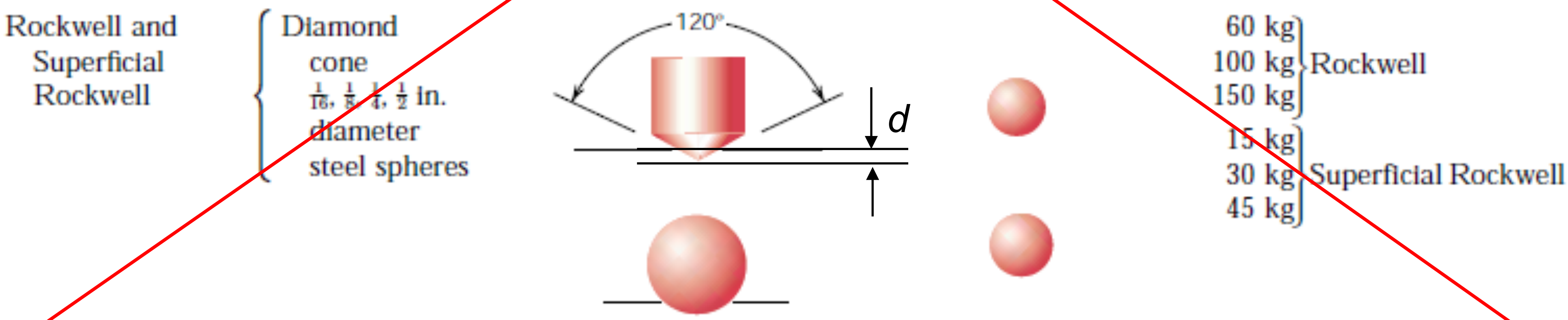


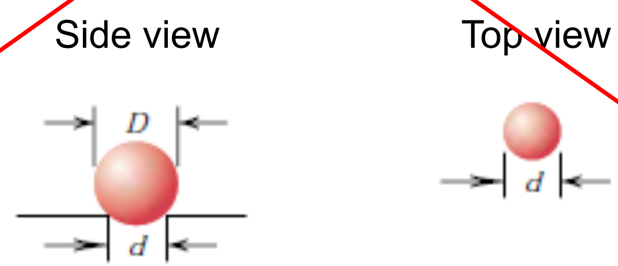
Fig. 3-15: Rockwell hardness testing technique.

Hardness
Brinell Hardness Tests

- In Brinell tests, as in Rockwell measurements, a hard, spherical indenter (10 mm in diameter) is forced into the surface of the metal to be tested.
- Standard loads range between 500 and 3000 kg.
- The load is then divided into the indentation area to get Brinell Hardness number.

Brinell

10-mm sphere of steel or tungsten carbide



$$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$$

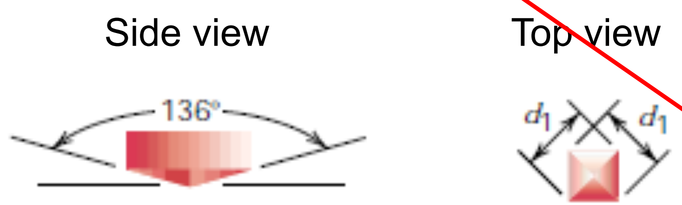
Fig. 3-15: Brinell hardness testing technique.

Hardness
Vickers Hardness Test

- Uses a pyramid-shaped diamond indenter (10 mm in diameter).
- Impressions made by this indenter are geometrically similar regardless of load.
- Value of load applied depends on the material's hardness.
- Applied loads are much smaller than for Rockwell and Brinell, ranging between 1 and 1000 g.

Vickers microhardness

Diamond pyramid



$$HV = 1.854P/d_1^2$$

Fig. 3-16: Vickers hardness testing technique.

Hardness
Knoop Hardness Test

- Uses a pyramid-shaped diamond indenter with length to width ratio of 7:1.
- Applied loads are the smallest comparing to Rockwell, Brinell and Vickers hardness.

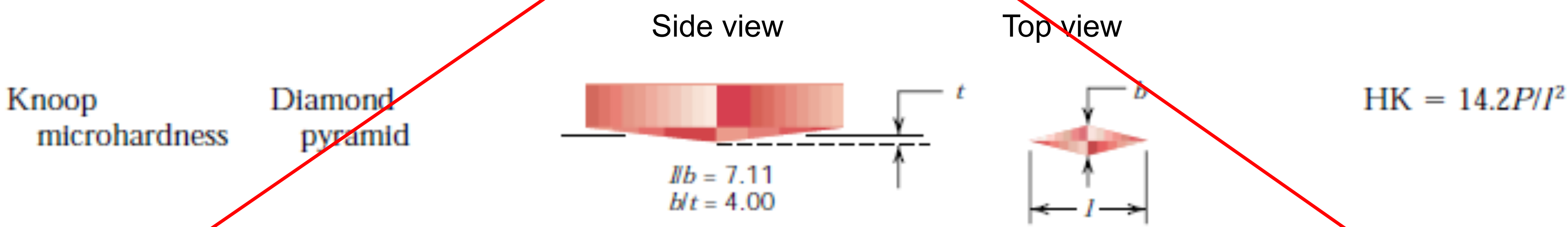


Fig. 3-17: Vickers hardness testing technique.

Hardness of Various Materials

- **Metals**: For most metals, hardness is closely related to strength.
- Hardness is a form of compression, so one would expect a good correlation between hardness and strength properties determined in a compression test.
- Compression and tensile tests are nearly the same, so the correlation with tensile properties would also be acceptable.
- Brinell hardness exhibits a close correlation with *TS* (MPa) for steels, and the formula is:

$$TS = 3.45HB$$

Metal	Brinell Hardness, HB	Rockwell Hardness, HR[a]
Aluminum, annealed	20	
Aluminum, cold worked	35	
Aluminum alloys, annealed[b]	40	
Aluminum alloys, hardened[b]	90	52B
Aluminum alloys, cast[b]	80	44B
Cast iron, gray, as cast[b]	175	10C
Copper, annealed	45	
Copper alloy: brass, annealed	100	60B
Lead	4	
Magnesium alloys, hardened[b]	70	35B
Nickel, annealed	75	40B
Steel, low C, hot rolled[b]	100	60B
Steel, high C, hot rolled[b]	200	95B, 15C
Steel, alloy, annealed[b]	175	90B, 10C
Steel, alloy, heat treated[b]	300	33C
Steel, stainless, austenitic[b]	150	85B
Titanium, nearly pure	200	95B
Zinc	30	

Hardness of Various Materials

- <u>Ceramics</u>: Brinell hardness is not appropriate for ceramics as they are usually harder than the Brinell hardness indenter.

- Instead, Vickers and Koop hardness tests are used to test ceramics.

Material	*Approximate Knoop Hardness*
Diamond (carbon)	7000
Boron carbide (B_4C)	2800
Silicon carbide (SiC)	2500
Tungsten carbide (WC)	2100
Aluminum oxide (Al_2O_3)	2100
Quartz (SiO_2)	800
Glass	550

Approximate Knoop Hardness (100 g load)
for Seven Ceramic Materials.

Hardness of Various Materials

- Polymers: Softer than metals and ceramics, and most hardness tests are conducted by penetration techniques similar to those described for metals. Rockwell and Brinell tests are frequently used for polymers.

Polymer	Brinell Hardness, HB	Polymer	Brinell Hardness, HB
Nylon	12	Polypropylene	7
Phenol formaldehyde	50	Polystyrene	20
Polyethylene, low density	2	Polyvinyl-chloride	10
Polyethylene, high density	4		

Fluid Properties

- Unlike solids, fluids flow; they take the shape of the container that holds them.
- Fluids include liquids and gases.
- Many manufacturing processes are done by converting the materials from the solid state to the liquid state.
- Examples are: metal casting, glass blowing and polymer molding.

Fluid Properties
Viscosity

- All fluids can flow. However, the tendency to flow differs for different fluids.

- **Viscosity**: is the resistance to flow, that is characteristic of a fluid. It is the property that determines fluid flow, and a measure of the internal friction that arises when velocity gradients are present in the fluid.

- In other words, the more viscous the fluid is, the higher the internal friction and the greater the resistance to flow.

- **Fluidity**: is the reciprocal of viscosity; the ease with which a fluid flows.

Fluid Properties
Viscosity

- Considering Fig. 3-20, viscosity can be defined more precisely.

- Two plates, one is stationary and the other is moving at velocity v (oriented to the *x*-axis). Plates are separated by a distance *d* (oriented to the *y*-axis). The space between the plates is occupied by a fluid.

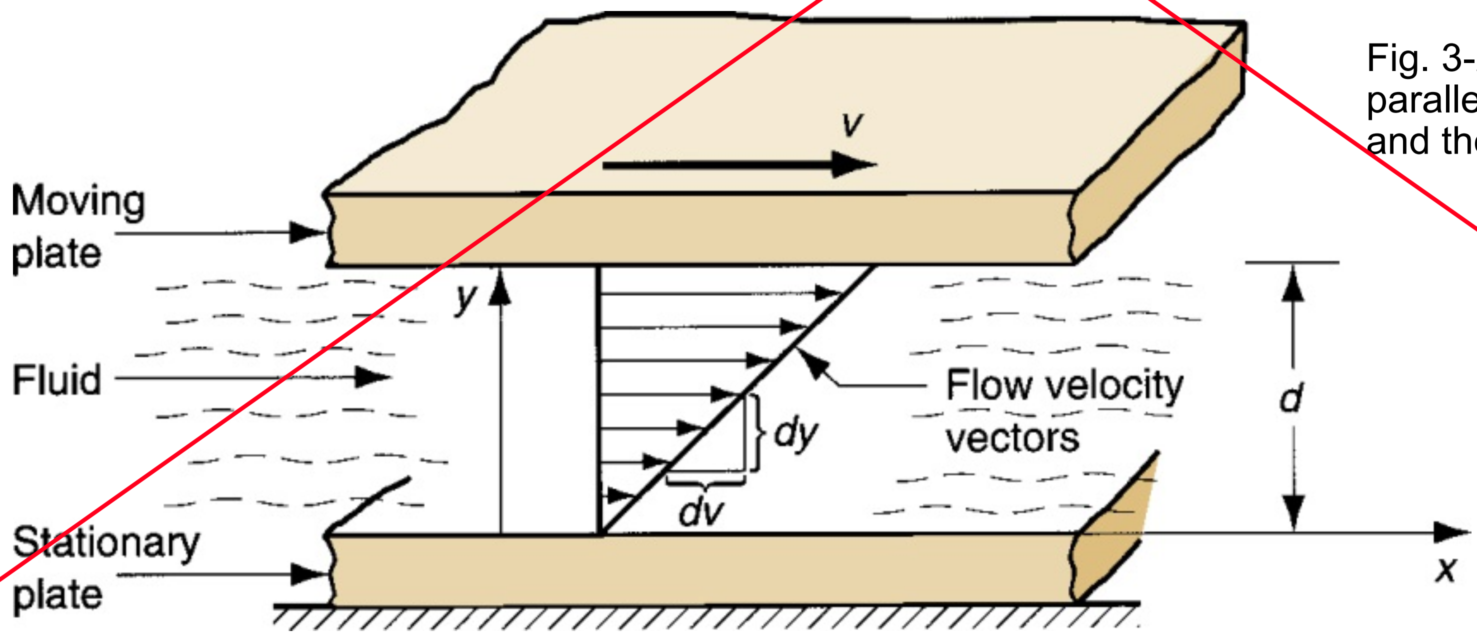


Fig. 3-20: Fluid flow between two parallel plates. One is stationary and the other is moving.

Fluid Properties
Viscosity

- The motion of the upper plate is resisted by force F that results from shear viscous action. This force can be described as shear stress:

$$\tau = \frac{F}{A}$$

Where τ is the shear stress in Pa (N/m^2).

- Shear stress is related to the rate of shear, which is defined as the change in velocity dv relative to the dy:

$$\dot{\gamma} = \frac{dv}{dy}$$

Where $\dot{\gamma}$ is the shear rate in 1/s; dv is the incremental change in velocity in m/s; and dy is the incremental change in distance y in m.

Fluid Properties
Viscosity

- The shear viscosity is the fluid property that defines the relationship between F/A and dv/dy:

  $$\frac{F}{A} = \eta \frac{dv}{dy} \quad \text{or} \quad \tau = \eta \dot{\gamma}$$ where η is the coefficient of viscosity (Pa-s).

- Rearranging, we get:

  $$\eta = \frac{\tau}{\dot{\gamma}}$$

- Thus, viscosity of a fluid can be defined as the ratio between shear stress to shear rate during flow; where shear stress is the frictional force exerted by a fluid per unit area , and shear rate is the velocity gradient perpendicular to the flow direction.

- Newton observed that viscosity is a constant property of a given fluid. Such a fluid is called ***Newtonian fluid***.

Fluid Properties
Viscosity in Manufacturing Processes

- In metals: many manufacturing processes require melting the metal; e.g. welding and casting.
- Success in these operations require low viscosity so that the molten metal fills the mold cavity or weld seam before solidifying.
- In forming processes, lubricants and coolants are used, and again the success of these fluids depends to some extent on their viscosity.
- In glasses: they exhibit gradual transition from solid to liquid. They become less and less viscous with the increase in temperature, until they can be finally shaped by blowing or molding at around 1100 ºC.

Metal Forming Processes

Chapter Fifteen:

Bulk Deformation Processes in Metal Working

Dr. Eng. Yazan Al-Zain
Department of Industrial Engineering

Introduction

عمليات تشوه الكتلة

- Bulk deformation processes in metal working include:

أهم اشي

- – Rolling.
- – Other deformation processes related to rolling.
- عمليات الطرق – Forging.
- – Other deformation processes related to forging.
- النتوء – Extrusion.
- عمليات سحب الاسلاك – Wire and Bar Drawing.

Introduction

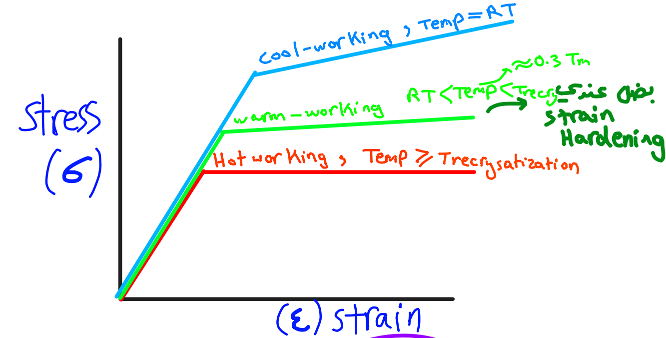
- Bulk deformation processes accomplish significant shape change in metal parts whose initial form is bulk rather than sheet.

- The starting forms include (1) cylindrical bars and billets, (2) rectangular billets and slabs, and (3) similar elementary geometries.

- The bulk deformation processes **refine the starting shapes**, sometimes improving mechanical properties, and **always** adding commercial value.

- Deformation processes work by **stressing** the metal sufficiently to cause it to plastically flow into the desired shape.

Introduction



- Bulk deformation processes are performed as (1) cold, (2) warm, and (3) hot working operations.
- Cold and warm working is appropriate when the shape change is less severe, and there is a need to improve mechanical properties and achieve good finish on the part.
- Hot working is generally required when massive (ضخم) deformation of large workparts is involved.

Hot working
- → No strain hardening
- → Strength ↓
- → Ductility ↑
- → Recrystalization

Cold working
- → strain hardening phenomena
- → Strength ↑
- → Ductility ↓

* يحصل (Plastic deformation) عند درجات حرارة عالية [Hot working]

Introduction

- The commercial and technological importance of bulk deformation processes derives from the following:
  - When performed as hot working operations, they can achieve significant change in the shape of the workpart. strength ↓
  - When performed as cold working operations, they can be used not only to shape the product, but also to increase its strength through strain hardening. strength ↑
  - These processes produce little or no waste as a byproduct of the operation. Some bulk deformation operations are near net shape or net shape processes; they achieve final product geometry with little or no subsequent machining.

Rolling

- ***Rolling***: is a deformation process in which the thickness of the work is reduced by compressive forces exerted by two opposing rolls.

- The rolls rotate to pull and simultaneously squeeze the workpart between them.

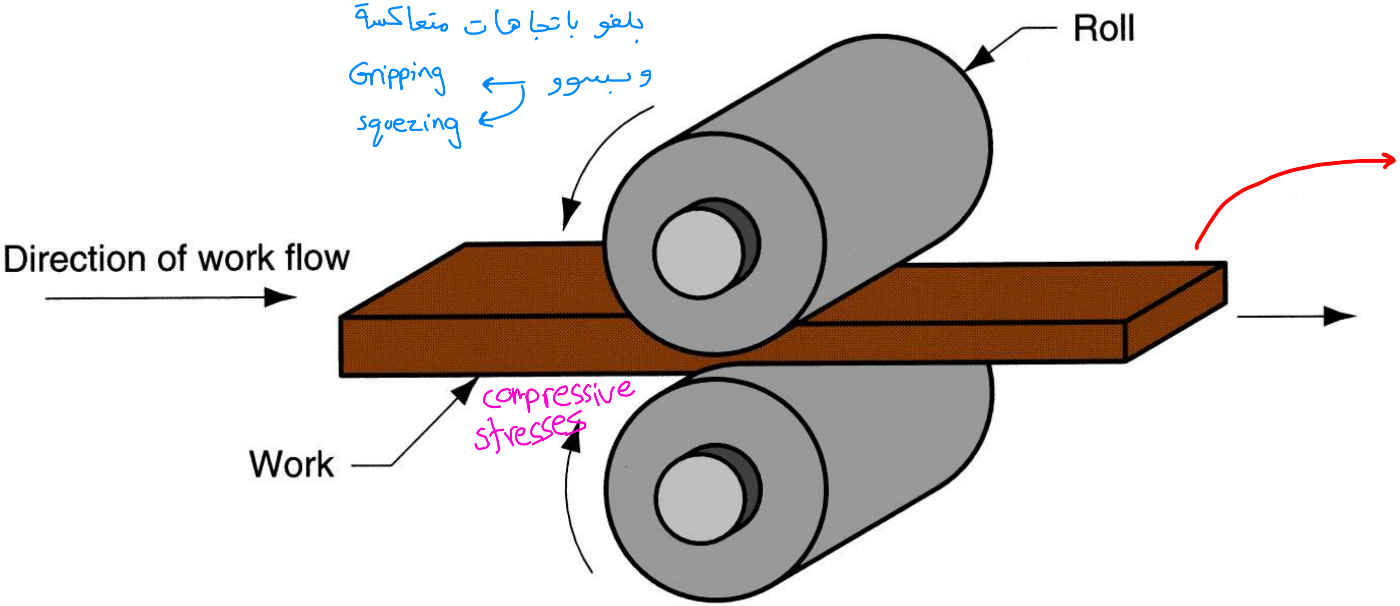


Figure 19.1 The rolling process (specifically, flat rolling).

- According to the part geometry, the rolling processes can be divided into:

التركيز هنا

  – ***Flat rolling***: used to reduce the thickness of a rectangular cross section.

  – ***Shape rolling***: related to flat rolling, in which a square cross section is formed into a shape such as an I-beam.

Tolerance
↳ Range of error

Rolling

- Rolling can be carried out at high or low (ambient) temperatures.

محيط

  – ***Hot rolling***: most rolling is carried out by hot working, due to the large amount of deformation required.

  is more common

  – Hot-rolled metal is generally free of residual stresses, and its properties are isotropic (similar properties in different directions).

  very important

  – Disadvantages of hot rolling are that the product cannot be held to close tolerances, and the surface has a characteristic oxide scale.

بسبب ارتفاع Temp

مثال
10 cm ± 0.01 cm
9.99 ~ 10.01 cm
(close tolerance)
↳ with cold working

10 cm + 1 cm
9 ~ 11 cm
(loose tolerance)
↳ with hot working

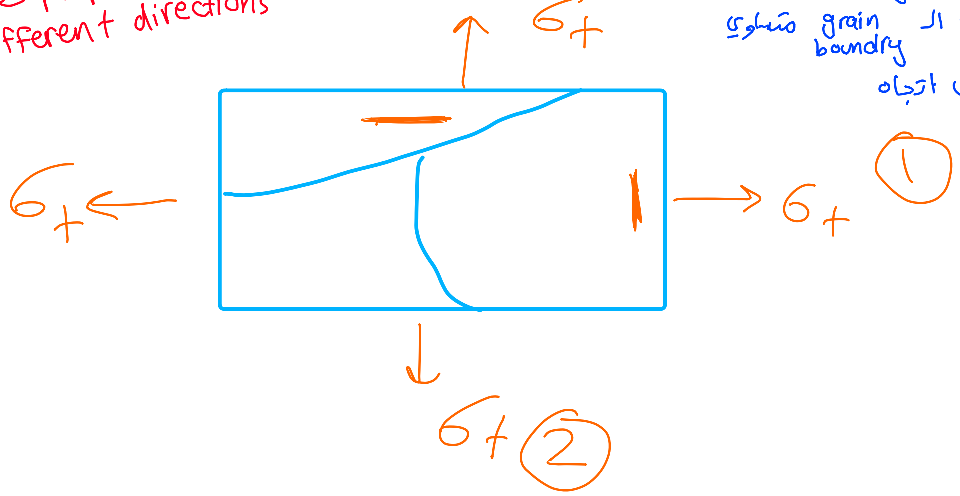
Hot working في ال
بنتخلص من ال Dislocations و ال Stresses
compression, Tension, shear

grain boundry
بالنسبة لل dislocation
تعتبر obstacle
عائق

Isotropic properties
→ same properties in different directions

Hot-worked product

بفعل يصير في instantenuous recrestalyzation
وكدر ال grain boundry متساوي لكل اتجاه



$$UTS① = UTS②$$

$$GBA① = GBA②$$

Isotropy

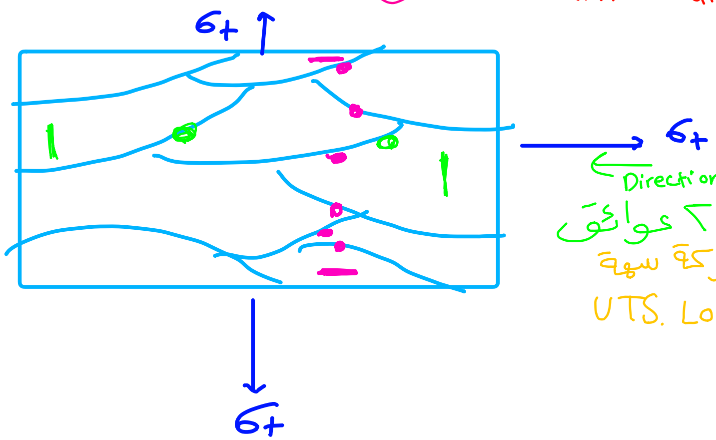
Cold-working Product

عوائق ↑

الحركة صعبة
UTS high

Direction ②

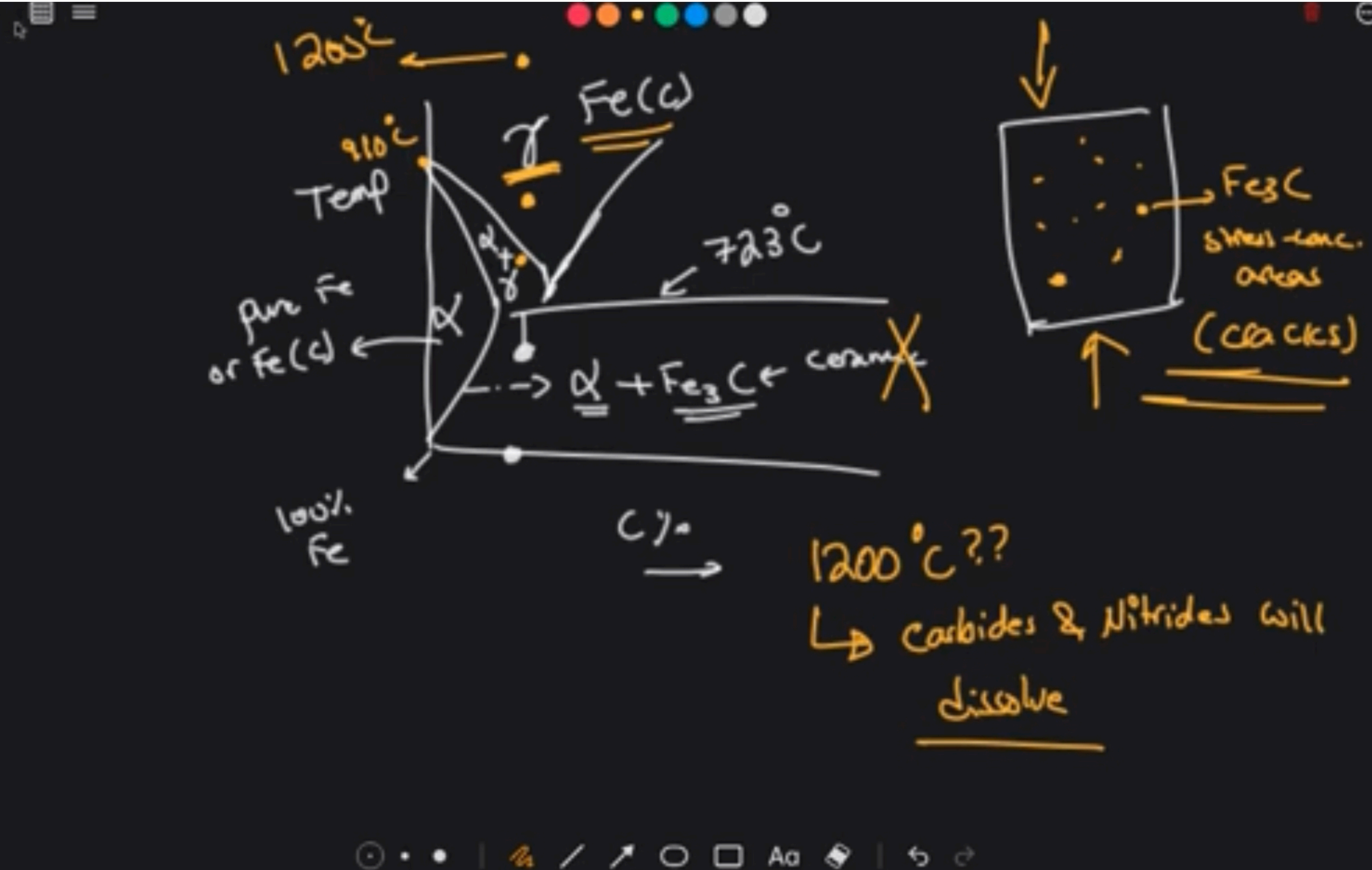
(Anisotropic Properties)
→ different properties for different directions



عوائق ↓
الحركة سهلة
UTS. Low

UTS
yield strength
في الاتجاه ② أكبر

Phase Diagram



Rolling

- Rolling can be carried out at high or low (ambient) temperatures.
  - ***Cold rolling***: less common than hot rolling. close tolerance
  - Cold rolling strengthens the metal and permits a tighter tolerance on thickness.
  - غياب المقياس
  - the surface of the cold-rolled sheet is absent of scale and generally superior to the corresponding hot-rolled product.

Rolling

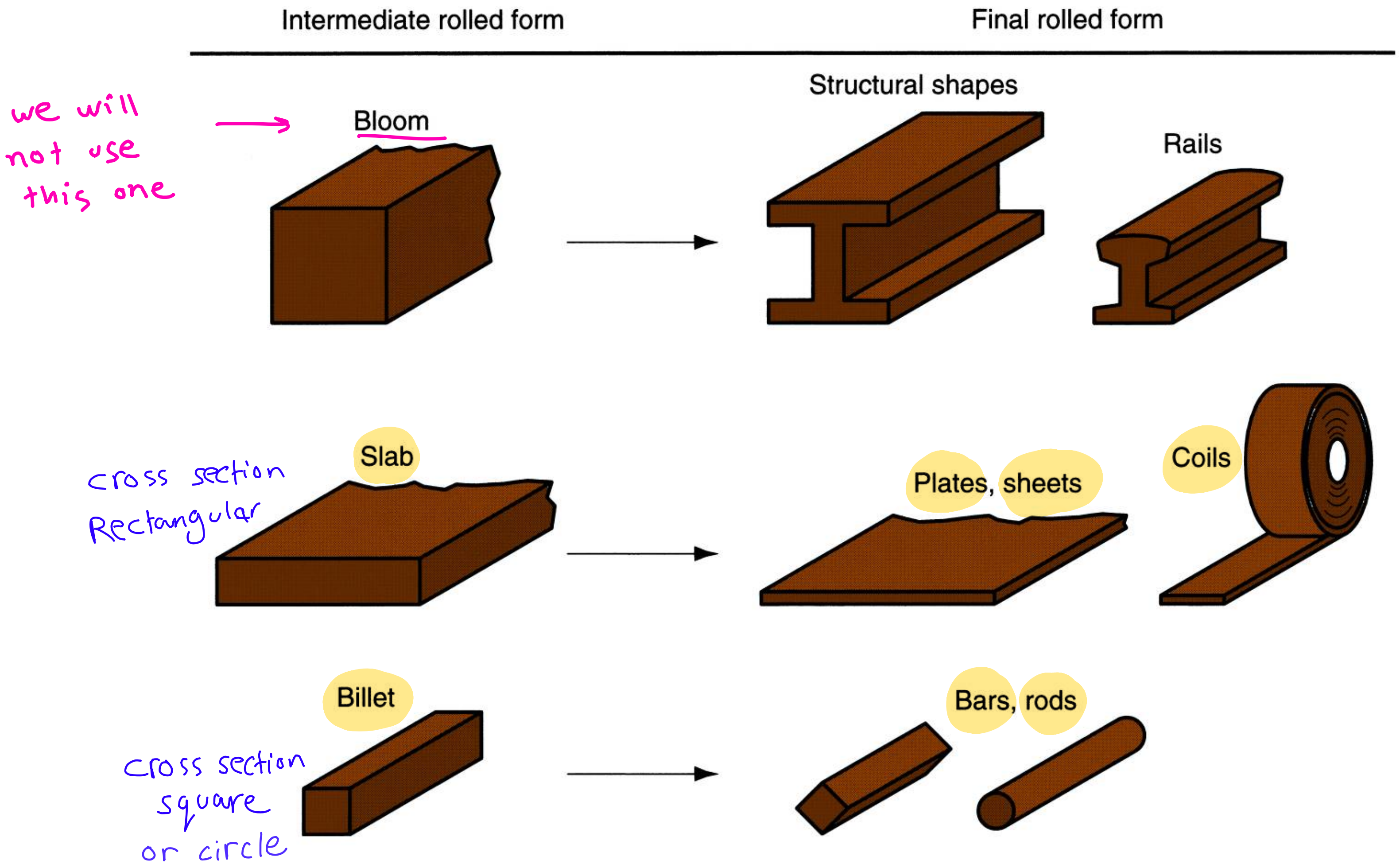
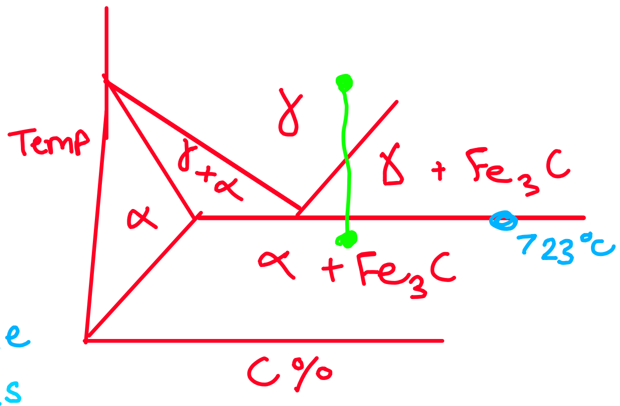


Figure 19.2 Some of the steel products made in a rolling mill.

There is a video
"مهم جداً"

slab ⟹ heating to 1200 °C



why we have to put 1200 °c if the melting is 700 °c → ① بسبب crystalization

② in order to dissolve the carbides and Nitrides we raise to 1200

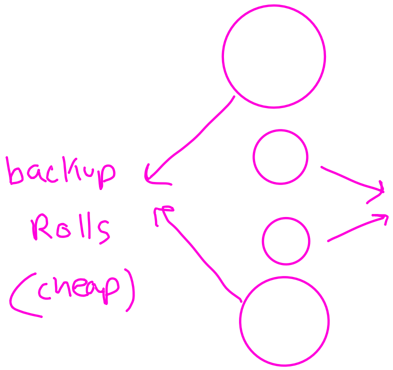
درجة الحرارة ما بتنزل كتير عشان ال friction

① * Roughing stage
(22 cm → 3 cm)

vertical Rolls
الهدف منهم
to control the width
لكي لا يزيد

② Finishing stage
3 cm → 1.6 ~ 1.8 cm

Rollings



oxide is a ceramic material and it is brittle

③ بقدر اضيف ال
Cold Roll working
عشان ازيد ال strength
for the material

* basically we can change (the coolling Rate) to control the properties of the material later

Rolling
Flat Rolling and Its Analysis

- Flat rolling involves the rolling of workparts of rectangular cross section in which the width is greater than the thickness; e.g. slabs, strips, sheets and plates.

- ***Draft*** is amount of thickness reduction and described as:

$$d = t_0 - t_f$$

where d = draft, mm; t_0 = starting thickness, mm; and t_f = final thickness, mm.

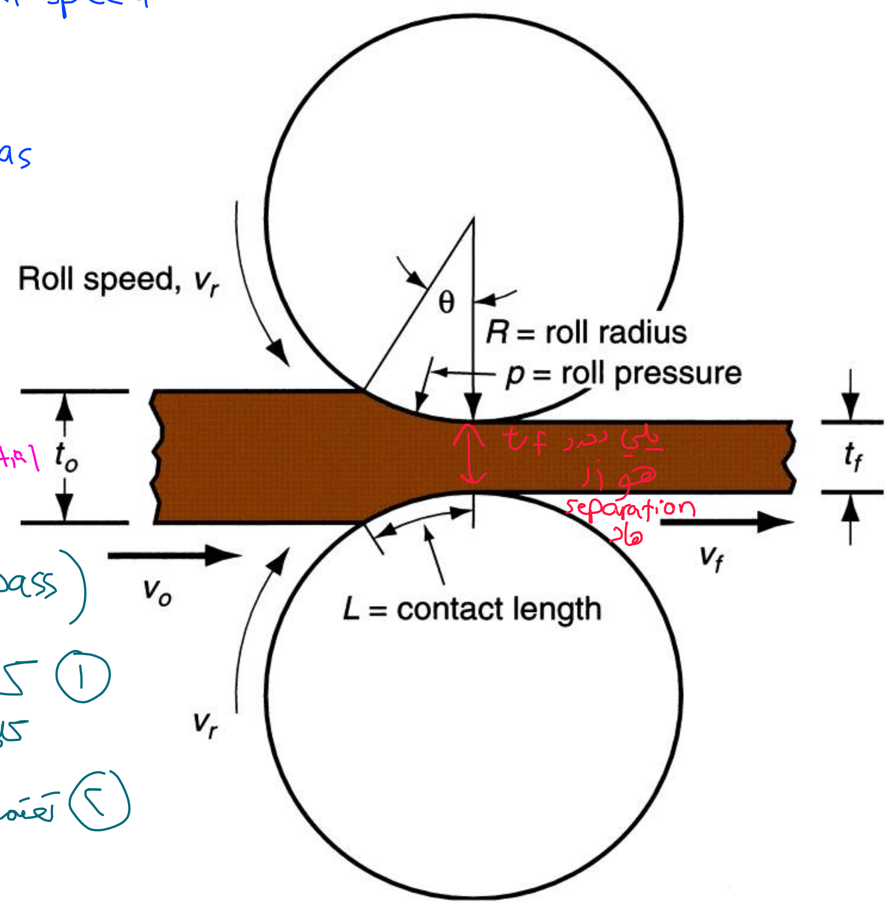
- Draft is sometimes expressed as a fraction of the starting stock thickness, called the ***Reduction*** (r):

$$r = \frac{d}{t_0}$$

Rolling
Flat Rolling and Its Analysis

$$N = \frac{V}{2\pi R}$$

N → Rotational speed rps; V → directional speed; R → Radias



تعتمد على (Maximum draft per pass)

1. كلما كانت الـ Radias أكبر
كلما كانت الـ Roll أقوى
2. تعتمد على الـ coefficient of friction

Figure 19.3 Side view of flat rolling, indicating before and after thicknesses, work velocities, angle of contact with rolls, and other features.

Manufactures

True values

Rolling
Flat Rolling and Its Analysis

- ***Spreading***: the increase in width due to rolling, described as:

$$t_o w_o L_o = t_f w_f L_f$$

where w_o and w_f are the before and after work widths, mm; and L_o and L_f are the before and after work lengths, mm.

- Similarly, before and after volume rates of material flow must be the same, so the before and after velocities can be related:

$$t_o w_o v_o = t_f w_f v_f$$

where v_o and v_f are the entering and exiting velocities of the work.

Rolling

Flat Rolling and Its Analysis

- True strain is expressed by:

$$\varepsilon = \ln \frac{t_o}{t_f}$$

- The true strain can be used to determine the average flow stress $\overline{Y}_f$ (MPa) applied to the work material in flat rolling:

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

The average flow stress is used to compute estimates of force and power in rolling.

Rolling
Flat Rolling and Its Analysis

- There is a limit to the maximum possible draft that can be accomplished in flat rolling with a given coefficient of friction, defined by:

(μ)

$$d_{max} = \mu^2 R$$

where d_{max} = maximum draft, mm; μ = coefficient of friction; and R = roll radius, mm.

- Rolling force (F, N) can be expressed as:

$$F = Y_f w L$$

- Contact length (L, mm) is described as:

$$L = \sqrt{R(t_o - t_f)}$$

for one pass

Rotational speed rps

$$N = \frac{V}{2\pi R}$$

- The torque (T) and the power required to drive each roll (P, J/s) are:

$$T = 0.5FL$$

and

$$P = 2\pi NFL$$

where P = power, J/s or W; N = rotational speed, 1/s; F = rolling force, N; and L = contact length, m.

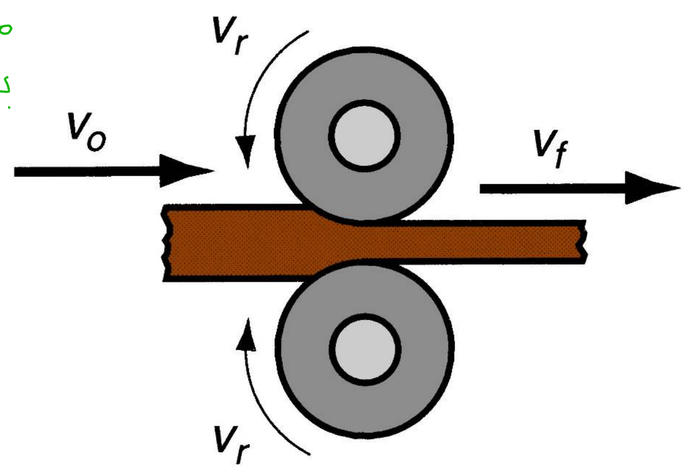
Rolling
Shape Rolling

- In shape rolling, the work is deformed into a contoured cross section.
- Products include construction shapes such as I-beams, L-beams, and U-channels; rails for railroad tracks; and round and square bars and rods.
- The process is accomplished by passing the work through rolls that have the reverse of the desired shape.
- Most of the principles that apply in flat rolling are also applicable to shape rolling.
- Shaping rolls are more complicated; and the work, usually starting as a square shape, requires a gradual transformation through several rolls in order to achieve the final cross section.

Rolling
Rolling Mills

- Rolling mill configurations:
  - ***Two-high***: consists of two opposing rolls, and the configuration can be either reversing or nonreversing.

إذا بدي اقلل ال thickness كمان
مرة بعد ما تطلع من هون O
بوقف ال machine وبخليها
تشتغل O



(a)

Figure 19.4 Various configurations of rolling mills: (a) two-high rolling mill.

Rolling
Rolling Mills

- Rolling mill configurations:
  - ***Three-high***: three rolls in a vertical column, and the direction of rotation of each roll remains unchanged.

more practical

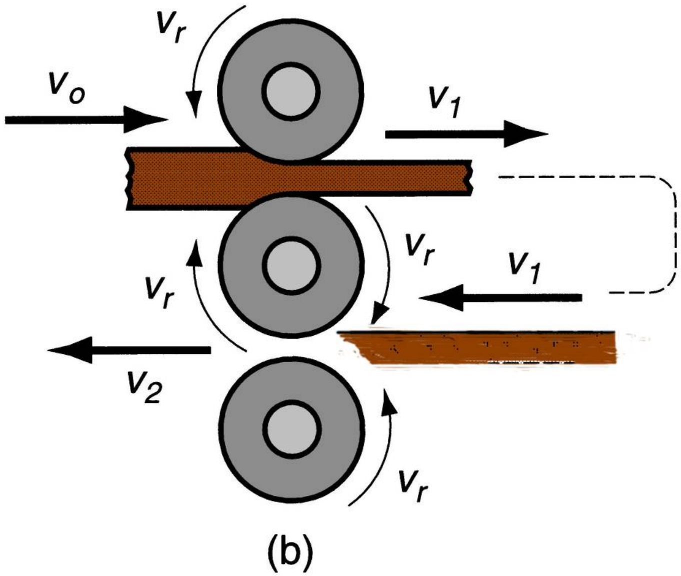
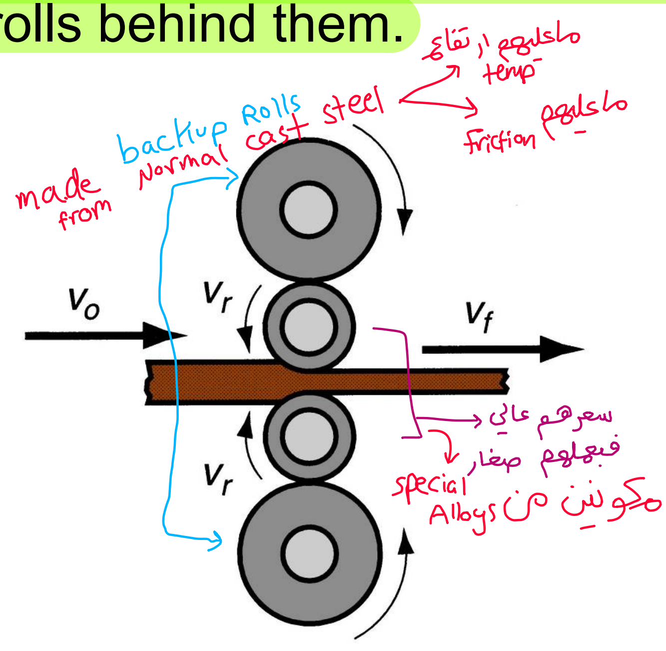


Figure 19.4 Various configurations of rolling mills: (b) three-high rolling mill.

Rolling
Rolling Mills

- Rolling mill configurations:
  - ***Four-high***: uses two smaller-diameter rolls to contact the work and two backing rolls behind them.



(c)

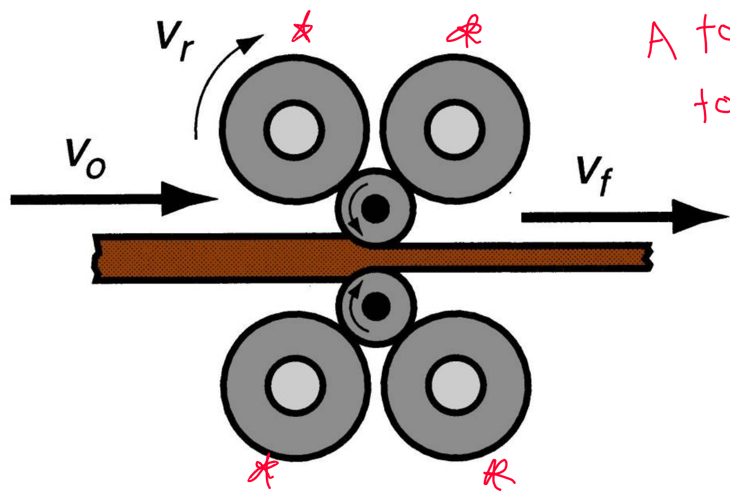
Figure 19.4 Various configurations of rolling mills: (c) four-high rolling mill.

Rolling
Rolling Mills

- Rolling mill configurations:

تجمع أكثر من Roll

  – ***Cluster mill***: roll configuration that allows smaller working rolls against the work (smaller than in four-high mills).



A total of 4 backup Rolls to get higher backup force and more efficiency

(d)

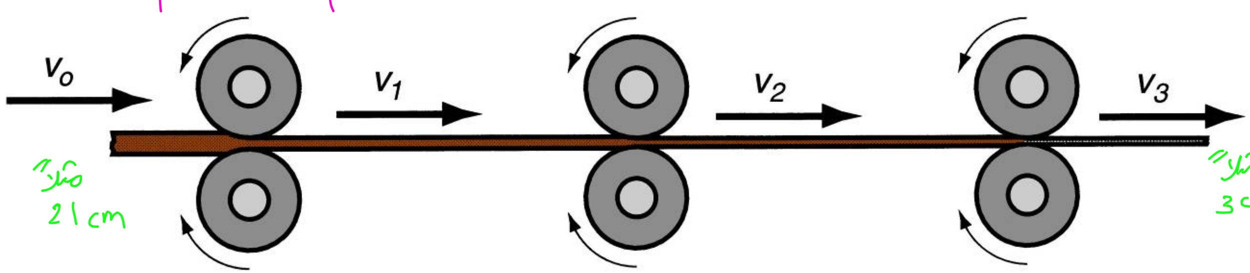
Figure 19.4 Various configurations of rolling mills: (d) cluster mill.

Rolling
Rolling Mills

- Rolling mill configurations:
  - ***Tandem rolling mill***: consists of a series of rolling stands, aimed at higher throughput rates.

process
الهدف عشان تكون ال continuous
وما نطفي ال machine

Maximum draft
per past



(e)

1. Roll Radias
2. coefficient of friction

Figure 19.4 Various configurations of rolling mills: (e) tandem rolling mill.

Other Deformation Processes Related to Rolling

- ***Thread Rolling***:
  - Used to form threads on cylindrical parts by rolling them between two dies.
  - The most important commercial process for mass producing external threaded components.
  - Performed by cold working in thread rolling machines. These are equipped with special dies that determine the size and form of the thread.
  - Advantages of thread rolling over thread cutting and rolling include:
    - Higher production rates.
    - Better material utilization.
    - Smoother surface.
    - Stronger threads and better fatigue resistance due to work hardening.

Other Deformation Processes Related to Rolling

- ***Thread Rolling***:

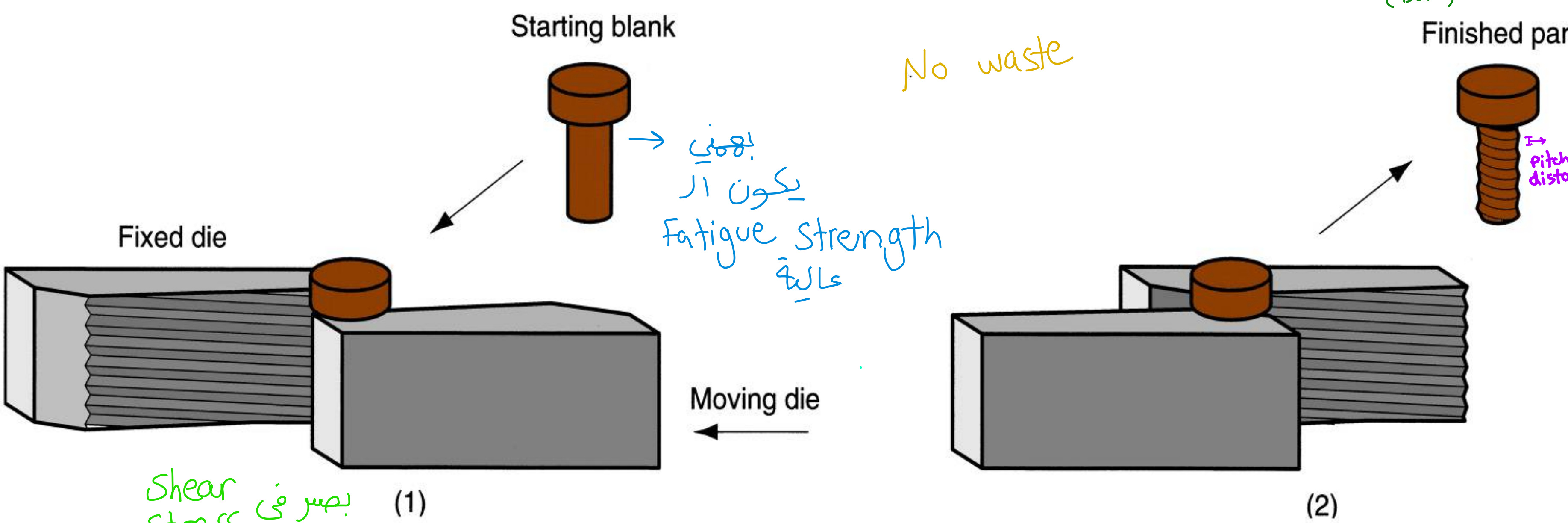


Figure 19.5 Thread rolling with flat dies: (1) start, and (2) end of cycle.

Video (Thread Rolling)

Rollers → cylinderical
Rollers → flat

the metal is displaced or rearranged (no cutting)

cold working ← إذا ال material لها Ductility عالية

Hot working ← إذا ال strength عالي لل material

وبعدها

بتحددلي ال minor diameter

ال distance between the two plates

Fasteners → externally threaded fasteners (to fix things together)

First cold working is done then after Rolling we may use hot working in order to promote recrystalization

بنقدر نعمل hardening → through heat treatment

5 to 10 rev to complete the thread

ممكن ننتج parts with larger diameter using circular Rollers

Other Deformation Processes Related to Rolling

- ***Ring Rolling***: a deformation process in which a thick-walled ring of smaller diameter is rolled into a thin-walled ring of larger diameter.
  - As the thick-walled ring is compressed, the deformed material elongates, causing the diameter of the ring to be enlarged.

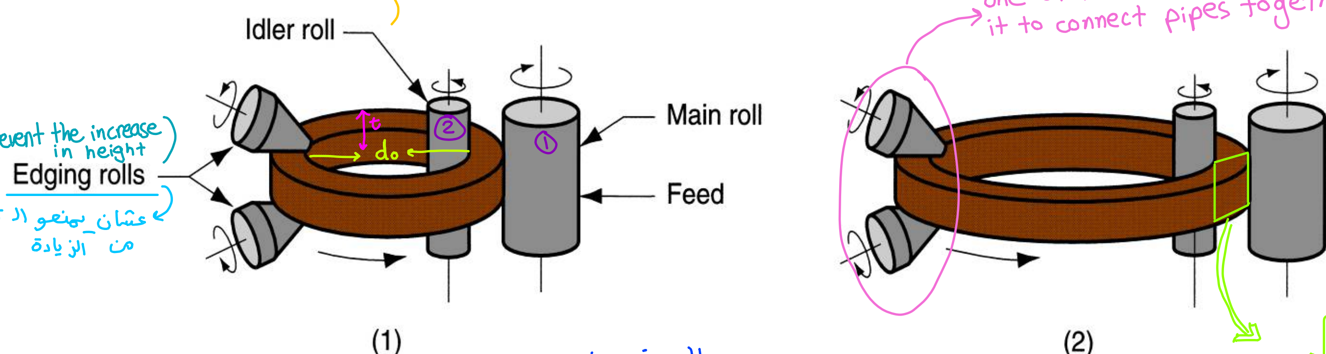


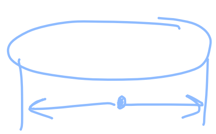
Figure 19.6 Ring rolling used to reduce the wall thickness and increase the diameter of a ring: (1) start, and (2) completion of process.

Other Deformation Processes Related to Rolling

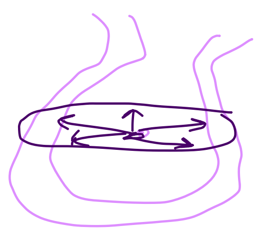
- ***Ring Rolling*:**
  - Usually performed as a hot-working process for large rings and as a cold-working process for smaller rings.
  - Applications include ball and roller bearing races, steel tires for railroad wheels, and rings for pipes, pressure vessels, and rotating machinery.
  - Advantages over processes producing similar products include: (1) raw material savings, (2) ideal grain orientation for the application, and (3) strengthening through cold working.

لأنه مافي cutting

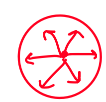
مثل اسطوانة الغاز



بهمني ال material تكون strong عشان تقاوم ال stresses



أكبر كمية من ال stresses بتكون (من ال center باتجاه الخارج)



Other Deformation Processes Related to Rolling

- ***Roll Piercing***: a specialized hot working process for making seamless thick-walled tubes.
  - Based on the principle that when a solid cylindrical part is compressed on its circumference, high tensile stresses are developed at its center. If compression is high enough, an internal crack is formed.
  - Compressive stresses on a solid cylindrical billet are applied by two rolls, whose axes are oriented at slight angles (6^o) from the axis of the billet, so that their rotation tends to pull the billet through the rolls. A mandrel is used to control the size and finish of the hole created by the action.

Other Deformation Processes Related to Rolling

- ***Roll Piercing***:

only done in hot working processes

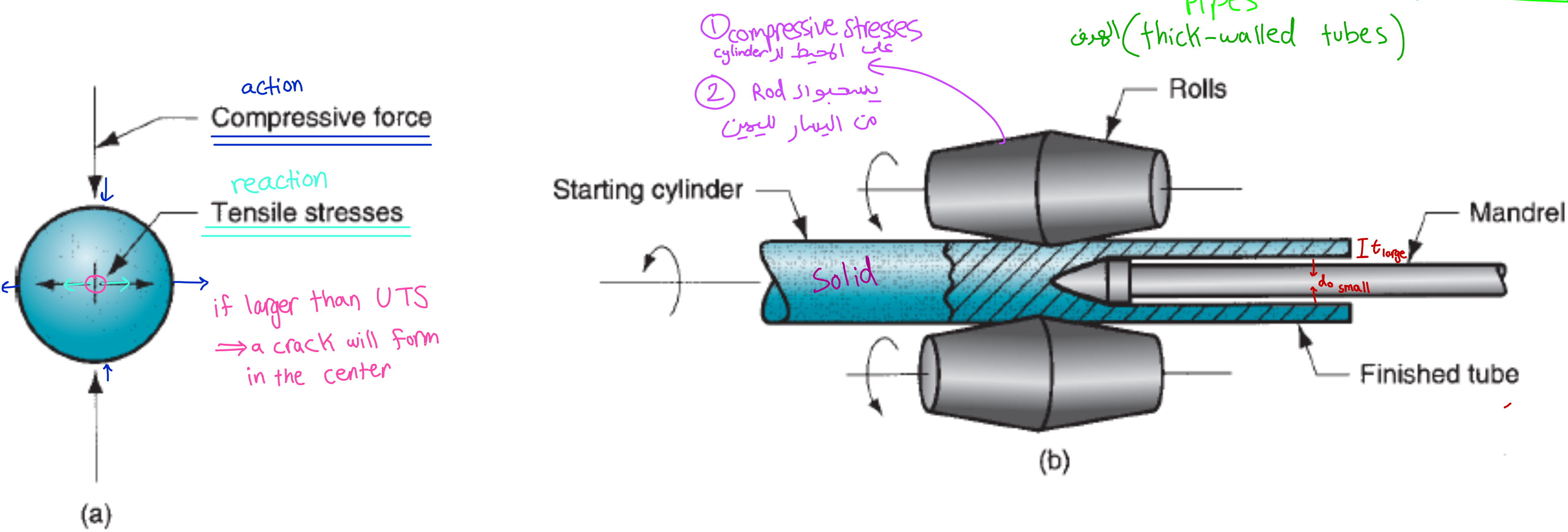


Figure 19.7 Roll piercing: (a) formation of internal stresses and cavity by compression of cylindrical part; and (b) setup of Mannesmann roll mill for producing seamless tubing.

Forging

عمليات الطرق

- ***Forging***: a deformation process in which the work is compressed between two dies, using either impact or gradual pressure to form the part.
  - Dates back to perhaps 5000 BCE.
  - Today, forging is an important industrial process used to make a variety of high-strength components for automotive, aerospace, and other applications.
  - These components include engine crankshafts and connecting rods, gears, aircraft structural components, and jet engine turbine parts.
  - In addition, steel and other basic metals industries use forging to establish the basic form of large components that are subsequently machined to final shape and dimensions.

Forging

- Forging can be classified in many ways, one is working temperature.
  - ***Hot*** or ***warm forging***: done when significant deformation is demanded by the process and when strength reduction and increase of ductility is required.
  - ***Cold forging***: its advantage is the increased strength that results from strain hardening of the component.
- The other way is by the way the forging is carried out:
  - ***Forging hammer***: a forging machine that applies an impact load.
  - ***Forging press***: a forging machine that applies gradual load.

Forging

- Forging can be also classified according to the degree to which the flow of the work metal is constrained by the dies.
  - ***Open-die forging***: the work is compressed between two flat dies, thus allowing the metal to flow without constraint in a lateral direction relative to the die surfaces.
  - ***Impression-die forging***: the die surfaces contain a shape or impression that is imparted to the work during compression, thus constraining metal flow to a significant degree. Here, flash will form.
  - ***Flashless forging***: the work is completely constrained within the die and no excess flash is produced.

Forging

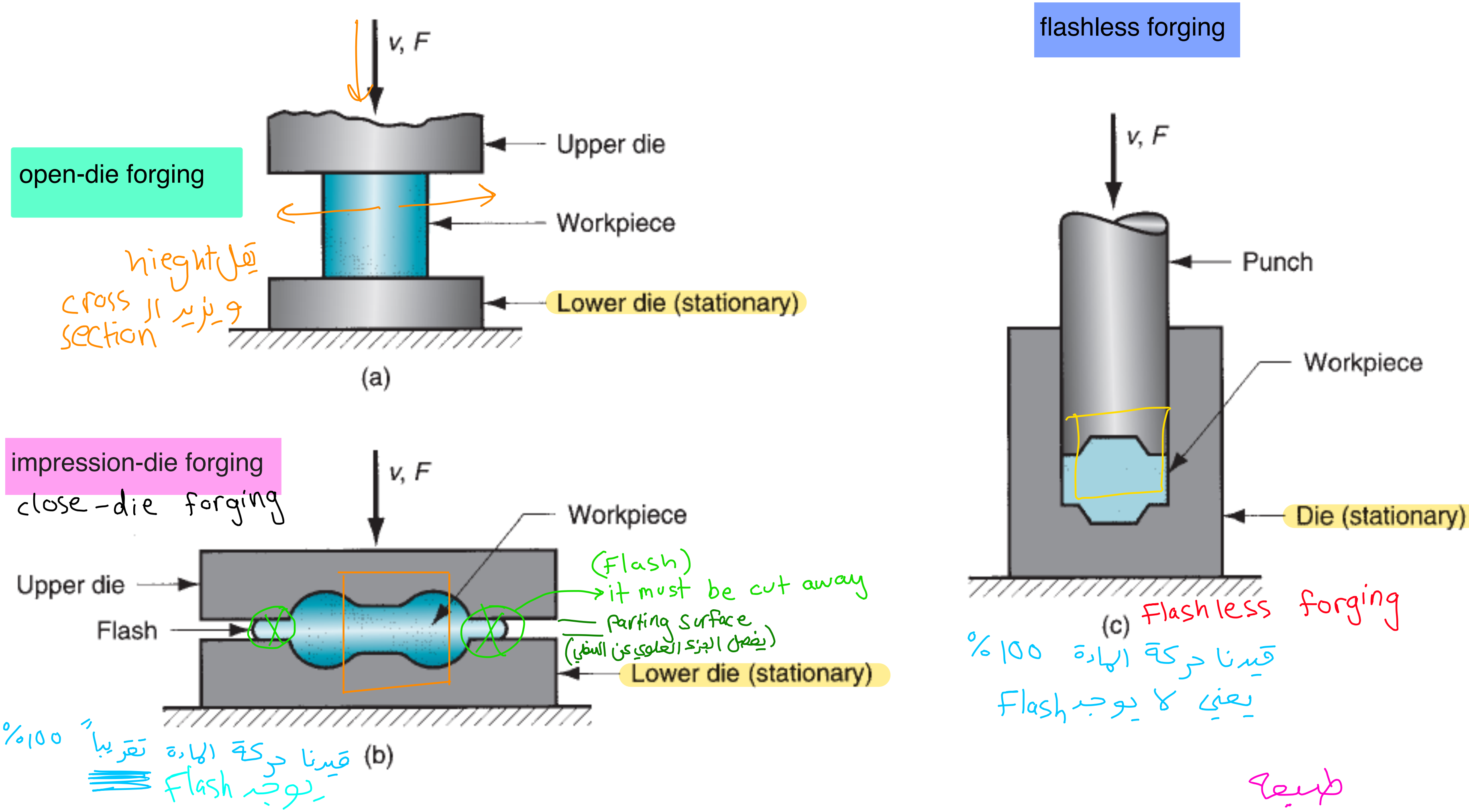


Figure 19.8 Three types of forging operation: (a) open-die forging, (b) impression-die forging, and (c) flashless forging.

video

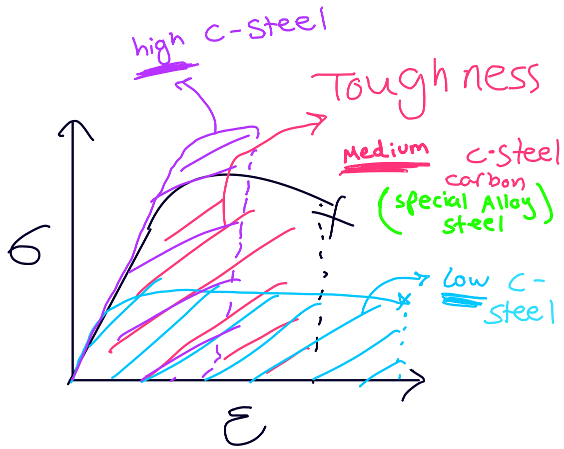
Reduce the cross section

advantage → we eliminate prosity in cast ingoty
مسامية

Rod mill forms

forged products

cross section ال بزيد
length لما نقلل ال



Although fairly complex can be produced by (opendie forging)
تعقيد بسيط

عشان يتحملوا ال dies القوالب وال accessory tools درجة الحرارة العالية
لازم يكونو من special Alloy Steel

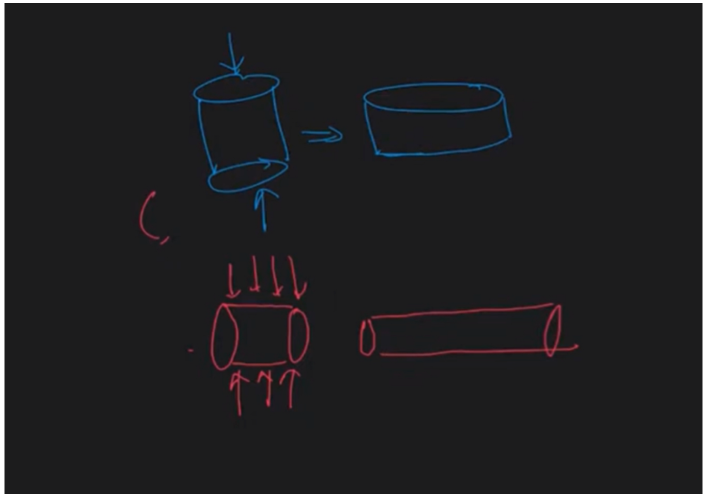
in open die forging
die → Flat
→ semiround
→ V shape

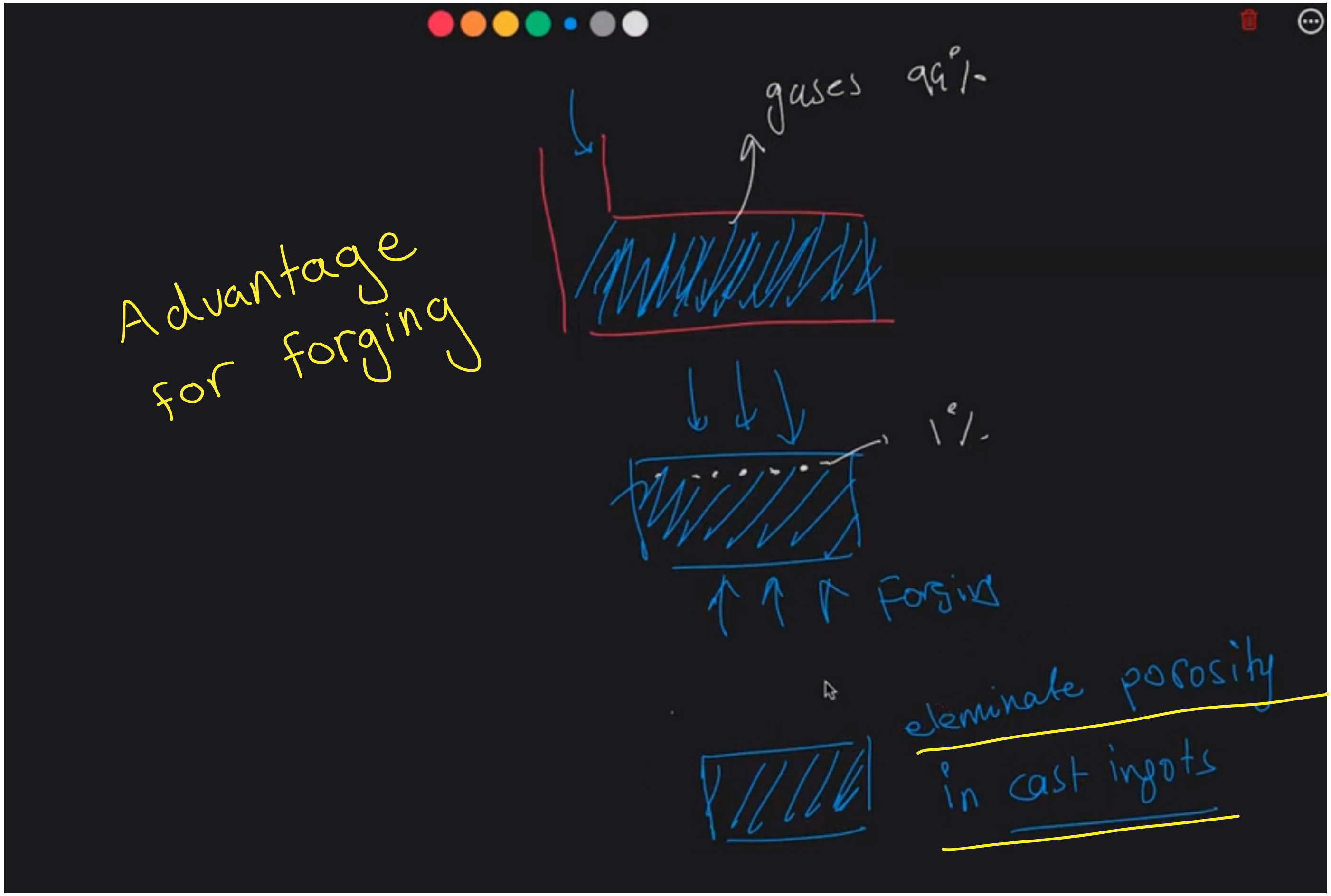
لما نحط ب die قالب ساخن عشان ال material
to minimize chilling and cooling

★ Preforming operations :-

1. Edging is an open die process increase cross section
2. blocking close die process وتعتبر مثل ال forging (الهدف to refine the shape to finish forging)
3. Finishing forging لما تكمل الشكل الا لما يطلع ال Flash (الهدف to complete the shape)

ال Flash
→ ① prevent the bulk of the material from leaving the cavity
→ ② it helps the material to taking its final shape will all details
← يبرد بسرعة لإنه مساحته قليلة is stronger the strength is higher





Advantage for forging
gases 99%
1%
Forging
eleminate porosity in cast ingots

Forging
Open-Die Forging

- Known as ***upsetting*** or ***upset forging***.
- Involves compression of a workpart of cylindrical cross section between two flat dies, much in the manner of a compression test.
- It reduces the height of the work and increases the diameter.

Forging
Open-Die Forging

- Analysis of Open-Die Forging:
  - If carried out under ideal conditions of no friction between work and die surfaces, then homogeneous deformation occurs, and the flow of the material is uniform throughout its height.

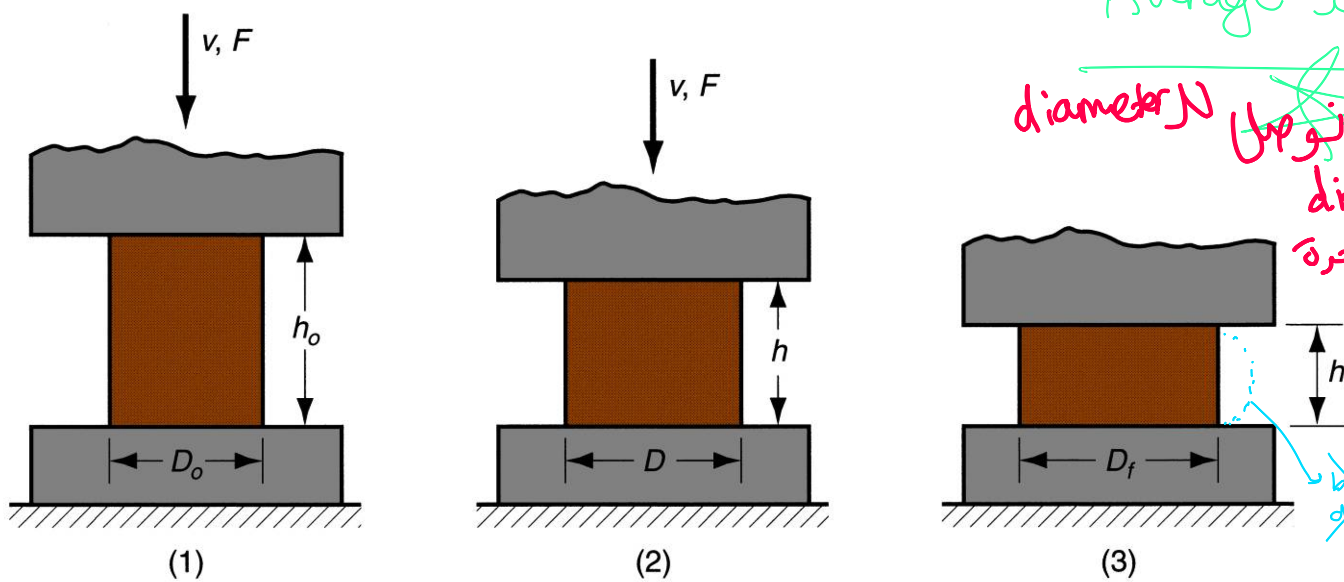


Figure 19.9 Homogeneous deformation of a cylindrical workpart under ideal conditions in an open-die forging operation: (1) start of process with workpiece at its original length and diameter, (2) partial compression, and (3) final size.

Forging
Open-Die Forging

- Analysis of Open-Die Forging:
  - Under these ideal conditions, the true strain experienced by the work during the process can be determined by:

$$\varepsilon = \ln \frac{h_o}{h}$$

  - The force to perform upsetting at any height is given by:

$$F = Y_f A$$

where F = force, N; A = cross-sectional area, mm^2; and Y_f = flow stress, MPa.

Forging
Open-Die Forging

- Analysis of Open-Die Forging:
  - If carried out under conditions where friction between work and die surfaces is accounted for, a barreling effect is created.

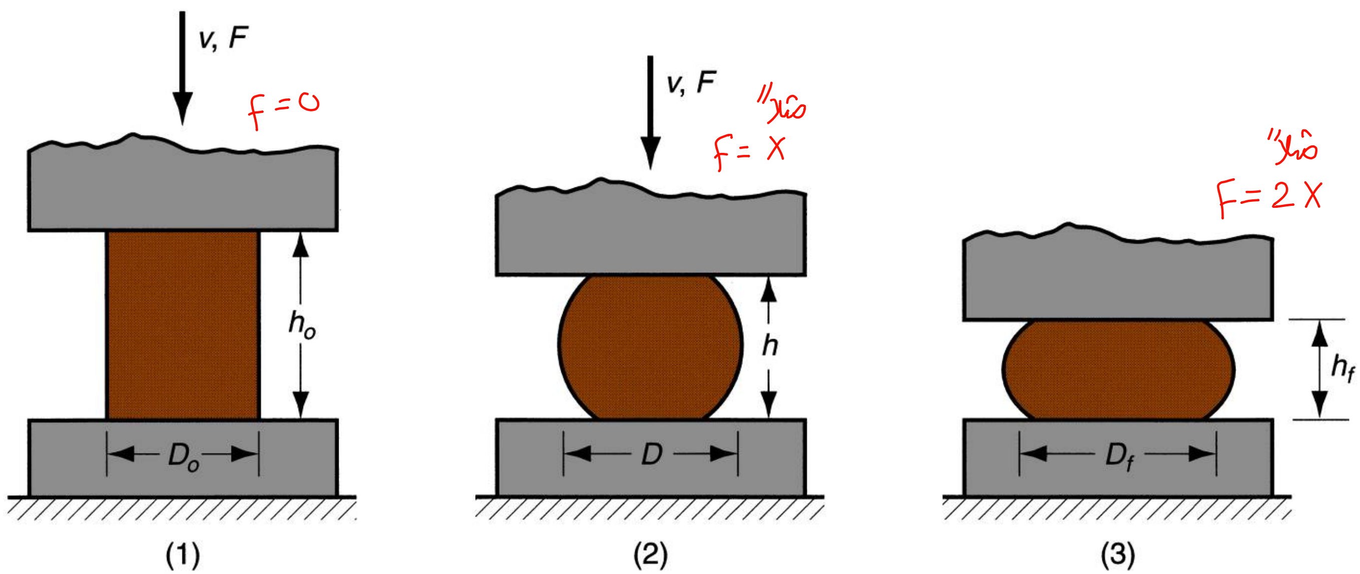


Figure 19.10 Actual deformation of a cylindrical workpart in open-die forging, showing pronounced barreling: (1) start of process, (2) partial deformation, and (3) final shape.

Forging
Open-Die Forging

- Analysis of Open-Die Forging:
  - Friction causes the actual upsetting force to be greater than what is predicted the previous equation:

$$F = K_f Y_f A$$

where K_f is the forging shape factor, defined as:

$$K_f = 1 + \frac{0.4\mu D}{h}$$

where μ = coefficient of friction; D = workpart diameter or other dimension representing contact length with die surface, mm; and h = workpart height, mm.

Forging
Open-Die Forging

- In practice, open-die forging can be classified into:
  - ***Fullering***: a forging operation performed to reduce the cross section and redistribute the metal in a workpart in preparation for subsequent shape forging (dies have convex surfaces).

    أسطح مقعرة.
  - ***Edging***: similar to fullering, except that the dies have concave surfaces.
  - ***Cogging***: consists of a sequence of forging compressions along the length of a workpiece to reduce cross section and increase length.

time عالي
cost عالي
waste عالي

strain hardening لا يوجد

ولو بوصل
accuracy?
عالية

Forging
Open-Die Forging

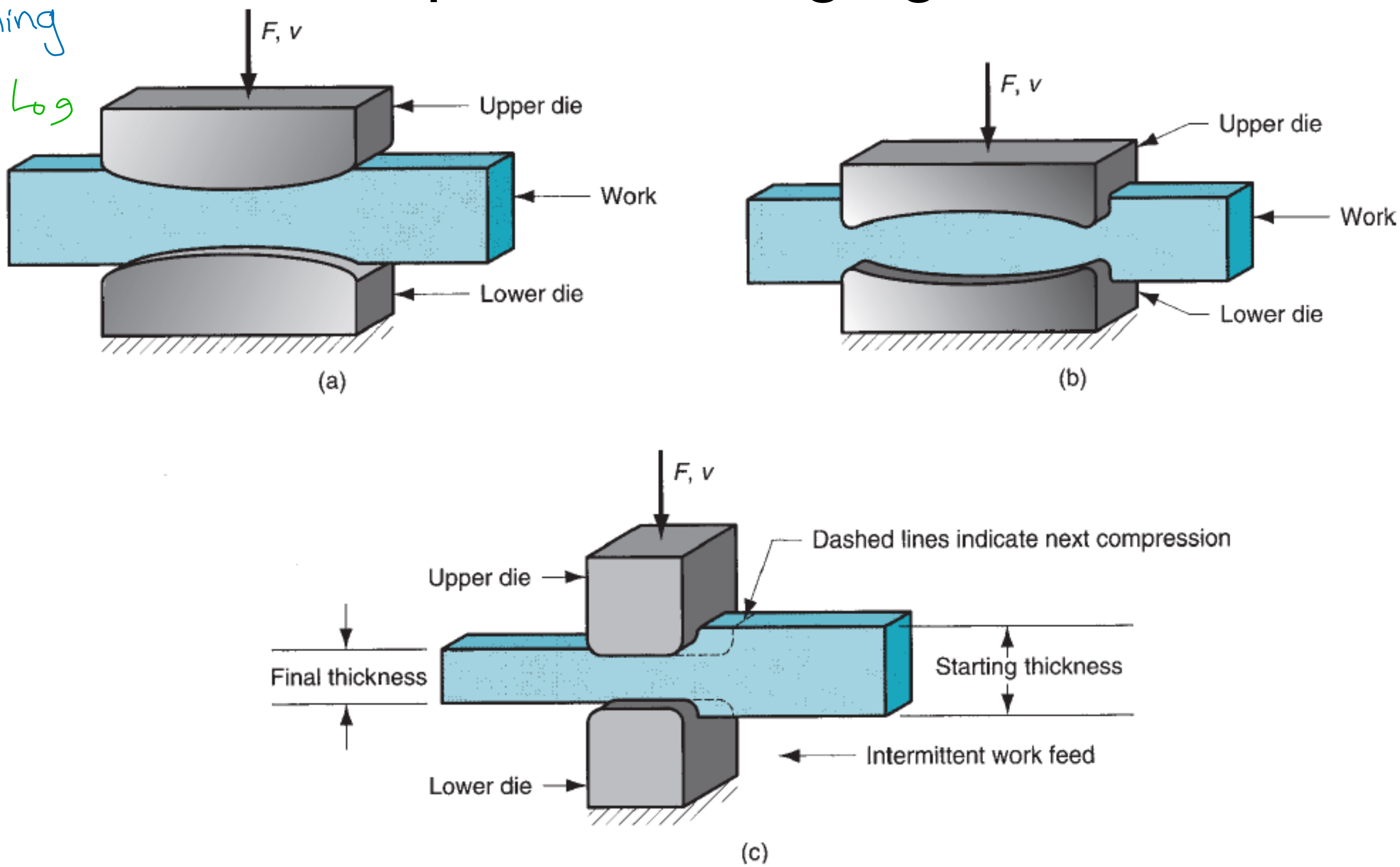


Figure 19.11 Several open-die forging operations: (a) fullering, (b) edging, and (c) cogging.

Forging
Impression-Die Forging

- ***Impression-die forging*** (sometimes called ***closed-die forging***): performed with dies that contain the inverse of the desired shape of the part.
  - As the die closes to its final position, flash is formed by metal that flows beyond the die cavity and into the small gap between the die plates.
  - Although this flash must be finally cut away, it serves an important function during impression-die forging.
    - As the flash begins to form, friction resists continued flow of metal into the gap, thus constraining the bulk of the work material to remain in the die cavity.
    - In hot forging, metal flow is further restricted because the thin flash cools quickly against the die plates, thereby increasing its resistance to deformation.
    - Accordingly, compression pressure is increased, thus forcing the material to fill the whole cavity.

Forging
Impression-Die Forging

- Sequence in impression-die forging:

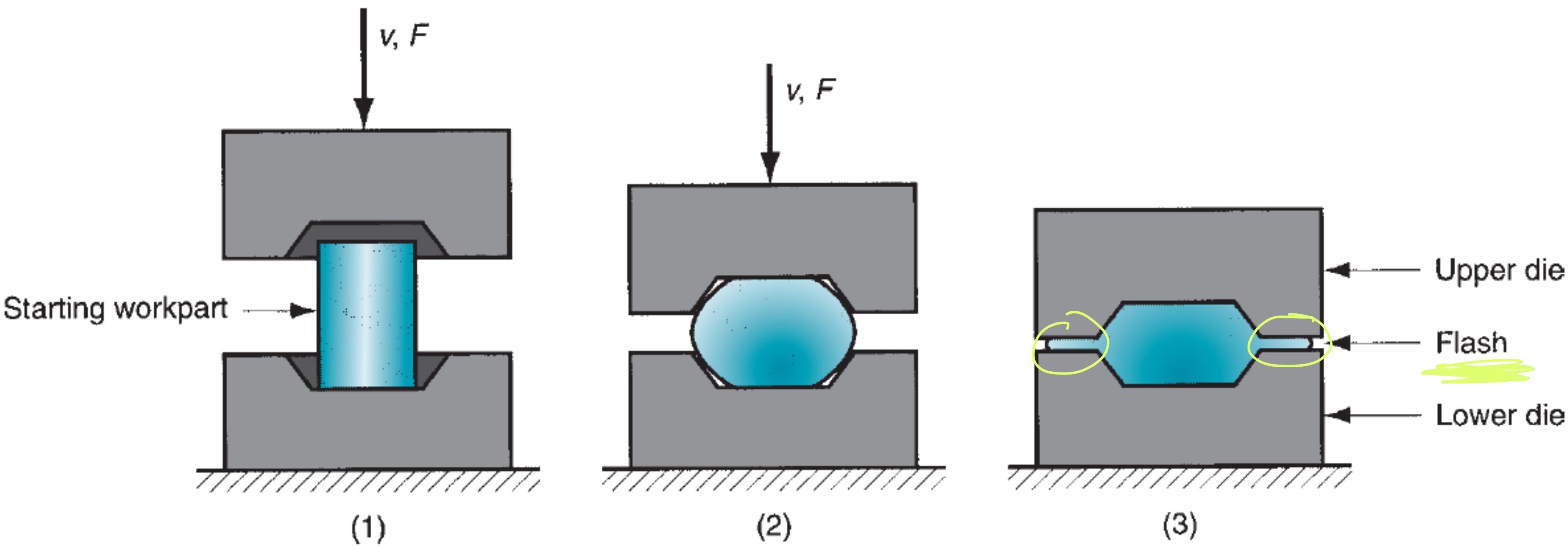


Figure 19.12 Sequence in impression-die forging: (1) just prior to initial contact with raw workpiece, (2) partial compression, and (3) final die closure, causing flash to form in gap between die plates.

Forging
Impression-Die Forging

- Advantages of impression-die forging compared to machining from solid stock include: higher production rates, less waste of metal, greater strength and favorable grain orientation in the metal.

- Limitations include: the incapability of close tolerances and machining is often required to achieve accuracies and features needed.

Forging
Flashless Forging

- ***Flashless Forging***: the raw workpiece is completely contained within the die cavity during compression, and no flash is formed.

- Several requirements:
  - The work volume must equal the space in the die cavity within a very close tolerance.
  - If the starting blank is too large, excessive pressures may cause damage to the die or press. If the blank is too small, the cavity will not be filled.
  - Simple geometries required.
  - Best for soft metals, such as aluminum and cupper and their alloys.
  - Sometimes classified as ***Precision Forging***.

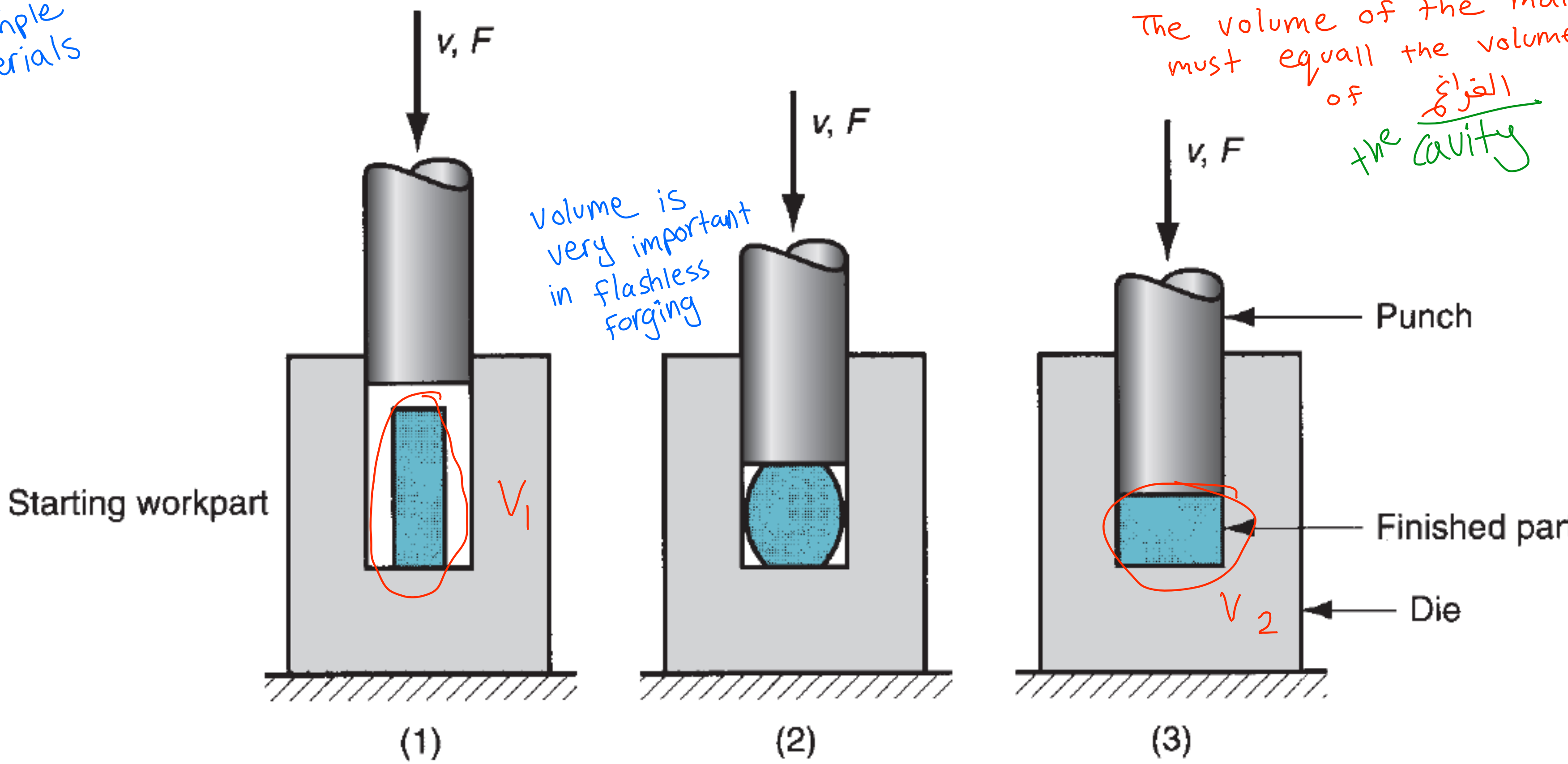
Forging
Flashless Forging

→ precision forging

Used for Soft + simple materials

The volume of the material must equall the volume of الفراغ the cavity

Volume is very important in flashless forging



$V_1 = V_2$

Figure 19.13 Flashless forging: (1) just before initial contact with workpiece, (2) partial compression, and (3) final punch and die closure.

تستخدم عندما the amount of deformation is small

Forging
Flashless Forging

- ***Coining***: is a type of flashless forging, in which fine details in the die are impressed into the top and bottom surfaces of the workpart. There is little flow of metal in coining.

مثلاً: مثل النص دينار

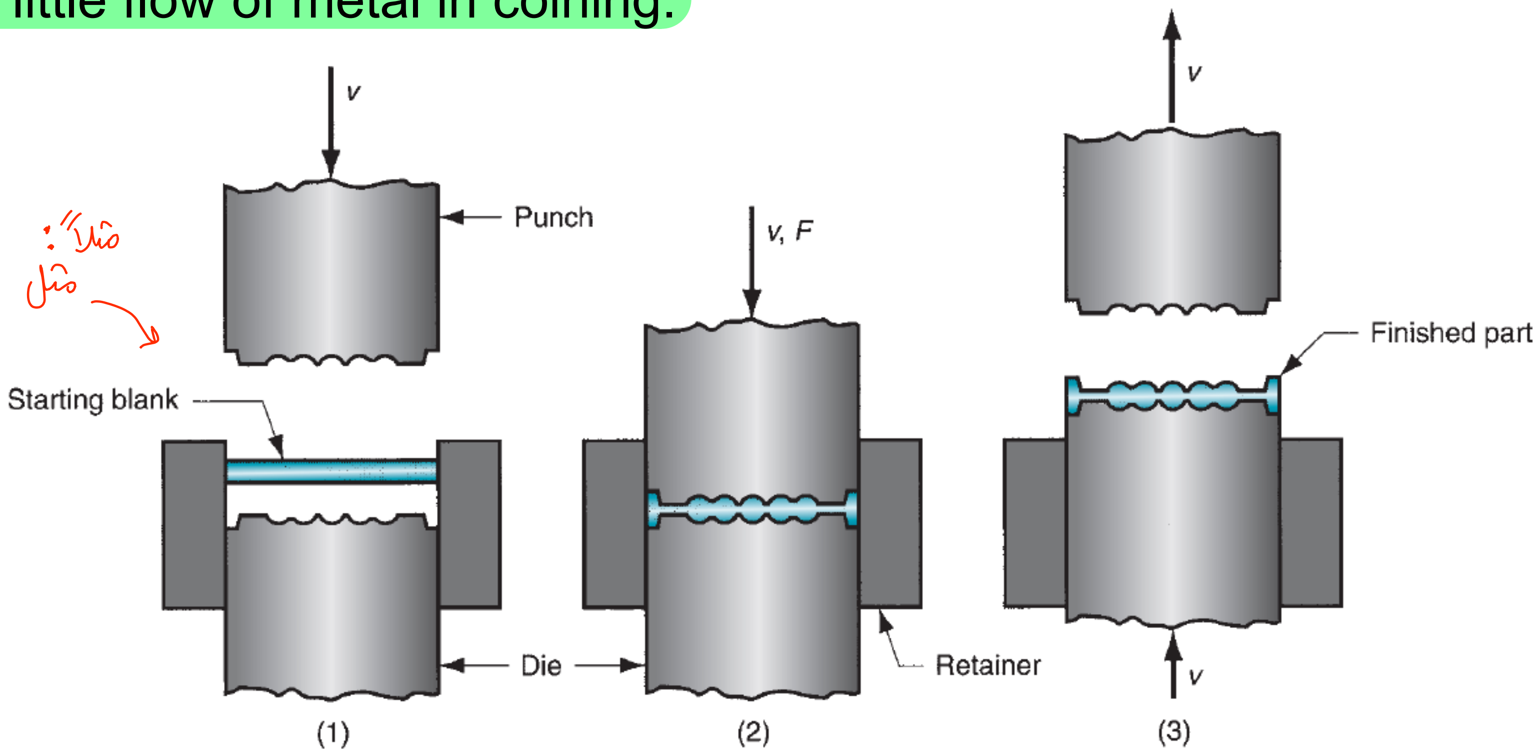


Figure 19.14 Coining operation: (1) start of cycle, (2) compression stroke, and (3) ejection of finished part.

Forging
Forging Hammers and Presses

impact gradual

- Equipment used in forging consists of forging machines, classified as hammers or presses, and forging dies.
- In addition, auxiliary equipment is needed, such as furnaces to heat the work, mechanical devices to load and unload the work, and trimming stations to cut away the flash in impression-die forging.

Forging
Forging Hammers and Presses

(1) ***Forging Hammers***: operate by applying an impact loading against the work. They deliver impact energy to the workpiece.

- Used for impression-die forging.
- The upper portion of the forging die is attached to the ram, and the lower portion is attached to the anvil.
- The work is placed on the lower die, and the ram is lifted and then dropped.
- When the upper die strikes the work, the impact energy causes the part to assume the form of the die cavity.
- Several blows of the hammer are often required to achieve the desired change in shape.

Forging
Forging Hammers and Presses

- Forging hammers are classified into:

(1) ***Gravity drop hammers***: achieve their energy by the falling weight of a heavy ram, and the force of the blow is determined by the height of the drop and the weight of the ram.

(2) ***Power drop hammers***: accelerate the ram by pressurized air or steam.

- Disadvantage: a large amount of the impact energy is transmitted through the anvil and into the floor of the building.

Forging
Forging Hammers and Presses

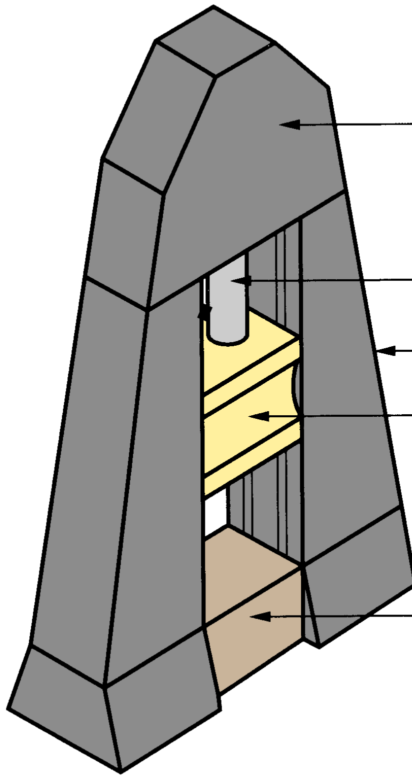


Figure 19.15 Diagram showing details of a drop hammer for impression−die forging.

Forging
Forging Hammers and Presses

(2) ***Forging Presses***: apply gradual pressure, rather than sudden impact, to accomplish the forging operation.
تأثير مفاجئ

- Include mechanical presses, hydraulic presses, and screw presses.
- Mechanical presses convert the rotating motion of a drive motor into the translation motion of the ram.
- Hydraulic presses use a hydraulically driven piston to drive the ram.
- Screw presses apply force by a screw mechanism that drives the vertical ram.

Other Deformation Processes Related to Forging

- ***Upsetting*** and ***Heading***: a deformation operation in which a cylindrical workpart is increased in diameter and reduced in length.

- Used in the fastener industry to form heads on nails, bolts, etc (in these applications, it is referred to as heading).

- More parts produced by upsetting than any other forging operation.

- Performed cold, hot or warm on special upset forging machines, called headers or formers.

- Long wire is fed into the machines, the end of the stock is upset forged, and then the piece is cut to length to make the desired hardware item.

Other Deformation Processes Related to Forging

Flashless

- ***Upsetting*** and ***Heading***: a deformation operation in which a cylindrical workpart is increased in diameter and reduced in length.

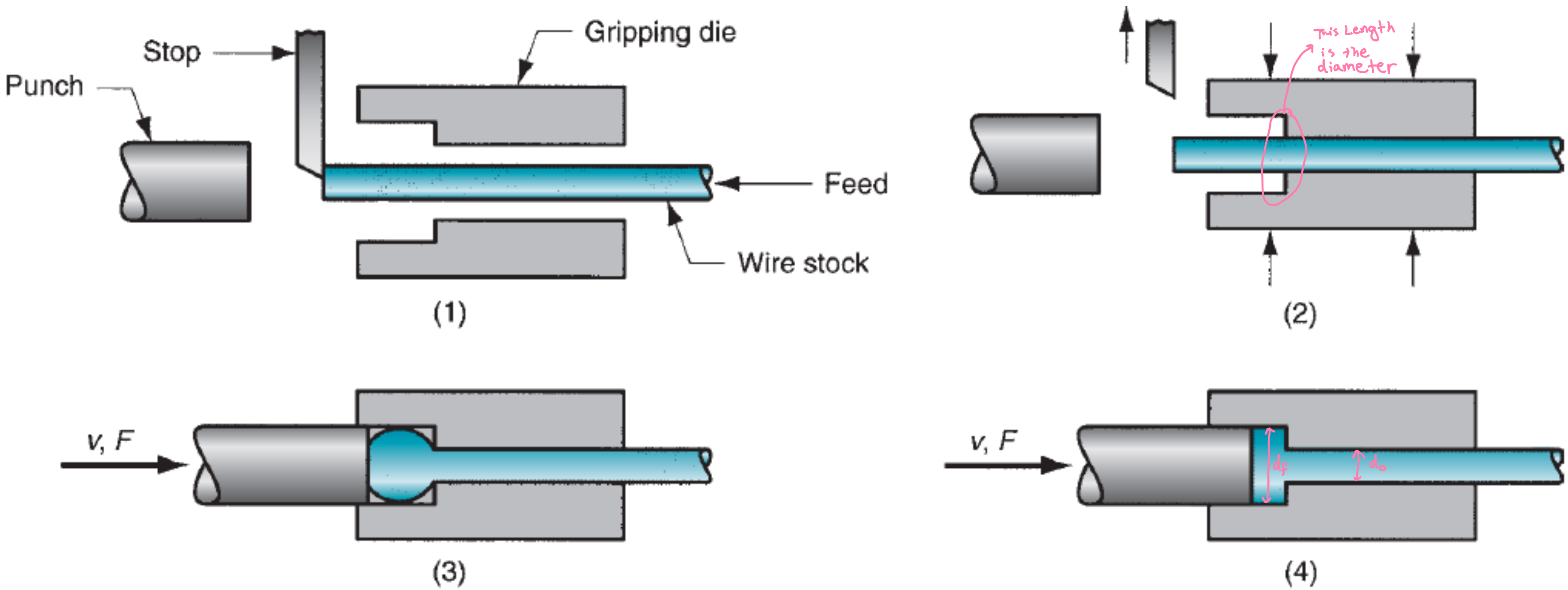


Figure 19.16 An upset forging operation to form a head on a bolt. (1) wire stock is fed to the stop; (2) gripping dies close on the stock and the stop is retracted; (3) punch moves forward; and (4) bottoms to form the head.

Other Deformation Processes Related to Forging

- ***Upsetting*** and ***Heading***: a deformation operation in which a cylindrical workpart is increased in diameter and reduced in length.

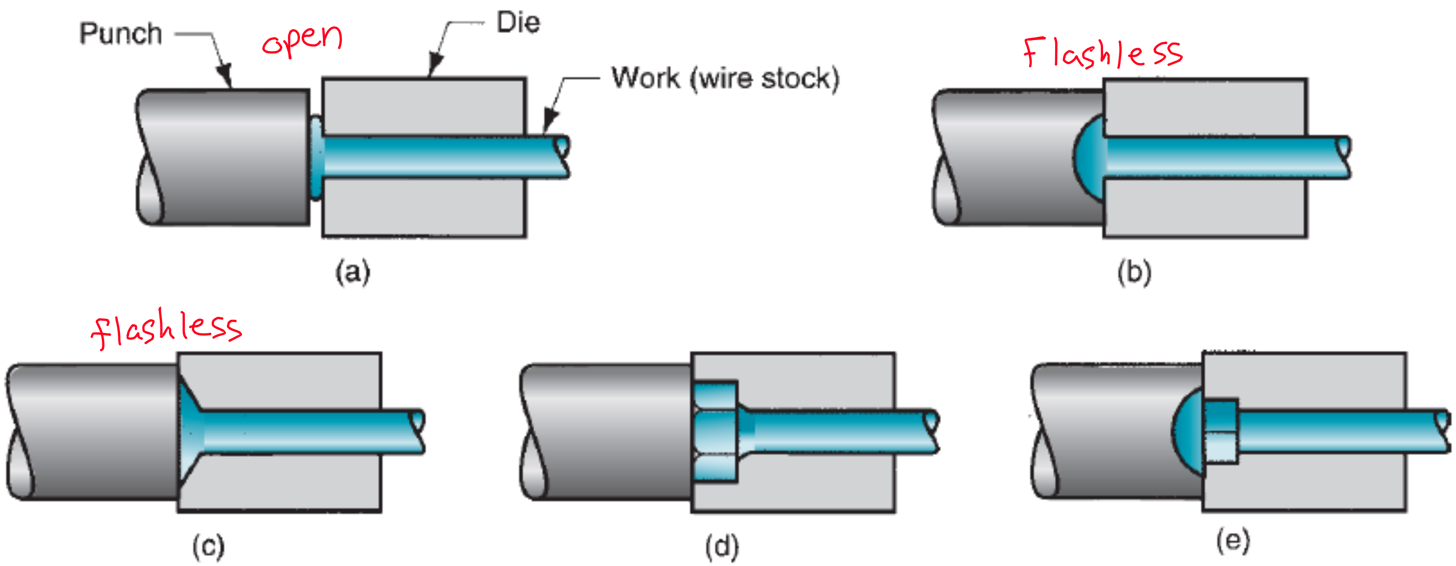


Figure 19.17 Examples of heading (upset forging) operations: (a) heading a nail using open dies, (b) round head formed by punch, (c) and (d) heads formed by die, and (e) carriage bolt head formed by punch and die.

Other Deformation Processes Related to Forging

- ***Swaging*** and ***Radial Forging***: forging processes used to reduce the diameter of a tube or solid rod.

- The ***swaging*** process is accomplished by means of rotating dies that hammer a workpiece radially inward to taper it as the piece is fed into the dies.

- ***Radial forging*** is similar to swaging in its action against the work and is used to create similar part shapes. The difference is that in radial forging the dies do not rotate around the workpiece; instead, the work is rotated as it feeds into the hammering dies.

Other Deformation Processes Related to Forging

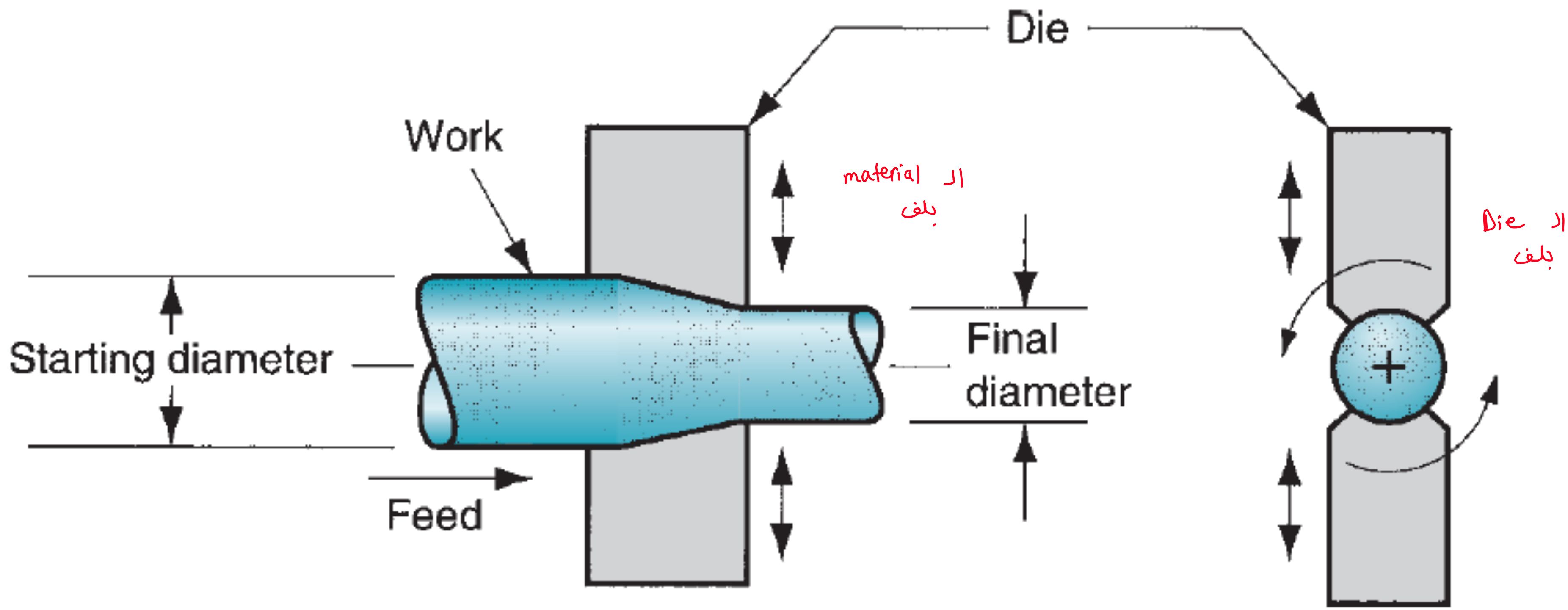
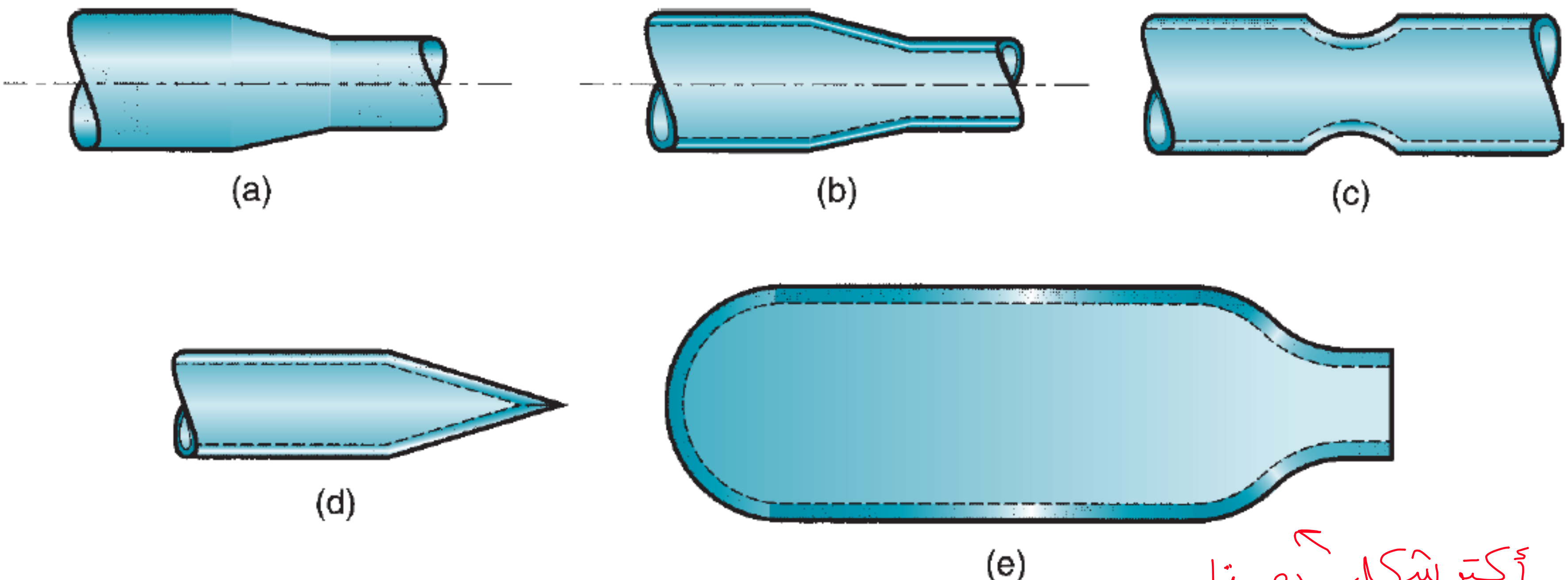


Figure 19.18 Swaging process to reduce solid rod stock; the dies rotate as they hammer the work. In radial forging, the workpiece rotates while the dies remain in a fixed orientation as they hammer the work.

Other Deformation Processes Related to Forging



أكثر شكل يهمنا

Figure 19.19 Examples of parts made by swaging: (a) reduction of solid stock, (b) tapering a tube, (c) swaging to form a groove on a tube, (d) pointing of a tube, and (e) swaging of neck on a gas cylinder.

Other Deformation Processes Related to Forging

- ***Trimming:*** an operation used to remove flash on the workpart in impression-die forging.
- In most cases, trimming is accomplished by shearing.
- Trimming is usually done while the work is still hot.
- In cases where the work might be damaged by the cutting process, trimming may be done by alternative methods, such as grinding or sawing.

Other Deformation Processes Related to Forging

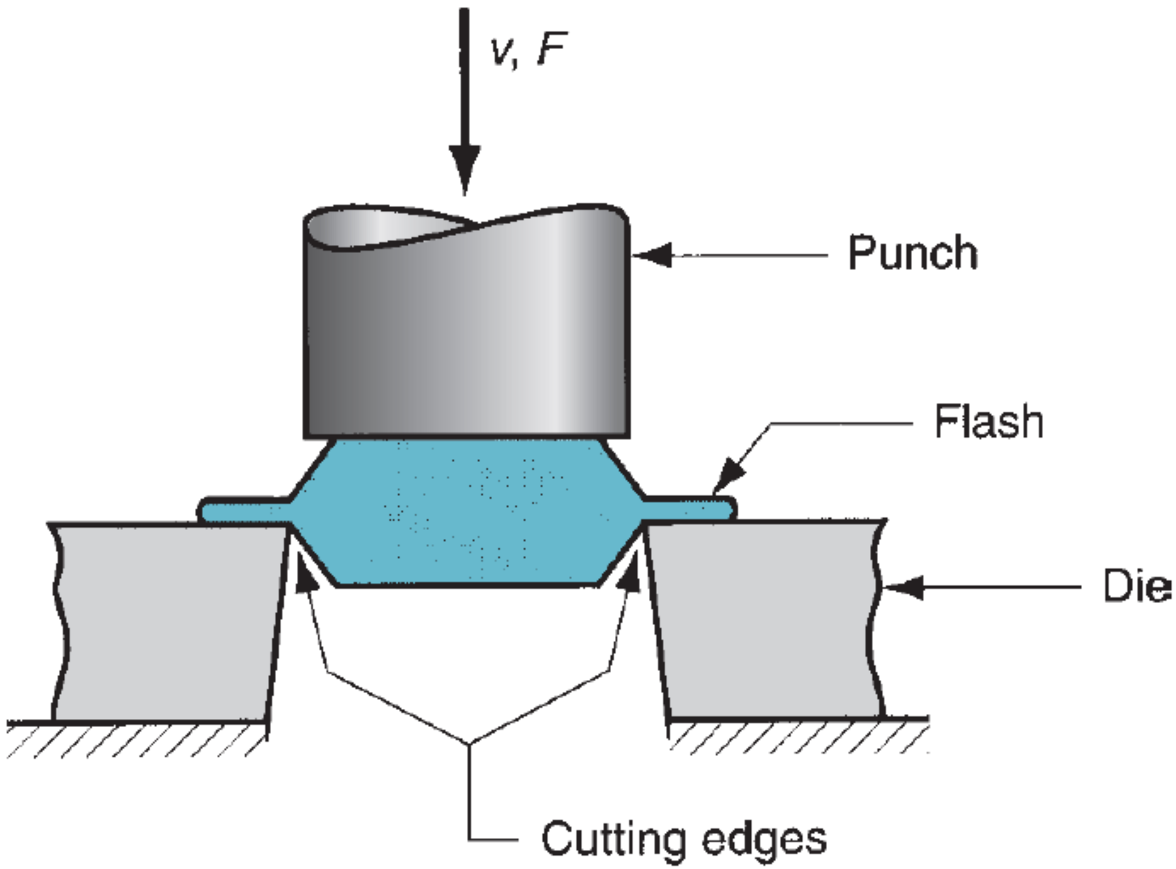


Figure 19.20 Trimming operation (shearing process) to remove the flash after impression-die forging.

Midterm

ussualy we use hot extrusion

Extrusion

we use compressive stresses

- ***Extrusion:*** a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape.

- Imagine squeezing toothpaste out of toothpaste tube.

- Advantages include:
  - A variety of shapes are possible (especially in hot extrusion).
  - Microstructure and strength are enhanced in cold and warm extrusion.
  - Close tolerances are possible, especially in cold extrusion.
  - in some extrusion operations, little or no wasted material is created.

Extrusion
Types of Extrusion

- Extrusion can be classified in various ways:
  - By physical configuration: ***Direct Extrusion*** and ***Indirect Extrusion***.
  - By working temperature: ***Cold***, ***Warm***, or ***Hot Extrusion***.
  - Finally, it is performed as either a ***Continuous*** or ***Discrete process***.

Extrusion
Types of Extrusion

- ***Direct*** versus ***Indirect Extrusion***: (1) Direct extrusion (also called ***forward extrusion***) is illustrated in the Figure below.

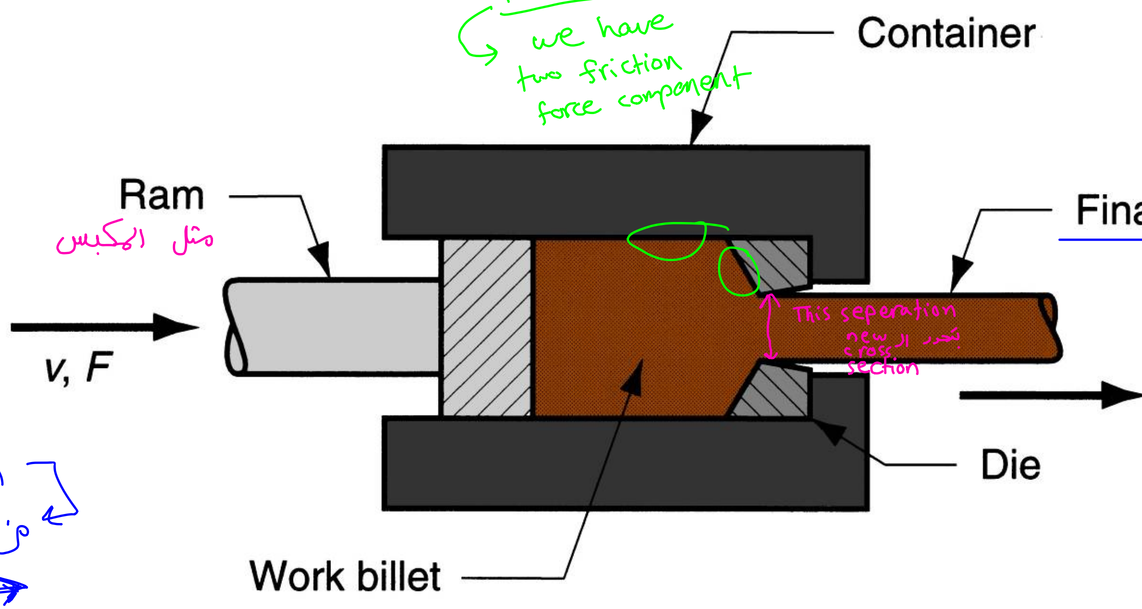


Figure 19.21 Direct extrusion.

Now there is a video (2 min)

Rolling بال
ال material اسمو (slab)

The hot billet is loaded in a thin walled
كتير

(uppsetting force)
→ in order to fill the container

* Direct extrusion
Motion of the Ram is in the same direction of the extrusion for the material

Ram
يركب عليه
dummy block
to prevent one of the extrusion defects

The surface of the billet ~~slays~~ slides along on the wall of container
يعني يوجد friction وبالتالي بحتاج force أعلى

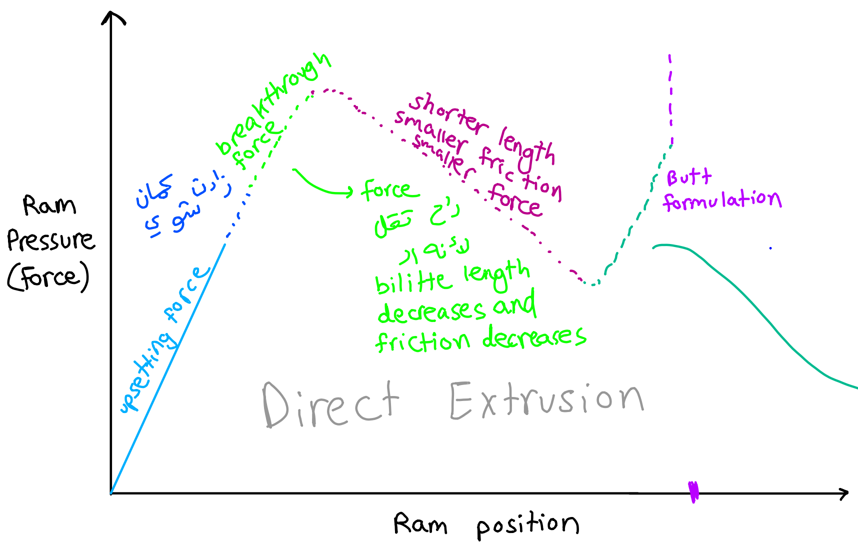
Graphite ← مثال على Lubricant

ال friction بيعتمد على الطول
و الطول كم يقل إذا ال friction and force بقلو

بحط force كبيرة في البداية
Force increases rapidly to fill the container

break through force
يعني ال material بدها تبلش تخترق

cross section Ratio extrusion = initial Area / final Area

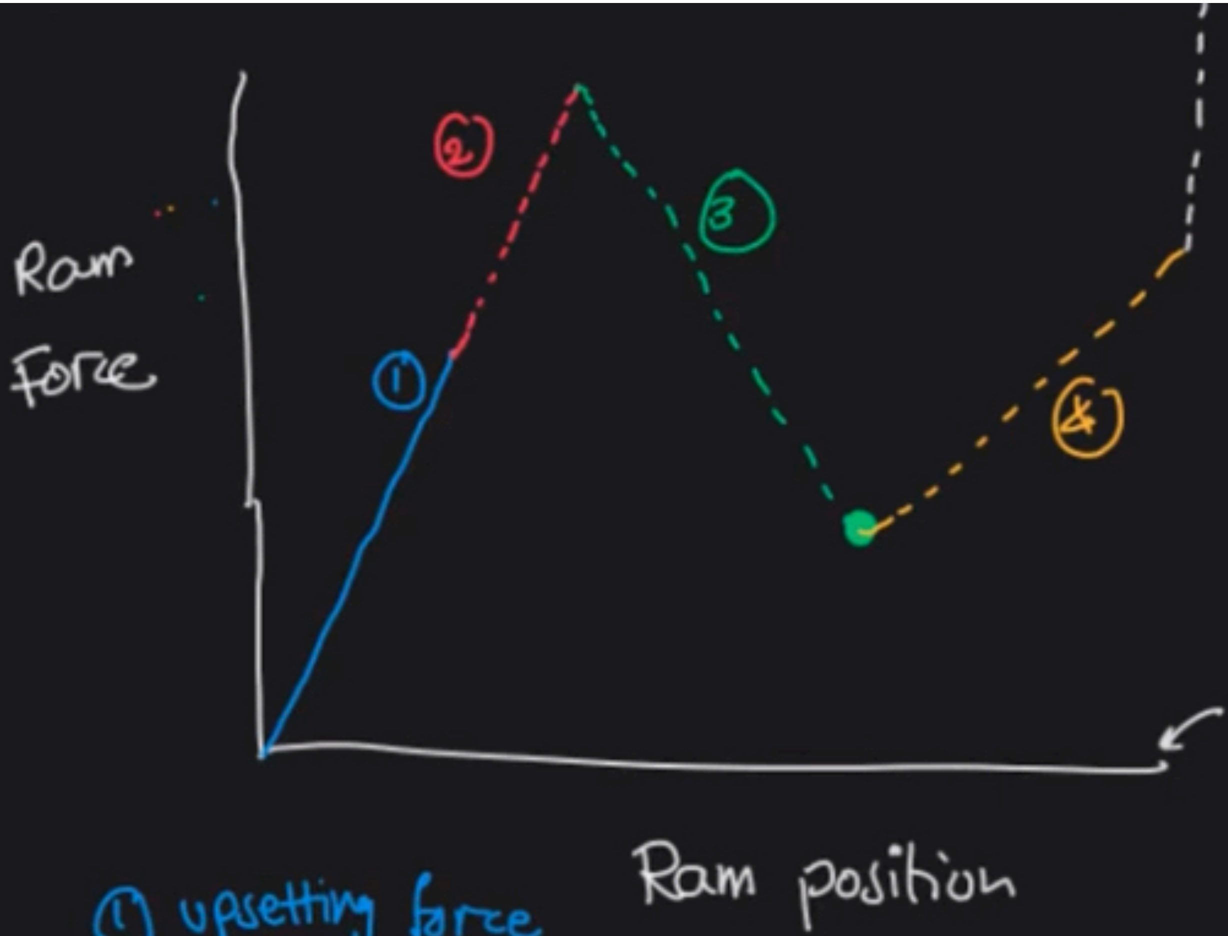


بالآخر Force increases rapidly
To continue metal flow rapidly toward the die opening force ↑

آخر اشي بضل كمية صغيرة
ما بقدر اعملها extrusion
بدها Force
فبفتح ال material و بطلعها و بسوي recycle

يجب الرجوع للكتاب
يوجد شكل لـ (indirect extrusion)
مطلوب معنا *

Direct Extrusion



Butt formation

* Indirect extrusion → self study
v. imp.

1. upsetting force
2. Breakthrough force
3. shorter length → smaller friction

4. To continue metal flow radialy toward the die opening. (Too short length)

Pressure depends on :-

- Billet Material & Temper
- Cross-Section & Complexity
- Length & Temperature
- Extrusion Speed
- Reduction/Extrusion Ratio

Extrusion
Direct Extrusion

- A metal billet is loaded into a container, and a ram compresses the material, forcing it to flow through one or more openings in a die at the opposite end of the container.
- As the ram approaches the die, a small portion of the billet remains that cannot be forced through the die opening.
- This extra portion, called the ***butt***, is separated from the product by cutting it just beyond the exit of the die.
- Friction between container's walls and workpiece is one big problem in extrusion (so higher forces are needed to accomplish the process).
- تفاقمت بشكل متفاقم
  The problem is aggravated in hot extrusion due to formation of oxide layer.

اعلى friction
عند درجات حرارة أعلى

Extrusion
Direct Extrusion

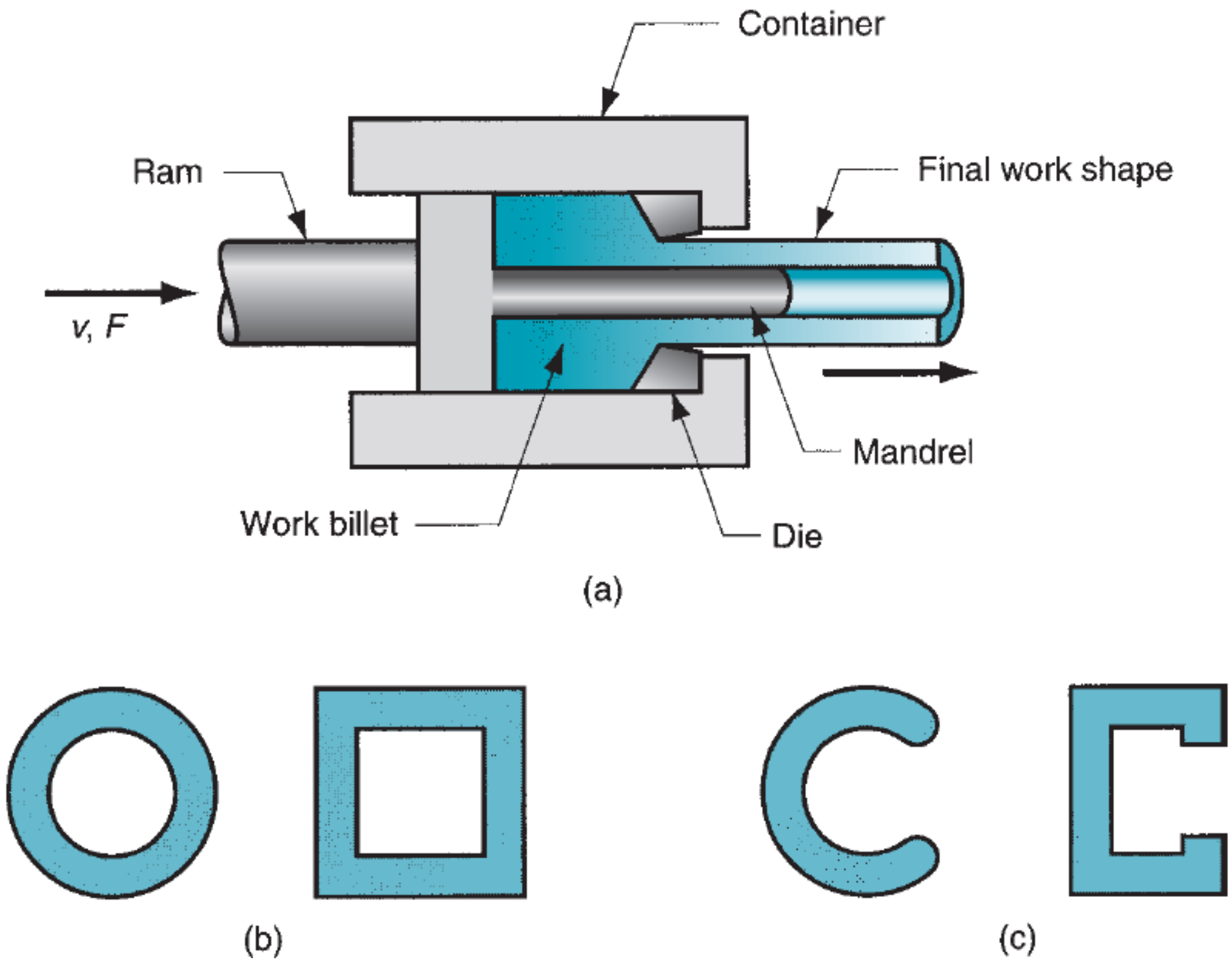


Figure 19.22 (a) Direct extrusion to produce a hollow or semi-hollow cross section; (b) hollow and (c) semi-hollow cross sections.

Extrusion
Types of Extrusion

- ***Direct*** versus ***Indirect Extrusion***: (2) Indirect extrusion (also called ***backward extrusion***) is illustrated in the Figure below.

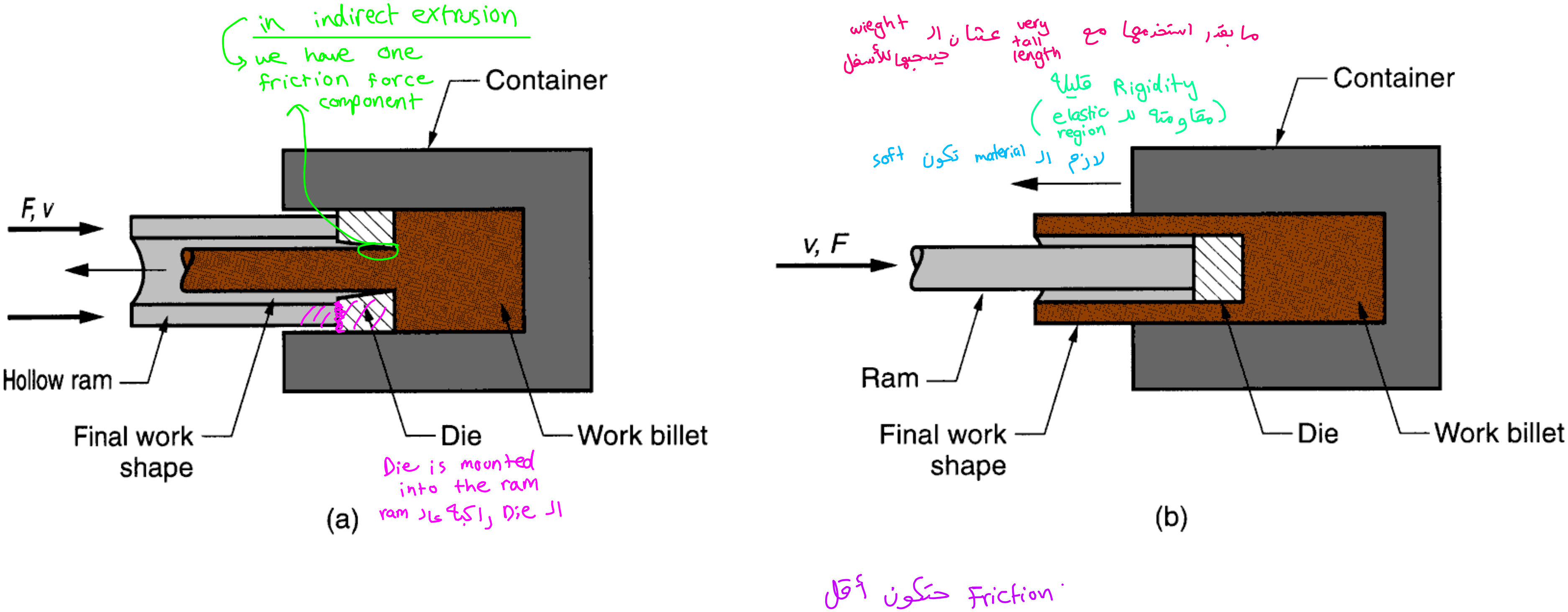


Figure 19.23 Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section.

Extrusion
Indirect Extrusion

- The die is mounted to the ram rather than at the opposite end of the container.

- As the ram penetrates into the work, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram.

- Since the billet is not forced to move relative to the container, there is no friction at the container walls, and the ram force is therefore lower than in direct extrusion.

- Limitations of indirect extrusion are imposed by the lower rigidity of the hollow ram and the difficulty in supporting the extruded product as it exits the die.

Extrusion
Types of Extrusion

- ***Hot*** versus ***Cold Extrusion***:
  - Extrusion can be performed either hot or cold, depending on work metal and amount of strain to which it is subjected during deformation.
  - Hot extruded metals include: Al, Cu, Mg, Zn, Sn, and their alloys (sometimes extruded cold as well).
  - Steel alloys are usually extruded hot, although the softer, more ductile grades are sometimes cold extruded (e.g. low C-steels).
  - Al is probably the most ideal metal for extrusion (hot and cold).
  - Products include: doors and window frames.

الالمنيوم أشهر material for extrusion

in Discret

بكل impact بنطلع one product

Extrusion
Types of Extrusion

- ***Hot Extrusion***:
  - Involves prior heating of the billet to a temperature above its recrystallization temperature.
  - This reduces strength and increases ductility.
  - Additional advantages include reduction of ram force, and increased ram speed.

Extrusion
Types of Extrusion

- ***Cold Extrusion***:
  - Used to produce discrete parts, in finished (or near finished) form.
  - Impact Extrusion: indicates high-speed cold extrusion.
  - Advantages: increased strength due to strain hardening, close tolerances, improved surface finish, absence of oxide layers, and high production rates.

Extrusion
Types of Extrusion

- ***Continuous*** versus ***Discrete Extrusion***:
  - ***Continuous Extrusion***: producing very long sections in one cycle, but these operations are limited by the size of the starting billet that can be loaded into the extrusion container. In nearly all cases, the long section is cut into smaller lengths in a subsequent sawing or shearing operation.
  - ***Discrete Extrusion***: a single part is produced in each extrusion cycle. Impact extrusion is an example of the discrete processing case.

Extrusion
Analysis of Extrusion

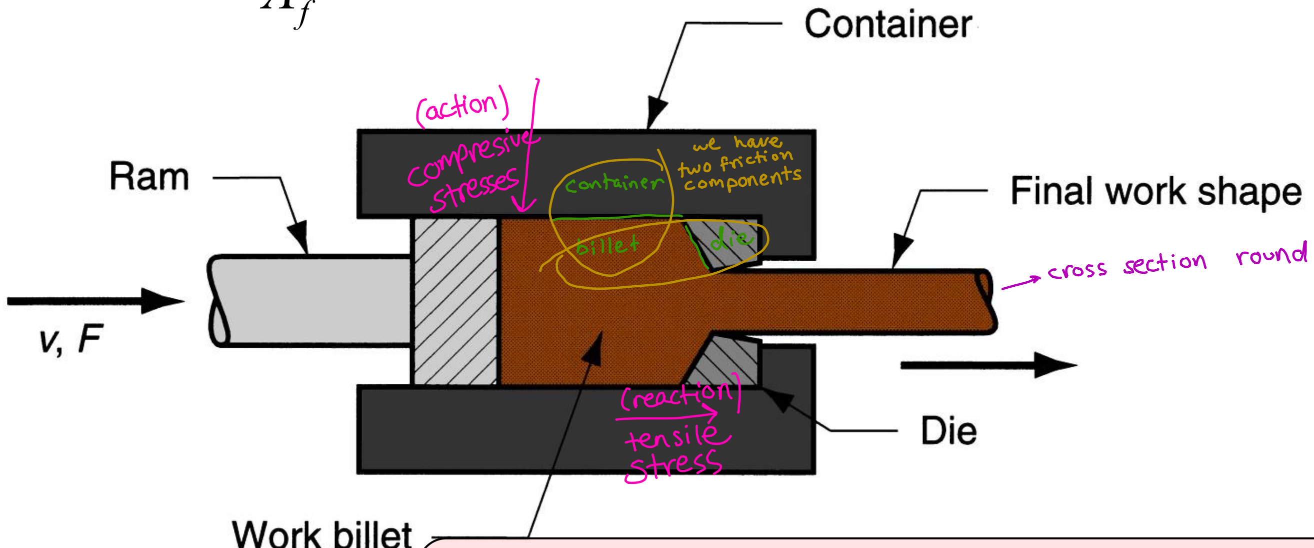
- Consider the figure below:

Extrusion ratio: $r_x = \dfrac{A_o}{A_f}$

True strain: $\varepsilon = \ln \dfrac{A_o}{A_f}$

Ideal (no friction) case, pressure p: $p = \overline{Y_f} \ln r_x$

Average flow stress (MPa): $\overline{Y_f} = \dfrac{K\varepsilon^n}{1+n}$



NOTE: This is ideal case (no friction considered).

The workpiece has round cross section

Extrusion
Analysis of Extrusion

- Consider the figure below:

Extrusion ratio: $r_x = \frac{A_o}{A_f}$

True strain: $\varepsilon = \ln\frac{A_o}{A_f}$

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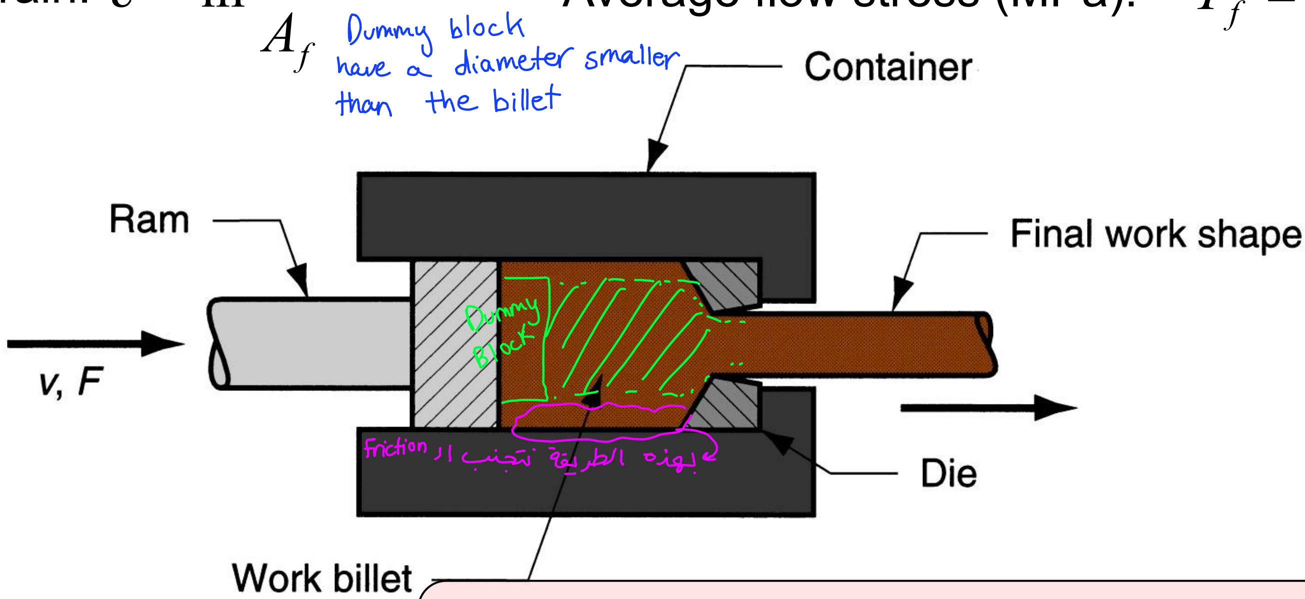


NOTE: This is ideal case (no friction considered).

The workpiece has round cross section

Extrusion
Analysis of Extrusion

- If friction is considered:

Extrusion strain: $\varepsilon_x = a + b \ln r_x$ where a & b are constants for a given die angle: a = 0.8 & b = 1.2 to 1.5.

For indirect extrusion: $p = \overline{Y}_f \varepsilon_x$

For direct extrusion, friction is higher, so: $p = \overline{Y}_f \left(\varepsilon_x + \dfrac{2L}{D_o} \right)$

Ram forces in indirect or direct extrusion, F (N): $F = pA_o$

Power required P (J/s): $P = Fv$ v is velocity in m/s

NOTE: friction considered and cross section is round.

Extrusion
Extrusion Dies and Presses

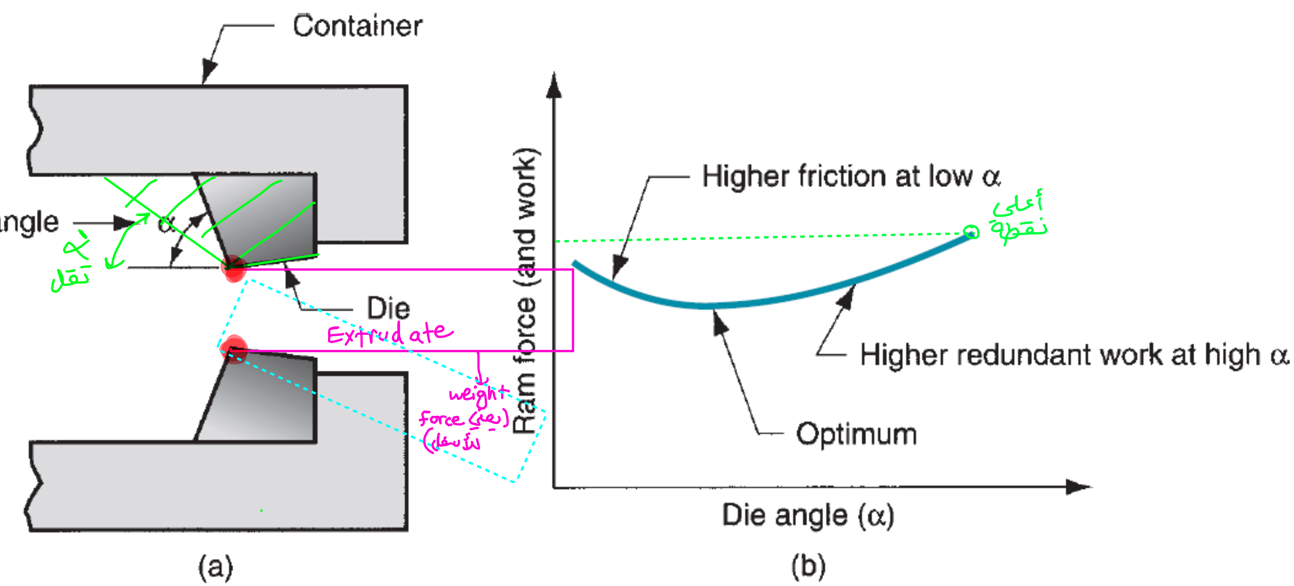


Figure 19.24 (a) Definition of die angle in direct extrusion; (b) effect of die angle on ram force.

Low die angles (α): high friction so high ram force.

High die angles (α): more turbulence, so increased ram force.

An optimum die angle exists.

Extrusion
Extrusion Dies and Presses

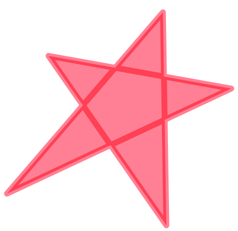
- The effect of the die orifice shape can be assessed by the die shape factor, can be expressed as follows:

$$K_x = 0.98 + 0.02\left(\frac{C_x}{C_c}\right)^{2.25}$$

where K_x = die shape factor in extrusion; C_x = perimeter of the extruded cross section, mm; and C_c = perimeter of a circle of the same area as the extruded shape, mm.

K_x for circular shape = 1

K_x for hollow, thin-walled sections is higher.



For indirect extrusion: $p = K_x \overline{Y_f} \varepsilon_x$

For direct extrusion: $p = K_x \overline{Y_f}\left(\varepsilon_x + \frac{2L}{D_o}\right)$

For shapes other than round.

Extrusion
Extrusion Dies and Presses

$C_x : 4(10)$

$= 40$ mm

10

10

محيط دائرة لها نفس الـ area تبع الـextrudate

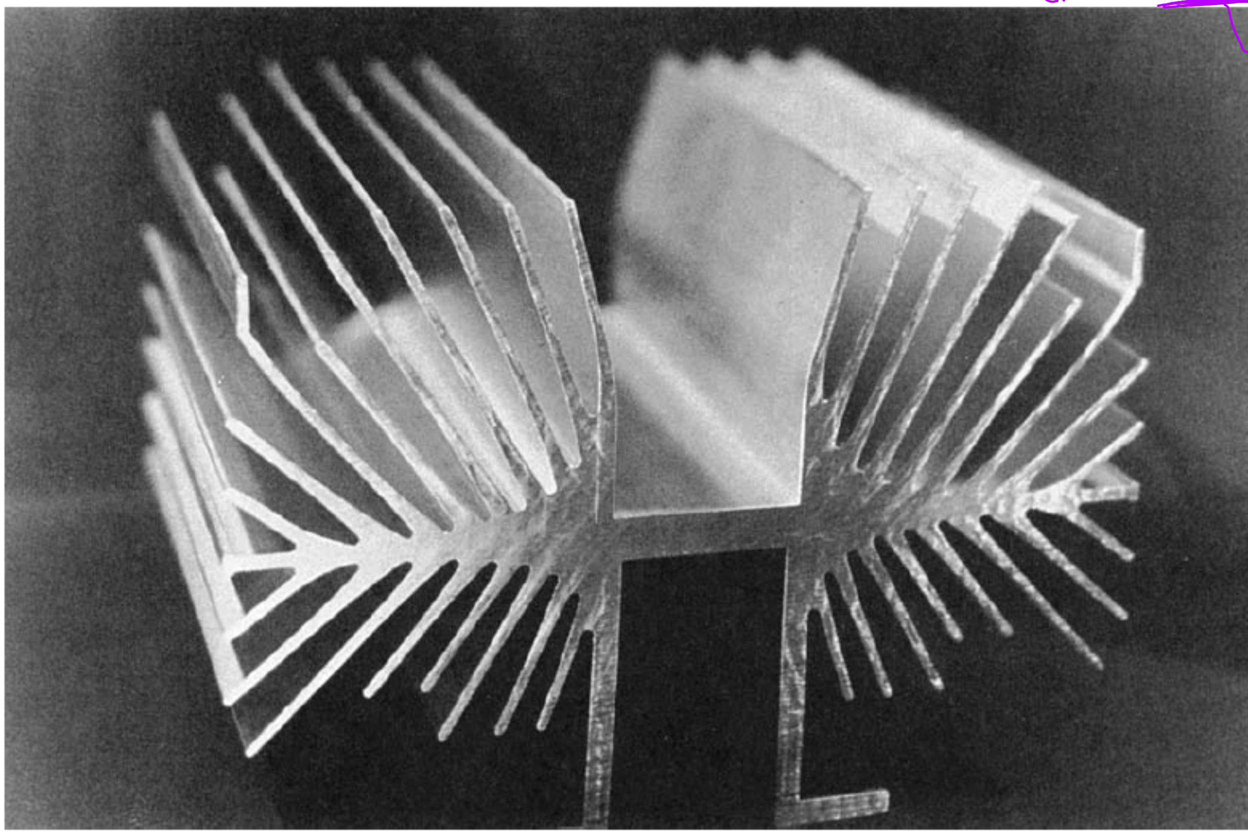
$C_c :$

$\rightarrow A_x = 100 mm^2$

$100 = \frac{\pi}{4} D^2$

$D = 11$ mm

$* \; C_c = \pi(11) = (11\pi) mm$



كل ما زاد تعقيد الشكل
تزداد (K_x)

chiller

Figure 19.25 A complex extruded cross section for a heat sink. (Photo courtesy of Aluminum Company of America, Pittsburg, Pennsylvania).

Extrusion
Extrusion Dies and Presses
قوالب البثق والمكابس

- ***Extrusion presses***: either horizontal or vertical, depending on orientation of the work axis.

- Usually hydraulically driven.

- This drive is especially suited to semi-continuous production of long sections, as in direct extrusion.

- Mechanical drives are often used for cold extrusion of individual parts, such as in impact extrusion.

Extrusion
Defects in Extrusion

- ***Centerburst***: an internal crack that develops as a result of tensile stresses along the centerline of the workpart during extrusion. Conditions that promote centerburst are high die angles, high extrusion ratios, and impurities.

- ***Piping***: a defect associated with direct extrusion. It is the formation of a sink hole in the end of the billet. The use of a dummy block whose diameter is slightly less than that of the billet helps to avoid piping.

- ***Surface cracking***: results from high workpart temperatures that cause cracks to develop at the surface. They often occur when extrusion speed is too high, leading to high strain rates and associated heat generation.

Extrusion speed منخفضة نسبياً
عشان ما يصير crack

حكى الدكتور انه كل ال impurities
ما لحقت اكتبها

Extrusion
Defects in Extrusion

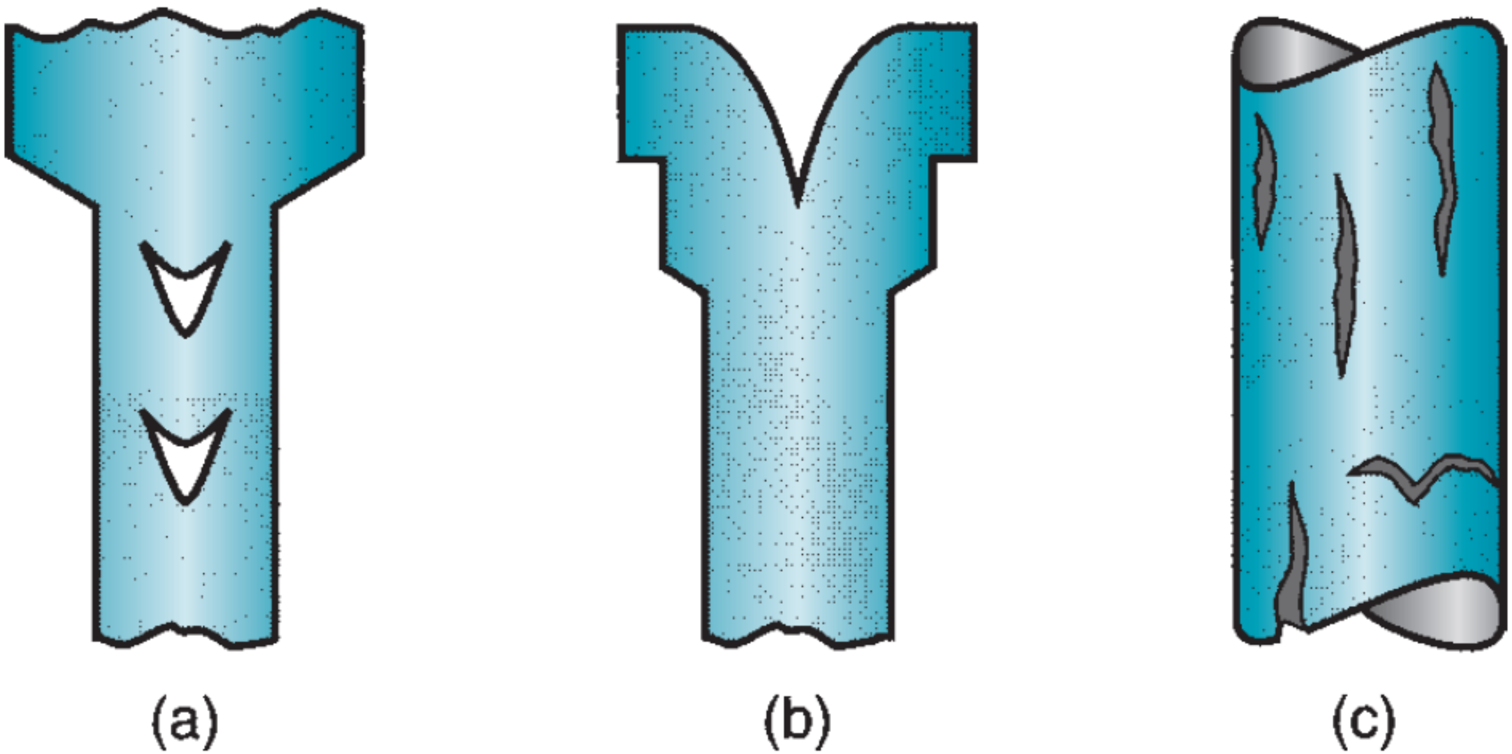


Figure 19.26 Some common defects in extrusion: (a) centerburst, (b) piping, and (c) surface cracking.

Wire and Bar Drawing

- ***Drawing***: is an operation in which the cross section of a bar, rod, or wire is reduced by pulling it through a die opening.

- The difference between drawing and extrusion: the work is pulled through the die in drawing, whereas it is pushed through the die in extrusion.

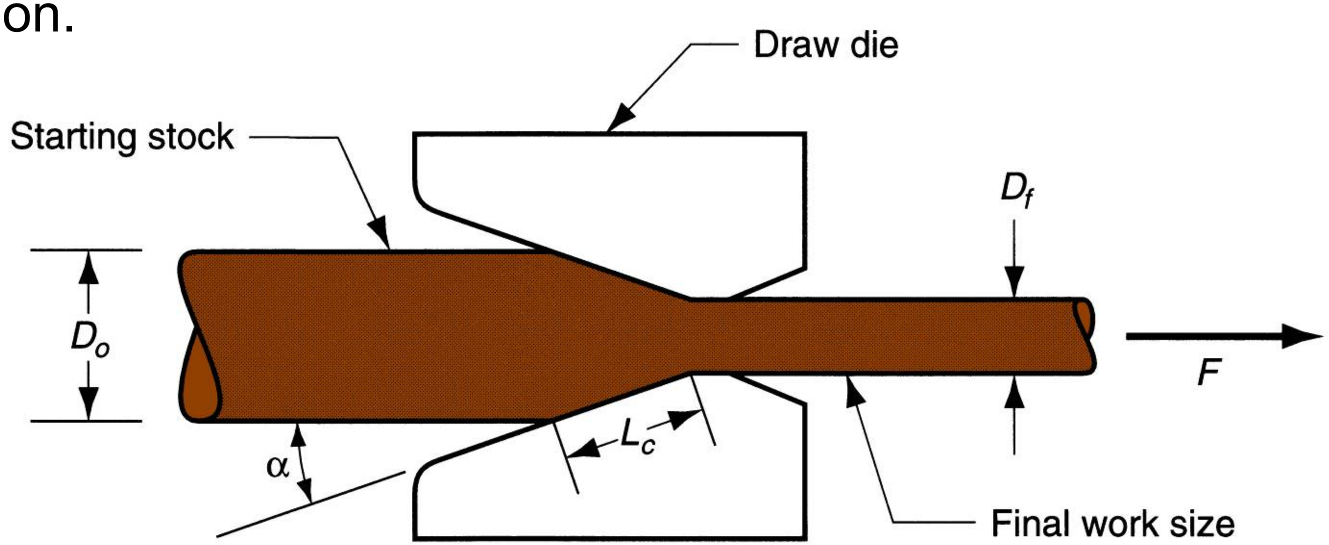


Figure 19.27 Drawing of bar, rod, or wire.

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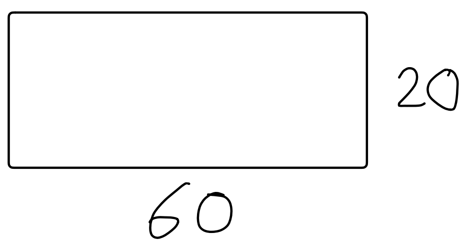
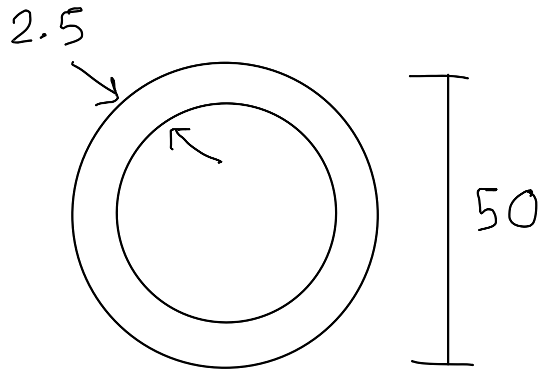
Question (19.32) in the book

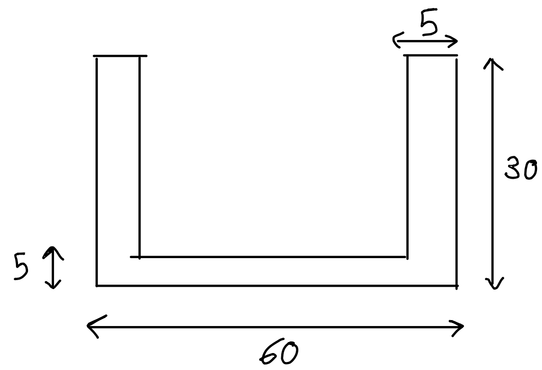
Determine the shape factor for each of the extrusion die orfice shapes below :-



(a)



(b)



(c)

$$C_x = 50\pi + 45\pi = 95\pi \, mm$$

$$A_x = \frac{\pi}{4}(50^2 - 45^2) = 373 \, mm^2 = \frac{\pi}{4} D^2$$

$$D = 21.8 \, mm, \quad C_c = 21.8\pi \, mm$$

$$K_x = 0.98 + .02 \left(\frac{95\pi}{21.8\pi}\right)^{2.25} = 1.54$$

Wire and Bar Drawing

- ***Bar drawing***: the term used for large diameter bars.
- ***Wire drawing***: applies to small diameter bars (wire sizes down to 0.03 mm are possible in wire drawing).
- Two stress components are present is drawing; ***tensile stresses*** due to the pulling action and ***compressive stresses*** because the metal is squeezed down as it passes through the die opening.
- Change in size of work (given by area reduction): $r = \dfrac{A_o - A_f}{A_o}$
- Draft: difference between original and final diameter: $d = D_o - D_f$

Note: A is in (mm^2) and D is in (mm).

Wire and Bar Drawing
Analysis of Drawing

- ***Mechanics of Drawing***: assume no friction.

True strain: $\varepsilon = \ln \dfrac{A_o}{A_f} = \ln \dfrac{1}{1-r}$

Stress: $\sigma = \overline{Y_f}\varepsilon = \overline{Y_f} \ln \dfrac{A_o}{A_f}$ where $\overline{Y_f} = \dfrac{K\varepsilon^n}{1+n}$

Wire and Bar Drawing
Analysis of Drawing

- ***Mechanics of Drawing***: assuming friction, consider Figure 19.27 .

$$\sigma_d = \overline{Y_f}\left(1 + \frac{\mu}{\tan\alpha}\right)\phi \ln\frac{A_o}{A_f}$$

where σ_d = draw stress, MPa; μ = die-work coefficient of friction; α = die angle; and Φ is a factor that accounts for inhomogeneous deformation.

$$\phi = 0.88 + 0.12\frac{D}{L_c}$$

where D = average diameter of work during drawing, mm; and L_c = contact length of the work with the draw die.

$$D = \frac{D_o + D_f}{2} \quad \text{and} \quad L_c = \frac{D_o - D_f}{2\sin\alpha}$$

Accordingly, $$F = A_f\sigma_d = A_f\overline{Y_f}\left(1 + \frac{\mu}{\tan\alpha}\right)\phi \ln\frac{A_o}{A_f}$$ where F = drawing force, N.

Wire and Bar Drawing
Analysis of Drawing

- ***Maximum Reduction per Pass***: why entire reduction is not taken in one pass?
  - As the reduction increases, draw stress increases.
  - If the reduction is large enough, draw stress will exceed the yield strength of the exiting metal.
  - When that happens, the drawn wire will simply elongate instead of new material being squeezed through the die opening.
  - For wire drawing to be successful, maximum draw stress must be less than the yield strength of the exiting metal.

Wire and Bar Drawing
Analysis of Drawing

- ***Maximum Reduction per Pass:*** assuming perfectly plastic material; then (n = 0 hence $\overline{Y_f} = Y$), and no friction:

$$\sigma_d = \overline{Y_f} \ln \frac{A_o}{A_f} = Y \ln \frac{A_o}{A_f} = Y \ln \frac{1}{1-r} = Y$$

- This means that ln (A_o/A_f) = ln ($1/(1-r)$) = 1. Hence, $A_o/A_f = 1/(1 - r)$ must equal the natural logarithm base e. that is, the maximum possible strain is 1.0:

$$\varepsilon_{\max} = 1.0$$

- The maximum possible area ratio is: $$\frac{A_o}{A_f} = e = 2.7183$$

- The maximum possible reduction is: $$r_{\max} = \frac{e-1}{e} = 0.632$$

Wire and Bar Drawing
Drawing Practice

- Drawing is usually performed as a cold working operation.
- Most frequently used to produce round cross sections, but other shapes are also drawn.
- Drawn products include:
  - Electrical wire and cable; wire stock for fences, coat hangers, and shopping carts.
  - Rod stock to produce nails, screws, rivets, springs, and other hardware items.
  - Bar drawing is used to produce metal bars for machining, forging, and other processes.

Wire and Bar Drawing
Drawing Practice

- Advantages include:
  - Close dimensional control.
  - Good surface finish.
  - Improved mechanical properties such as strength and hardness.
  - Adaptability to mass production.

Wire and Bar Drawing
Drawing Practice

- ***Drawing Equipment***: (Bar Drawing)
  - Draw bench: consists of an entry table, die stand, carriage, and exit rack.
  - The carriage is used to pull the stock through the draw die.
  - Powered by hydraulic cylinders or motor-driven chains.

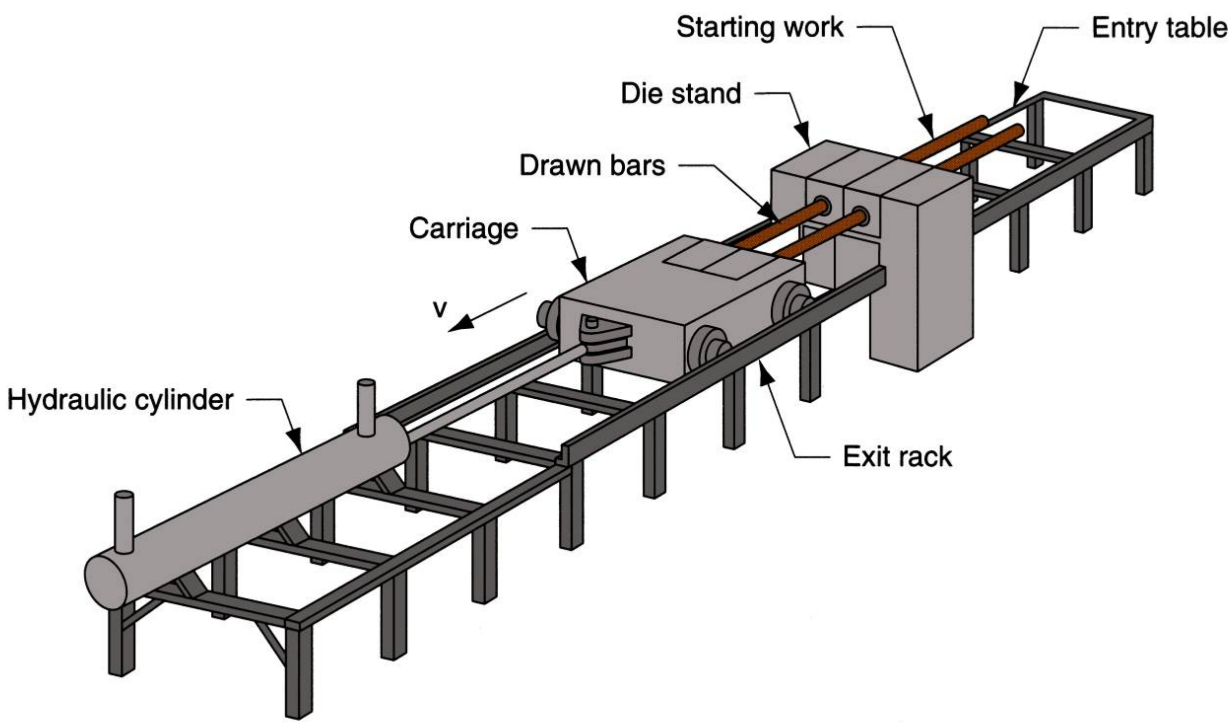


Figure 19.28 Hydraulically operated draw bench for drawing metal bars.

Wire and Bar Drawing
Drawing Practice

- ***Drawing Equipment***: (Wire Drawing)
  - Done on continuous drawing machines that consist of multiple draw dies, separated by accumulating drums between the dies.
  - Each drum, called a ***capstan***, is motor driven to provide the proper pull force to draw the wire stock through the upstream die.
  - It also maintains a modest tension on the wire as it proceeds to the next draw die in the series.
  - Each die provides a certain amount of reduction in the wire, so that the desired total reduction is achieved by the series.

Wire and Bar Drawing
Drawing Practice

- ***Drawing Equipment***: (Wire Drawing)

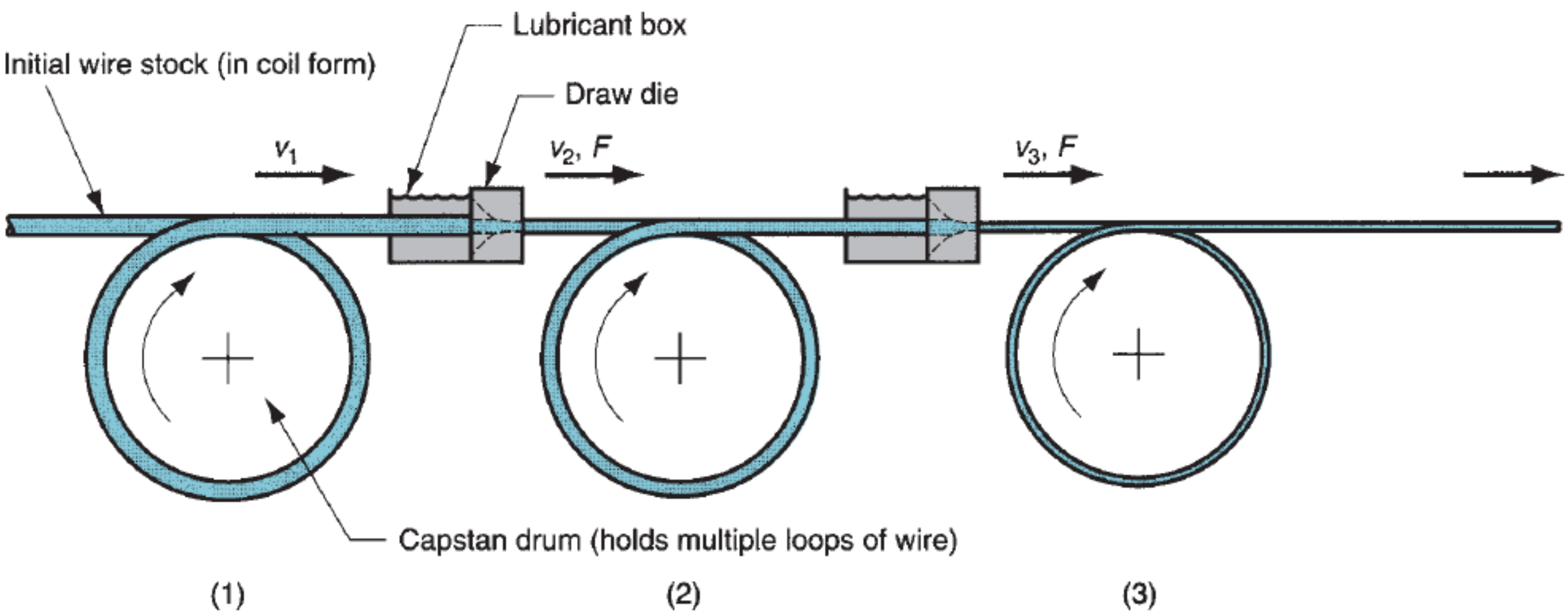


Figure 19.29 Continuous drawing of wire.

Wire and Bar Drawing
Drawing Practice

- ***Drawing Dies*** are made of tool steel, cemented carbides or diamond and they consist of 4 regions:

  (1) ***Entry Region***: usually a bell-shaped mouth that does not contact the work. Its purpose is to funnel the lubricant into the die and prevent scoring of work and die surfaces.

  (2) The ***Approach Region***: is where the drawing process occurs. It is cone-shaped with an angle (half-angle) normally ranging from about 6 to 20^o.

  (3) The ***Bearing Surface*** (***Land***): determines the size of the final drawn stock.

  (4) The ***Back Relief***: is the exit zone. It is provided with a back relief angle (half-angle) of about 30^o.

Wire and Bar Drawing
Drawing Practice

- ***Drawing Dies***:

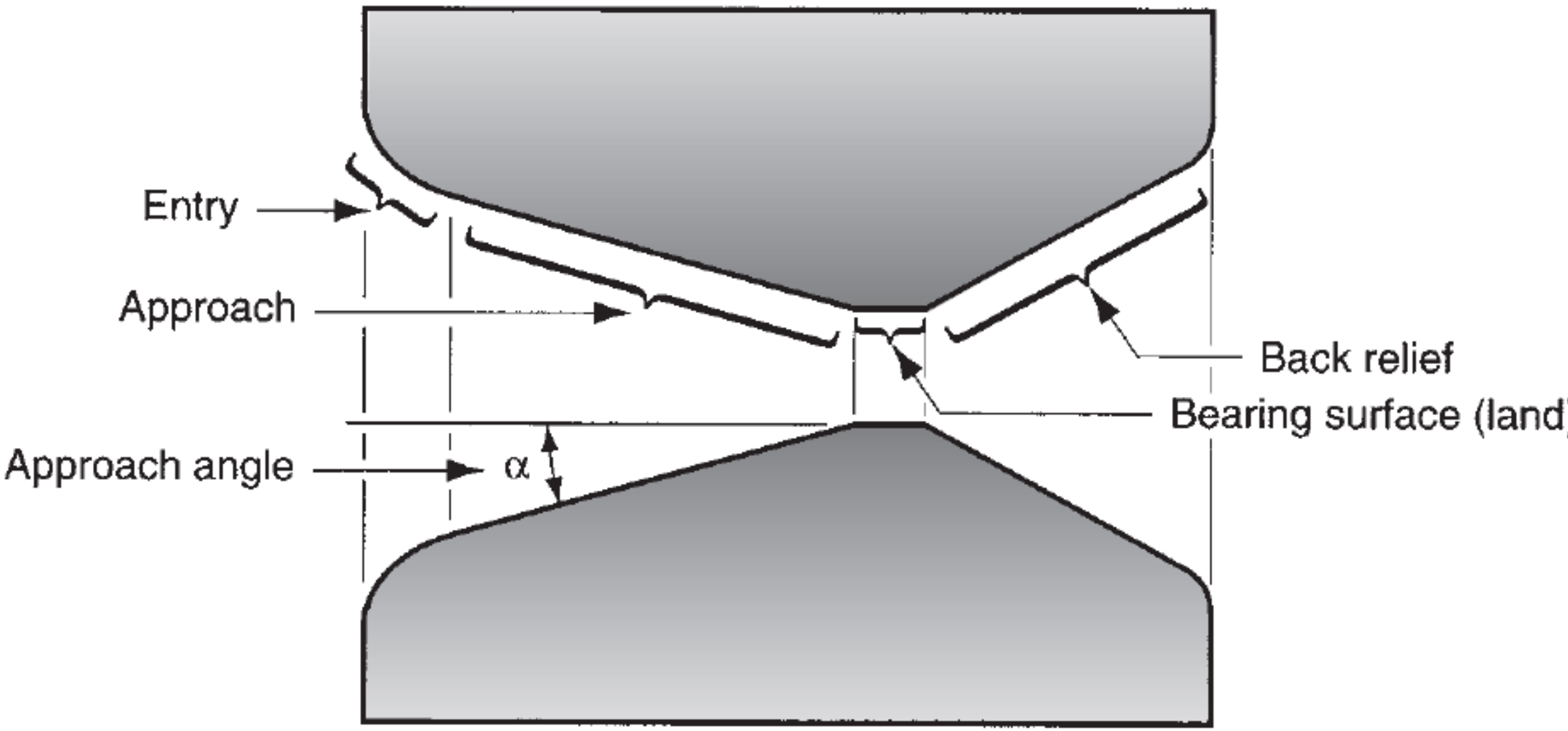


Figure 19.30 Draw die for drawing of round rod or wire.

Wire and Bar Drawing
Drawing Practice

- ***Preparation of work***: involves three steps: (1) annealing, (2) cleaning, and (3) pointing.

  (1) ***Annealing***: done to increase the ductility of the stock.

  (2) ***Cleaning***: required to prevent damage of the work surface and draw die.

  (3) ***Pointing***: involves the reduction in diameter of the starting end of the stock so that it can be inserted through the draw die to start the process. This is usually accomplished by swaging, rolling, or turning.

Manufacturing Processes

Chapter Sixteen:

Sheet Metalworking

Dr. Eng. Yazan Al-Zain
Department of Industrial Engineering

Introduction

- ***Sheet Metalworking*** includes cutting and forming operations performed on relatively thin sheets of metal.

- Typical sheet-metal thicknesses are between 0.4 mm and 6 mm.

- For thickness more than 6 mm, the stock is usually referred to as plate rather than sheet.

- The sheet or plate stock used in sheet metalworking is produced by flat rolling.

- The most commonly used sheet metal is low carbon steel (0.06%–0.15% C). Its low cost and good formability, combined with sufficient strength for most product applications, make it ideal as a starting material.

Aluminium

part → product

we never use Hot working in sheet metal working

Introduction

- Products that include sheet or plate metal parts: automobile and truck bodies, airplanes, railway cars, locomotives, farm and construction equipment, appliances, office furniture, and more.

- Accordingly, the commercial importance of sheet metalworking is significant.

مهم

products

because of cold-working (strain hardened)

- Sheet metal parts are generally characterized by high strength, good dimensional accuracy, good surface finish, and relatively low cost.

- Economical mass-production: designed to process the parts. Aluminum beverage cans are a prime example.

when the sheet is relatively large it is named "plates" and it have low ductility so we use warm working so there will be ① no recrystalization and there will be ② strain hardening

Introduction

- Sheet-metal processing is usually performed at room temperature (cold working).
- The exceptions are when the stock is thick, the metal is brittle, or the deformation is significant. These are usually cases of warm working rather than hot working.

*No Hot-working in Sheets and plates

- ***Stamping Presses***: machine tools on which most sheet-metal operations are performed.
- ***A Punch-and-Die*** (***Stamping Die***): the tooling that performs sheet metalwork.
- ***Stampings***: the sheet-metal products.

Cutting Operations

Rolling تأتي من ال

- Cutting of sheet metal is accomplished by a shearing action between two sharp cutting edges.

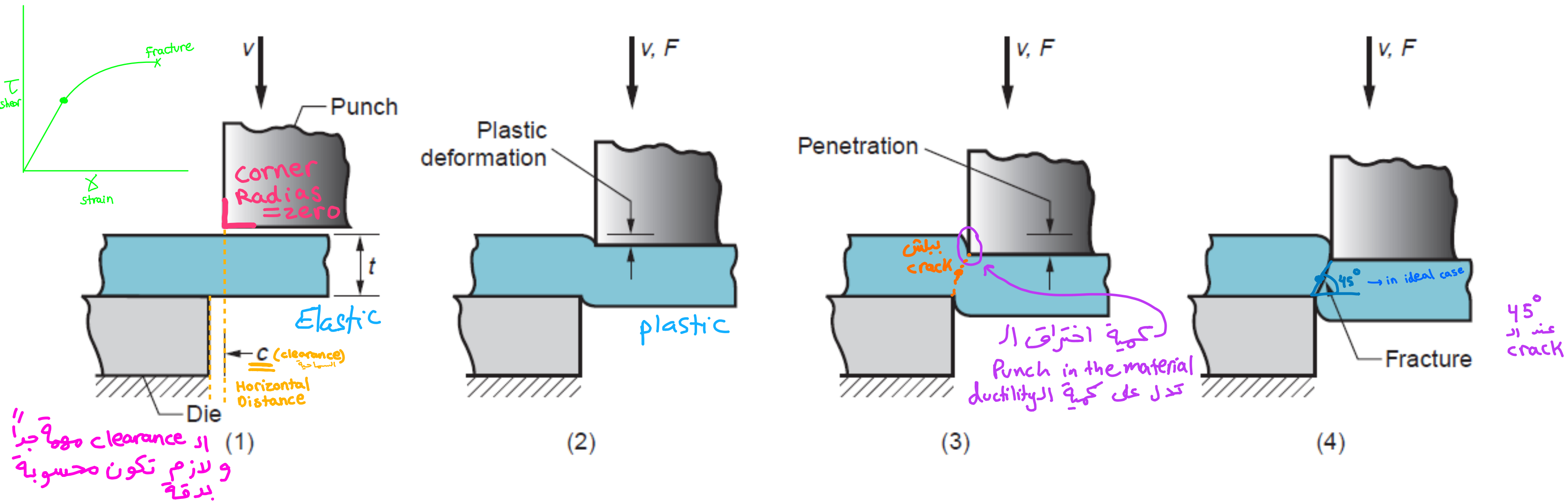


Figure 16.1 Shearing of sheet metal between two cutting edges: (1) just before the punch contacts work; (2) punch begins to push into work, causing plastic deformation; (3) punch compresses and penetrates into work causing a smooth cut surface; and (4) fracture is initiated at the opposing cutting edges that separate the sheet. Symbols *v* and *F* indicate motion and applied force, respectively, *t* = stock thickness, *c* = clearance.

Cutting Operations
Shearing, Blanking & Punching

- The three most important operations in pressworking that cut metal by the shearing mechanism: ***Shearing***, ***Blanking***, and ***Punching***.
  - ***Shearing***: a sheet-metal cutting operation along a straight line between two cutting edges.
  - Used to cut large sheets into smaller sections for subsequent pressworking operations.
  - Performed on a machine called ***a power shears***, or ***squaring shears***.
  - The upper blade of the power shears is often inclined to reduce the required cutting force.

Cutting Operations
Shearing, Blanking & Punching

– ***Shearing*:**

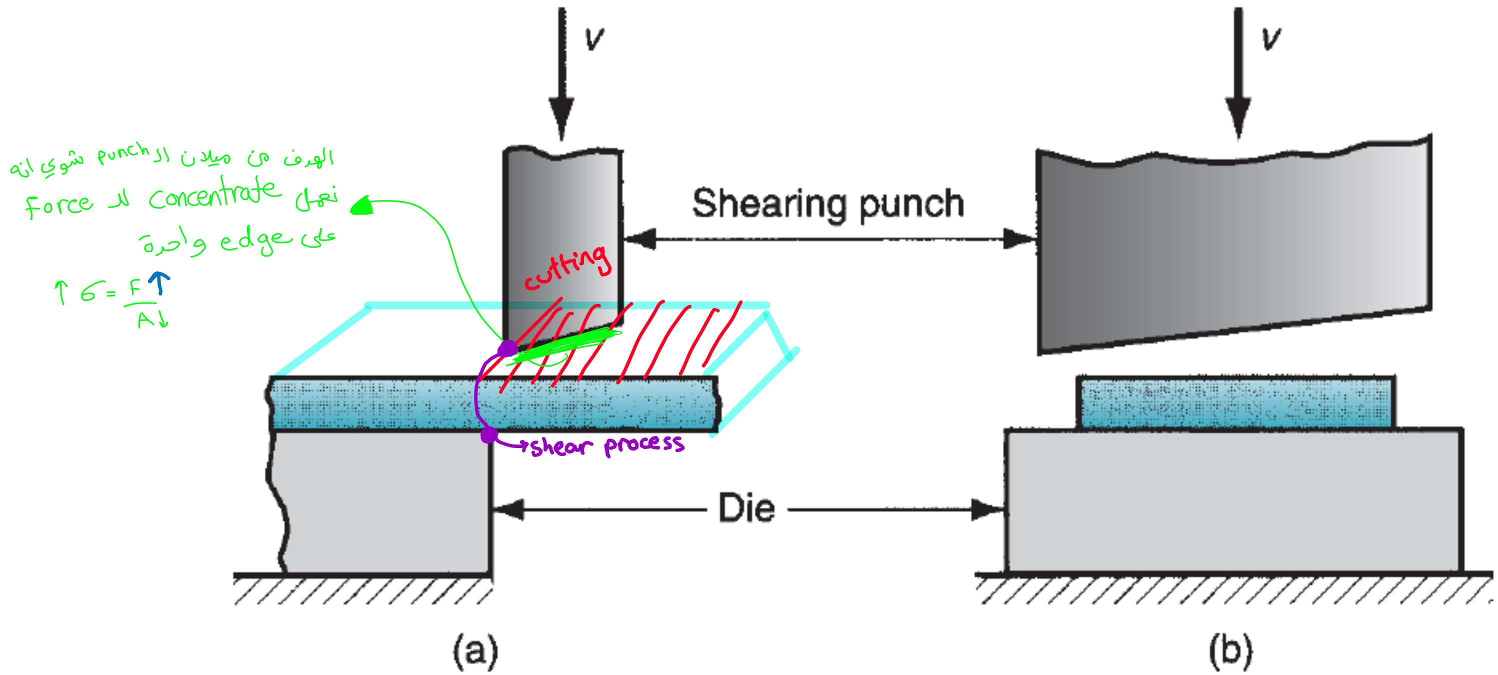


Figure 16.2 Shearing operation: (a) side view of the shearing operation; (b) front view of power shears equipped with inclined upper cutting blade.

Cutting Operations
Shearing, Blanking & Punching

- The three most important operations in pressworking that cut metal by the shearing mechanism: ***Shearing***, ***Blanking***, and ***Punching***.

  - ***Blanking***: involves cutting of the sheet metal along a closed outline in a single step to separate the piece from the surrounding stock.

  - The part that is cut out is the desired product in the operation and is called the ***blank***.

  - ***Punching***: similar to blanking except that it produces a hole, and the separated piece is scrap, called the ***slug***.

  - The remaining stock is the desired part.

Cutting Operations
Shearing, Blanking & Punching

– ***Blanking*** and ***Punching***:

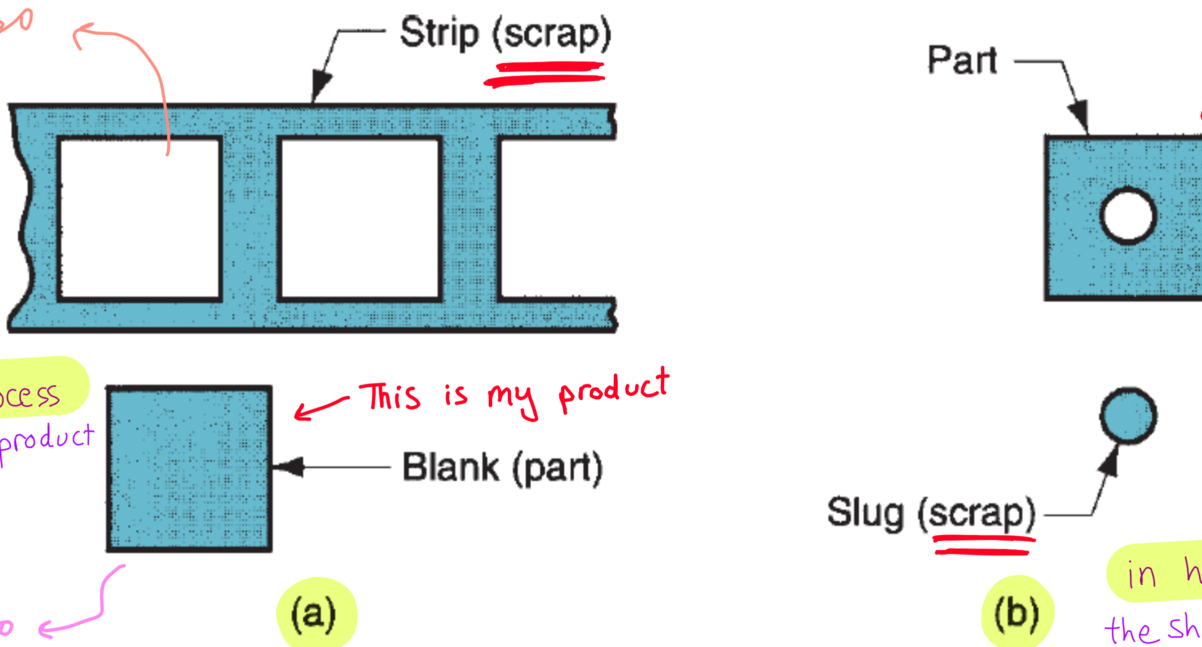


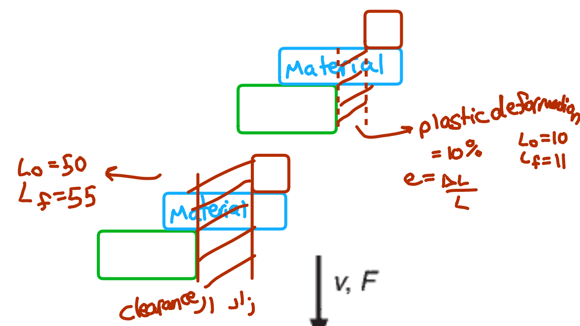
Figure 16.3 (a) Blanking and (b) punching.

Cutting Operations
Engineering Analysis of Sheet-Metal Cutting

- Process parameters in sheet-metal cutting are:
  - Clearance between punch and die.
  - Stock thickness.
  - Type of metal and its strength.
  - Length of the cut.

Cutting Operations
Engineering Analysis of Sheet-Metal Cutting

- ***Clearance***: The clearance *c* in a shearing operation is the distance between the punch and die, as shown in Figure 16.1(1).
  - Usually range between 4% and 8% of the sheet-metal thickness.
  - Improper clearance: see Figure below.



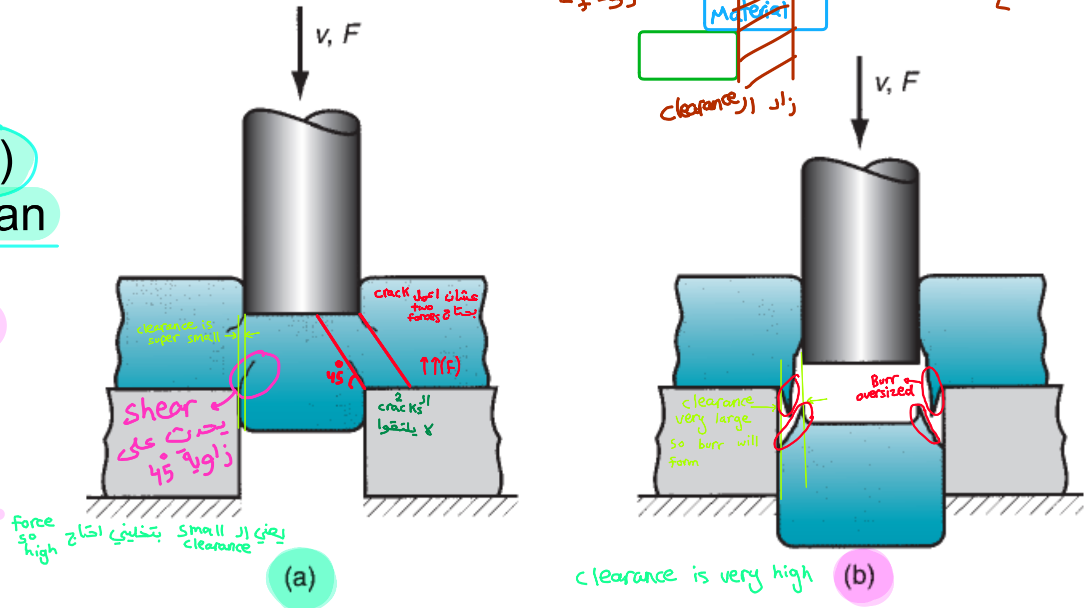
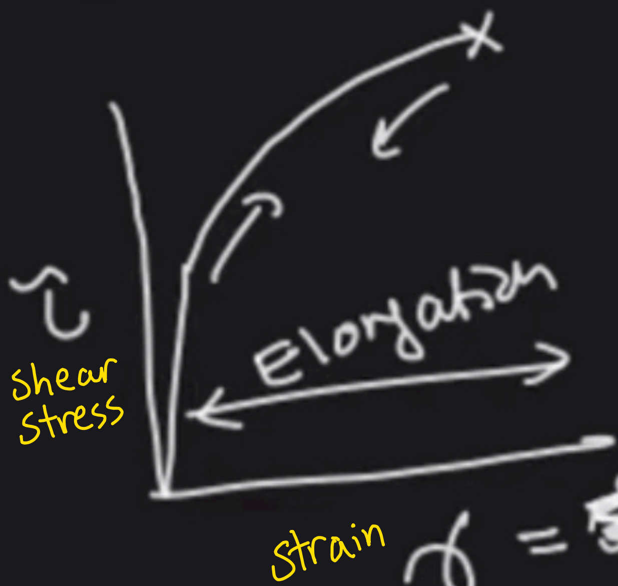
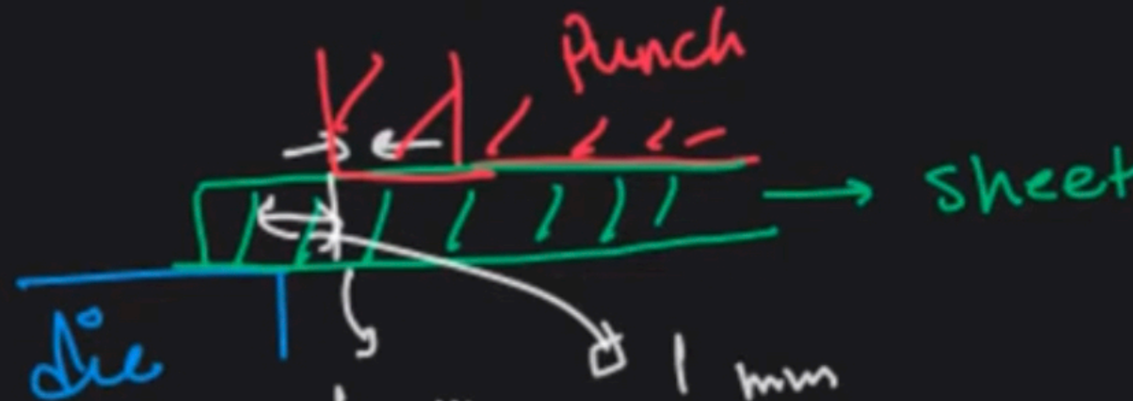


Figure 16.4 Effect of clearance: (a) clearance too small causes less than optimal fracture and excessive forces; and (b) clearance too large causes oversized burr (a sharp corner on the edge caused by elongation of the metal during final separation of the two pieces).





$\gamma = 10\%$

$e = \frac{\Delta L}{L}$

10mm → 11 mm → 1 mm Burr

1 mm → 1.1 mm → 0.1 mm Burr

$l_0 = 10\,mm$

$\hookrightarrow l_f = 11\,m$

Cutting Operations
Engineering Analysis of Sheet-Metal Cutting

- ***Clearance***: correct value depends on ① sheet metal type and ② thickness. ③ Heat treatment
  تأخذها من جهتين
- $c = A_c \times t$ where c = clearance, mm; a = allowance; and t = thickness, mm.
- Allowance depends on the sheet-metal type.

TABLE 20.1 Clearance allowance value for three sheet-metal groups.

Metal Group	A_c
1100S and 5052S aluminum alloys, all tempers	0.045
2024ST and 6061ST aluminum alloys; brass, all tempers; soft cold-rolled steel, soft stainless steel	0.060
Cold-rolled steel, half hard; stainless steel, half-hard and full-hard	0.075

- These calculated clearance values can be applied to conventional blanking and hole punching operations to determine the proper punch and die sizes.

Cutting Operations
Engineering Analysis of Sheet-Metal Cutting

- Whether to add the clearance value to the die size or subtract it from the punch size depends on whether the part being cut out is a blank or a slug, as illustrated below for a circular part.

Punch and dies sizes for a round blank of diameter D_b:

Blanking punch diameter = $D_b - 2c$

Blanking die diameter = D_b

Punch and dies sizes for a round hole of diameter D_h:

Hole punch diameter = D_h

Hole die diameter = $D_h + 2c$

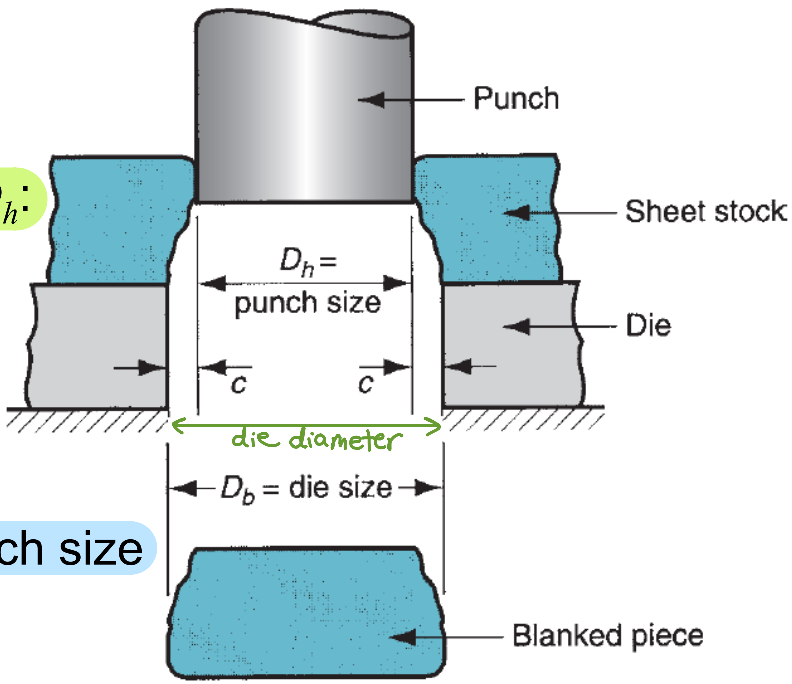


Figure 20.5 Die size determines blank size D_b; punch size determines hole size D_h.

Cutting Operations
Engineering Analysis of Sheet-Metal Cutting

- In order for the slug or blank to drop through the die, the die opening must have an angular clearance of 0.25º to 1.5º on each side.

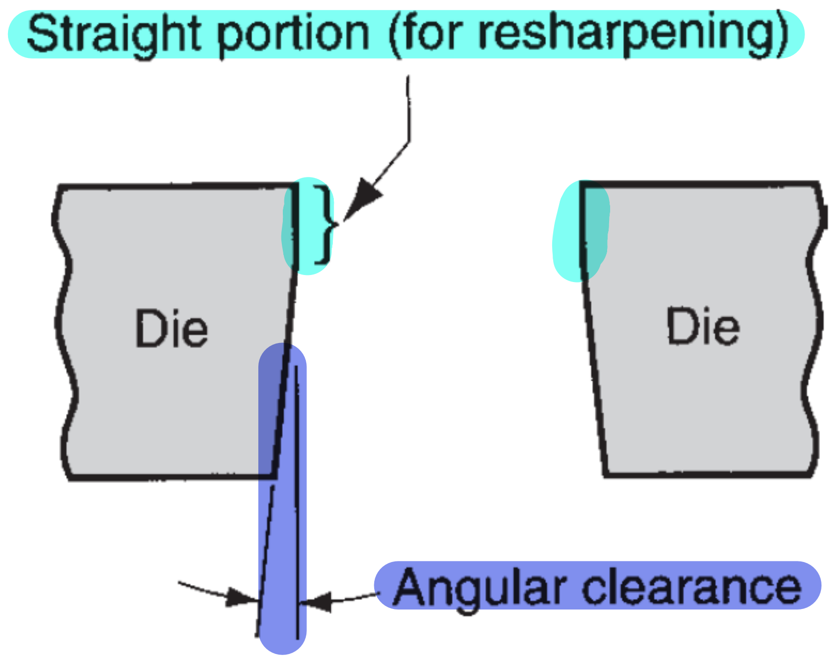


Figure 16.6 Angular clearance.

Cutting Operations
Engineering Analysis of Sheet-Metal Cutting

- ***Cutting Forces***: important as they determine the size of the press needed.

Tonnage press

$$F = StL$$

where F = cutting force (N); S = shear strength of the metal (MPa); t = stock thickness (mm); and L = length of the cut edge (mm).

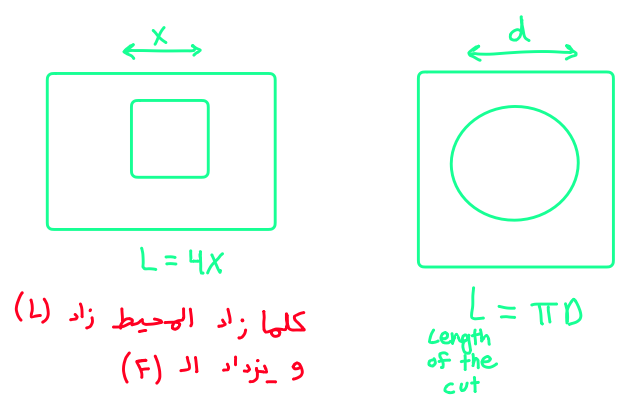
محيط المربع
محيط الدائرة
(محيط)

- In case the shear strength was unknown, then:
- $$F = 0.7TStL$$ where TS = ultimate tensile strength (MPa).

$$S = 0.7\,TS$$

F = 100 N ⟶ tons
÷ 4.4482 x 2000 ⟶ للتحويل من N لـ tonn

مثلاً
= 14.6 tons
ما بصير يكون كسور
∴ 15 tons ← بسوي Round up



Cutting Operations
Other Sheet-Metal-Cutting Operations

- In addition to shearing, blanking, and punching, there are several other cutting operations in pressworking.
  - ***Cutoff*** and ***Parting***. (Blanking)
  - ***Slotting***, ***Perforating***, and ***Notching***. (Punching)
  - ***Trimming***, ***Shaving***, and ***Fine Blanking***.

Cutting Operations
Other Sheet-Metal-Cutting Operations

both are blanking processes

- ***Cutoff*** and ***Parting***.

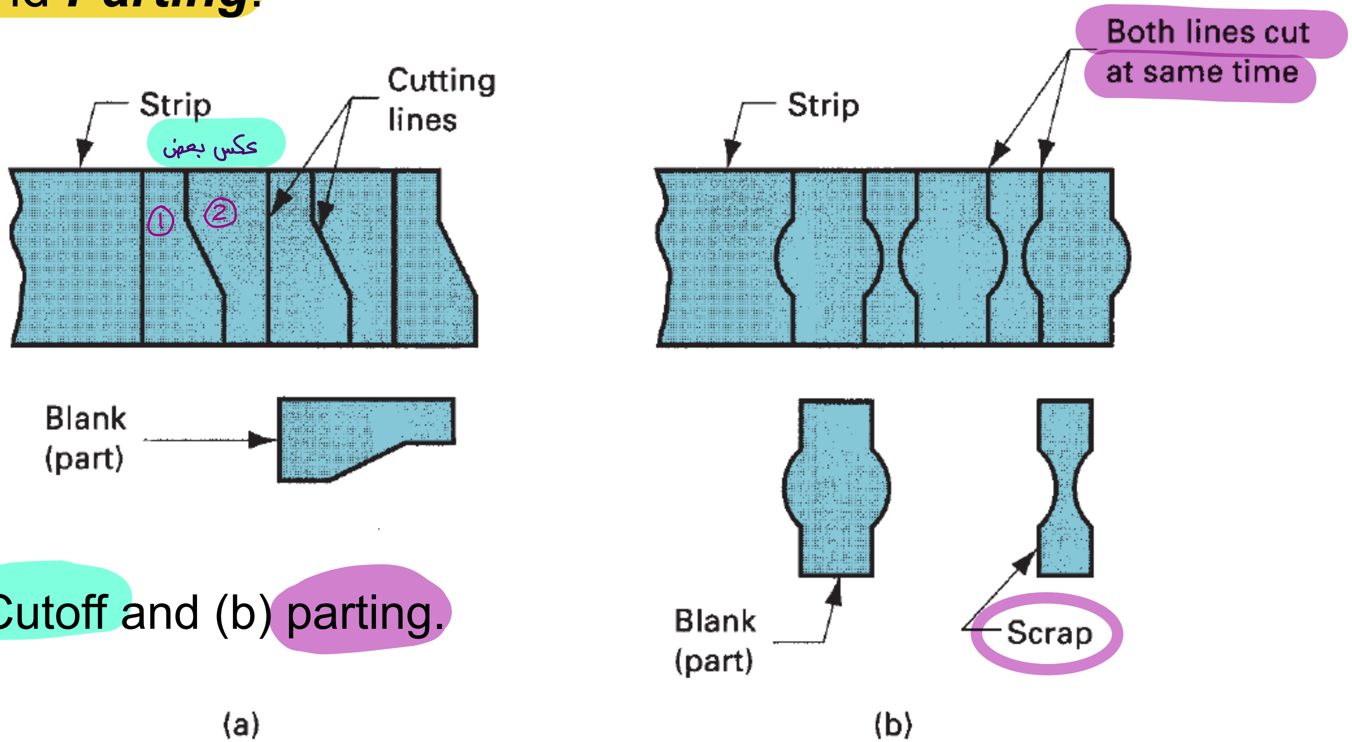


Figure 16.7 (a) Cutoff and (b) parting.

No scrap

Scrap forms

Cutting Operations
Other Sheet-Metal-Cutting Operations

- ***Slotting***, ***Perforating***, and ***Notching***.

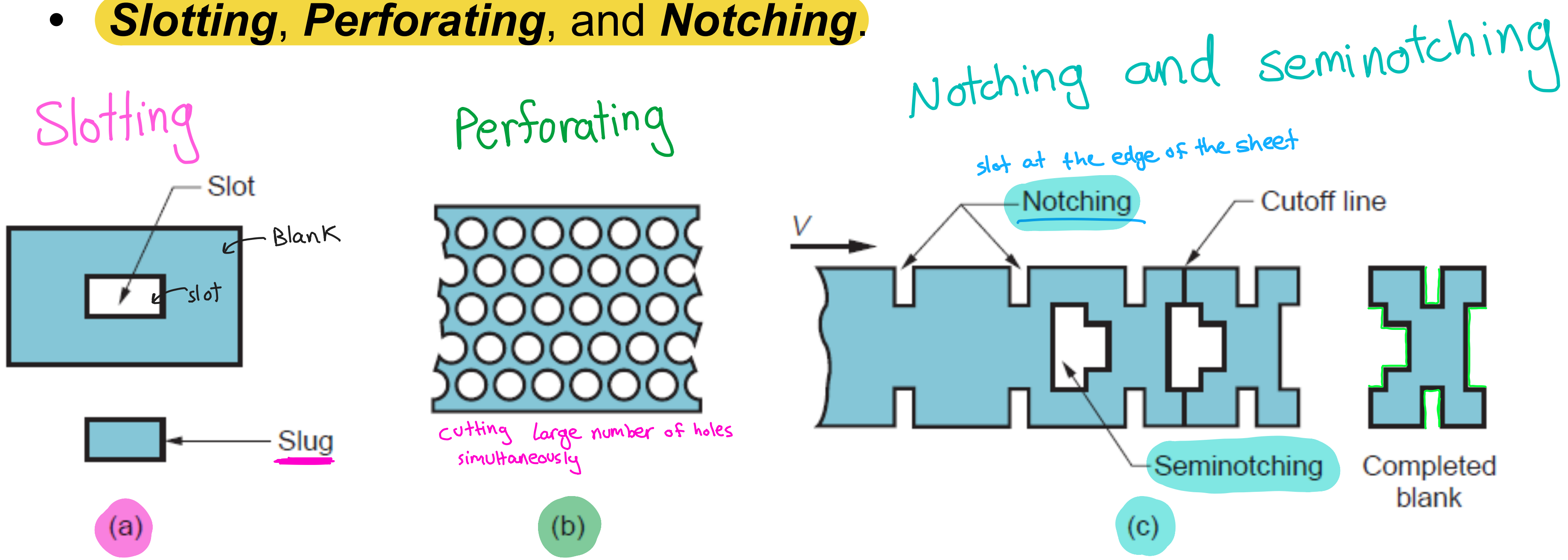


Figure 16.8 (a) Slotting (cutting out elongated or rectangular hole), (b) perforating (simultaneous punching of a pattern of holes), (c) notching (cutting out a portion of metal from the side of the sheet) and seminotching (removes a portion of metal from the interior of the sheet).

Cutting Operations
Other Sheet-Metal-Cutting Operations

- ***Trimming***, ***Shaving***, and ***Fine Blanking***.

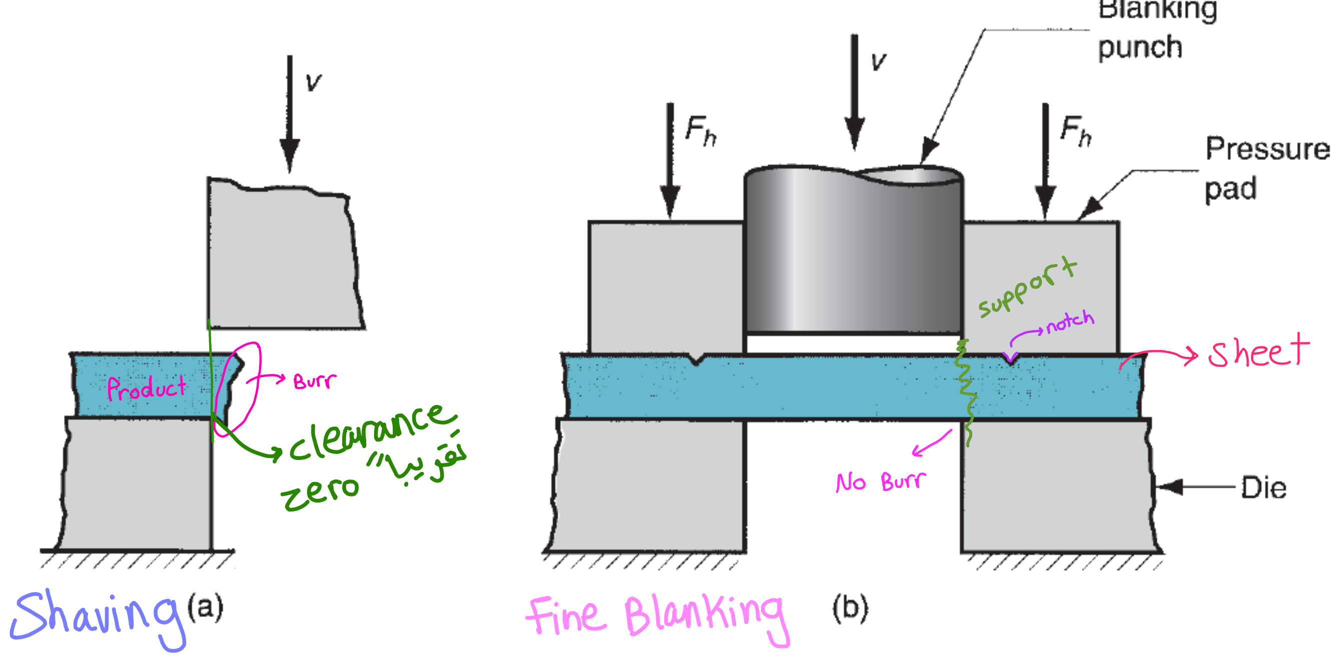


Figure 16.9 (a) Shaving (to cut unsmooth edges and get accurate dimensions) and (b) fine blanking (gives close tolerance and smooth, straight edges).

* [plastic deformations بر ما Bur بنتج . ما كشان] متأكدة

video (Sheet Metal cutting operation) punching and Blanking

very soft material → Ductility يعني عالية

(6 min)

Types of deformation → Bending, Stretching, Drawing

Basic Die operations :-

- Cutting
- Bending
- Forming
- Drawing
- Squeezing

Bending →
1. To gain rigidity (strain hardening يعني)
2. To get specific shape (shaping)

Formality factors →
- Metal's Ductility
- Die Design
- stamping press
- press speed
- Lubrication
- Sheet Metal feeding Mechanisms
- Monitering/control systems

Flanging (90°) → bending لجزء معين على ال edge

* use of Flanged edge →
  - Part Appearance
  - Part Rigidity
  - Edge strengthening
  - Remove a sheared edge
  - Fastening Surface

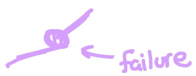
Elastic → Plastic → (مدري) → Shearing

Burnish edge → soft edge يعني

الطوي
* Hemming (180°) → Flanging on two sides
to provide a smooth rounded edge and to attach sheet metal parts together

(Mild steel) → 1. Medium ductility
Medium

Punch distance لما ينزل ال cutting بصير [illegible] $\left(\frac{1}{3}\right)$



Hemming (4 types) →
- Flat Hem (Too much bending, R very small, high ductility)
- Tear Drop Hem (is used for materials lack ductility (Britlle))
- Open Hem → To join Sheet Metals Together
- Rope Hem → To join Sheet Metals Together

2. * Hard Materials
penetration will be maybe less than $\left(\frac{1}{3}\right)$ of the material thickness

3. Soft materials may require almost full penetration $\left(\frac{3}{3}\right)$ before fracture occurs

Trimming → to remove the excess of the material

penetration → نزل على ال ductility

Bending Operations

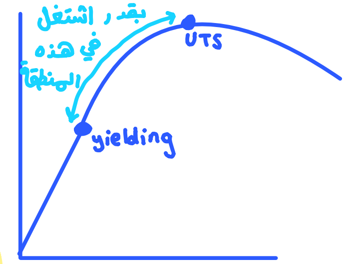
- ***Bending*** in sheet-metalwork: the straining of the metal around a straight axis.

- During the bending: the metal on the inside of the neutral plane is compressed, while the metal on the outside is stretched.

- The metal is plastically deformed so that the bend takes a permanent set upon removal of the stresses that caused it.

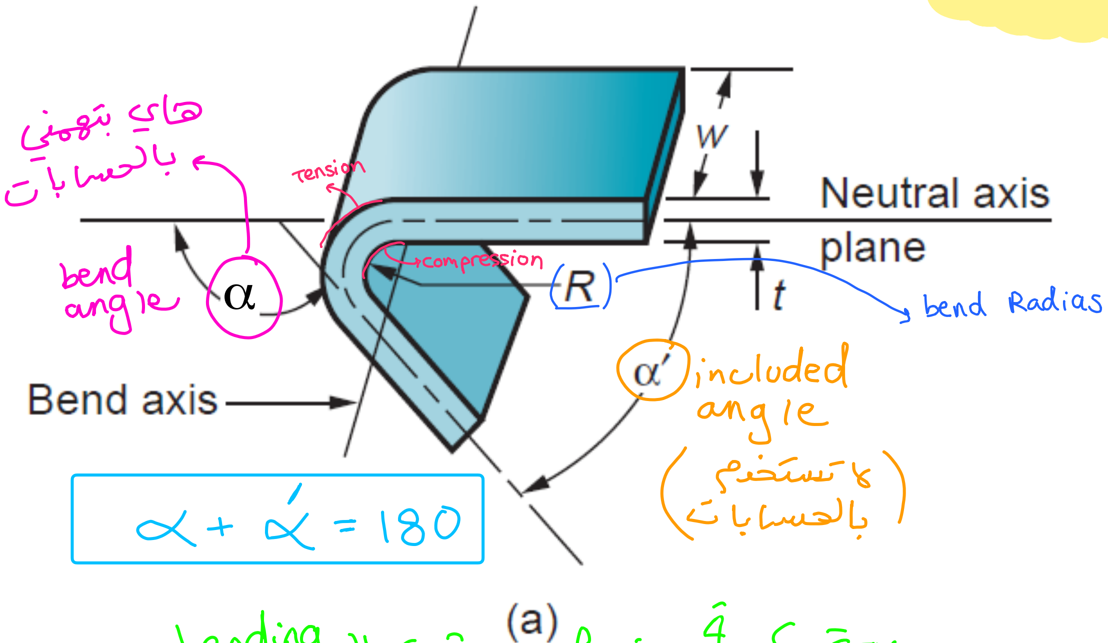
- Bending produces little or no change in the thickness of the sheet metal.

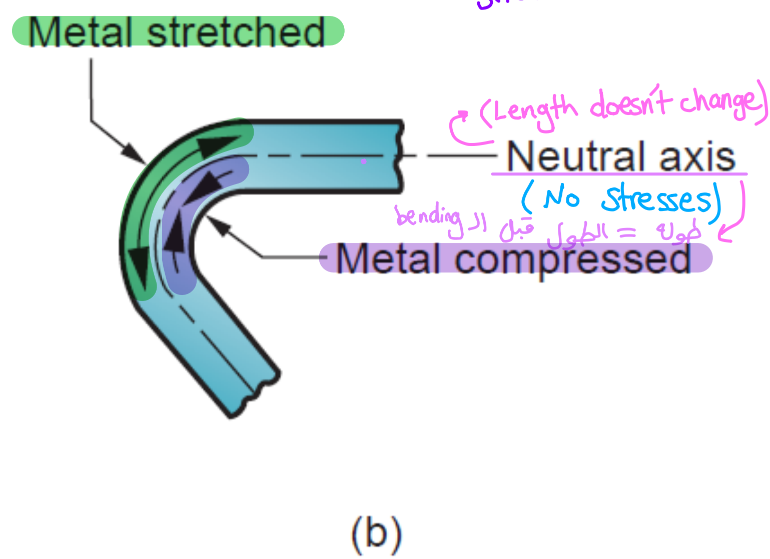
Bending Operations



بنشتغل above the yield and bellow the UTS

طول initial sheet = طول Neutral axis





علاقة عكسية بين R و شدة الـ bending

(كل ما كانت R أصغر يعني قوة الـ bending أكبر)

Figure 16.10 (a) Bending of sheet metal; (b) both compression and tensile elongation of the metal occur in bending.

Bending Operations
V-Bending & Edge-Bending

- Bending operations are performed using punch and die tooling.

- The two common bending methods and associated tooling are V- bending, performed with a V-die; and edge-bending, performed with a wiping die.

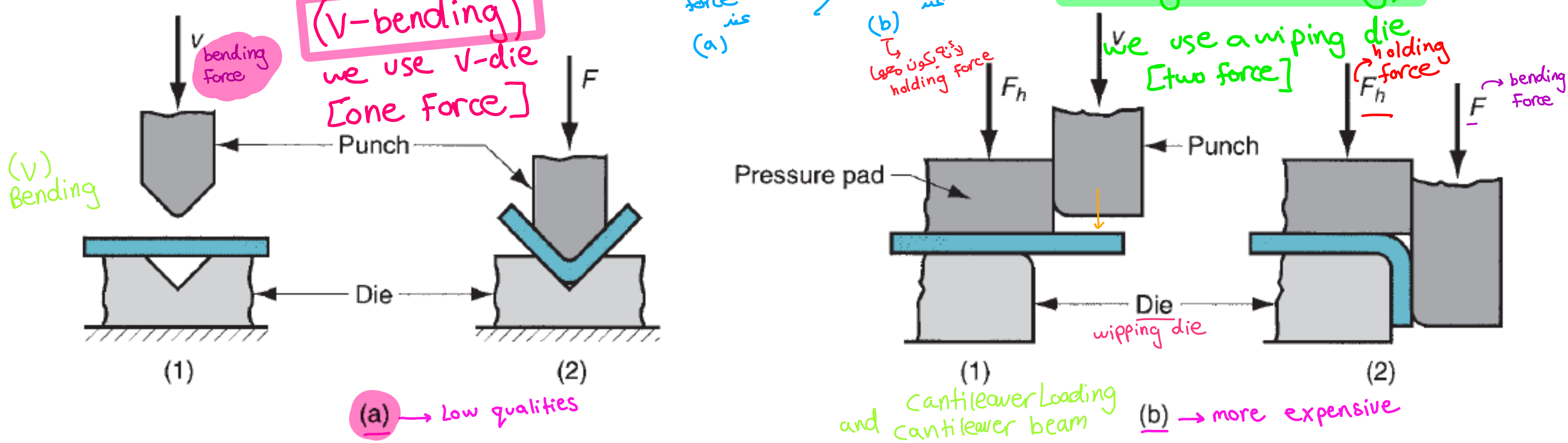


Figure 16.11 Two common bending methods: (a) V-bending and (b) edge-bending; (1) before and (2) after bending. v = motion, F = applied bending force, F_h = blank.

Bending Operations
V-Bending & Edge-Bending

- ***V-Bending***: the sheet metal is bent between a V-shaped punch and die.
  - Angles ranging from very obtuse to very acute can be made with V-dies.
  - Generally used for low-production operations.
  - V-dies are relatively simple and inexpensive.

- ***Edge-Bending***: involves cantilever loading of the sheet metal.
  - A pressure pad is used to apply a force F_h to hold the base of the part against the die, while the punch forces the part to yield and bend over the edge of the die.
  - Because of the pressure pad, wiping dies are more complicated and costly than V-dies and are generally used for high-production work.

Bending Operations
Engineering Analysis of Bending

[1] Metal of thickness *t* is bent through an angle called the bend angle α.

[2] Result: a sheet-metal part with an included angle α', where $\alpha + \alpha' = 180^{o}$.

[3] Bend radius (*R*): specified on the inside of the part, and is determined by the radius on the tooling used to perform the operation.

[4] The bend is made over the width of the workpiece *w*.

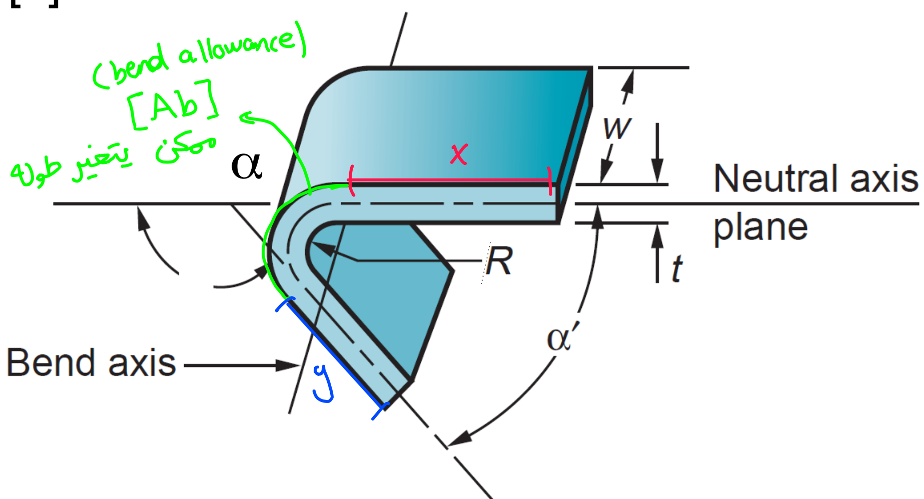


Figure 16.12 (a) Bending of sheet metal.

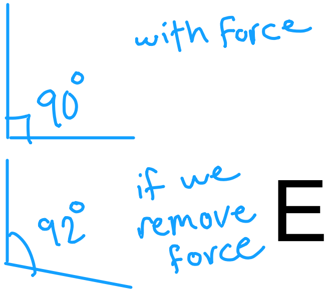
Bending Operations
Engineering Analysis of Bending

- ***Bend Allowance***: If the bend radius is small relative to stock thickness, the metal tends to stretch during bending.
  - It is important to be able to estimate the amount of stretching, so that the final part length will match the specified dimension.
  - The problem is to determine the length of the neutral axis before bending to account for stretching of the final bent section.
  - This length is called the ***bend allowance***.

$$A_b = 2\pi \frac{\alpha}{360}(R + K_{ba}t)$$

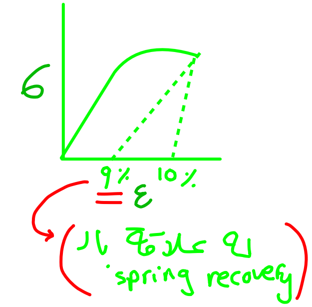
where A_b = Bend allowance, mm; α = bend angle, degrees; R = bend radius, mm; t = stock thickness, mm; and K_{ba} is factor to estimate stretching.

values recommended for K_{ba}: if R $<2t$, K_{ba} = 0.33; and if $R \geq 2t$, K_{ba} = 0.50. The values of K_{ba} predict that stretching occurs only if bend radius is small relative to sheet thickness.



Bending Operations
Engineering Analysis of Bending

لازم ازيد ال force حتى اوصل ال ١٥٪

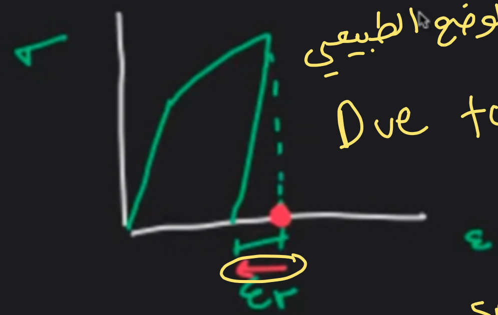


- ***Spring Back***: when the bending pressure is removed at the end of the deformation operation, elastic energy remains in the bent part, causing it to recover partially toward its original shape.
  - This elastic recovery is called ***springback***.
  - It is the increase in included angle of the bent part relative to the included angle of the forming tool after the tool is removed.

$$SB = \frac{\alpha' - \alpha'_t}{\alpha'_t}$$

where SB = springback; α' = included angle of the sheet-metal part, degrees; and α'_t = included angle of the bending tool, degrees.

Although not as obvious, an increase in the bend radius also occurs due to elastic recovery. The amount of springback increases with modulus of elasticity E and yield strength Y of the work metal.



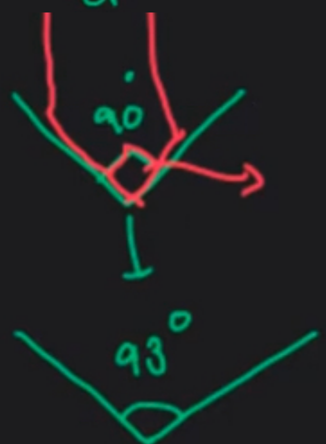
في الوضع الطبيعي

Due to elastic recovery

للتغلب على ال spring back
(elastic recovery)

* حالة ①

نزيد كمية ال plastic deformation عشان
لما ترتد ترتد للمكان المطلوب



* حالة ②

ال Punch وال Die
نعمل ال angles
slightly smaller
مثلاً 88° أو 87°

Bending Operations
Engineering Analysis of Bending

- Amount of springback can be compensated by:
  - ***Overbending***: the punch angle and radius are fabricated slightly smaller than the specified angle on the final part so that the sheet metal springs back to the desired value.
  - ***Bottoming***: squeezing the part at the end of the stroke, thus plastically deforming it in the bend region.

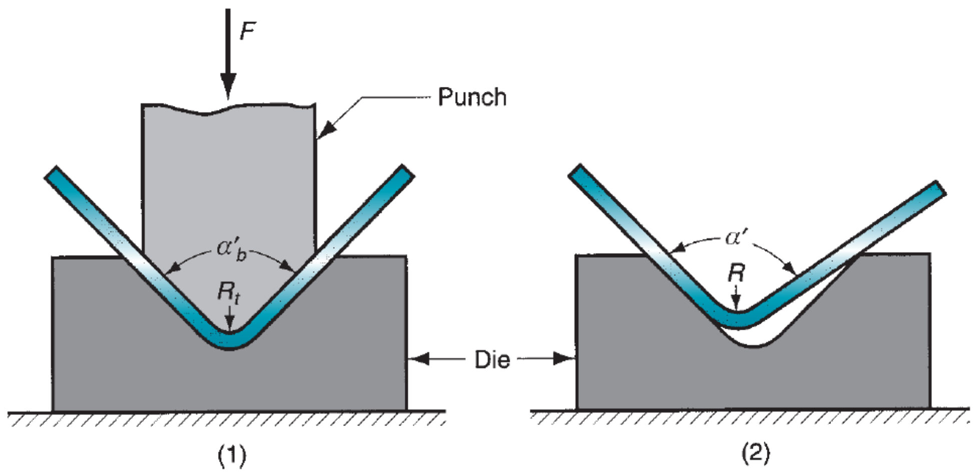


Figure 16.13 Springback in bending shows itself as a decrease in bend angle and an increase in bend radius: (1) during the operation, the work is forced to take the radius R_t and included angle α'_t is determined by the bending tool (punch in V-bending); (2) after the punch is removed, the work springs back to radius R and included angle α'.

Bending Operations
Engineering Analysis of Bending

- ***Bending Force***: force required to perform bending depends on geometry of the punch-and-die and strength, thickness, and length of the sheet metal.

$$F = \frac{K_{bf}(TS)wt^2}{D}$$

where F = bending force, N; (TS) = tensile strength of the sheet metal, MPa; w = width of part in the direction of the bend axis, mm; t = stock thickness, mm; and D = die opening dimension as defined in Figure 20.12, mm.

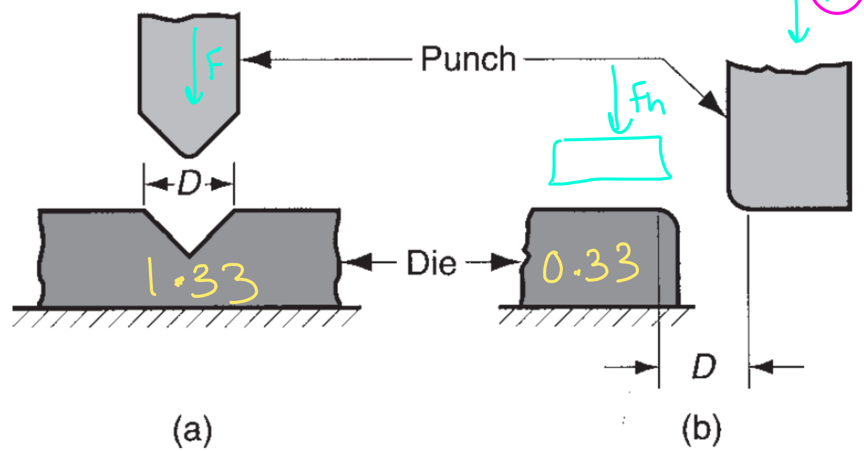


Figure 16.14 Die opening dimension D: (a) V-die, (b) wiping die.

This equation is based on bending of a simple beam in mechanics, and K_{bf} is a constant that accounts for differences encountered in an actual bending process. Its value depends on type of bending: for V-bending, K_{bf} = 1.33; and for edge bending, K_{bf} = 0.33.

Bending Operations
Other Bending & Forming Operations

- ***Flanging***: a bending operation in which the edge of a sheet-metal part is bent at a 90º angle (usually) to form a rim or flange.
  - Often used to strengthen or stiffen sheet metal.
  - The flange can be formed over a straight bend axis.
  - It may also involve some stretching or shrinking of the metal.

- ***Hemming***: involves cantilever loading of the sheet metal.
  - Bending edge of the sheet over on itself, in more than one bending step.
  - Often done to eliminate the sharp edge on the piece, to increase stiffness, and to improve appearance.

Bending Operations
Other Bending & Forming Operations

- ***Seaming***: a related operation in which two sheet-metal edges are assembled.

- ***Curling*** (***beading***): forms the edges of the part into a roll or curl.

  – Done for purposes of safety, strength, and aesthetics.
  – Applications include hinges, pots and pans.

Bending Operations
Other Bending & Forming Operations

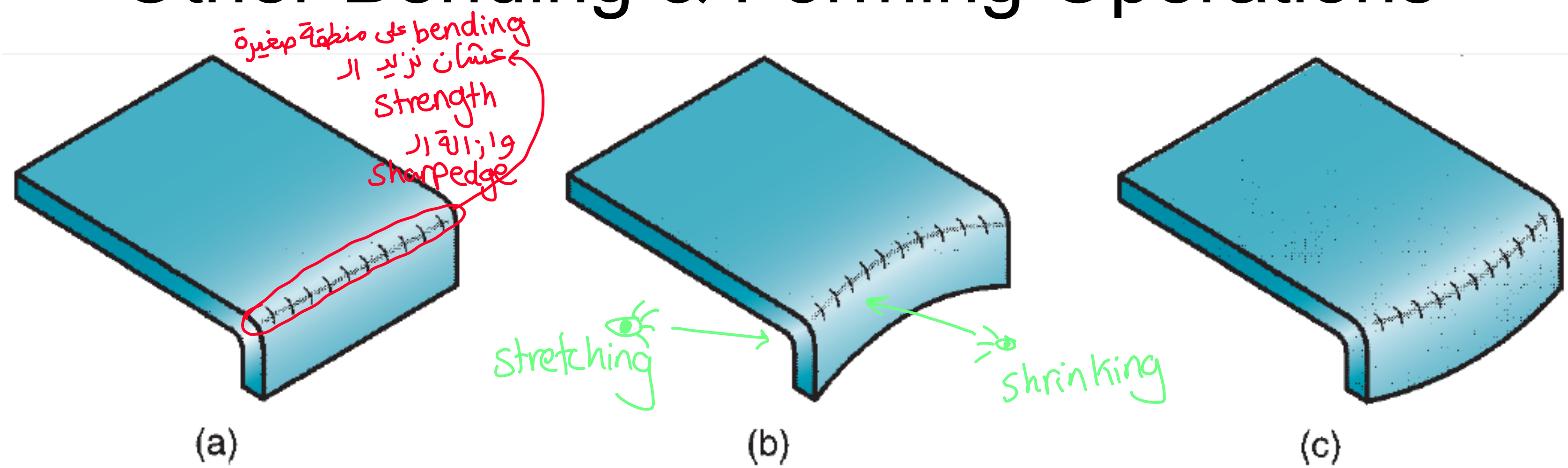


Figure 20.15 Flanging: (a) straight flanging, (b) stretch flanging, and (c) shrink flanging.

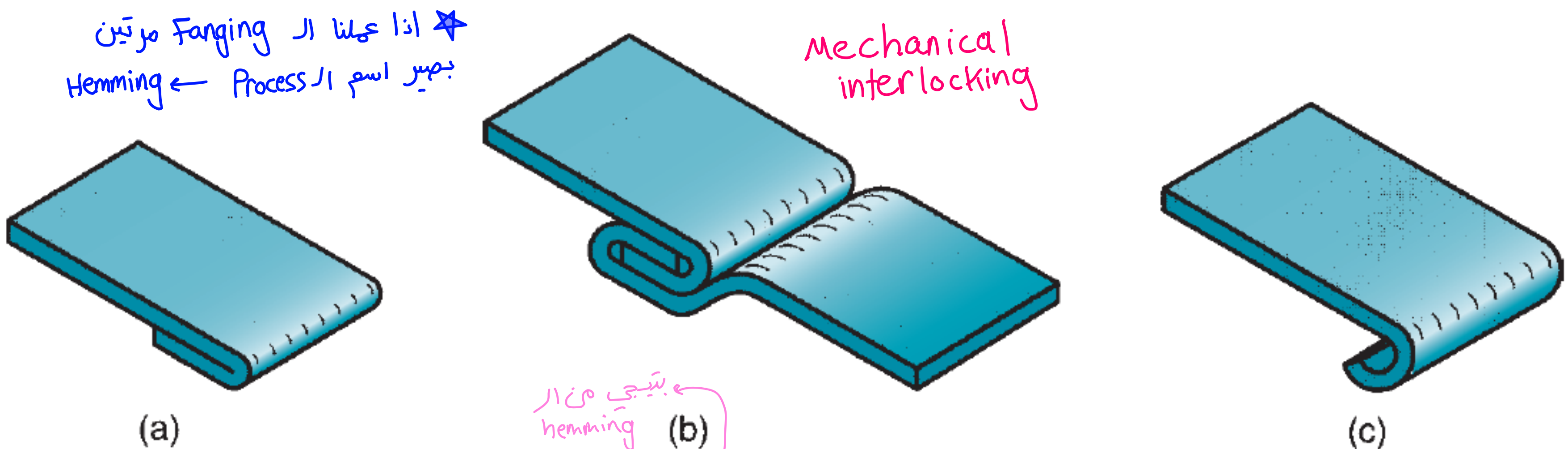
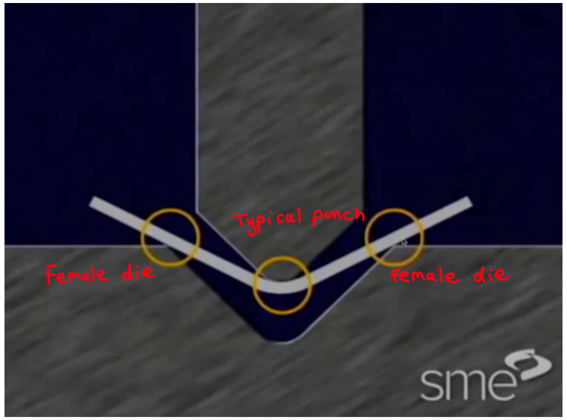


Figure 20.16 (a) Hemming, (b) seaming, and (c) curling.

video [Sheet metal bending] (1.46 min)



3 contact points → Typical punch, Female die, Female die

No Cutting (only bending)

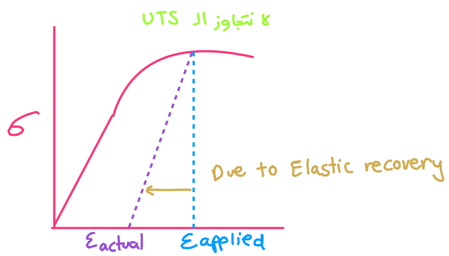
* The larger the die opening the smaller the force required to form a give angle

(علاقة عكسية)

* The principle terms used to describe bending on press breaks are

- Bend Allowance] * very important
- Bend Angle
- Bend Radias
- Springback] → The tendency of the material to come back to its form
  - الارتداد (2° ~ 4°)
  - و السبب هو ال (Elastic Energy)

Springback ussualy falls between 2 to 4 degrees



* للتوضيح

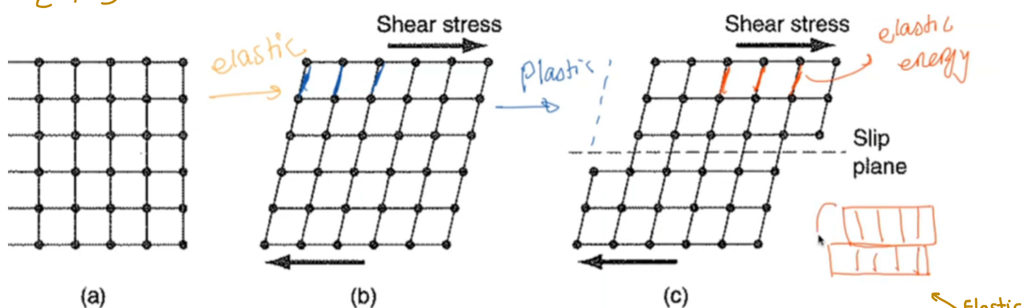
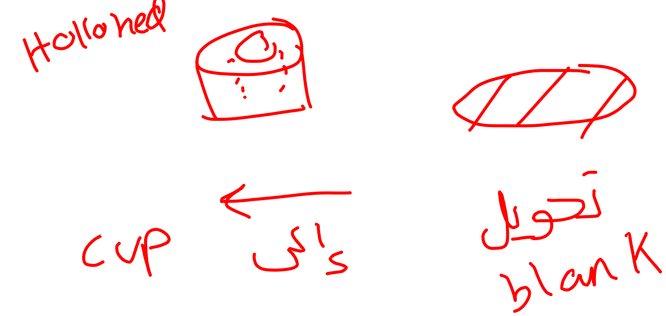


Fig. 2-16: (a) original crystal (b) elastic deformation (c) plastic deformation .

Deep Drawing

Drawing



- ***Drawing***: a sheet metal forming to make cup−shaped, box−shaped, or other complex−curved, hollow−shaped parts .
  - Performed by placing a piece of sheet metal over a die cavity and then pushing the metal into the opening with a punch.
  - The blank must usually be held down flat against the die by a blankholder.
  - Examples on parts made by drawing: beverage cans, cooking pots, and automobile body panels.

Drawing

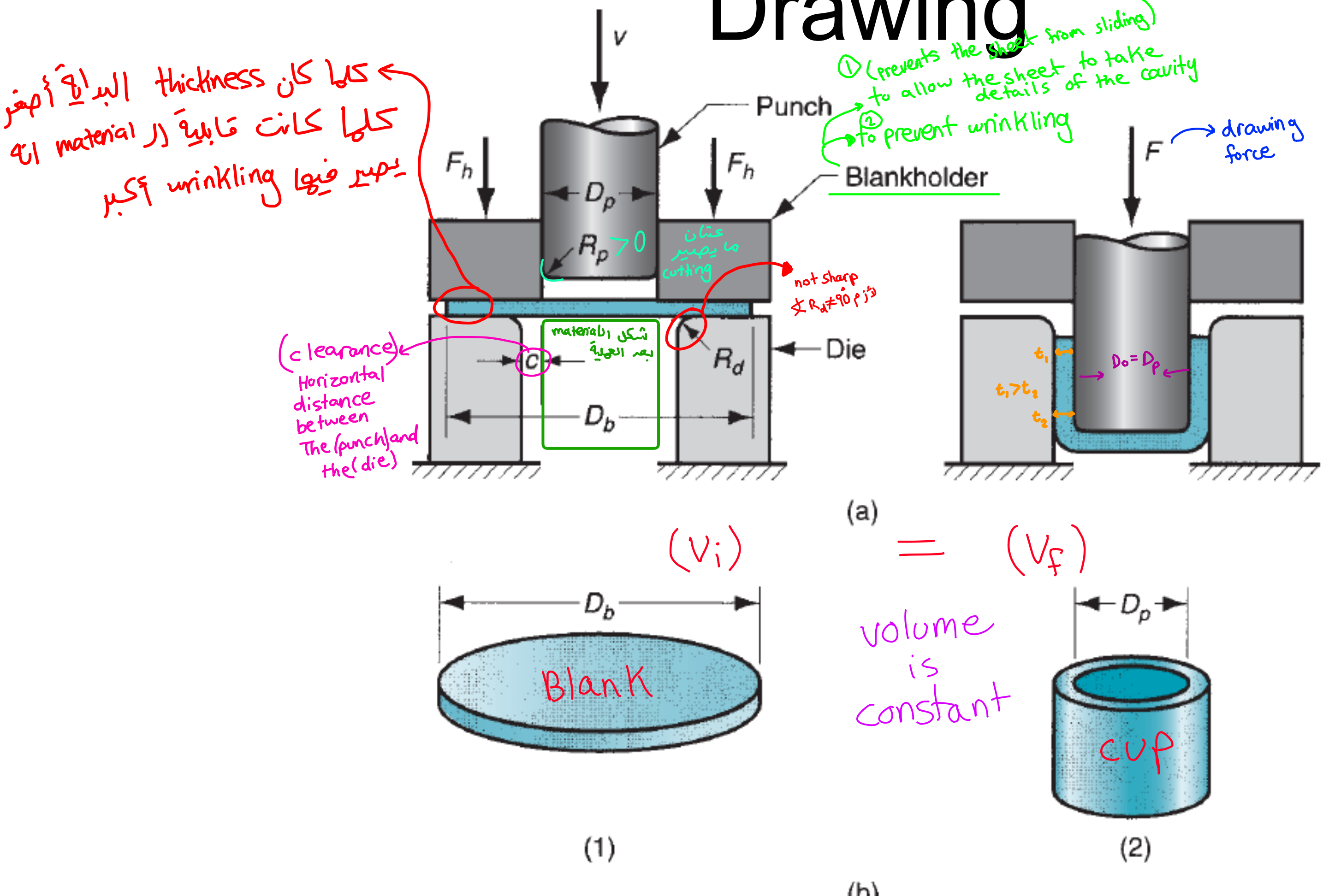


Figure 16.17 (a) Drawing of a cupshaped part: (1) start of operation before punch contacts work, and (2) near end of stroke; and (b) corresponding workpart: (1) starting blank, and (2) drawn part. Symbols: c = clearance, D_b = Blank diameter, D_p = Punch diameter, R_d = die corner radius, R_p = punch corner radius, F = drawing force, F_h = holding force.

Drawing
Mechanics of Drawing

- A blank of diameter D_b is drawn into a die cavity by means of a punch with diameter D_p.

- The punch and die must have corner radii, given by R_p and R_d.

- If the punch and die were to have sharp corners (R_p and $R_d = 0$), a hole-punching operation would be accomplished rather than a drawing operation.

- The sides of the punch and die are separated by a clearance c. This clearance in drawing is about 10% greater than the stock thickness:

$$c = 1.1t$$

- The punch applies a downward force F to accomplish the deformation of the metal, and a downward holding force F_h is applied by the blankholder.

* Complex sequence of stresses and strain

Bending → Tensile → compression

Holding Force (Fh) → must be high enough to prevent wrinkling but not too high because fracture might occur.

Drawing
Mechanics of Drawing

- As the punch proceeds downward toward its final bottom position, the work experiences a complex sequence of stresses and strains as it is gradually formed into the shape defined by the punch and die cavity, as shown below:

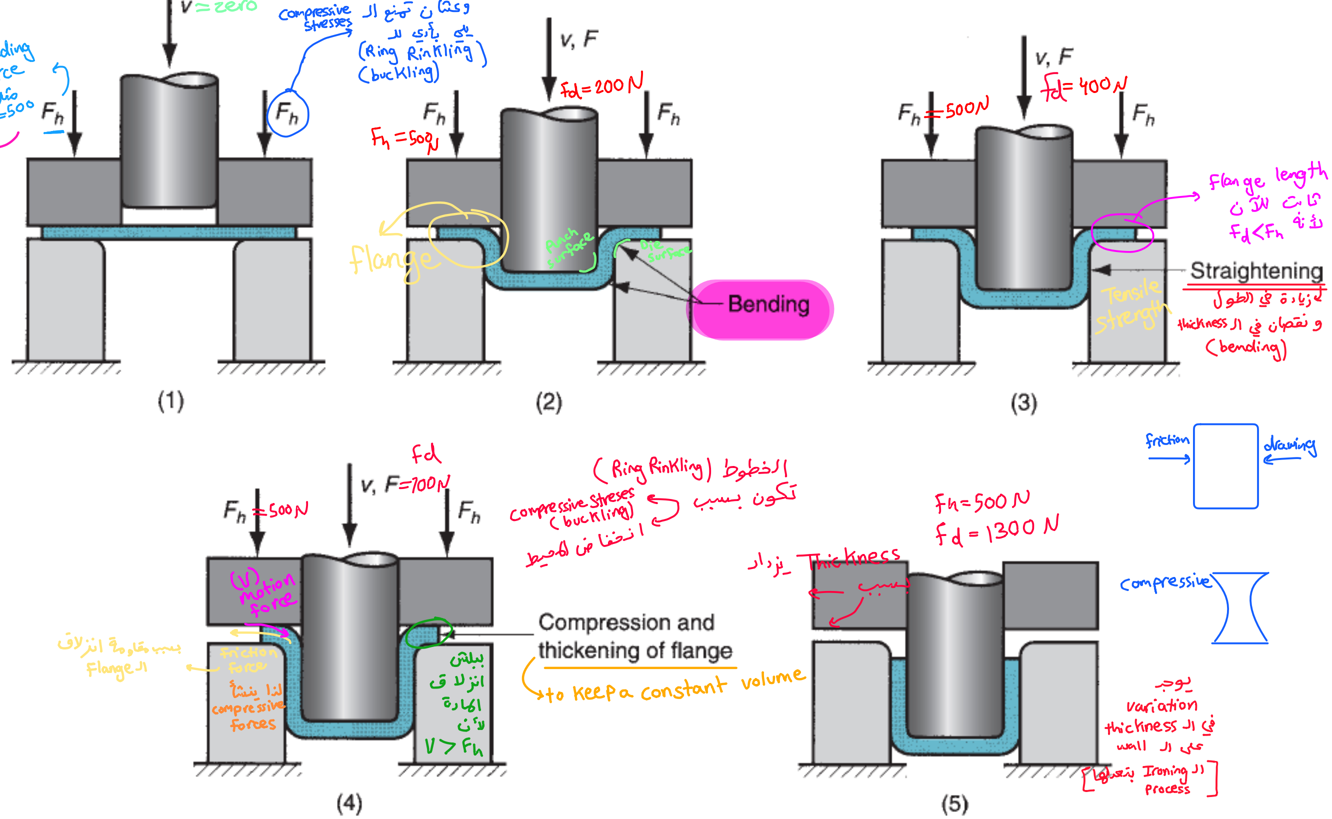


Figure 16.18 Stages in deformation of the work in deep drawing: (1) punch makes initial contact with work, (2) bending, (3) straightening, (4) friction and compression, and (5) final cup shape showing effects of thinning in the cup walls.

Drawing
Mechanics of Drawing

1. As the punch first begins to push into the work, the metal is subjected to a ***bending*** operation. The sheet is simply bent over the corner of the punch and the corner of the die. The outside perimeter of the blank moves in toward the center in this first stage, but only slightly.

2. As the punch moves further down, a ***straightening*** action occurs in the metal that was previously bent over the die radius. The metal at the bottom of the cup, as well as along the punch radius, has been moved downward with the punch, but the metal that was bent over the die radius must now be straightened in order to be pulled into the clearance to form the wall of the cylinder. At the same time, more metal must be added to replace that being used in the cylinder wall. This new metal comes from the outside edge of the blank. This type of metal flow through a constricted space gives the drawing process its name.

Drawing
Mechanics of Drawing

3. During this stage of the process, ***friction*** and compression play important roles in the flange of the blank. In order for the material in the flange to move toward the die opening, friction between the sheet metal and the surfaces of the blankholder and the die must be overcome. (use of lubricants to reduce friction)

4. In addition to friction, ***compression*** is also occurring in the outer edge of the blank. As the metal in this portion of the blank is drawn toward the center, the outer perimeter becomes smaller. Because the volume of metal remains constant, the metal is squeezed and becomes thicker as the perimeter is reduced.

This often results in wrinkling of the remaining flange of the blank, especially when thin sheet metal is drawn, or when the blankholder force is too low.

If the blankholder force is too large, it will prevent the flow resulting in possible tearing of the metal.

Drawing
Engineering Analysis of Drawing

- ***Measure of Drawing***:
  - Drawing can be characterized in 3 different ways; ***Drawing Ratio*** ($DR=D_b/D_p$), ***Reduction*** ($r=(D_b-D_p)/D_b$), and ***Thickness-to-Diameter Ratio*** (t/D_b).

    DR ≤ 2   r < 0.5

  - DR should be equal to or less than 2, while r should be less than 0.5.
  - The greater the ratio, the more severe the drawing.
  - The t/D_b is desirable to be greater than 1% (to avoid wrinkling).

All of them must be satisfied To let the process successfull

Drawing
Engineering Analysis of Drawing

- ***Force***: the ***drawing force*** required to perform a given operation can be estimated roughly by:

$$F = \pi D_p t(TS)\left(\frac{D_b}{D_p} - 0.7\right)$$

where F = drawing force, N; t = original blank thickness, mm; TS = tensile strength, MPa; and D_b and D_p are the starting blank diameter and punch diameter, respectively, mm. The constant 0.7 is a correction factor to account for friction.

$F_h = \frac{1}{3} F$ → only if (R_d) and/or (σ_y) are not given

- ***Holding force***, expressed by:

إذا اعطانا السؤال جدول لازم استعمل ال equation

exactly

$$F_h = 0.015 Y\pi\left\{D_b^{\,2} - (D_p + 2.2t + 2R_d)^2\right\}$$

(Y) yield strength

where F = holding force, N; Y = yield strength of the sheet metal, MPa; t = starting stock thickness, mm; R_d = die corner radius, mm.

تقريبا //

The holding force is usually about 1/3 of the drawing force.

إذا ماكان معطيني Y و Rd

Drawing
Engineering Analysis of Drawing

- ***Blank Size Determination***: for the final dimensions to be achieved on the cylindrical drawn shape, the correct starting blank diameter is needed.
  - Must be large enough to supply sufficient metal to complete the cup.
  - Yet if there is too much material, unnecessary waste will result.
  - The blank diameter can be calculated by setting the initial blank volume equal to the final volume of the product and solving for diameter D_b.

Drawing
Other Drawing Operations

- ***Redrawing***: drawing done in more than a step, in case shape change is too severe. The second drawing step, and any further drawing steps if needed, are referred to as redrawing.

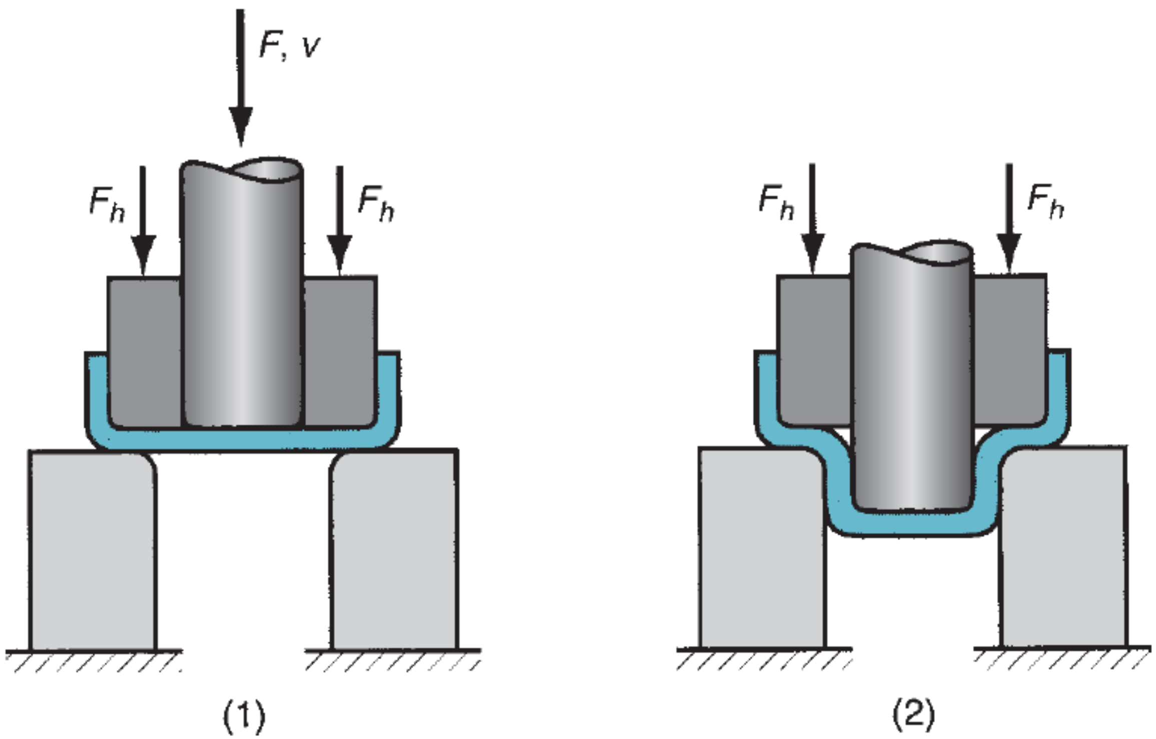


Figure 16.19 Redrawing of a cup: (1) start of redraw, and (2) end of stroke.

Drawing
Other Drawing Operations

- ***Redrawing***: drawing done in more than a step, in case shape change is too severe. The second drawing step, and any further drawing steps if needed, are referred to as redrawing.

- First draw: max. reduction 40 to 45%. Second: 30%. Third: 16%.

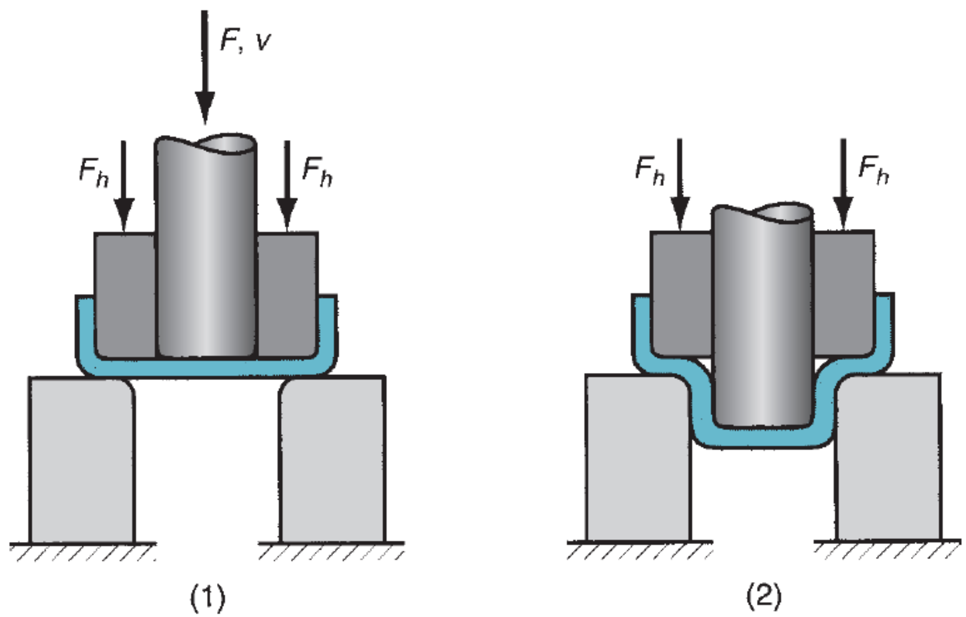


Figure 16.20 Redrawing of a cup: (1) start of redraw, and (2) end of stroke.

Drawing
Other Drawing Operations

- ***Drawing of Shapes Other Than Cylindrical Cups***: square or rectangular boxes (as in sinks), cups with spherical rather than flat bases, and irregular curved forms (as in automobile body panels).

- ***Drawing Without a Blankholder***: one of the primary functions of a blankholder is to prevent wrinkling. If the t/D_b ratio is large enough, drawing can be accomplished without a blankholder.

- The limiting condition of this process being: $D_b - D_p < 5t$.

- The draw die must have the shape of the funnel or cone.

- Advantages: lower cost tooling and a simpler press.

Drawing
Other Drawing Operations

- ***Drawing Without a Blankholder***:

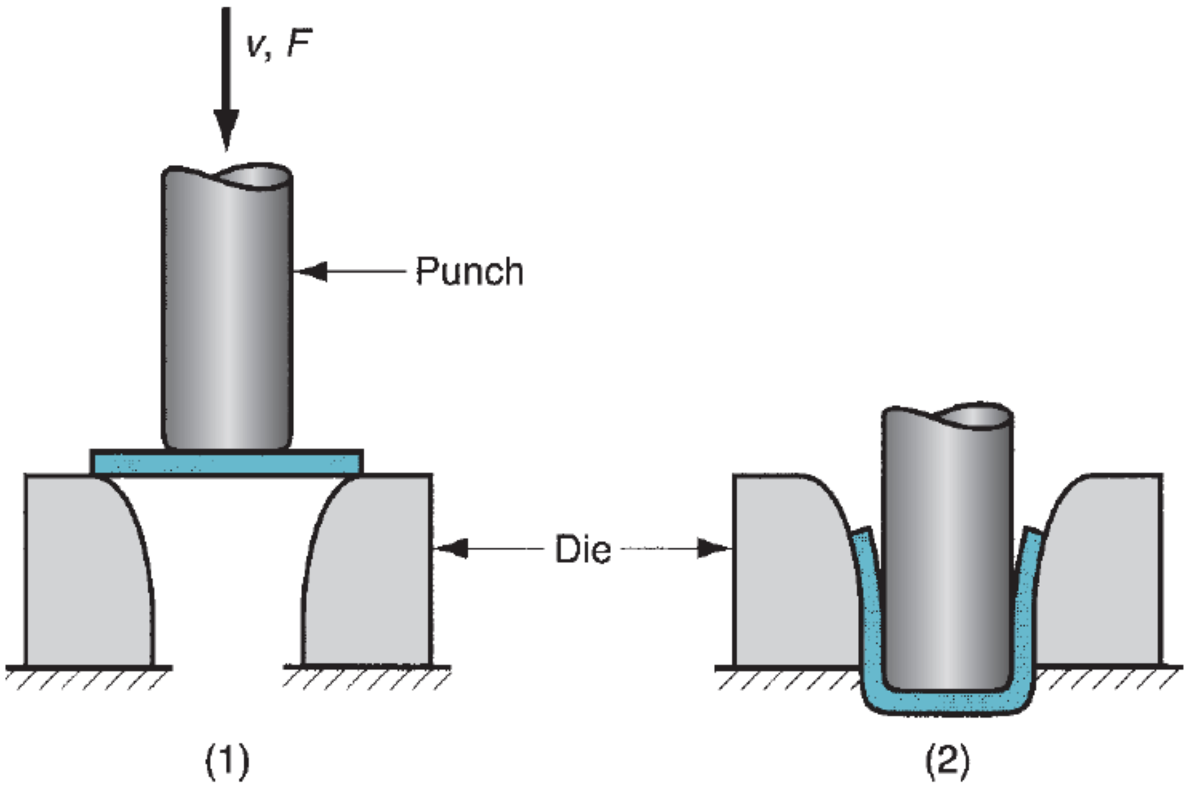


Figure 16.21 Drawing without a blankholder: (1) start of process, (2) end of stroke.

Drawing
Defects in Drawing

- ***Wrinkling*** in the flange: consists of a series of ridges that form radially in the undrawn flange of the workpart due to compressive buckling.

- ***Wrinkling*** in the wall: If and when the wrinkled flange is drawn into the cup, these ridges appear in the vertical wall.

- ***Tearing***: an open crack in the vertical wall, usually near the base of the drawn cup, due to high tensile stresses that cause thinning and failure of the metal at this location.

- ***Earing***: the formation of irregularities (called ears) in the upper edge of a deep drawn cup, caused by anisotropy in the sheet metal.

- ***Surface scratches***: occur on the drawn part if the punch and die are not smooth or if lubrication is insufficient.

Drawing
Defects in Drawing

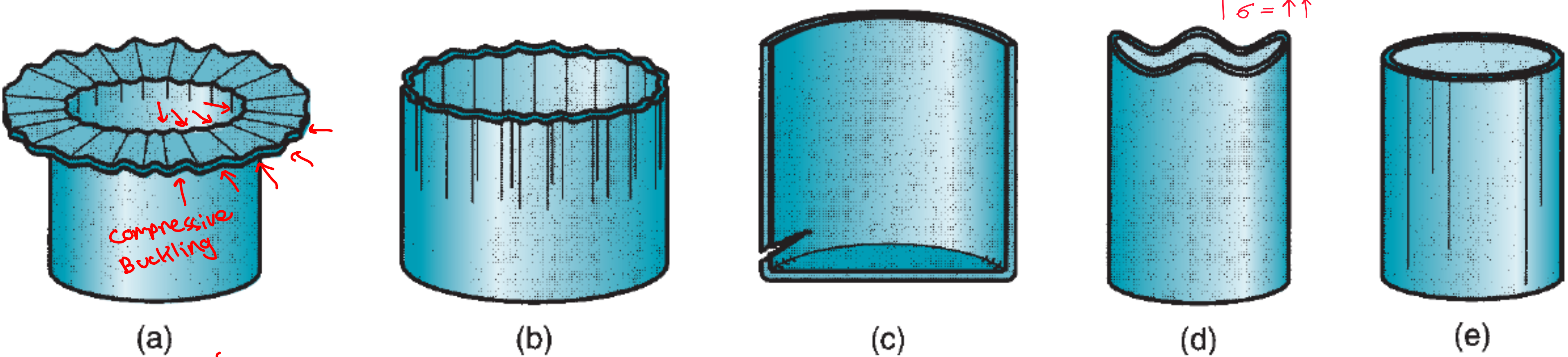


Figure 16.22 Common defects in drawn parts: (a) wrinkling can occur either in the flange or (b) in the wall, (c) tearing, (d) earing, and (e) surface scratches.

Drawing

video

يبلش من دقيقة ٣

(sheet metal cutting)

video (Deep Drawing 1)

Other Sheet-Metal-Forming Operations

- ***Ironing***: done to correct the higher thickness at the edge of the blank (refer to point 4 in drawing mechanics).

- Ironing makes the cylindrical cup more uniform in wall thickness.

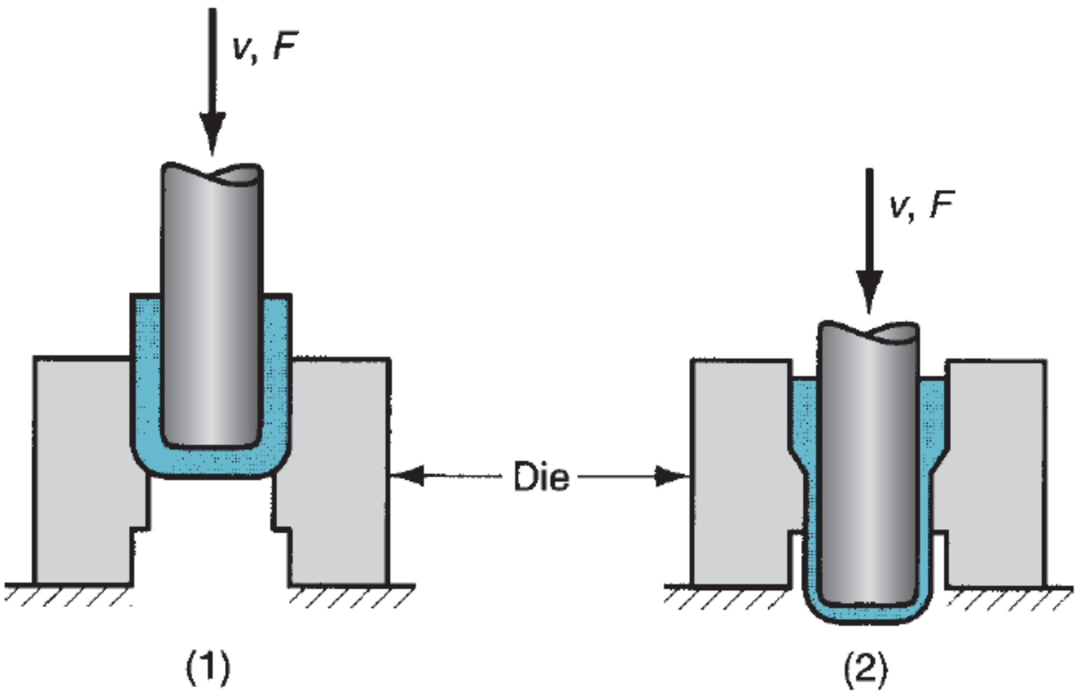


Figure 16.23 Ironing to achieve a more uniform wall thickness in a drawn cup: (1) start of process; (2) during process.

Other Sheet-Metal-Forming Operations

- ***Coining***: frequently used in sheet-metal work to form indentations and raised sections in the part (it is also a bulk deformation process as discussed in chapter 15).

- ***Embossing***: similar to coining, however, embossing dies possess matching cavity contours, the punch containing the positive contour and the die containing the negative; whereas coining dies may have quite different cavities in the two die halves

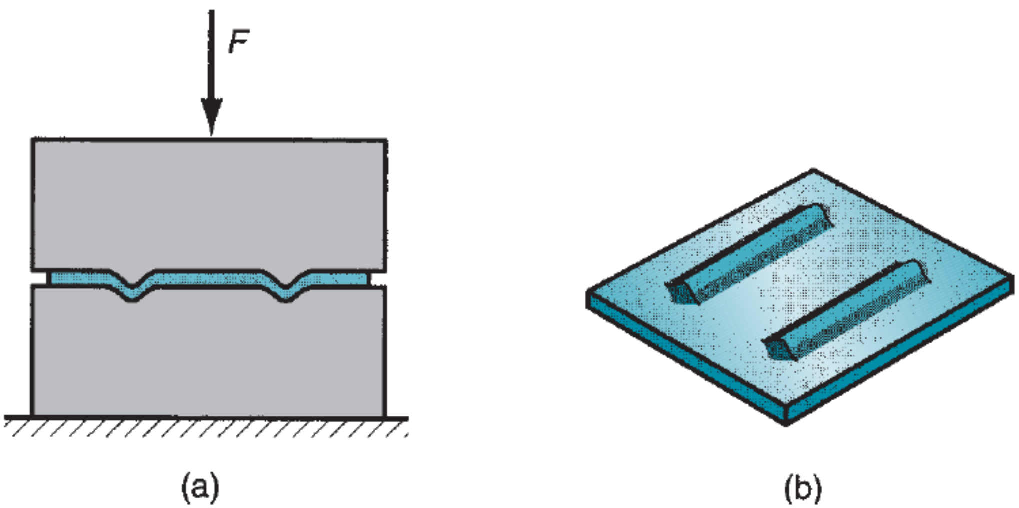


Figure 16.24 Embossing: (a) cross section of punch and die configuration during pressing; (b) finished part with embossed ribs.

Other Sheet-Metal-Forming Operations

- ***Lancing***: a combined cutting and bending or cutting and forming operation performed in one step to partially separate the metal from the sheet.
  - Example: used to make louvers in sheet metal air vents for heating and air conditioning systems in buildings.

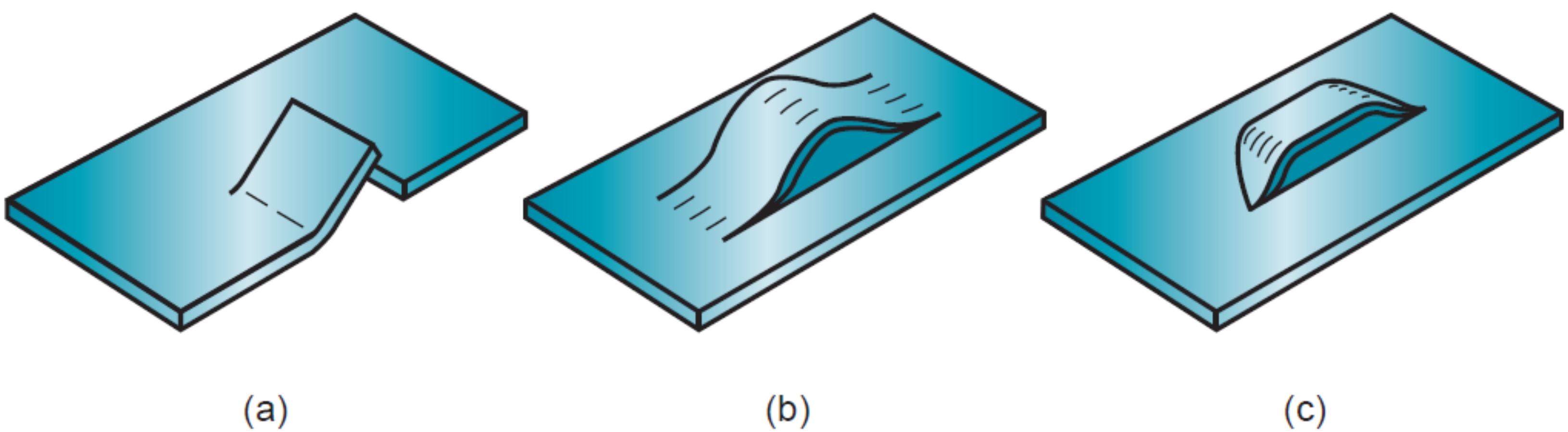


Figure 16.25 Lancing in several forms: (a) cutting and bending; (b) and (c) two types of cutting and forming.

Dies and Presses for Sheet Metal Processes
Dies

Punch & die are the working components.

Bushing & Guide pins ensure proper alignment between punch & die.

Stripper prevents sheet metal from sticking to the punch after operation.

Stop: prevents sheet metal from advancing through the die between cycles. (e.g. In case of coils).

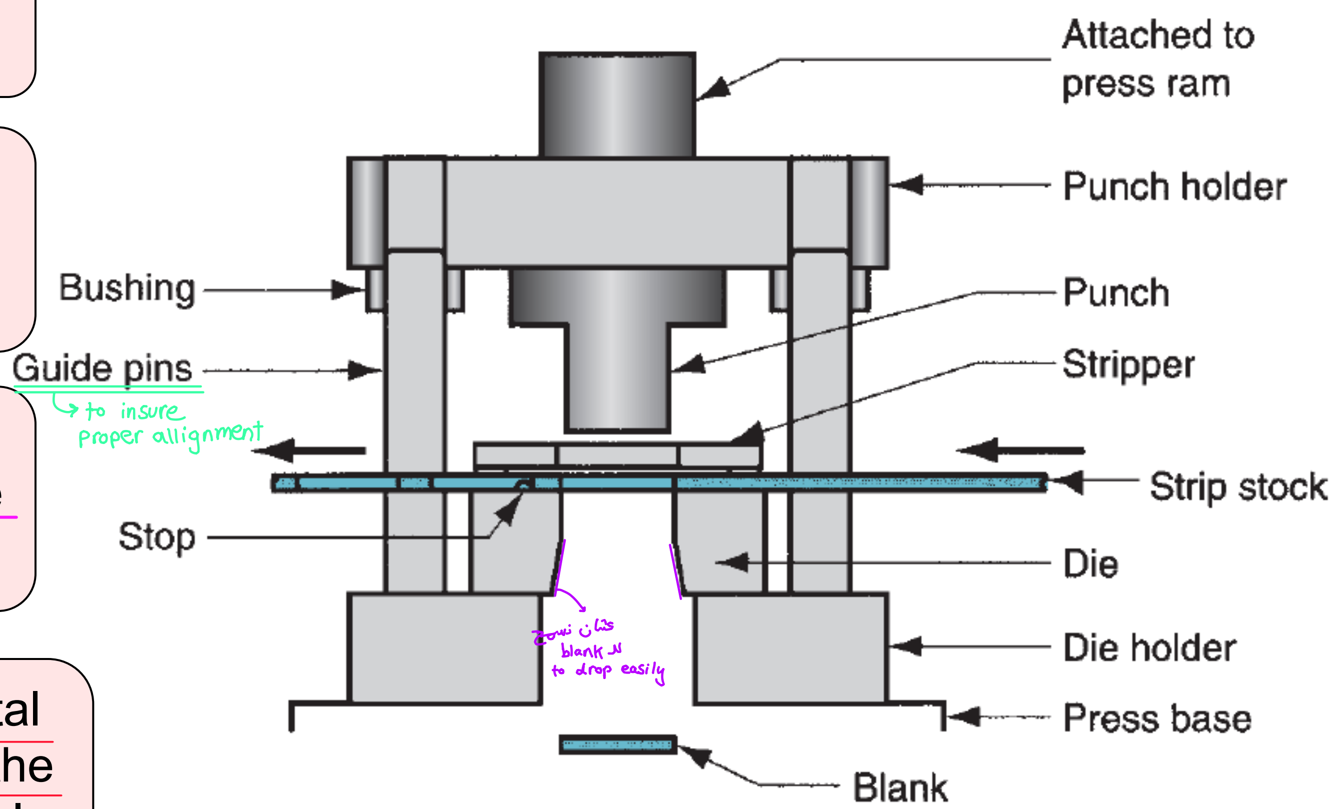


Figure 16.26 Components of a punch and die for a blanking operation.

Dies and Presses for Sheet Metal Processes
Presses

- ***Press***: a machine tool with a stationary ***bed*** and a powered ***ram*** that can be driven toward and away from the bed to perform various cutting and forming operations.
  - ***The Frame***: establishes the relative positions of the bed and ram.
  - Punch holder is attached to the ***ram*** and the die holder is attached to a ***bolster plate***.
  - ***Type of frame***: the physical construction of the press.
- Two types of frames:
  - ***Gap Frame Presses.***
  - ***Straight-sided frame presses.***

Dies and Presses for Sheet Metal Processes
Presses

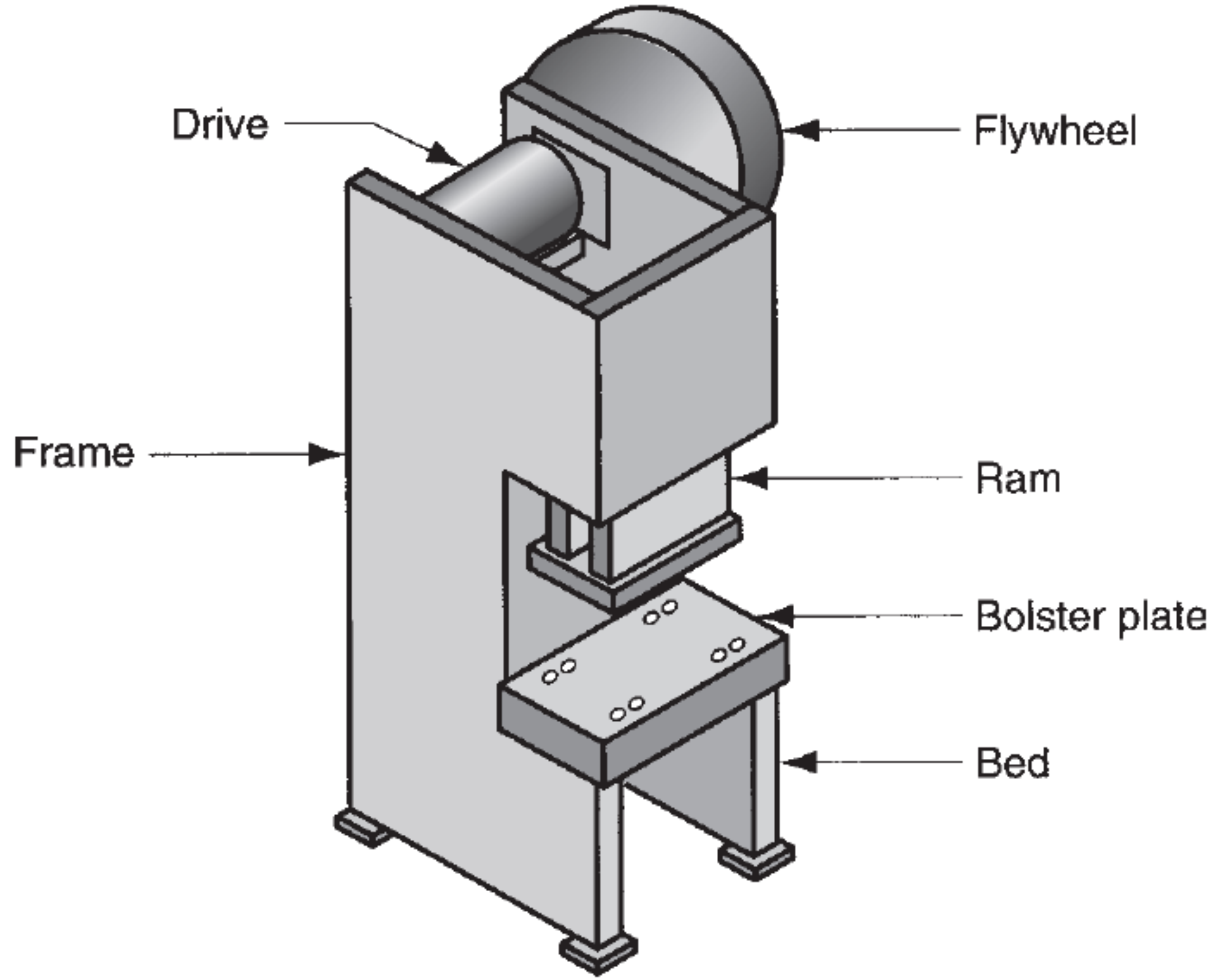


Figure 16.27 Components of a typical (mechanical drive) stamping press.

Dies and Presses for Sheet Metal Processes
Presses

- Two types of frames:
  - ***Gap Frame Presses***: has the general configuration of the letter C and is often referred to as a C-frame.
    - Provide good access to the die.
    - Usually open in the back to permit convenient ejection of stampings or scrap.
    - Available in a range of sizes, with capacities up to around 1000 tons.
  - ***Straight-sided frame presses***: posses greater structural rigidity for high tonnage.
    - Have full sides (box-like appearance).
    - Capacities up to 4000 tons are available.

Dies and Presses for Sheet Metal Processes

Presses

very easy to reach the die and the capacity can reach 1000 ton

we use it to increase the rigidity and strength and it can reach 4000 ton

Figure 16.28 Gap-Frame Press.

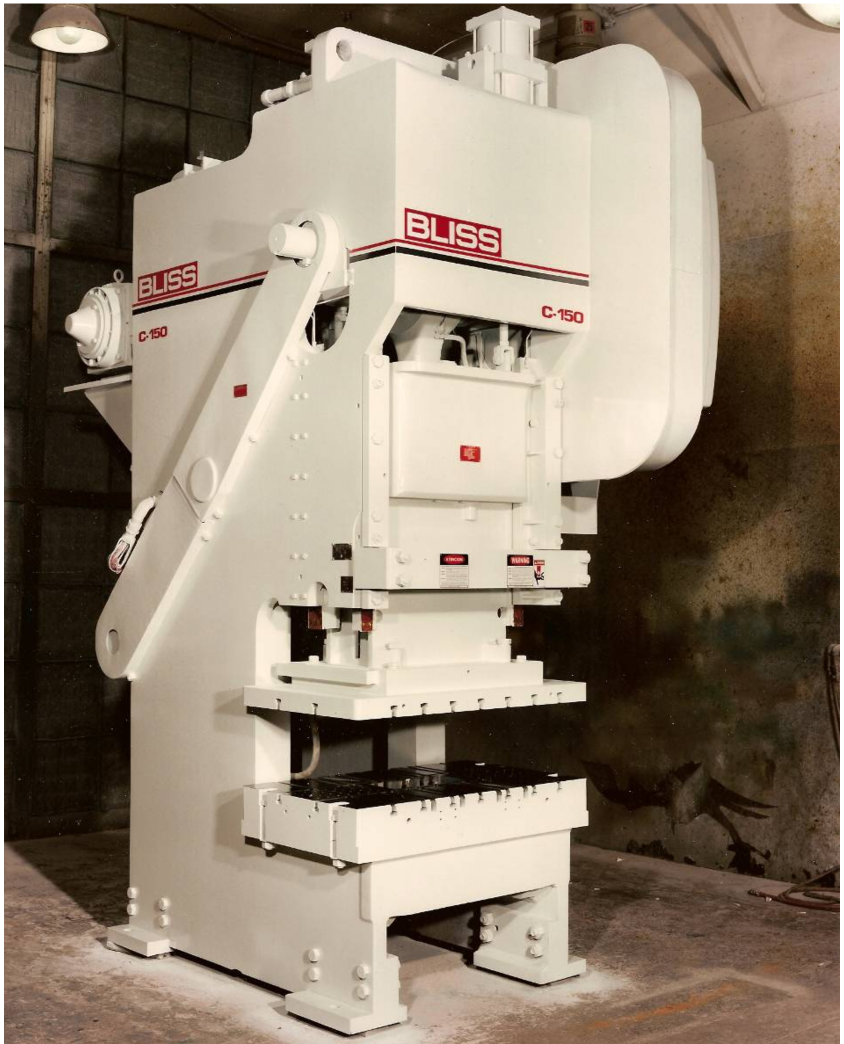


Figure 16.29 Straight-Sided Frame Press.

Sheet-Metal Operations Not Performed on Presses

- There are a number of sheet-metal operations not performed on conventional stamping presses. These include:
  - ***Stretch Forming.***
  - ***Roll Bending and Forming.***
  - ***Spinning.***
  - ***High-Energy-Rate Forming Processes.***

Sheet-Metal Operations Not Performed on Presses

stretching and bending

- ***Stretch Forming***: a sheet-metal deformation process in which the sheet metal is intentionally stretched and simultaneously bent in order to achieve shape change.

لازم نتجاوز ال yield strength ل material

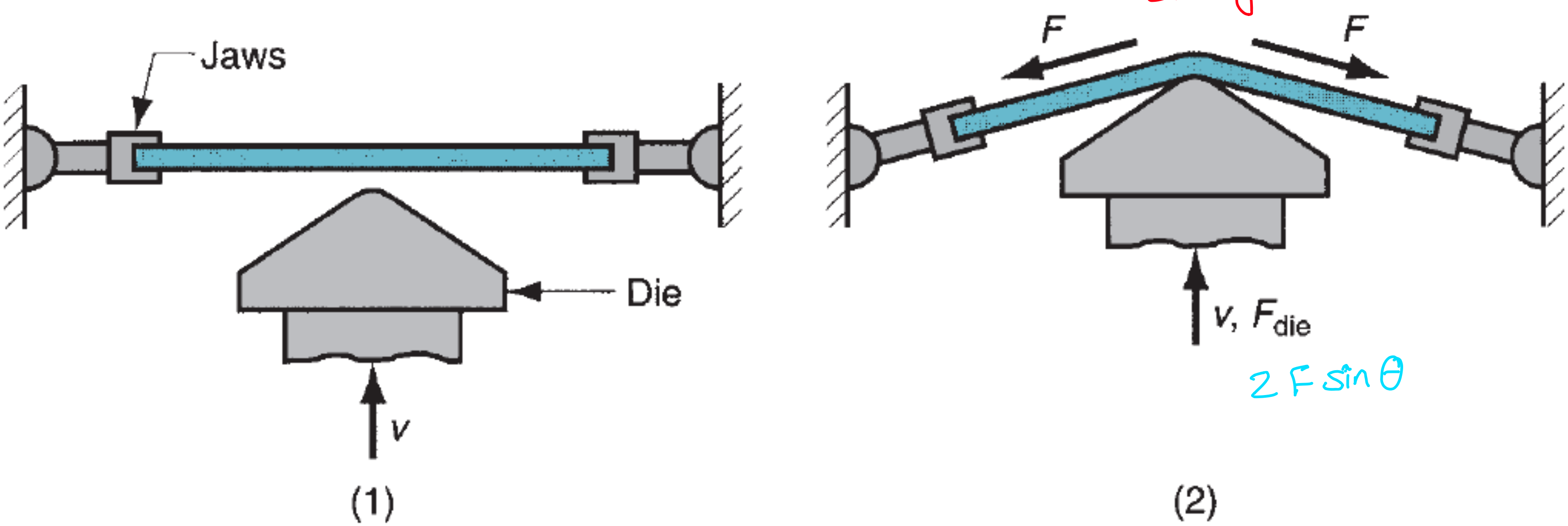


Figure 16.30 Stretch forming: (1) start of process; (2) form die is pressed into the work with force F_{die}, causing it to be stretched and bent over the form. F = stretching force.

Sheet-Metal Operations Not Performed on Presses

- ***Stretch Forming***:
  - Workpart is gripped by one or more jaws on each end and then stretched and bent over a positive die containing the desired form.
  - Tension level: above yield point, and force required to stretch forming:

$$F = LtY_f$$

Kε^n

where F = stretching force, N; Y_f = flow strength of the sheet metal, MPa; t = instantaneous stock thickness, mm; L = ~~length~~ Dimension of the sheet in a direction perpendicular to stretching, mm.

  - Die force F_{die} can be determined by balancing vertical force components.
  - Suitable for low-quantity large-size production; e.g. sheet-metal used in aircraft bodies.

video Increment Sheet....

the metal is strain hardened by cold working

Sheet-Metal Operations Not Performed on Presses

- ***Roll Bending***: an operation in which (usually) large sheet-metal or plate-metal parts are formed into curved sections by means of rolls.
  - Applications: Components for large storage tanks and pressure vessels and railroad rails.
  - ***Roll Straightening***: a related operation in which non-flat sheets are straightened by passing them between a series of rolls.

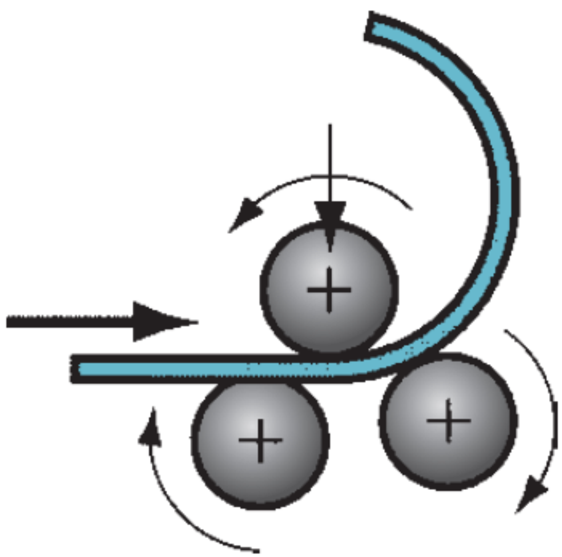


Figure 16.31 Roll bending: as the sheet passes between the rolls, the rolls are brought toward each other to a configuration that achieves the desired radius of curvature on the work.

Sheet-Metal Operations Not Performed on Presses

- ***Roll Forming***: a continuous bending process in which opposing rolls are used to produce long sections of formed shapes from coil or strip stock.
  - Several pairs of rolls are usually required to progressively accomplish the bending of the stock into the desired shape.
  - Products: include channels, pipes and tubing with seams.

Sheet-Metal Operations Not Performed on Presses

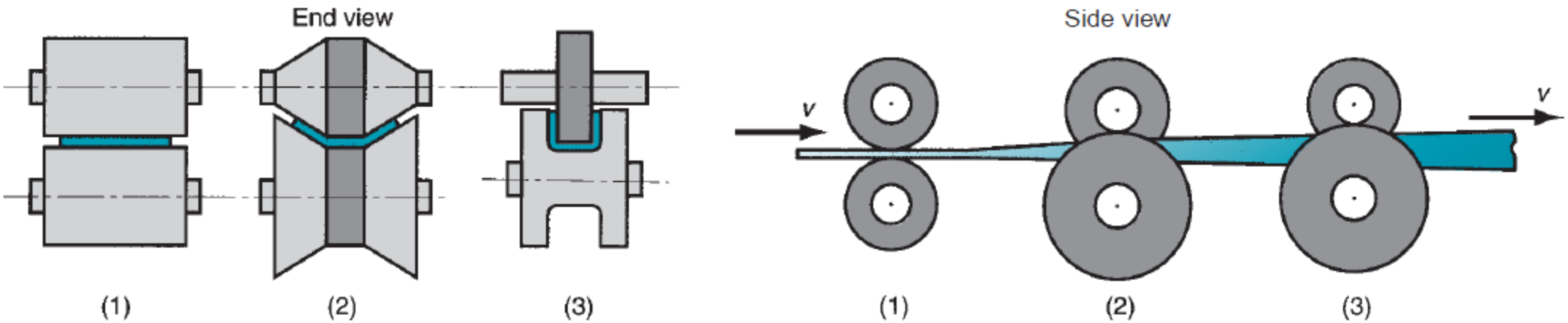


Figure 16.32 Roll forming of a continuous channel section: (1) straight rolls, (2) partial form, and (3) final form.

Although roll forming has the general appearance of a rolling operation (and the tooling certainly looks similar), the difference is that roll forming involves bending rather than compressing the work.

Sheet-Metal Operations Not Performed on Presses

cones of metal

- ***Spinning***: a metal-forming process in which an axially symmetric part is gradually shaped over a mandrel or form by means of a rounded tool or roller. Three types of spinning:

  راح ندرس هدول

  - ***Conventional Spinning.***
  - ***Shear Spinning.***
  - ***Tube Spinning.***

Sheet-Metal Operations Not Performed on Presses

– ***Conventional Spinning***: a sheet-metal disk is held against the end of a rotating mandrel of the desired inside shape of the final part, while the tool or roller deforms the metal against the mandrel.

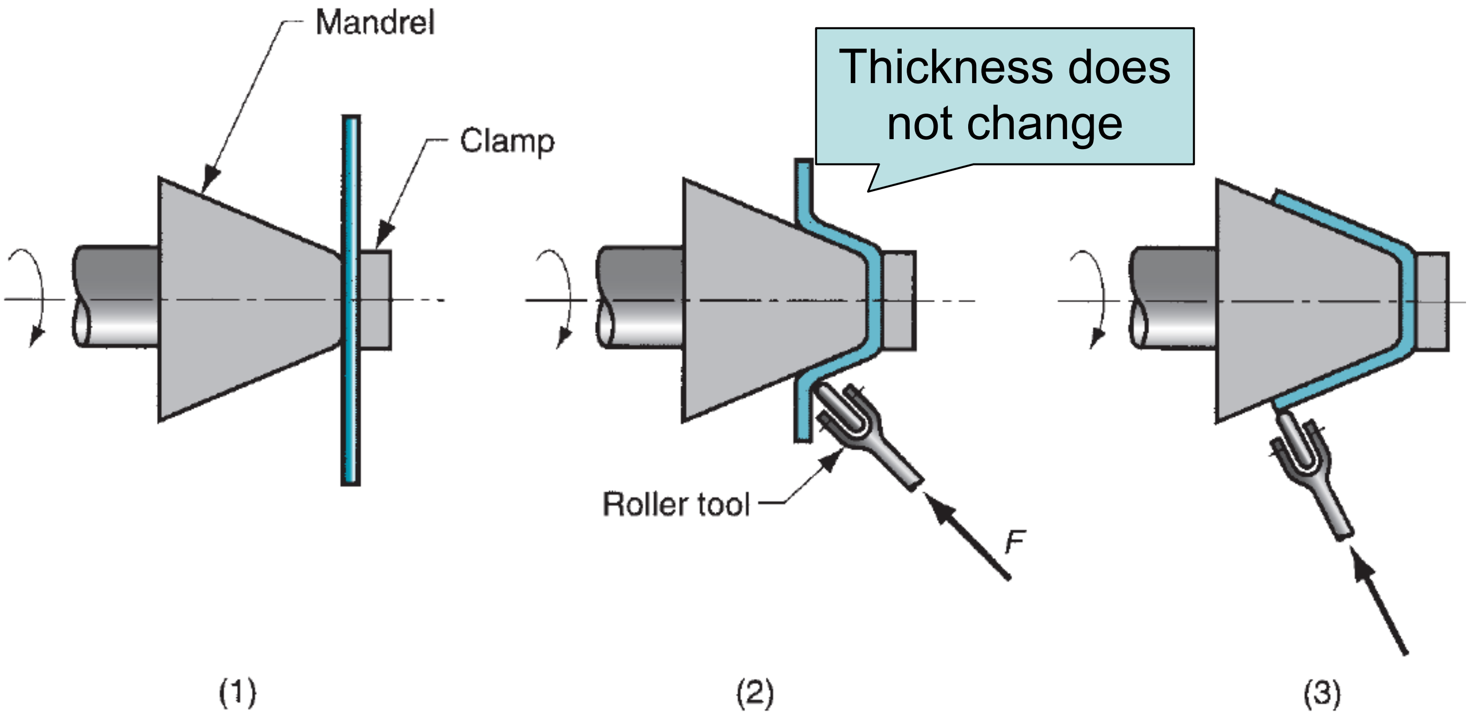


Figure 16.33 Conventional spinning: (1) setup at start of process; (2) during spinning; and (3) completion of process.

Sheet-Metal Operations Not Performed on Presses

– ***Conventional Spinning***.

- It ***bends*** the metal around a moving circular axis to conform to the outside surface of the axisymmetric mandrel.
- Applications include: production of conical and curved shapes in low quantities.
- Very large diameter parts up to 5 m or more can be made by spinning.
- Alternative sheet-metal processes would require excessively high die costs.
- The form mandrel in spinning can be made of wood or other soft materials that are easy to shape.
- It is therefore a low-cost tool compared to the punch and die required for deep drawing, which might be a substitute process for some parts.

Sheet-Metal Operations Not Performed on Presses

– ***Shear Spinning***: the part is formed over the mandrel by a ***shear*** deformation process (not bending) in which the outside diameter remains constant and the wall thickness is therefore reduced.

- Applied to aerospace industry to form large parts such as rocket nose cones.
- Thickness of the spun nose:

$$t_f = t \sin\alpha$$

where t_f = the final thickness of the wall after spinning, t = the starting thickness of the disk, and α = the mandrel half angle.

- Spinning reduction (***r***):

$$r = \frac{t - t_f}{t}$$

Sheet-Metal Operations Not Performed on Presses

– ***Shear Spinning***:

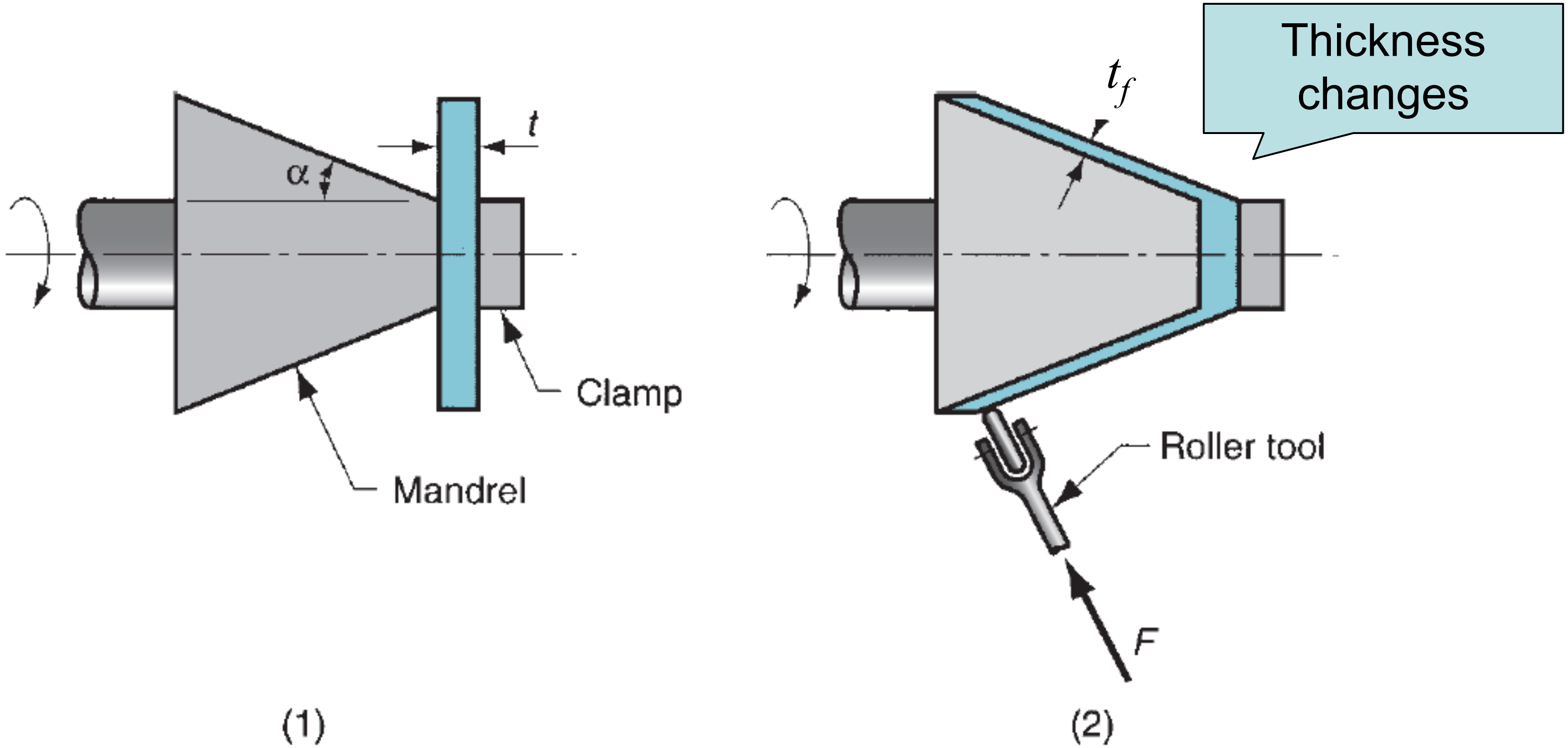


Figure 16.34 Shear spinning: (1) setup at start of process; and (2) completion of process.

Sheet-Metal Operations Not Performed on Presses

- ***High-Energy-Rate Forming*** (HERF): processes developed to form metals using large amounts of energy applied in a very short time, include:

راح ندرس هدول

  - ***Explosive Forming.***
  - ***Electrohydraulic Forming.***
  - ***Magnetic Forming.***

Sheet-Metal Operations Not Performed on Presses

– ***Explosive Forming:*** involves the use of an explosive charge to form sheet (or plate) metal into a die cavity.

  - The workpart is clamped and sealed over the die, and a vacuum is created in the cavity beneath.
  - The apparatus is then placed in a large vessel of water. An explosive charge is placed in the water at a certain distance above the work.
  - Detonation of the charge results in a shock wave whose energy is transmitted by the water to cause rapid forming of the part into the cavity.

Sheet-Metal Operations Not Performed on Presses

– ***Explosive Forming:***

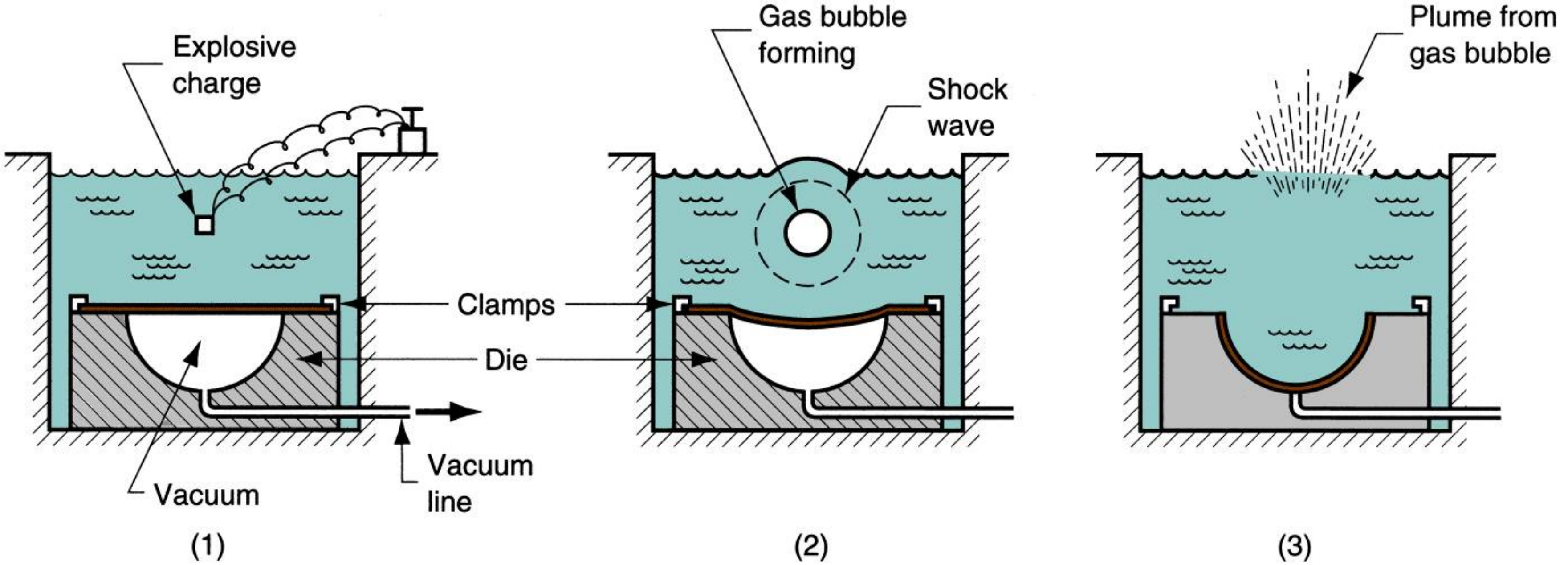


Figure 16.35 Explosive forming: (1) setup, (2) explosive is detonated, and (3) shock wave forms part and plume escapes water surface.

Sheet-Metal Operations Not Performed on Presses

– ***Electrohydraulic Forming:*** a HERF process in which a shock wave to deform the work into a die cavity is generated by the discharge of electrical energy between two electrodes submerged in a transmission fluid (water).

  - Electrical energy is accumulated in large capacitors and then released to the electrodes.

  - Electrohydraulic forming is similar to explosive forming. The difference is in the method of generating the energy and the smaller amounts of energy that are released.

  - This limits electrohydraulic forming to much smaller part sizes.

Sheet-Metal Operations Not Performed on Presses

- *Electrohydraulic Forming:*

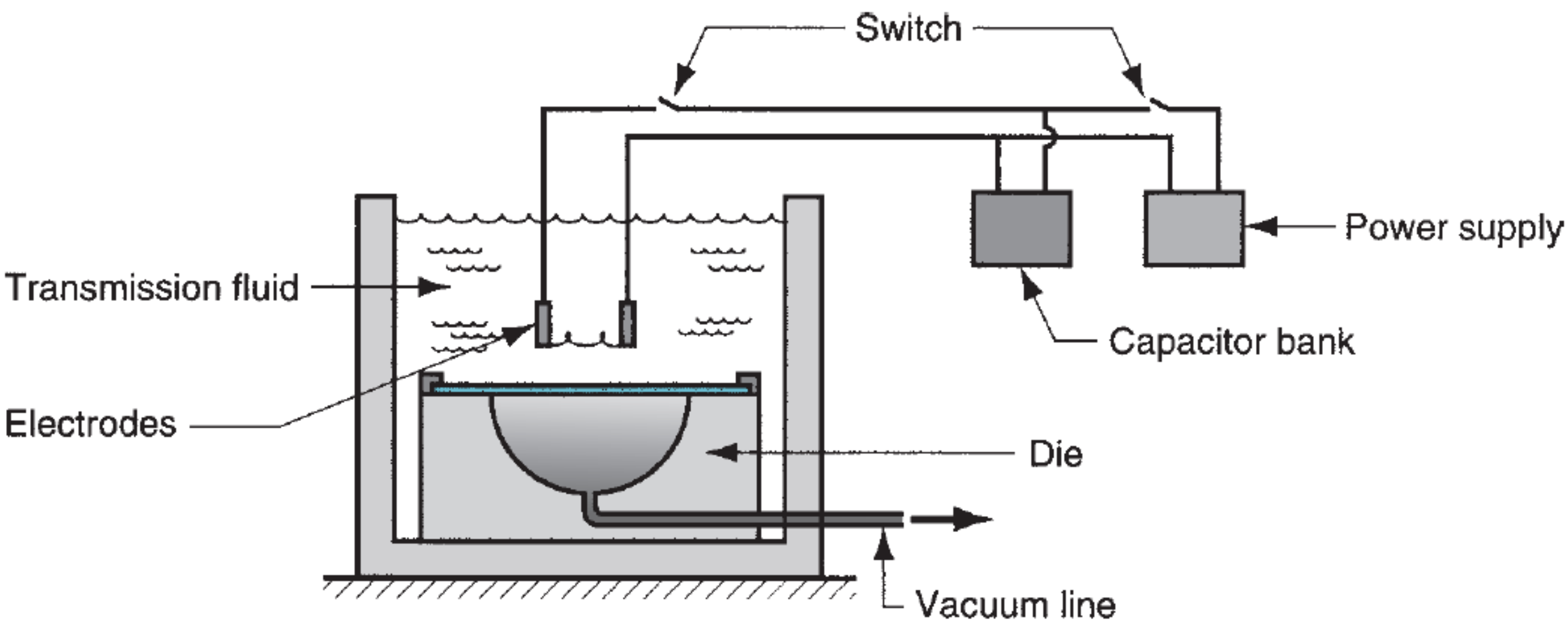


Figure 16.36 Electrohydraulic forming setup.

Bending of Tube Stock

- ***Bending of tube stock*** is more difficult than sheet stock because a tube tends to collapse and fold when attempts are made to bend it.

- Special flexible mandrels are usually inserted into the tube prior to bending to support the walls during the operation.

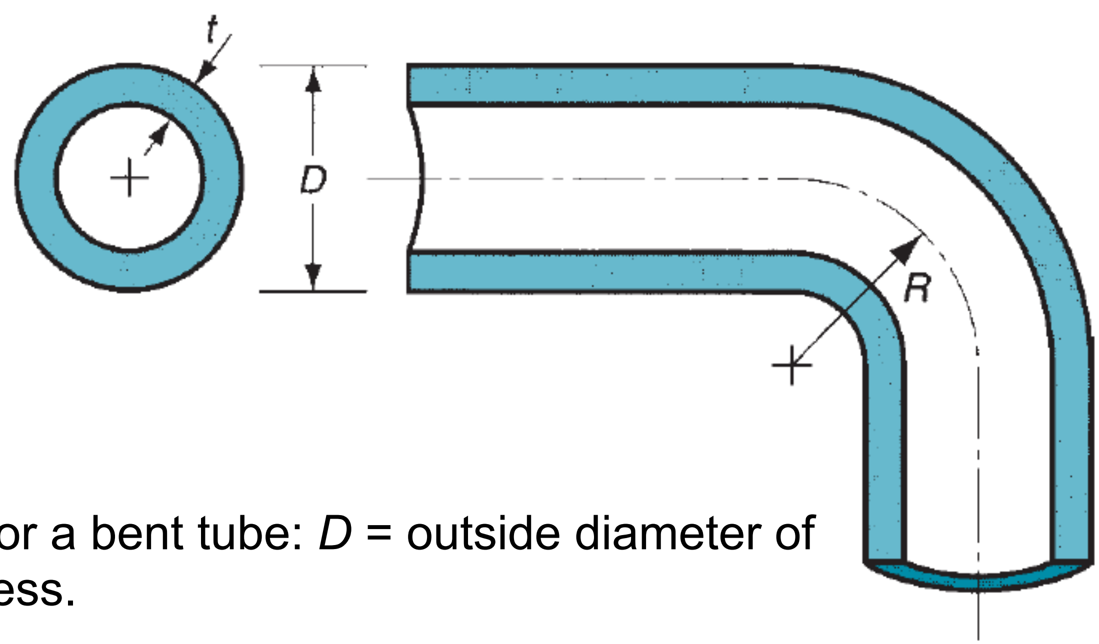


Figure 16.37 Dimensions and terms for a bent tube: *D* = outside diameter of tube, *R* = Bend radius, *t* = wall thickness.

Bending of Tube Stock

- The radius of the bend *R* is defined with respect to the centerline of the tube.
- When the tube is bent, the wall on the inside of the bend is in compression, and the wall at the outside is in tension.
- These stress conditions cause thinning and elongation of the outer wall and thickening and shortening of the inner wall.
- As a result, there is a tendency for the inner and outer walls to be forced toward each other to cause the cross section of the tube to flatten.
- Because of this flattening tendency, the minimum bend radius *R* that the tube can be bent is about 1.5 times the diameter *D* when a mandrel is used and 3.0 times *D* when no mandrel is used.
- The exact value depends on the wall factor *WF*, which is the diameter *D* divided by wall thickness *t*.
- Higher values of WF increase the minimum bend radius; that is, tube bending is more difficult for thin walls. ***Ductility*** is also a factor.

Bending of Tube Stock

كلما كانت R أصغر

كلما كان ال Bending أكثر

Mandrel

$R_{min} = 1.5D$

No Mandrel

$R_{min} = 3.0D$

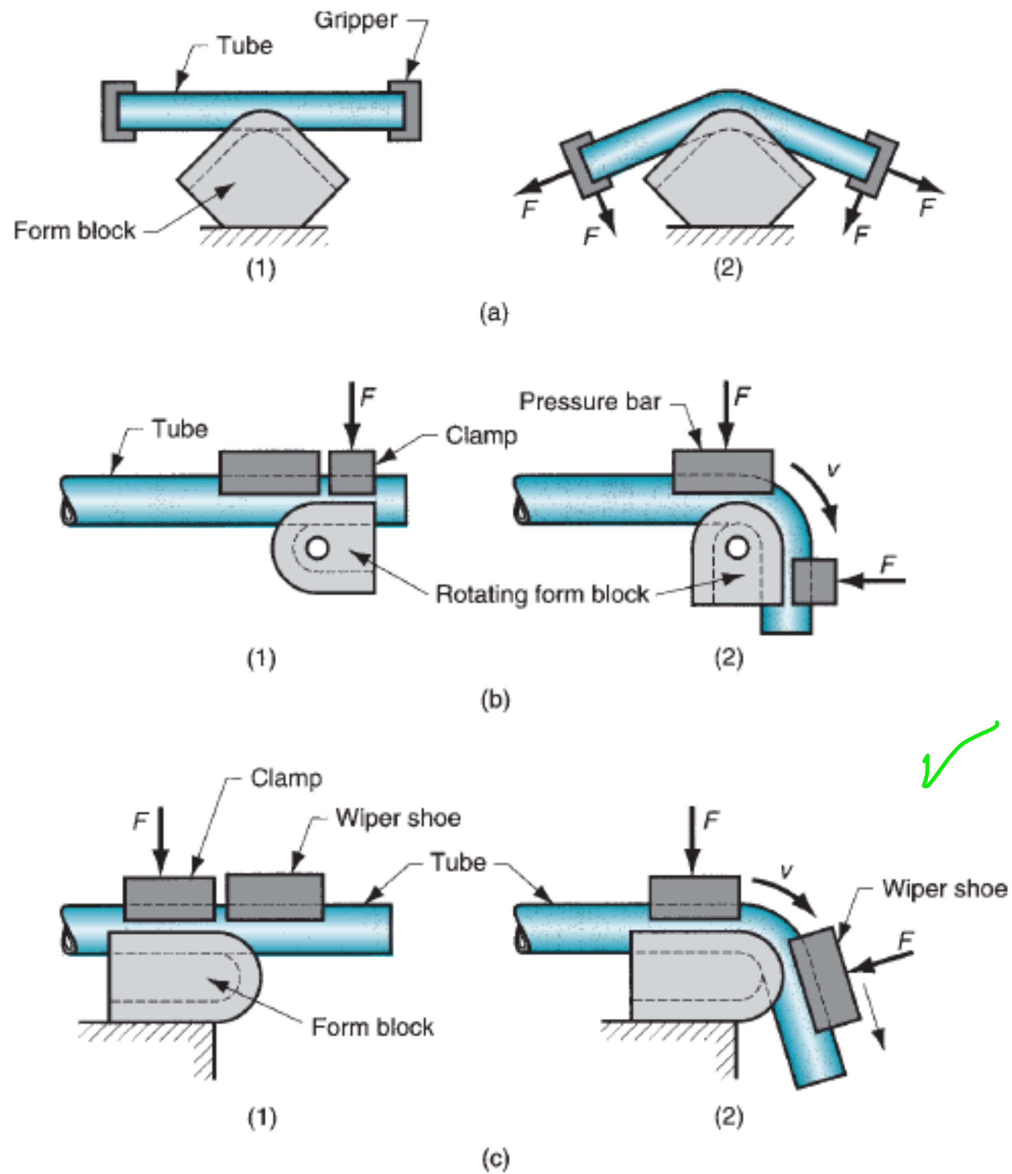


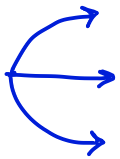
Figure 16.38 Tube bending methods: (a) stretch bending, (b) draw bending, and (c) compression bending. For each method: (1) start of process, and (2) during bending. Symbols *v* and *F* indicate motion and applied force, respectively.

video (Tube Bending)

لازم نتجاوز ال yield point

ولكن ممنوع تجاوز UTS

Tube outside diameter



video (hand tube bender)