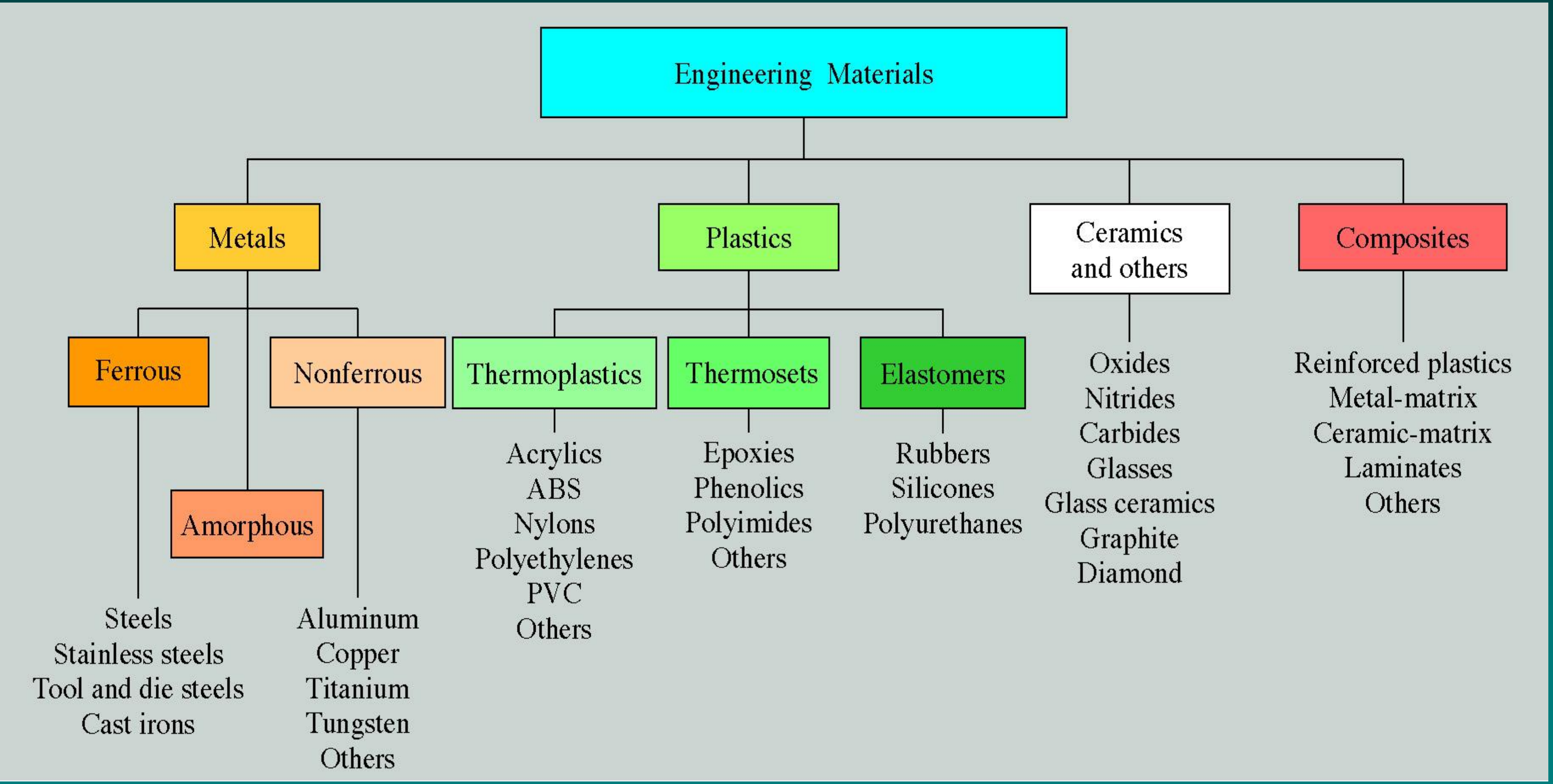
MANUFACTURING PROCESSES (SME 2713)

Introduction 3

Dept. of Materials, Manufacturing and Industrial Engineering,
Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia

1. **Materials in manufacturing**
    1. Engineering materials
    2. Material properties
    3. Material selection
2. **Manufacturing process**
    1. Brief overview
    2. Process selection

1. Engineering Materials



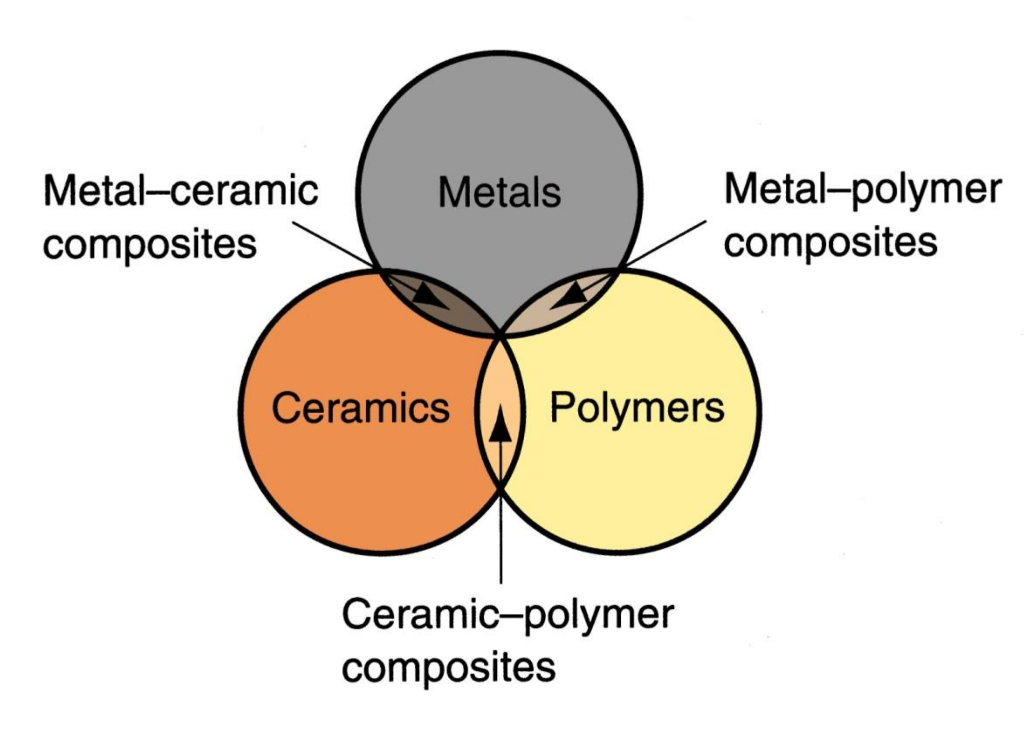
1. Materials in Manufacturing

- Most engineering materials can be classified into one of three basic categories:
  1. Metals
  2. Ceramics
  3. Polymers
- Their chemistries are different, their mechanical and physical properties are dissimilar, and these differences affect the manufacturing processes that can be used to produce products from them

- In addition to the three basic categories, there are:

4. Composites - nonhomogeneous mixtures of the other three basic types rather than a unique category

Figure 1.3 – Venn diagram of three basic Material types plus composites



1.1 Metals

Usually *alloys*, which are composed of two or more elements, at least one of which is metallic

- Two basic groups:
  1. Ferrous metals - based on iron, comprise ~ 75% of metal tonnage in the world:
     - *Steel = iron-carbon alloy with 0.02 to 2.11% C*
     - *Cast iron = alloy with 2% to 4% C*
  2. Nonferrous metals - all other metallic elements and their alloys: aluminum, copper, gold, magnesium, nickel, silver, tin, titanium, etc.

1.1 Ceramics

A compound containing metallic (or semi-metallic) and nonmetallic elements. Typical nonmetallic elements are oxygen, nitrogen, and carbon

- For processing purposes, ceramics divide into:

1. Crystalline ceramics – includes:
   - *Traditional ceramics, such as clay (hydrous aluminum silicates)*
   - *Modern ceramics, such as alumina (Al_2O_3)*
2. Glasses – mostly based on silica (SiO_2)

1.1 Polymers

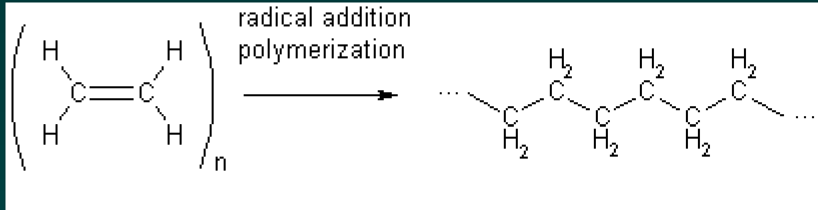


Fig 1: The polymerisation of ethene in to poly(ethene)

A compound formed of repeating structural units called *mers*, whose atoms share electrons to form very large molecules

- Three categories:
  1. *Thermoplastic polymers* - can be subjected to multiple heating and cooling cycles without altering their molecular structure
  2. *Thermosetting polymers* - molecules chemically transform (cure) into a rigid structure upon cooling from a heated plastic condition
  3. *Elastomers* - exhibit significant elastic behavior

1.1 Composites

A material consisting of two or more phases that are processed separately and then bonded together to achieve properties superior to its constituents

- A *phase* = a homogeneous mass of material, such as grains of identical unit cell structure in a solid metal
- Usual structure consists of particles or fibers of one phase mixed in a second phase
- Properties depend on components, physical shapes of components, and the way they are combined to form the final material

1.2 Material Properties

i. Mechanical properties
ii. Physical properties
iii. Manufacturing properties

1.2 Material Properties

i. Mechanical properties

- Stress & Strain relationships
- Elastic behaviour
- Plastic behaviour
- Toughness, ductility
- Strength
- Hardness, brittleness
- Creep
- Fatigue

Mechanical Properties in *Design and Manufacturing*

- Mechanical properties determine a material's behavior when subjected to mechanical stresses
  - Properties include elastic modulus, ductility, hardness, and various measures of strength
- Dilemma: mechanical properties desirable to the designer, such as high strength, usually make manufacturing more difficult
  - The manufacturing engineer should appreciate the design viewpoint and the designer should be aware of the manufacturing viewpoint

Stress-Strain Relationships

- Three types of static stresses to which materials can be subjected:
  1. Tensile - tend to stretch the material
  2. Compressive - tend to squeeze it
  3. Shear - tend to cause adjacent portions of material to slide against each other
- Stress-strain curve - basic relationship that describes mechanical properties for all three types

Tensile Test

- Most common test for studying stress-strain relationship, especially metals
- In the test, a force pulls the material, elongating it and reducing its diameter

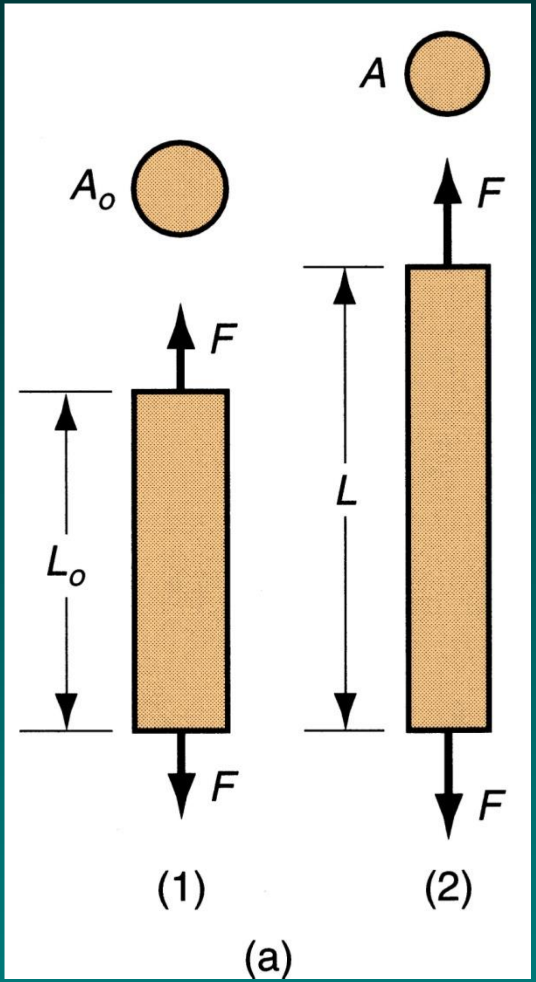
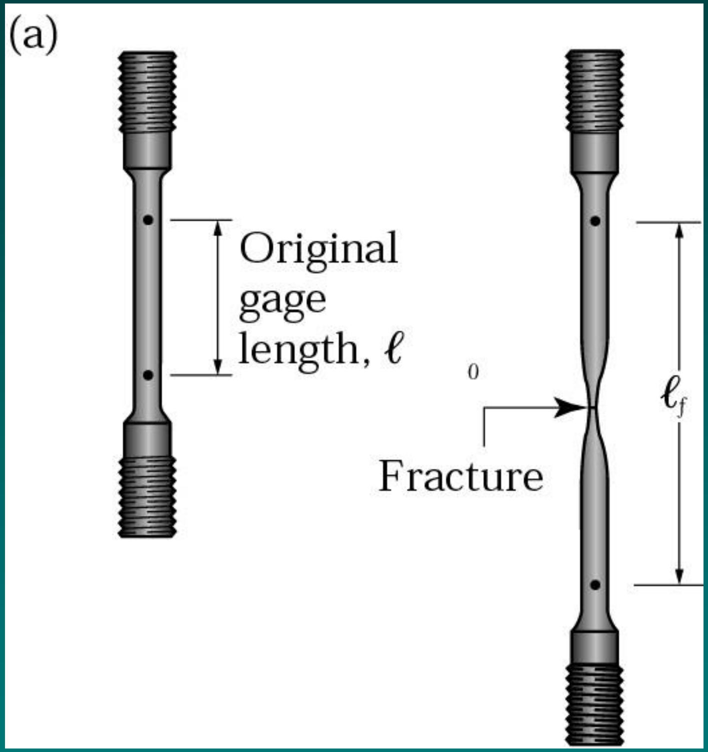
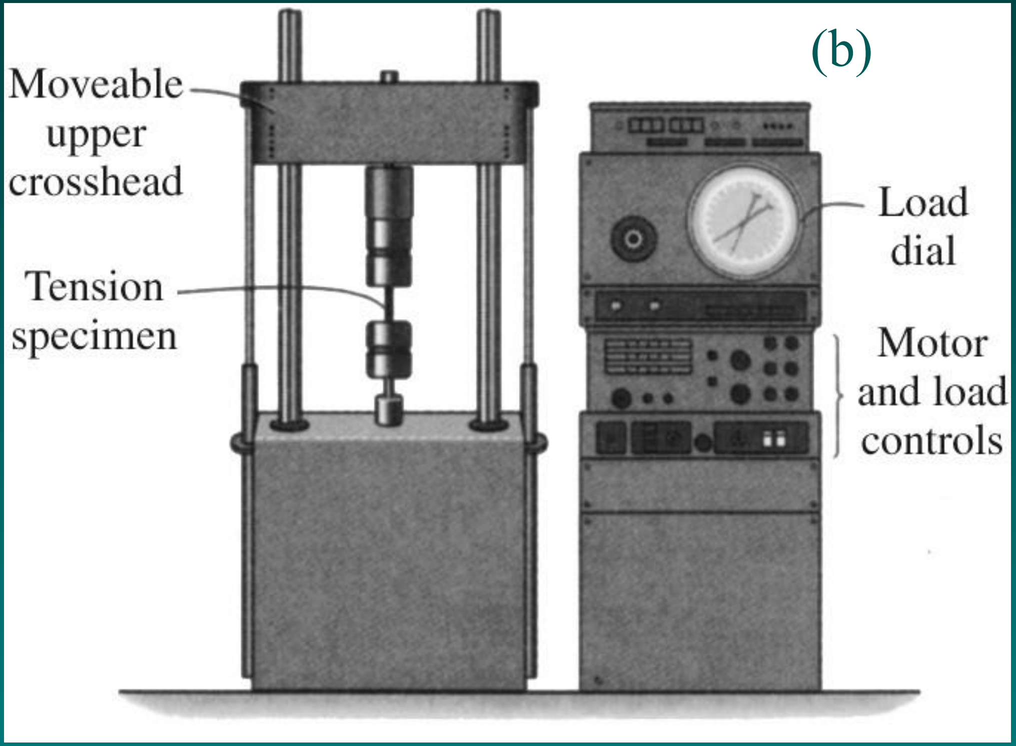


Figure 3.1 - Tensile test: (a) tensile force applied in (1) and (2) resulting elongation of material

Tensile-Test Specimen and Machine





(a) A standard tensile-test specimen before and after pulling, showing original and final gage lengths.
(b) A typical tensile-testing machine.

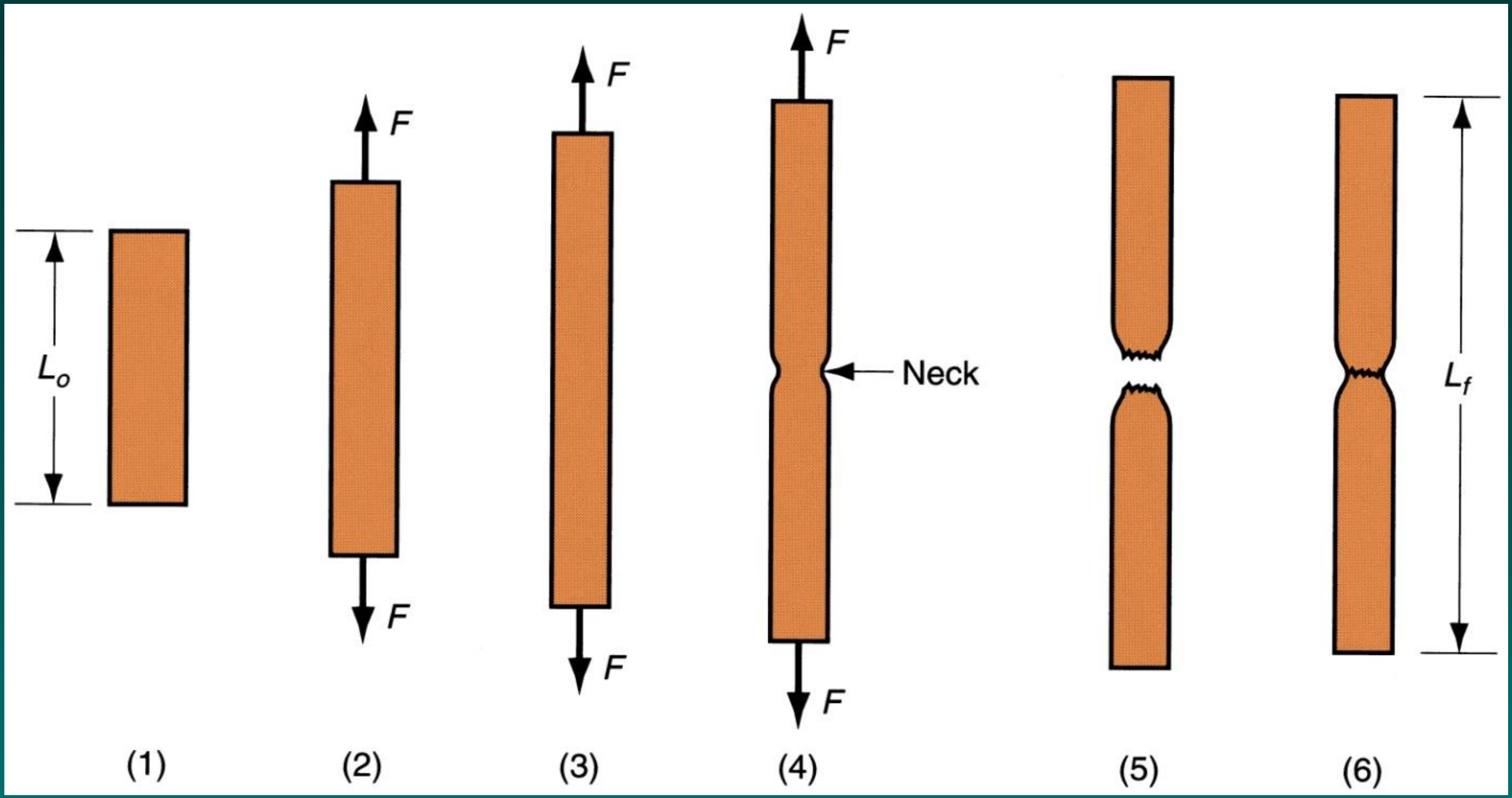


Figure 3.2 - Typical progress of a tensile test: (1) beginning of test, no load; (2) uniform elongation and reduction of cross-sectional area; (3) continued elongation, maximum load reached; (4) necking begins, load begins to decrease; and (5) fracture. If pieces are put back together as in (6), final length can be measured

- Elastic Deformation - **If a metal deformed by a force return to its original dimensions when the force is removed; the metal undergo *elastic deformation***
- Plastic deformation (metals) **Permanent deformation of metals due to the movement of dislocations on slip system.**

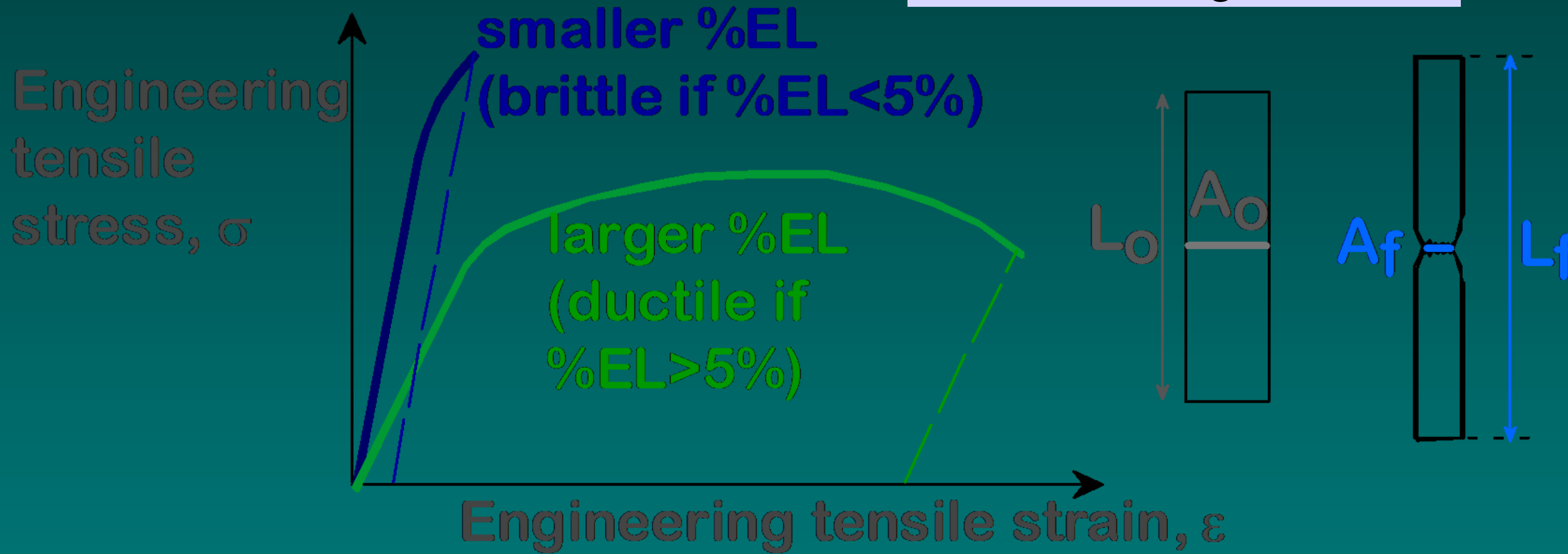
Ductility

- **Ductility** is a mechanical property used to describe the extent to which materials can be deformed plastically without fracture. Ductility is the most important parameter to consider in metal forming operations such as rolling, extrusion, and drawing. Examples of highly ductile metals are silver, gold, copper, and aluminium. The ductility of steel varies depending on the alloying constituents. Increasing levels of carbon decreases ductility, i.e., the steel becomes more brittle.
- Ductility can be quantified by the fracture strain , which is the engineering strain at which a test specimen fractures during a uniaxial tensile test. Another commonly used measure is the reduction of area at fracture *q*

Ductility

- **Plastic tensile strain at failure:**

$$\%EL = \frac{L_f - L_o}{L_o} \times 100$$



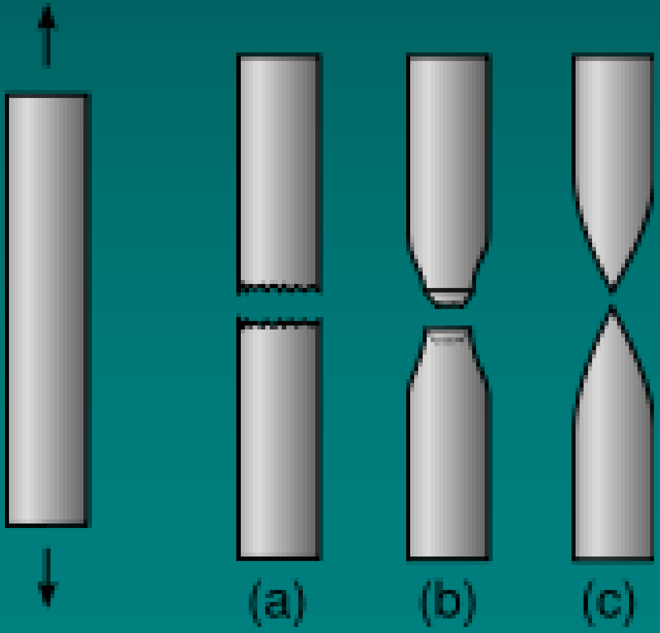
- **Another ductility measure:**

$$\%AR = \frac{A_o - A_f}{A_o} \times 100$$

- **Note: %AR and %EL are often comparable.**
  --Reason: crystal slip does not change material volume.
  --%AR > %EL possible if internal voids form in neck.

Ductility

- Schematic appearance of round metal bars after tensile testing.
  (a) Brittle fracture
  (b) Ductile fracture
  (c) Completely ductile fracture

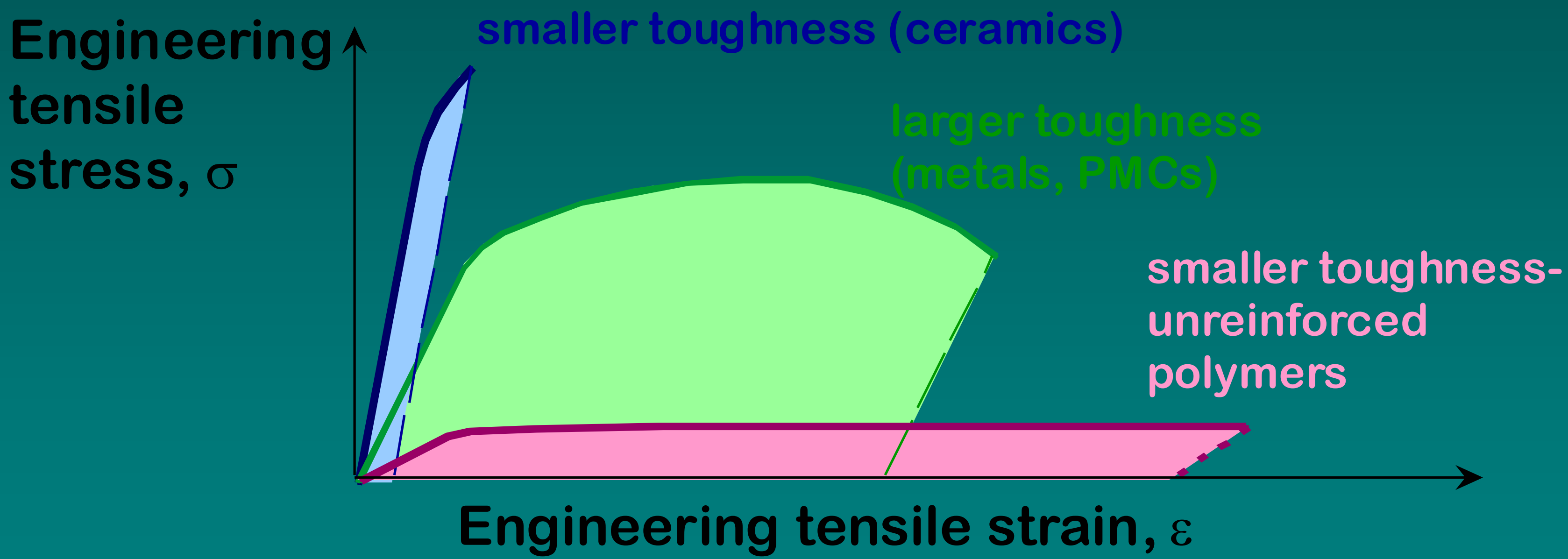


Toughness

- The toughness of a material is the maximum amount of energy it can absorb before fracturing, which is different than the amount of force that can be applied.
- Toughness tends to be small for brittle materials, because it is elastic and plastic deformations that allow materials to absorb large amounts of energy.

Toughness

- **Energy to break a unit volume of material**
- **Approximate by the area under the stress-strain curve.**



Yield Strength

- The **yield strength** or **yield point** of a material is defined in engineering and materials science as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed some fraction of the deformation will be permanent and non-reversible.
- Knowledge of the yield point is vital when designing a component since it generally represents an upper limit to the load that can be applied. It is also important for the control of many materials production techniques such as forging, rolling, or pressing

Strength

- Strength is a measure of the extent of a material's elastic range, or elastic and plastic ranges together.
- This is quantified as compressive strength, shear strength, tensile strength depending on the direction of the forces involved.
- Ultimate strength is measure of the maximum strain a material can withstand.

Tensile strength

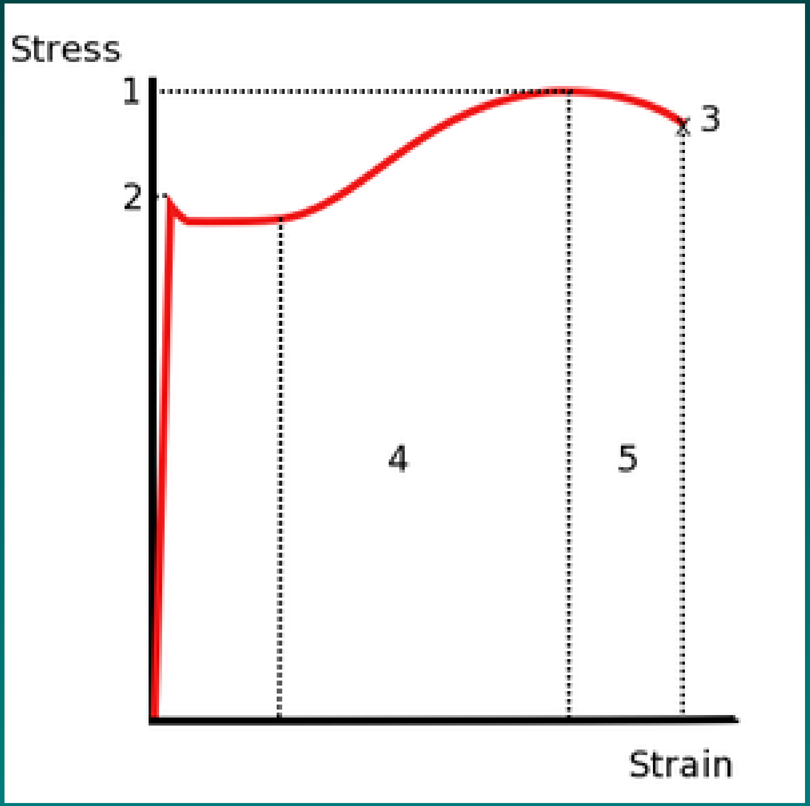
- **Tensile strength** σ_{UTS}, or S_U measures the engineering stress applied (to something such as rope, wire, or a structural beam) at the point when it fails. It is an intensive property of the material, which not only depends on the type of material but also the preparation of the specimen and the temperature of the test. In other words, the amount of force the material can withstand when being stretched. The tensile strength (TS) is the stress at the maximum on the stress-strain curve.

Tensile strength

- There are three definitions of tensile strength:
  - Yield strength. The stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently.
  - Ultimate strength. The maximum stress a material can withstand. Breaking strength The stress coordinate on the stress-strain curve at the point of rupture.
  - Breaking strength. The stress coordinate on the stress-strain curve at the point of rupture.

Tensile strength

- Stress vs. Strain curve typical of structural steel
  1. Ultimate Strength
  2. Yield Strength
  3. **Tensile strength**
  4. Strain hardening region
  5. Necking region.



Compressive strength

- **Compressive strength** is the capacity of a material to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed.
- Concrete can be made to have high compressive strength, e.g. many concrete structures have compressive strengths in excess of 50 MPa, whereas a material such as soft sandstone may have a compressive strength as low as 5 or 10 MPa.

Shear strength

- **Shear strength** in engineering is a term used to describe the strength of a material or component against the type of yield or structural failure where the material or component fails in shear.
- In structural and mechanical engineering the shear strength of a component is important for designing the dimensions and materials to be used for the manufacture/construction of the component. For example, beams, plates, bolts etc. In a reinforced concrete beam, the main purpose of stirrups is to increase the shear strength.

Creep

- **Creep** is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. It occurs as a result of long term exposure to levels of stress that are below the yield strength or ultimate strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and near the melting point. It is often observed in glasses. Creep always increases with temperature.
- The rate of this deformation is a function of the material properties, exposure time, exposure temperature and the applied load (stress).

Creep

- Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for ***example*** creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade.
- Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures.
- Creep is not necessarily a failure mode, but is instead a deformation mechanism. Moderate creep in concrete is sometimes welcomed because it relieves tensile stresses that otherwise may have led to cracking.

Fatigue

- In materials science, **fatigue** is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading.
- The maximum stress values are less than the ultimate tensile stress limit, and may be below the yield stress limit of the material.
- **Fatigue limit**, **endurance limit**, and **fatigue strength** are all expressions used to describe a property of materials: the amplitude (or range) of cyclic stress that can be applied to the material without causing fatigue failure.

Hardness

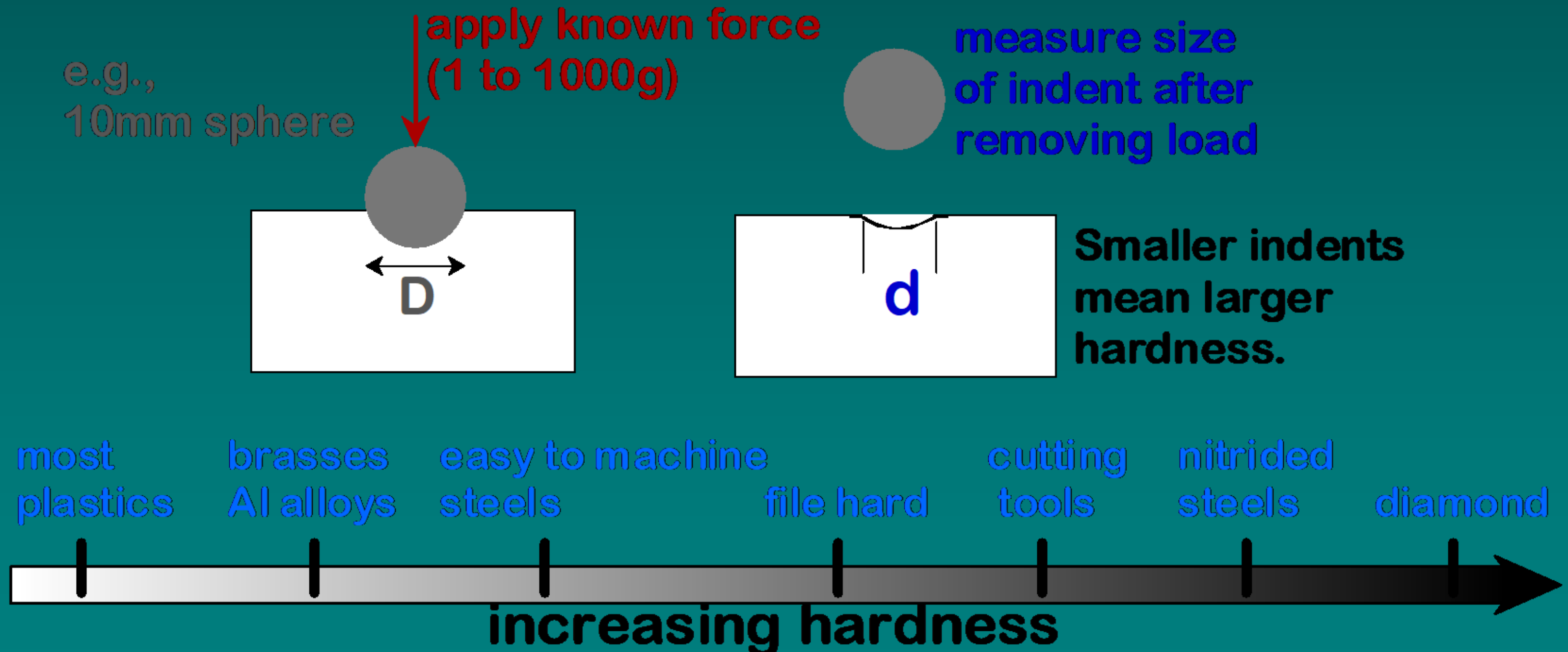
- **Hardness** refers to various properties of matter in the solid phase that give it high resistance to various kinds of shape change when force is applied. **Hard matter** is contrasted with soft matter.

HARDNESS

- **Resistance to permanently indenting the surface.**
- **Large hardness means:**

  --resistance to plastic deformation or cracking in compression.

  --better wear properties.



Adapted from Fig. 6.18, *Callister 6e.* (Fig. 6.18 is adapted from G.F. Kinney, *Engineering Properties and Applications of Plastics*, p. 202, John Wiley and Sons, 1957.)

1.2 Material Properties

ii. Physical properties
- Specific heat
- Thermal conductivity
- Coefficient of thermal expansion

Example

1.2 Properties of Materials

Table 3.2 Physical properties of various materials at room temperature

METAL	DENSITY (kg/m^3)	MELTING POINT (□C)	SPECIFIC HEAT (J/kgK)	THERMAL CONDUCTIVITY (W/m K)	COEFFICIENT OF THERMAL EXPANSION (μm/m□C)
Aluminum	2700	660	900	222	23.6
Aluminum alloys	2630-2820	476-654	880-920	121-239	23.0-23.6
Berylium	1854	1278	1884	146	8.5
Columbium (niobium)	8580	2468	272	52	7.1
Copper	8970	1082	385	393	16.5
Copper alloys	7470-8940	885-1260	337-435	29-234	16.5-20
Gold	19300	1063	129	317	19.3
Iron	7860	1537	460	74	11.5
Steels	6920-9130	1371-1532	448-502	15-52	11.7-17.3
Lead	11350	327	130	35	29.4
Lead alloys	8850-11350	182-326	126-188	24-46	27.1-31.1
Magnesium	1745	650	1025	154	26.0
Magnesium alloys	1770-1780	610-621	1046	75-138	26.0
Molybdenum alloys	10210	2610	276	142	5.1
Nickel	8910	1453	440	92	13.3
Nickel alloys	7750-8850	1110-1454	381-544	12-63	12.7-18.4
Silicon	2330	1423	712	148	7.63
Silver	10500	961	235	429	19.3
Tantalum alloys	16600	2996	142	54	6.5
Titanium	4510	1668	519	17	8.35
Titanium alloys	4430-4700	1549-1649	502-544	8-12	8.1-9.5
Tungsten	19290	3410	138	166	4.5
NONMETALLIC					
Ceramics	2300-5500	-	750-950	10-17	5.5-13.5
Glasses	2400-2700	580-1540	500-850	0.6-1.7	4.6-70
Graphite	1900-2200	-	840	5-10	7.86
Plastics	900-2000	110-330	1000-2000	0.1-0.4	72-200
Wood	400-700	-	2400-2800	0.1-0.4	2-60

1.2 Material Properties

- ***Thermal conductivity (λ)*** is the property of a material which relates its ability to conduct heat. Heat transfer by conduction involves transfer of energy within a material without any motion of the material as a whole. Conduction takes place when a temperature gradient exists in a solid (or stationary fluid) medium. Conductive heat flow occurs in the direction of decreasing temperature because higher temperature equates to higher molecular energy or more molecular movement. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide.

1.2 Material Properties

- ***Specific heat capacity***, also known simply as **specific heat**, is the measure of the heat energy required to increase the temperature of a unit quantity of a substance by a certain temperature interval. More heat energy is required to increase the temperature of a substance with high specific heat capacity than one with low specific heat capacity. For instance, eight times the heat energy is required to increase the temperature of an ingot of magnesium as is required for a lead ingot of the same mass.
- The specific heat of virtually any substance can be measured, including chemical elements, compounds, alloys, solutions, and composites.

1.2 Material Properties

- ***Thermal Expansion*** is the tendency of matter to change in volume in response to a change in temperature. When a substance is heated, its constituent particles move around more vigorously and by doing so generally maintain a greater average separation. Materials that contract with an increase in temperature are very uncommon; this effect is limited in size, and only occurs within limited temperature ranges. The degree of expansion divided by the change in temperature is called the material's coefficient of thermal expansion and generally varies with temperature.

- Heat-induced expansion has to be taken into account in most areas of engineering. A few examples are:
  - Metal framed windows need rubber spacers
  - Metal hot water heating pipes should not be used in long straight lengths
  - Large structures such as railways and bridges need expansion joints in the structures
  - One of the reasons for the poor performance of cold car engines is that parts have inefficiently large spacings until the normal operating temperature is achieved.
  - A Gridiron pendulum uses an arrangement of different metals to maintain a more temperature stable pendulum length.

- This phenomenon can also be put to good use, for example in the process of thermal shrink-fitting parts are assembled with each at a different temperature, and sized such that when they reach the same temperature, the thermal expansion of the parts forces them together to form a stable joint.
- Thermometers are another example of an application of thermal expansion — most contain a liquid which is constrained to flow in only one direction (along the tube) due to changes in volume brought about by changes in temperature. A bi-metal mechanical thermometer uses a bi-metal strip and registers changes based on the differing coefficient of thermal expansion between the two materials.

1.2 Material Properties

iii. Manufacturing properties

- – Hardenability, heat treatability
- – Castability
- – Formability
- – Weldability
- – Machinability

- Will be discussed in the respective topics

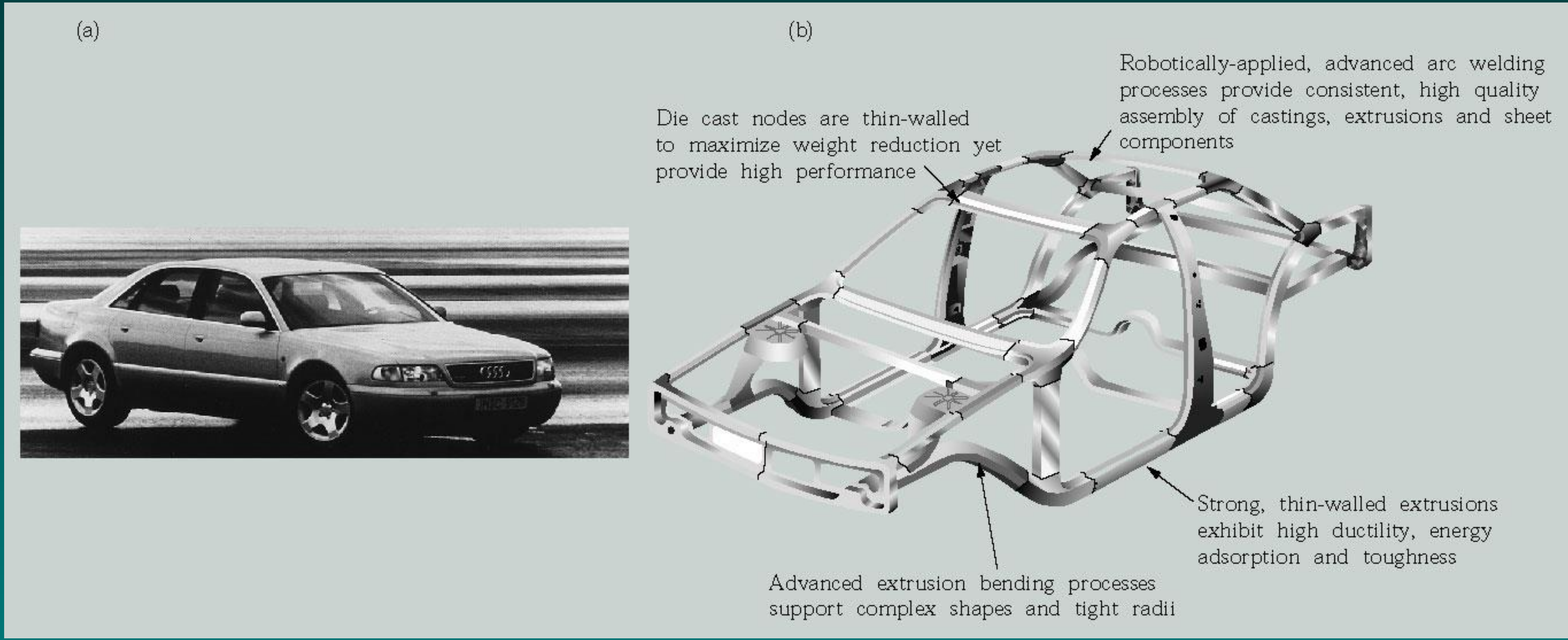
1.3 Material Selection

- All engineering disciplines need to know about material
- By studying material science & engineering, we will be
  - able to select a material for a given use based on considerations of cost and performance.
  - understand the limits of materials and the change of their properties with use

1.3 Material Selection

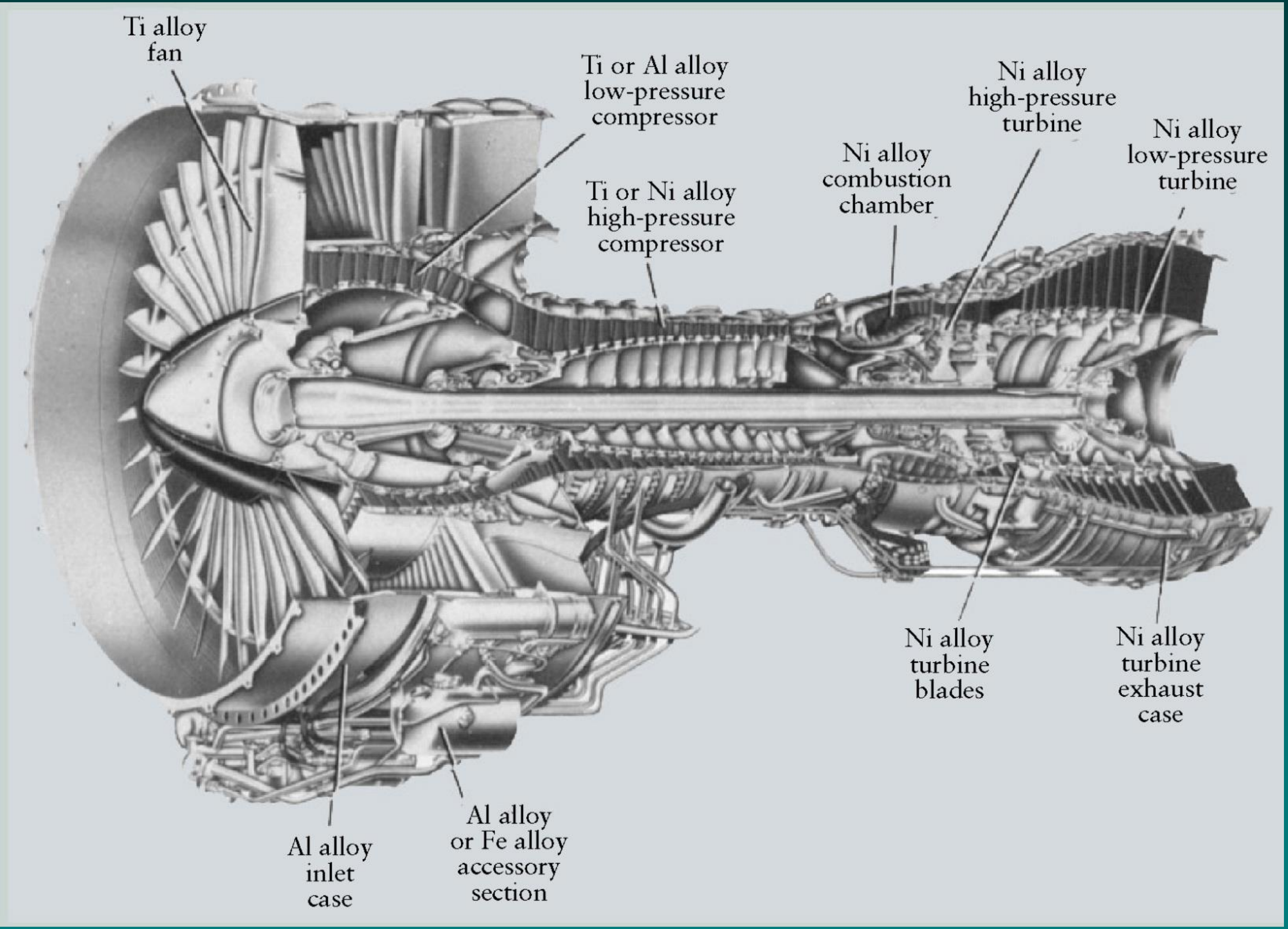
- Materials used in "High-Tech" applications, usually designed for maximum performance, and normally expensive.
  - Examples are titanium alloys for supersonic airplanes,
  - magnetic alloys for computer disks,
  - special ceramics for the heat shield of the space shuttle, etc.

Aluminum Automobile



(a) The Audi A8 automobile, an example of advanced materials construction; (b) The aluminum body structure, showing various components made by extrusion, sheet forming, and casting processes. Source: Courtesy of ALCOA, Inc.

Non-ferrous Alloys in a Jet Engine



- Cross-section of a jet engine (PW2037) showing various components and the alloys used in making them. *Source*: Courtesy of United Aircraft Pratt & Whitney.

1.3 Material Selection

- Some examples of Modern Material's needs
  - Engine efficiency increases at high temperatures: requires high temperature structural materials
  - Use of nuclear energy requires solving problem with residues, or advances in nuclear waste processing.
  - Hypersonic flight requires materials that are light, strong and resist high temperatures.
  - Optical communications require optical fibers that absorb light negligibly.
  - Civil construction – materials for unbreakable windows.
  - Structures: materials that are strong like metals and resist corrosion like plastics.

1.3 Material Selection

- Please refer to the supplementary note
  - Chapter 9 : Material selection, by DeGarmo et al.
  - Section 9.2, 9.4

2. Manufacturing Processes

Two basic types:

1. Processing operations - transform a work material from one state of completion to a more advanced state
   - Operations that change the geometry, properties, or appearance of the starting material
2. Assembly operations - join two or more components in order to create a new entity

Processing Operations

Alters a workpart's shape, physical properties, or appearance in order to add value to the material

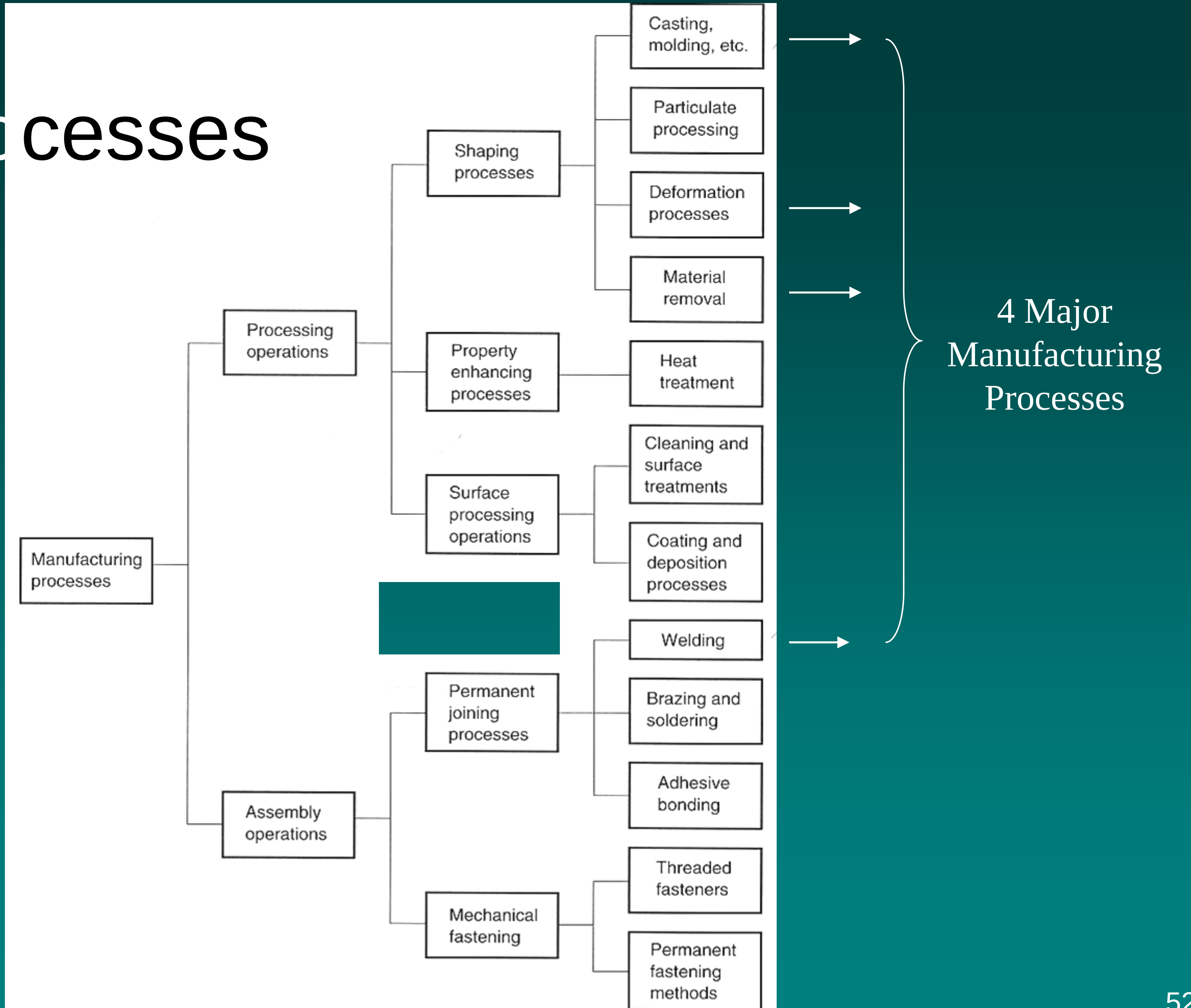
- Three categories of processing operations:

1. Shaping operations - alter the geometry of the starting work material
2. Property-enhancing operations - improve physical properties of the material without changing its shape
3. Surface processing operations - performed to clean, treat, coat, or deposit material onto the exterior surface of the work

Shaping Processes – Four Categories

1. ***Solidification processes*** - starting material is a heated *liquid* or *semifluid* that solidifies to form part geometry
2. ***Particulate processing*** - starting material is a *powder*, and the powders are formed into desired geometry and then sintered to harden
3. ***Deformation processes*** - starting material is a *ductile solid* (commonly metal) that is deformed
4. ***Material removal processes*** - starting material is a *solid* (ductile or brittle), from which material is removed so resulting part has desired geometry

Processes

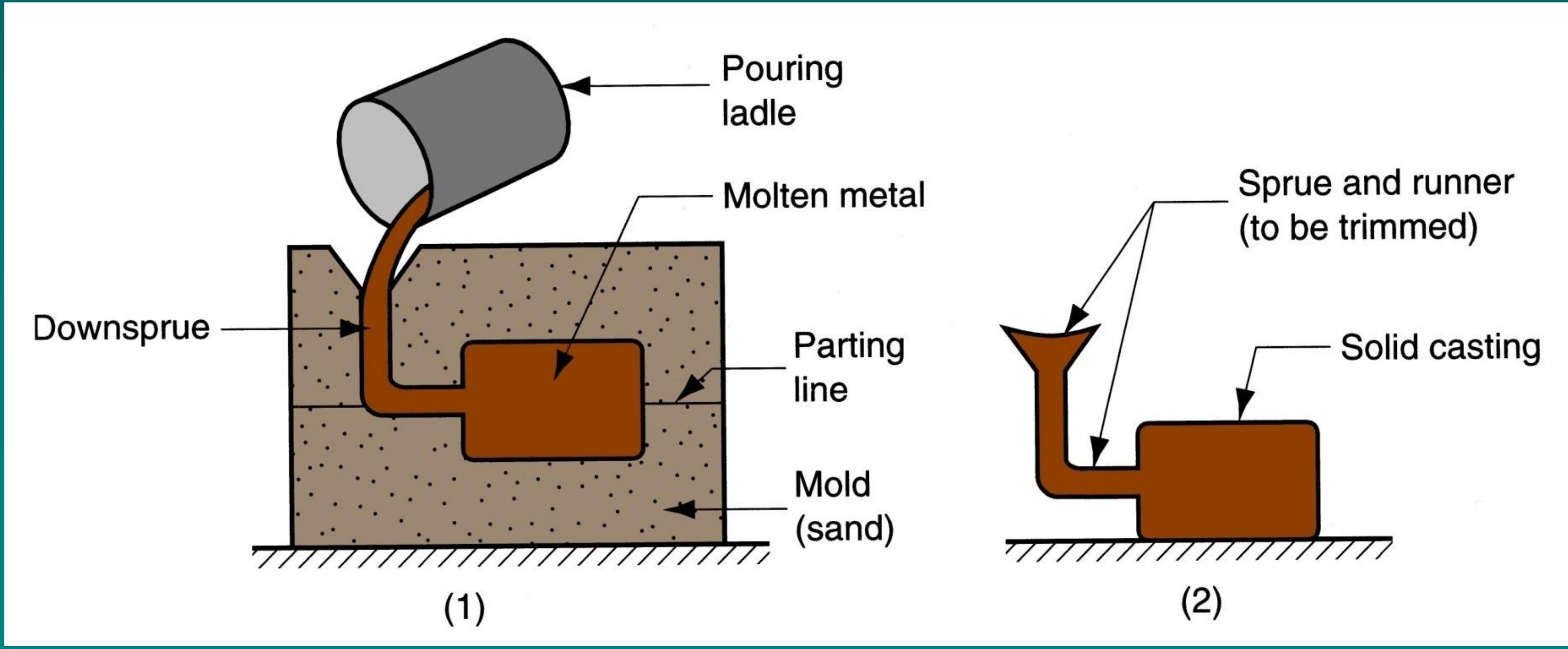

Manufacturing processes
Processing operations
Assembly operations
Shaping processes
Property enhancing processes
Surface processing operations
Permanent joining processes
Mechanical fastening
Casting, molding, etc.
Particulate processing
Deformation processes
Material removal
Heat treatment
Cleaning and surface treatments
Coating and deposition processes
Welding
Brazing and soldering
Adhesive bonding
Threaded fasteners
Permanent fastening methods
4 Major Manufacturing Processes

Process Groups

Family	Subgroup	Typical processes
Casting	Expendable mold	Sand casting Shell casting Investment casting Lost foam casting
	Multiple-use mold	Die casting Permanent mold casting
Material removal	Mechanical machining	Turning Milling Drilling Boring Sawing
	Nontraditional machining	Etching Electropolishing Electrodischarge machining Water jet Laser beam
Deformation processes	Hot bulk forming	Forging Rolling Extrusion
	Cold forming	Wire drawing Swaging Roll forming Deep drawing
Consolidation processes	Welding	Oxyfuel Arc Plasma Resistance Laser
	Brazing	
	Soldering	
	Adhesive bonding	
	Mechanical joining	Discrete fasteners Integral fasteners Press fit Shrink fit

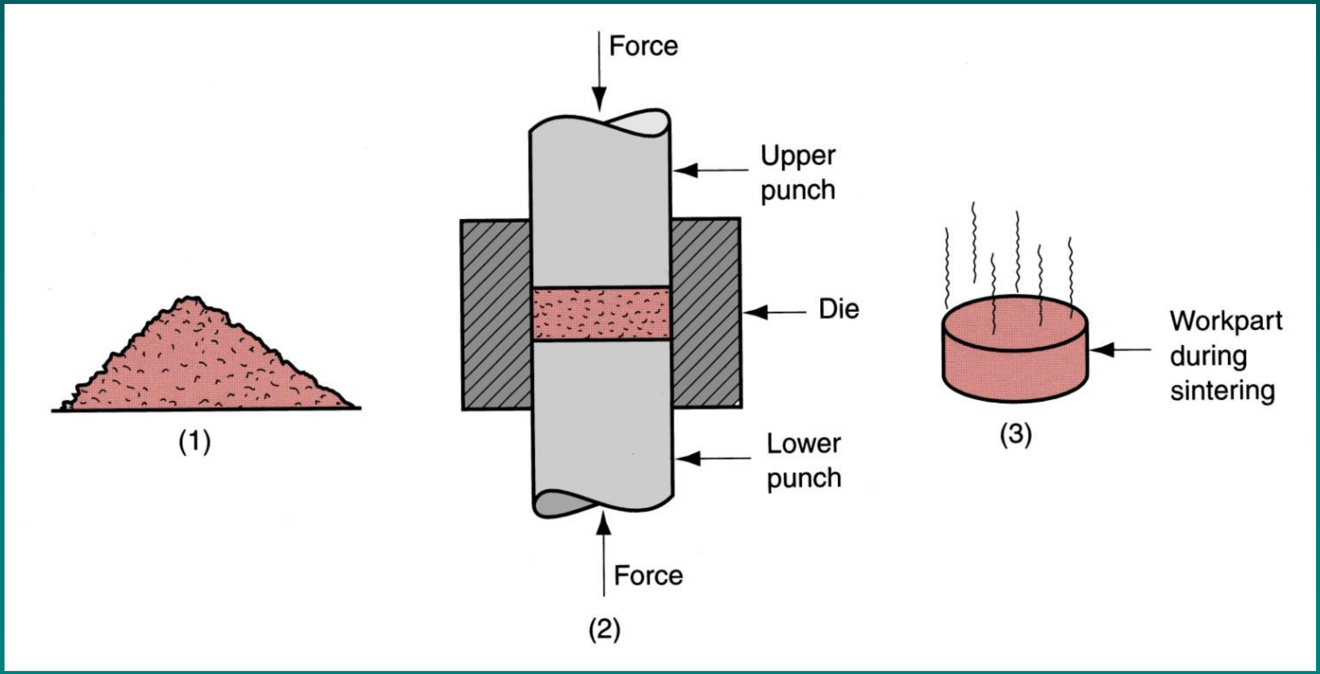
Solidification Processes

- Starting material is heated sufficiently to transform it into a liquid or highly plastic state
- Examples: Casting for metals, molding for plastics



Particulate Processing

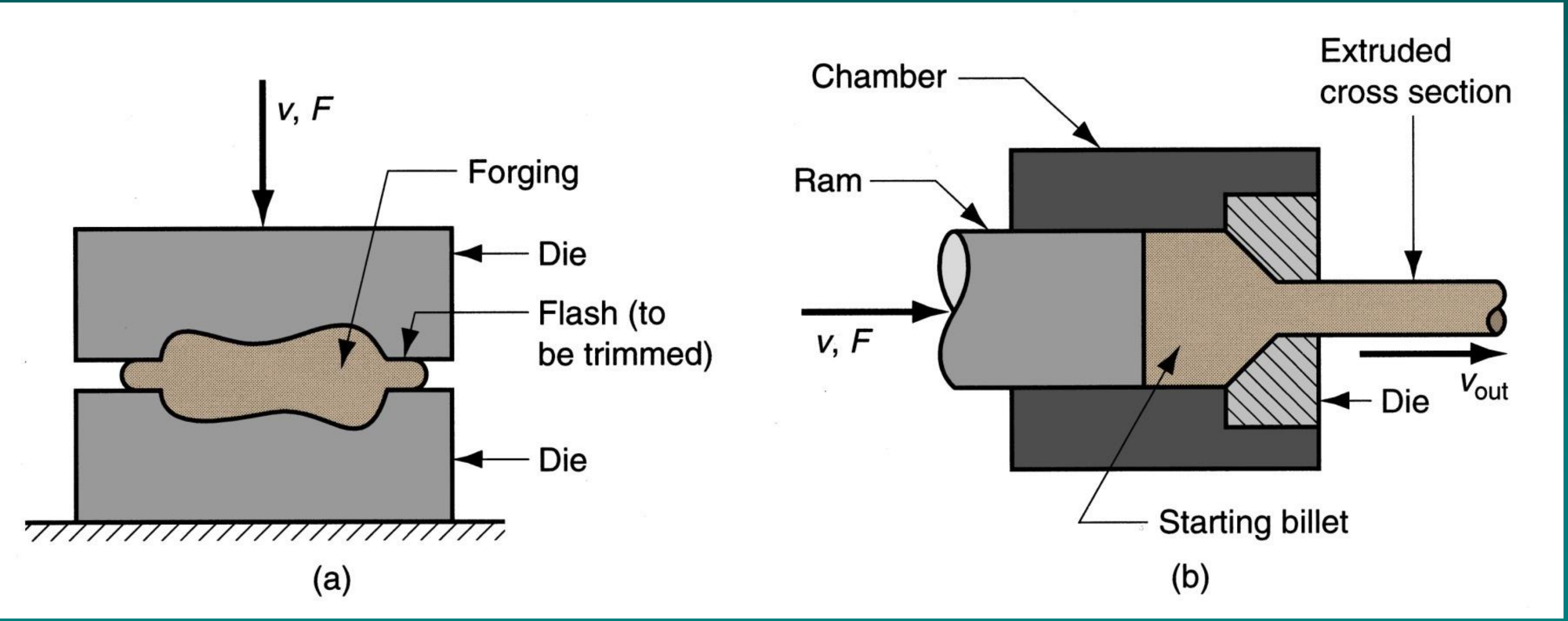
- Starting materials are powders of metals or ceramics
- Usually involves pressing and sintering, in which powders are first squeezed in a die cavity and then heated to bond the individual particles



Deformation Processes

Starting workpart is shaped by application of forces that exceed the yield strength of the material

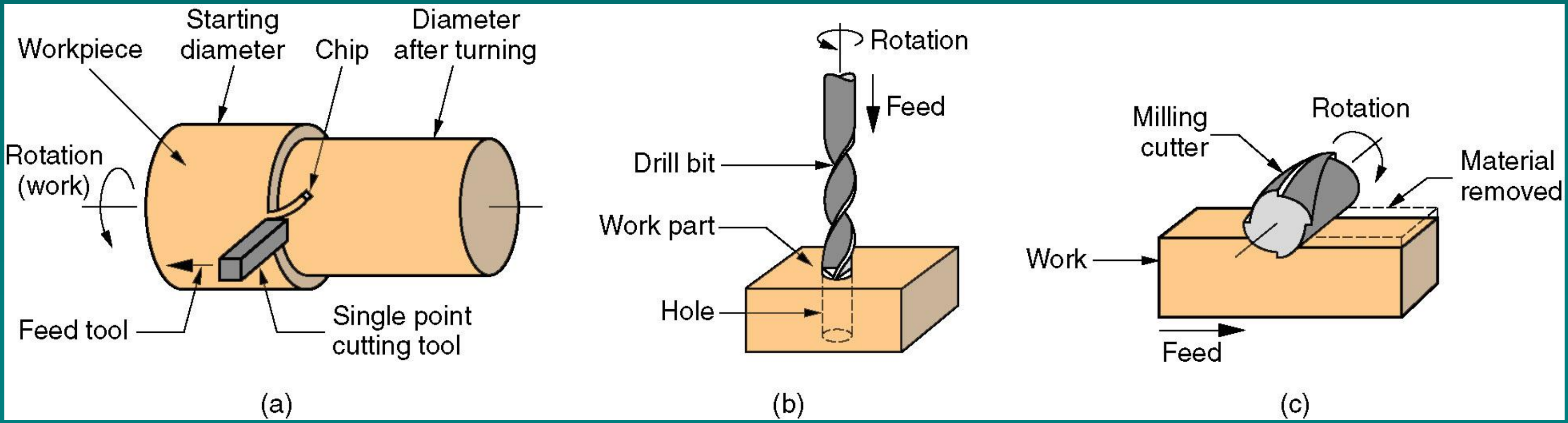
- Examples: (a) forging, (b) extrusion



Material Removal Processes

Excess material removed from the starting workpiece so what remains is the desired geometry

- Examples: machining such as turning, drilling, and milling; also grinding and nontraditional processes



Waste in Shaping Processes

It is desirable to minimize waste and scrap in part shaping

- Material removal processes tend to be wasteful in the unit operation, simply by the way they work
- Casting and molding usually waste little material
- Terminology:
  - *Net shape processes* - when most of the starting material is used and no subsequent machining is required to achieve final part geometry
  - *Near net shape processes* - when minimum amount of machining is required

Property-Enhancing Processes

- Performed to improve mechanical or physical properties of the work material
- Part shape is not altered, except unintentionally
- Examples:
  - Heat treatment of metals and glasses
  - Sintering of powdered metals and ceramics

Surface Processing Operations

1. Cleaning - chemical and mechanical processes to remove dirt, oil, and other contaminants from the surface
2. Surface treatments - mechanical working such as sand blasting, and physical processes like diffusion
3. Coating and thin film deposition - coating exterior surface of the workpart

- Several surface processing operations used to fabricate integrated circuits

Assembly Operations

Two or more separate parts are joined to form a new entity

- Types of assembly operations:

1. Joining processes – create a permanent joint.
   - *Examples: welding, brazing, soldering, and adhesive bonding*
2. Mechanical assembly – fastening by mechanical methods
   - Examples: use of screws, bolts, nuts, other threaded fasteners; press fitting, expansion fits

Type of Part	Iron	Carbon Steel	Alloy Steel	Stainless Steel	Tool Steel	Aluminum Alloys	Copper Alloys	Magnesium Alloys	Nickel Alloys	Zinc Alloys	Tin Alloys	Lead	Titanium	Precious Metals
Extrusions	—	○	○	○	—	●	●	●	○	○	○	○	○	—
Metal stampings	—	●	●	○	—	●	●	○	○	○	—	—	—	●
Metal spinnings	—	●	○	●	—	●	●	○	●	○	○	○	—	—
Cold-headed parts	—	●	○	○	—	●	●	—	○	—	—	○	—	—
Impact extrusions	—	●	○	—	—	●	●	●	○	●	●	●	—	—
Swaged and bent tubing	—	●	●	●	—	●	●	○	●	○	○	—	○	—
Roll-formed sections	—	●	●	●	—	●	●	—	—	●	—	—	—	—
Powder-metal parts	●	○	○	○	○	○	●	—	○	—	—	—	○	—
Forgings	—	●	●	●	○	●	●	●	○	—	—	—	○	—
Screw-machine parts	○	●	○	○	—	●	●	○	○	○	—	—	○	—
Electrical-discharge-machined parts	—	○	○	○	●	○	○	—	○	—	—	—	○	—
Electrochemically machined parts	—	○	●	○	●	—	○	—	●	—	—	—	●	—
Chemically machined parts	—	●	○	●	○	●	●	●	○	—	—	—	○	—
Sand-mold castings	●	●	●	●	○	●	●	●	●	○	○	○	—	—
Permanent-mold castings	●	○	—	—	—	●	●	●	○	○	○	○	—	—
Ceramic-mold castings	●	●	●	●	●	○	●	○	●	○	—	—	—	—
Plaster-mold castings	—	—	—	—	—	●	●	○	—	●	○	○	—	—
Centrifugal castings	●	●	●	—	—	●	●	—	●	—	—	—	—	—
Investment castings	—	●	●	●	●	●	●	○	●	—	—	—	—	○
Die castings	—	—	○	○	○	●	○	○	—	●	○	○	—	—

Note: ●, frequently processed with this method; ○, sometimes processed with this method; —, seldom or never processed with this method.
Source: [illegible]

TABLE 5.3 Forms of Energy Applied in Manufacturing and the Resulting Possible Surface and Subsurface Alterations That Can Occur

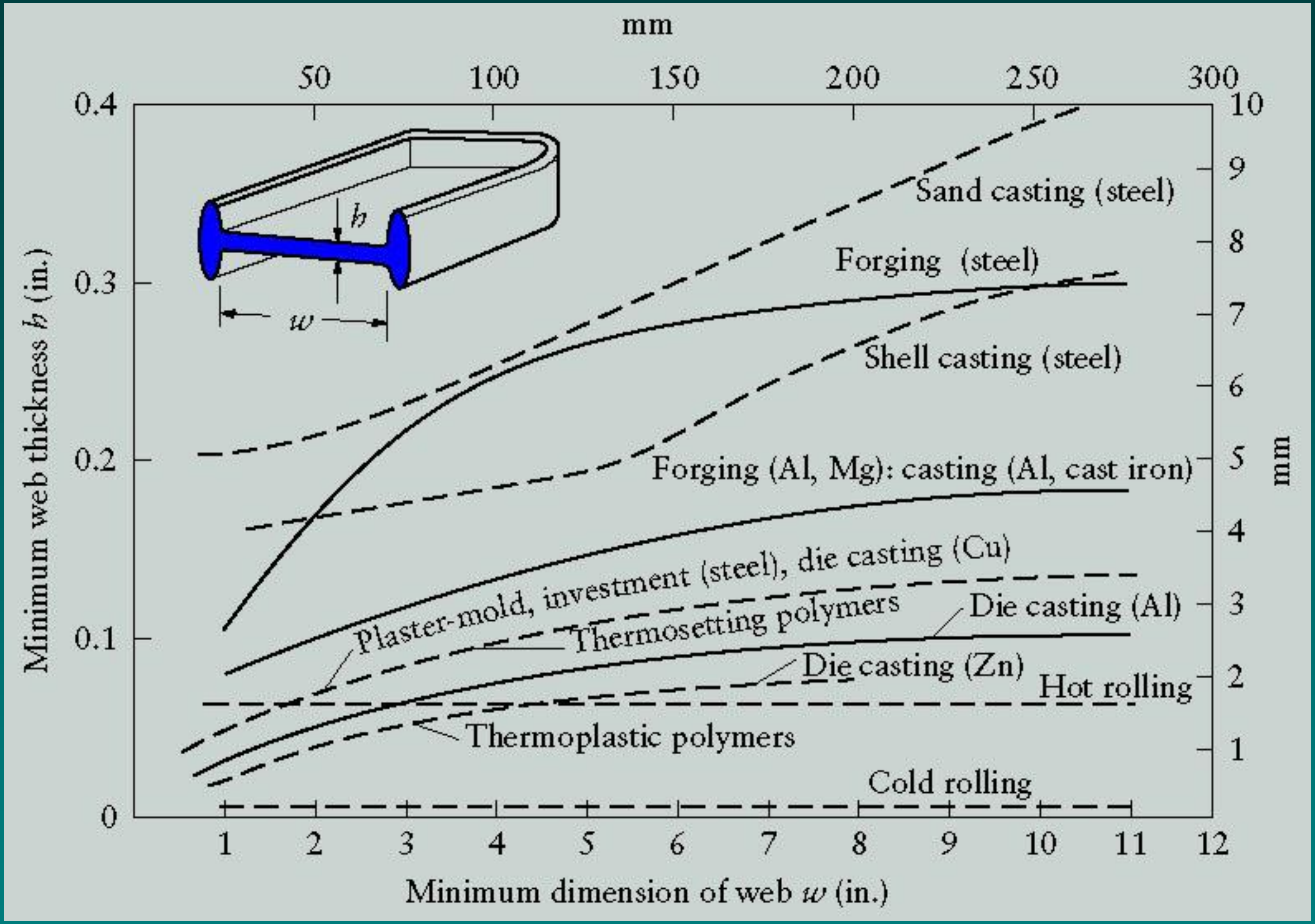
Energy form	Possible alterations and damages
Mechanical	Residual stresses in subsurface layer Cracks: microscopic and macroscopic Plastic deformation Laps, folds, or seams Voids or inclusions introduced mechanically Hardness variations (for example, work hardening)
Thermal	Metallurgical changes (recrystallization, grain size changes, phase changes at surface) Redeposited or resolidified material Heat-affected zone (includes some of the metallurgical changes listed above) Hardness changes
Chemical	Intergranular attack Chemical contamination Absorption of certain elements such as H and Cl in the metal surface Corrosion, pitting, and etching Stress corrosion Dissolving of microconstituents Alloy depletion and resulting hardness changes
Electrical	Changes in conductivity and/or magnetism Craters resulting from short circuits during certain electrical processing techniques

Manufacturing Processes for Materials

- E - Excellent, G - Good, F - Fair, VP - Very Poor, D - Difficult

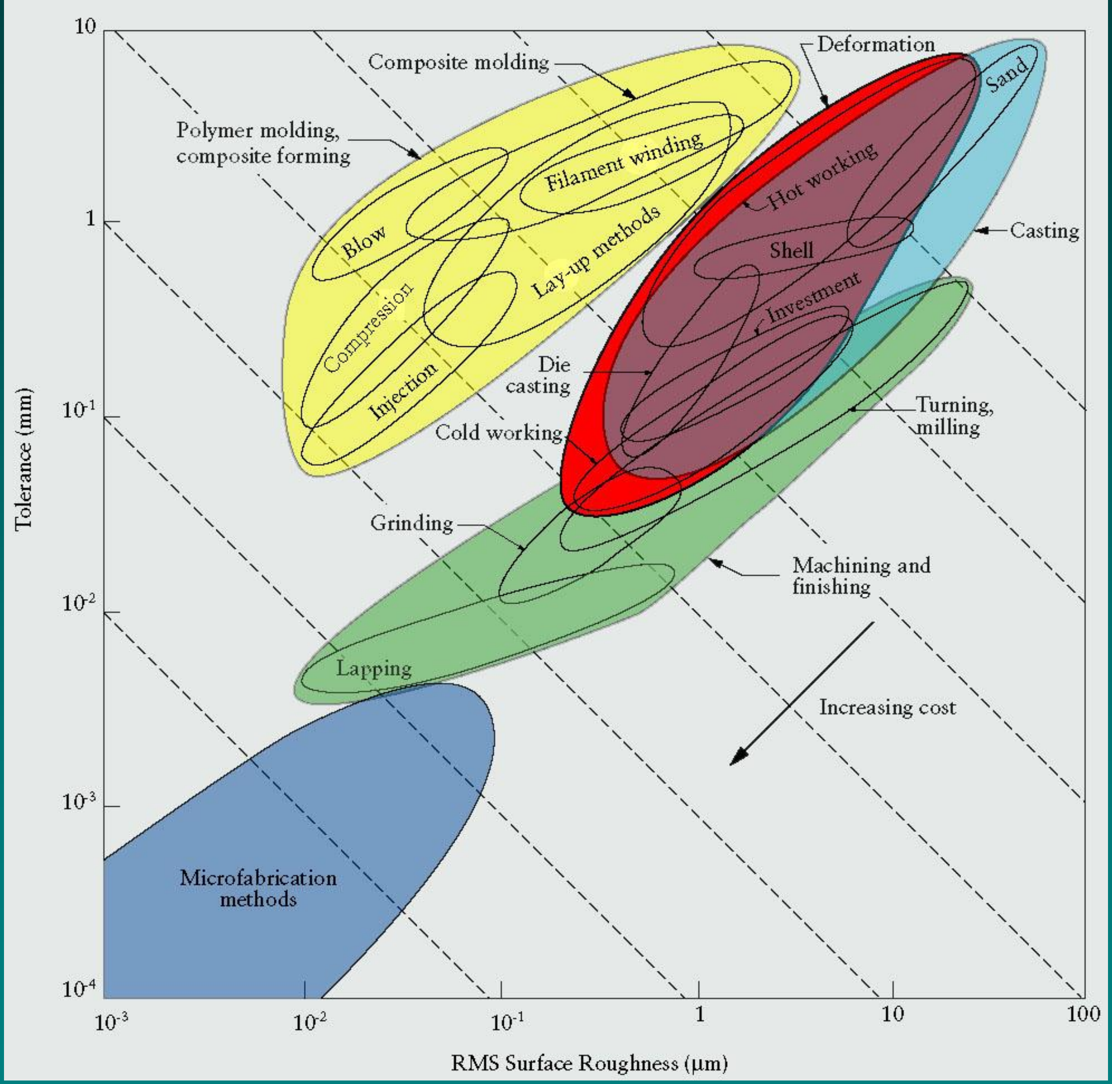
MATERIAL	APPLICATION	CAST	WELD	MACHINE
ALUMINIUM	Pistons, clutch housings, exhaust manifolds	E	F	G-E
COPPER	Pumps, valves, marine propellers	F-G	F	F-G
GREY IRON	Engine blocks, gears, brake disks and drums, machine bases	E	D	G
MAGNESIUM	Crank case, transmission housings	G-E	G	E
MALLEABLE IRON	Farm and construction machinery, heavy-duty bearings, rolling stock	G	D	G
NICKEL	Gas turbine blades, pump and valve components for chemical plants	F	F	F
NODULAR IRON	Crankshafts, heavy-duty gears	G	D	G
STEEL (CARBON AND LOW ALLOY)	Die blocks, heavy-duty gear blanks, aircraft undercarriage members, train wheels	F	E	F
STEEL (HIGH ALLOY)	Gas turbine housing, pump and valve components, rock crusher jaws	F	E	F
WHITE IRON	Train brake shoes, crushers and pulverisers	G	VP	VP
ZINC	Door handles, radiator grilles, carburettor bodies	E	D	E

Minimum Part Dimensions



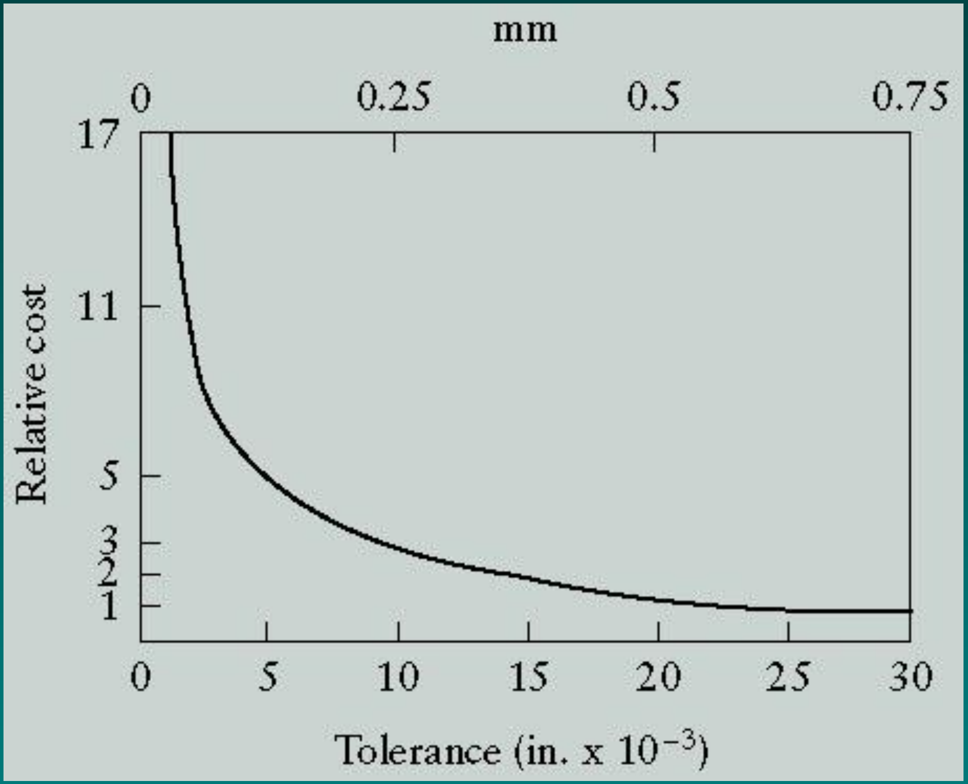
- Minimum part dimensions obtainable by various manufacturing processes..

Dimensional Tolerance/Surface Roughness



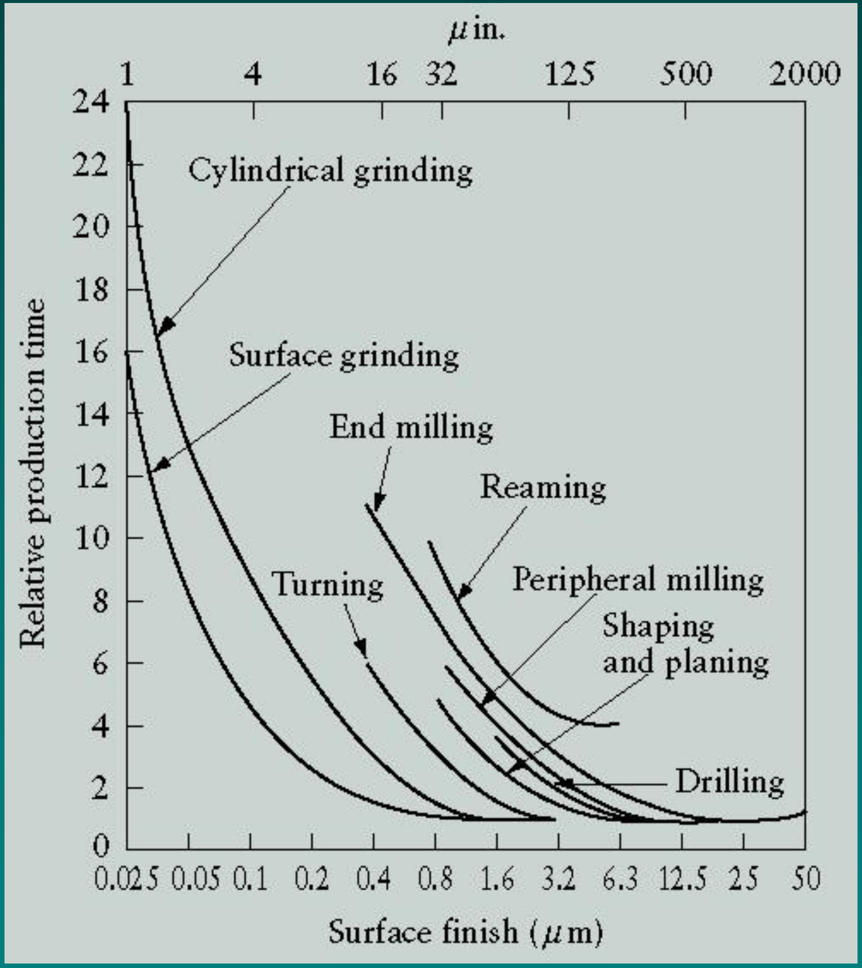
A plot of achievable dimensional tolerance versus surface roughness for assorted manufacturing operations. The dashed lines indicate cost factors; an increase in precision corresponding to the separation of two neighboring lines gives an increase in cost for a given process, of a factor of two.

Relative Cost/Dimensional Tolerance



Relationship between relative manufacturing cost and dimensional tolerance.

Relative Production Time/Surface Finish



Relative production time as a function of surface finish produced by various manufacturing processes. *Source: American Machinist*.

Process selection

a) Type of material involved and their characteristics.

b) Final required characteristics.

c) Size, shape, thickness and complicated of products.

d) Tolerance and surface finishing requirement.

e) Further processing requirement.

f) Design and equipment cost.

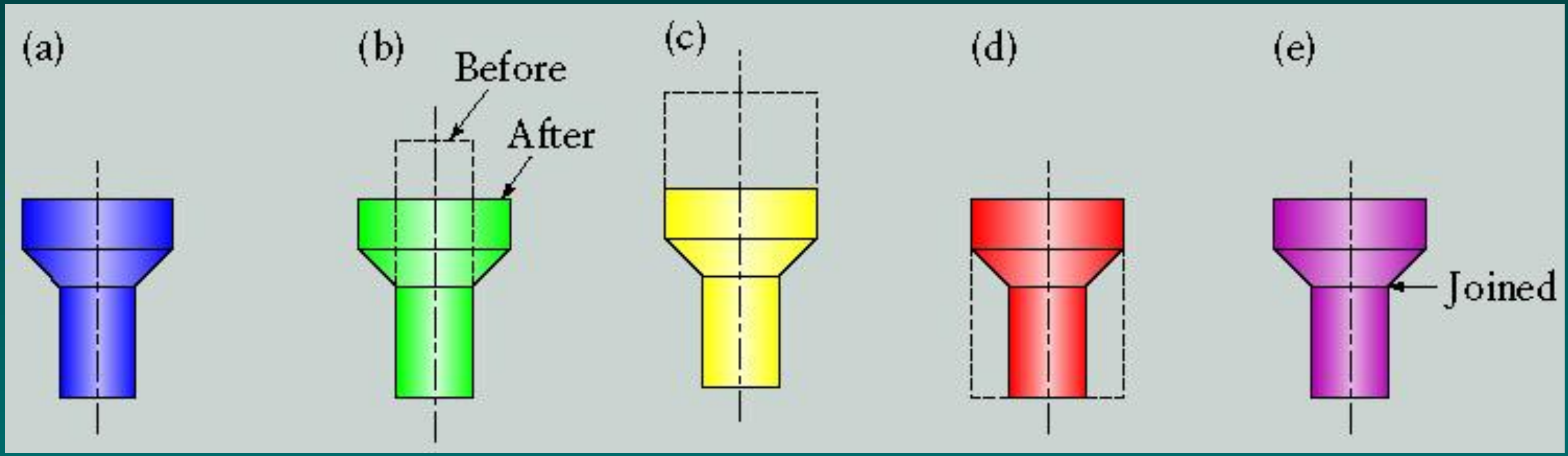
g) Scrap produced.

h) Availability of equipment and expertise to handle the equipment.

i) Production rate required.

j) Overall manufacturing/production cost.

Methods of Making a Simple Part



Various methods of making a simple part. (a) casting or powder metallurgy, (b) forging or upsetting, (c) extrusion, (d) machining, and (e) joining two pieces.