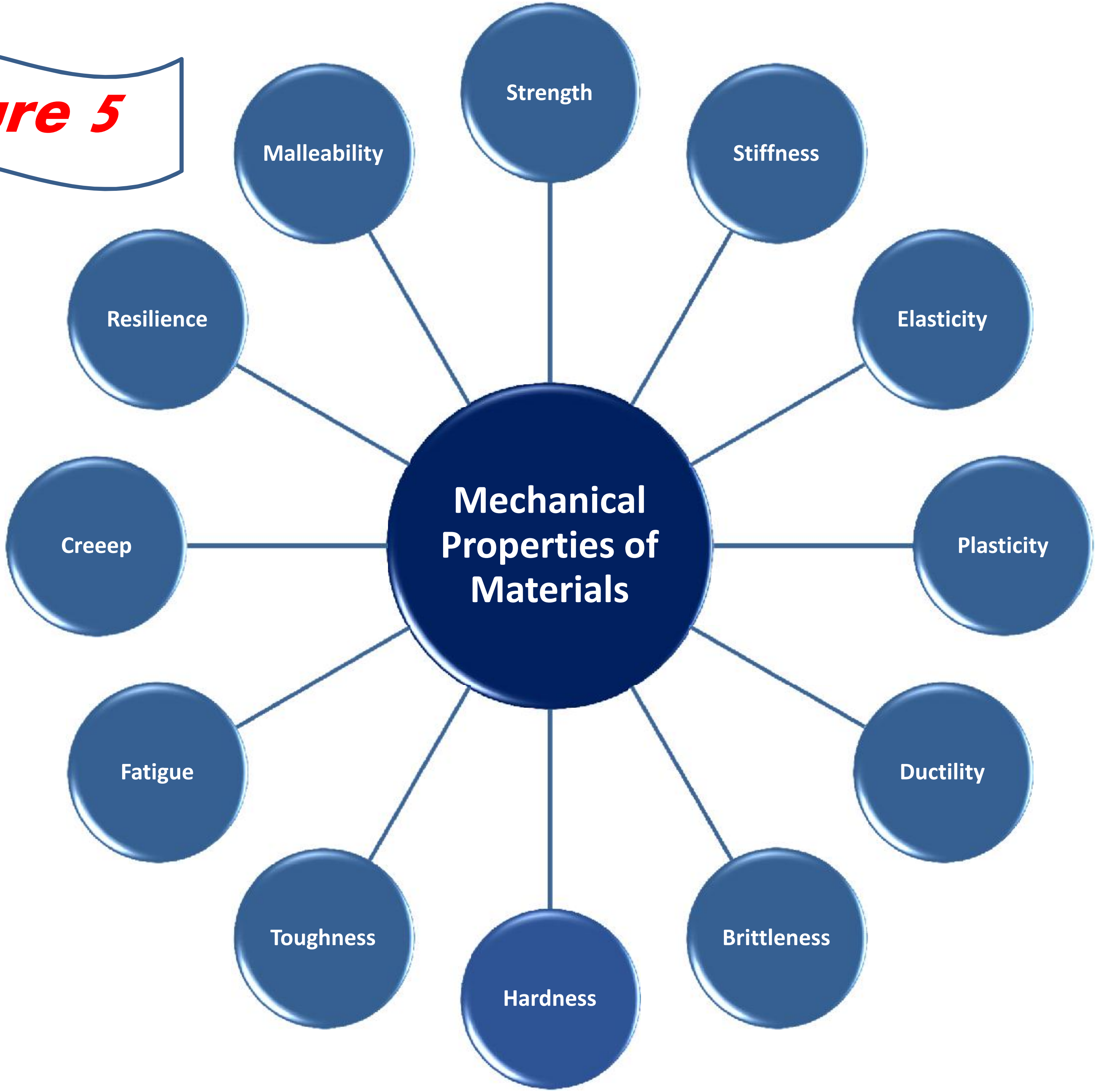
Lecture 5



Mechanical Properties of Materials
Strength
Stiffness
Elasticity
Plasticity
Ductility
Brittleness
Hardness
Toughness
Fatigue
Creeep
Resilience
Malleability

MECHANICAL PROPERTIES OF MATERIALS

- The characteristics of material that describe the behaviour under the action of external loads are referred as its mechanical properties. The common mechanical properties are as follows:

STRENGTH:

- It is defined as the ability of a material to resist loads without failure.
- the strength is divided into three types they are:

TENSILE STRENGTH:

- The tensile strength or tenacity is defined as the ability of material to resist a stretching (tensile) load without fracture.

COMPRESSIVE STRENGTH :

- The ability of a material to resist squeezing (compressive) load without fracture is called compressive strength.

SHEAR STRENGTH :

- The ability of a material to resist transverse loads i.e. loads tending to separate (or cut) the material is called shear strength.

STIFFNESS:

- It is the ability of material to resist deformation or deflection under load. Within the elastic limit, stiffness is measured by the modulus of elasticity.

HARDNESS:

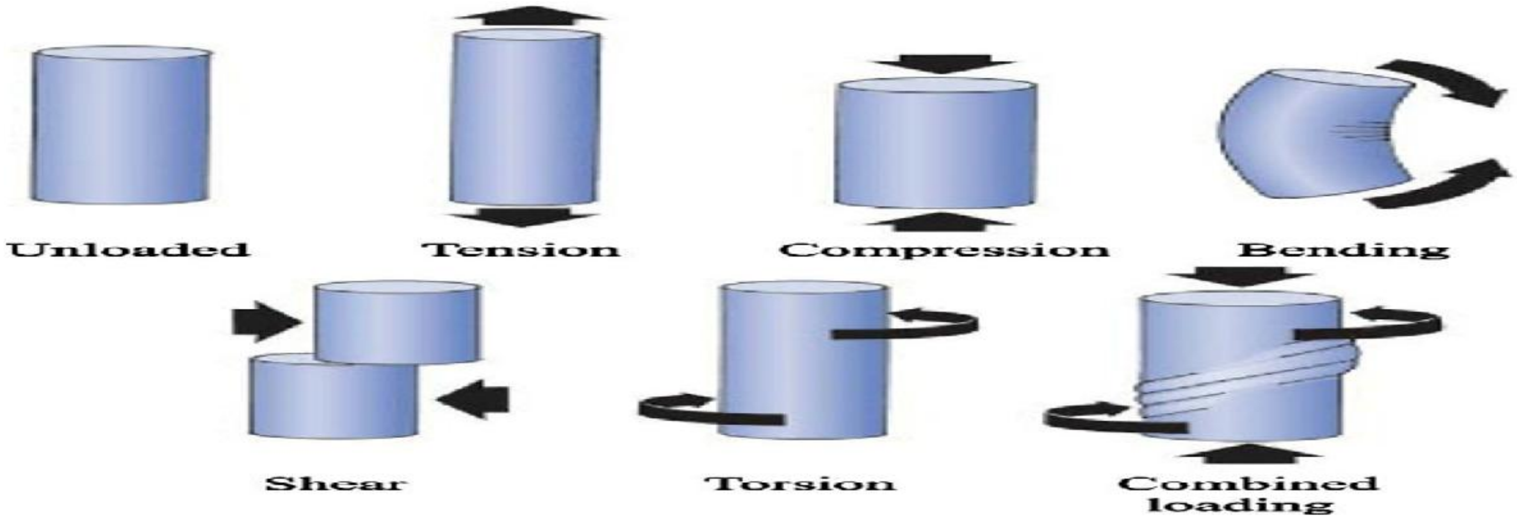
- It is defined as the ability of a material to resist scratching or indentation by another hard body and is associated with a large modulus of elasticity.

DUCTILITY:

It is the ability of a material to undergo plastic deformation without fracture. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area.

TOUGHNESS:

the ability to absorb energy up to fracture =the total area under the strain-stress curve up to fracture



PROPERTIES OF CERAMICS

- Low ductility
  - Very brittle
  - High elastic modulus
- Low toughness
  - Low fracture toughness
  - Indicates the ability of a crack or flaw to produce a catastrophic failure
- Low density
  - Porosity affects properties

Mechanical Properties

Ceramic materials are more brittle than metals. **Why is this so?**

Consider mechanism of deformation

- **Crystalline ceramics: Slip (dislocation motion)**

is very difficult. This is because ions of like charge have to be brought into close proximity of each other → large barrier for dislocation motion. In ceramics with covalent bonding slip is not easy as well (covalent bonds are strong) → ceramics are brittle.

- **Non-crystalline ceramic:**

there is no regular crystalline structure → no dislocations. Materials deform by **viscous flow, i.e.** by breaking and reforming atomic bonds, allowing ions/atoms to slide past each other (like in a liquid).

• Viscosity:

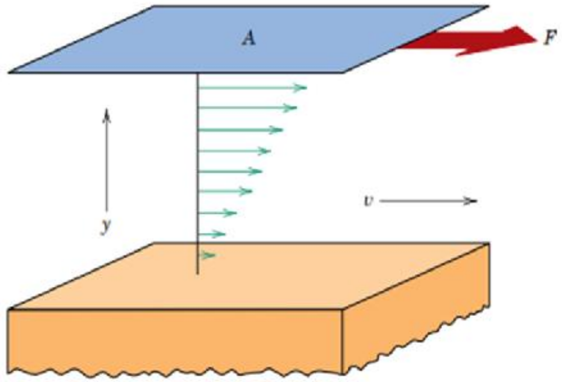
Viscosity is a measure of a non-crystalline (glass or liquid) material's resistance to deformation. High-viscosity fluids resist flow; low-viscosity fluids flow easily.

Units are Pa-s, or Poises (P)

1 P = 0.1 Pa-s

Viscosity of water at room temp is ~ 10^{-3} P

Viscosity of typical glass at room temp >> 10^{16} P



$$\eta = \frac{\tau}{dv/dy} = \frac{F/A}{dv/dy}$$

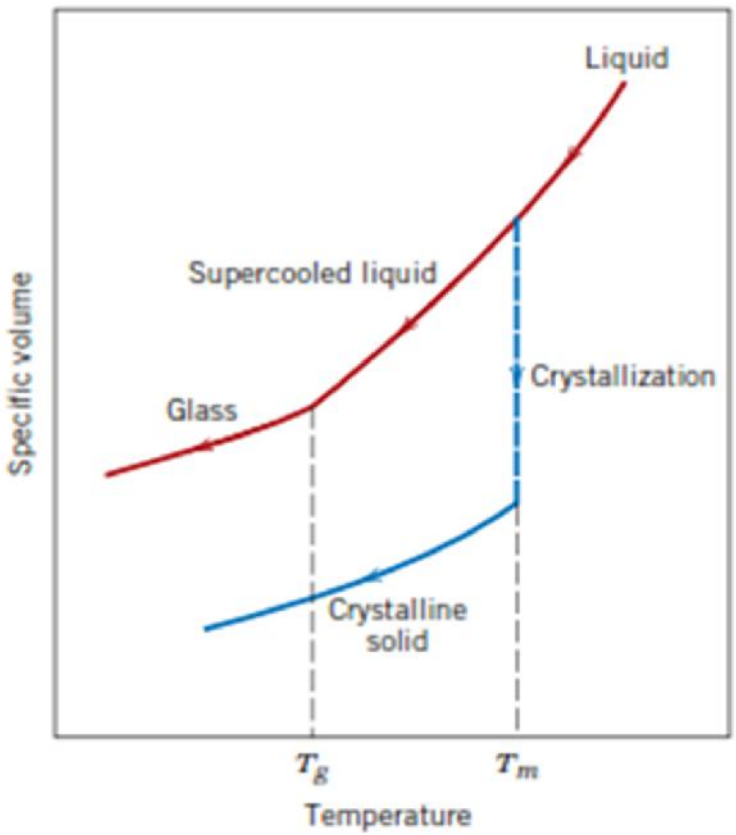
η (Viscosity)

τ (Shear Stress)

F (Force)

A (Area)

dv/dy (Velocity Gradient or Shear Rate)



Problem 1 (Ceramic Application)

During a glass forming process, a force of **20 N** is applied over an area of **2 m²**. If the velocity gradient is **0.5** , **calculate the viscosity of the material.**

Sol:

τ=20/2=10 Pa

η=10/0.5=20 Pa s

Homework:

1- A glassy material has the following properties: at which temperature can the material be formed?

Tg=600^{o}C

at 500^{o}C: η=10^12 Pa·s

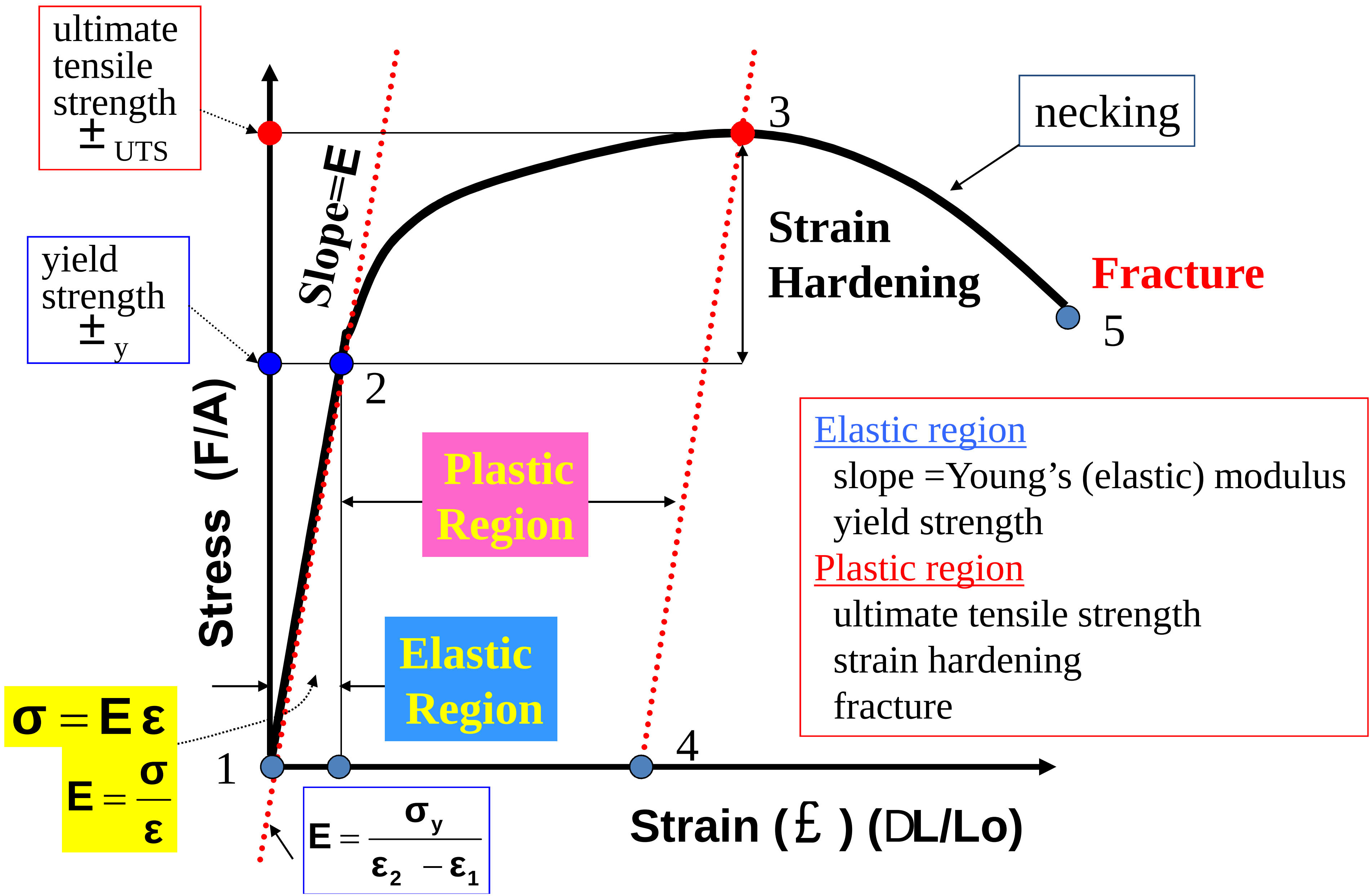
at 700^{o}C: η=10^6 Pa·s

2-Two ceramic materials are given:

- Which material is more rigid?
- Which material is suitable for forming?

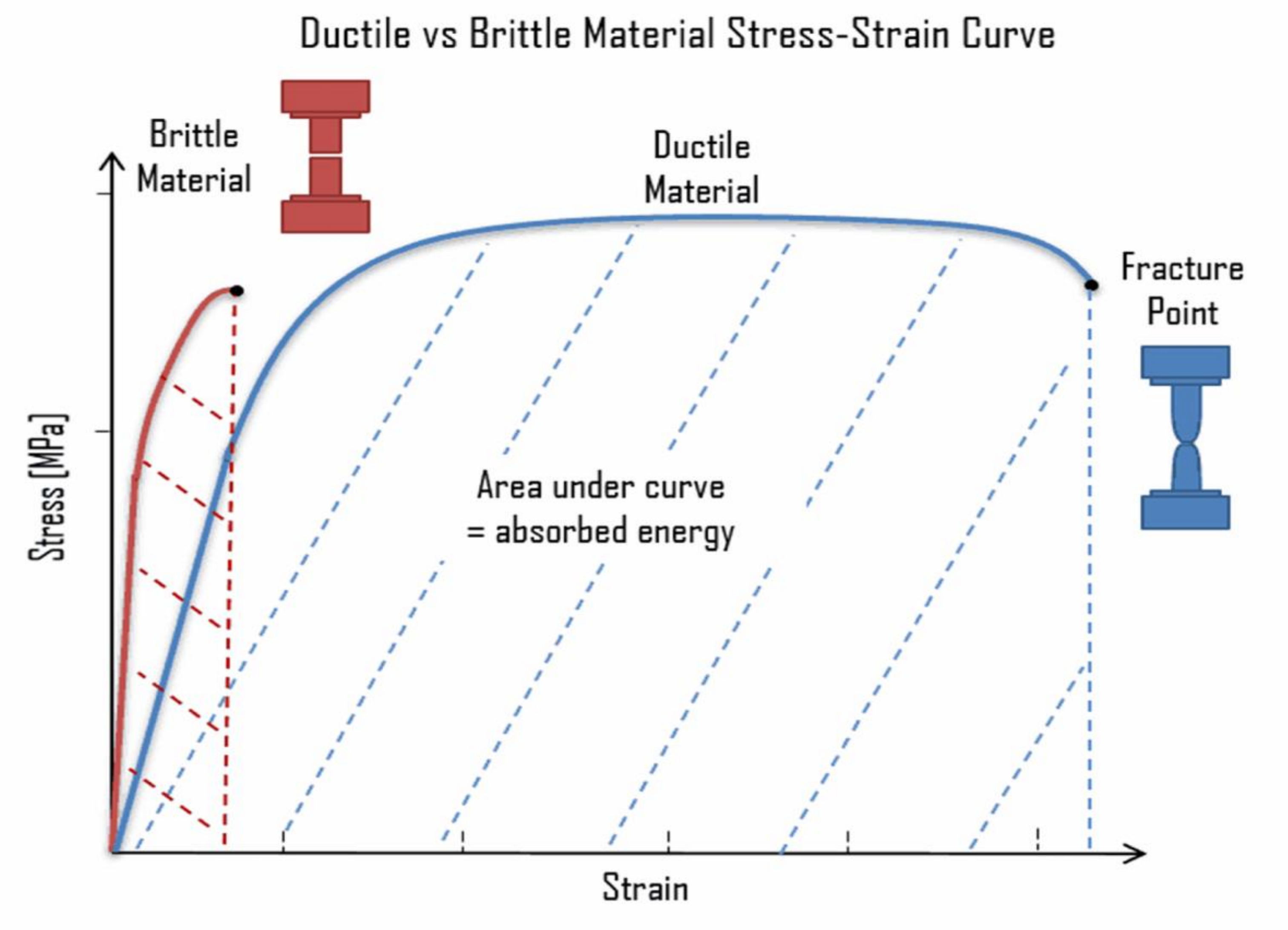
Case	Temperature	Viscosity
A	Below Tg	10^13Pa·s
B	Above Tg	10^7Pa·s

Stress-Strain Diagram



MECHANICAL PROPERTIES OF CERAMICS

STRESS-STRAIN BEHAVIUR of materials



Compressive Strength of Ceramics:

- ✓ The frailties that limit the tensile strength of ceramic material are not nearly so operative when compressive stress are applied

- ✓ Ceramics are substantially stronger in compression than in tension

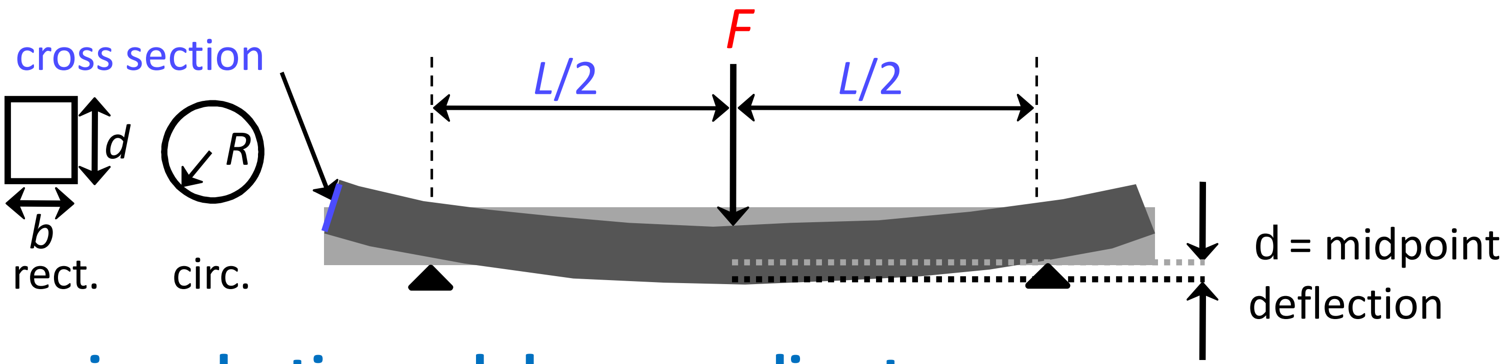
- ✓ For engineering and structural applications, the designers have learned to use ceramic components so that they are loaded in compression rather than tension

Flexural Tests – Measurement of Elastic Modulus

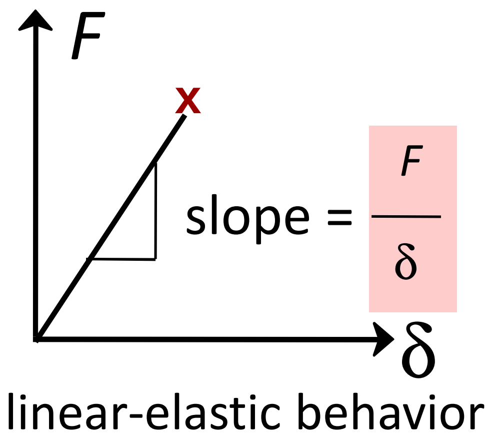
- **Flexural Strength**

The stress at fracture using this flexure test is known as the flexural strength.

- Room *T* behavior is usually elastic, with brittle failure.
- 3-Point Bend Testing often used.
  - tensile tests are difficult for brittle materials.



- **Determine elastic modulus according to:**

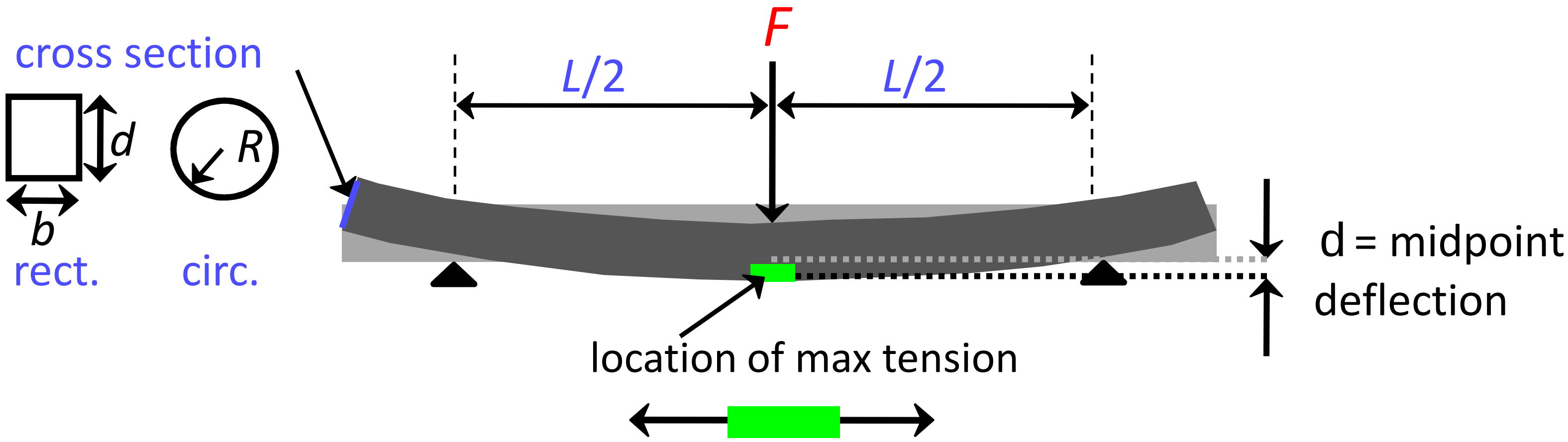


$$E = \frac{F}{\delta}\frac{L^3}{4bd^3} \quad \text{(rect. cross section)}$$

$$E = \frac{F}{\delta}\frac{L^3}{12\pi R^4} \quad \text{(circ. cross section)}$$

Flexural Tests – Measurement of Flexural Strength

- 3-point bend test to measure room-T flexural strength.



- **Flexural strength**:

$$\sigma_{fs} = \frac{3F_f L}{2bd^2} \quad \text{(rect. cross section)}$$

$$\sigma_{fs} = \frac{F_f L}{\pi R^3} \quad \text{(circ. cross section)}$$

- **Typical values:**

Material	σ_{fs} (MPa)	E(GPa)
Si nitride	250-1000	304
Si carbide	100-820	345
Al oxide	275-700	393
glass (soda-lime)	69	69

Homework:

12.42 A three-point bending test is performed on a glass specimen having a rectangular cross section of height $d = 5$ mm (0.2 in.) and width $b = 10$ mm (0.4 in.); the distance between support points is 45 mm (1.75 in.).

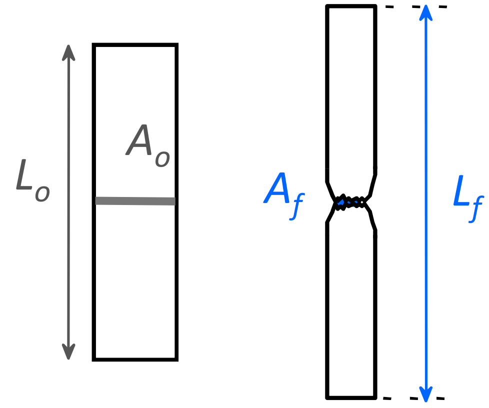
(a) Compute the flexural strength if the load at fracture is 290 N (65 lb_f).

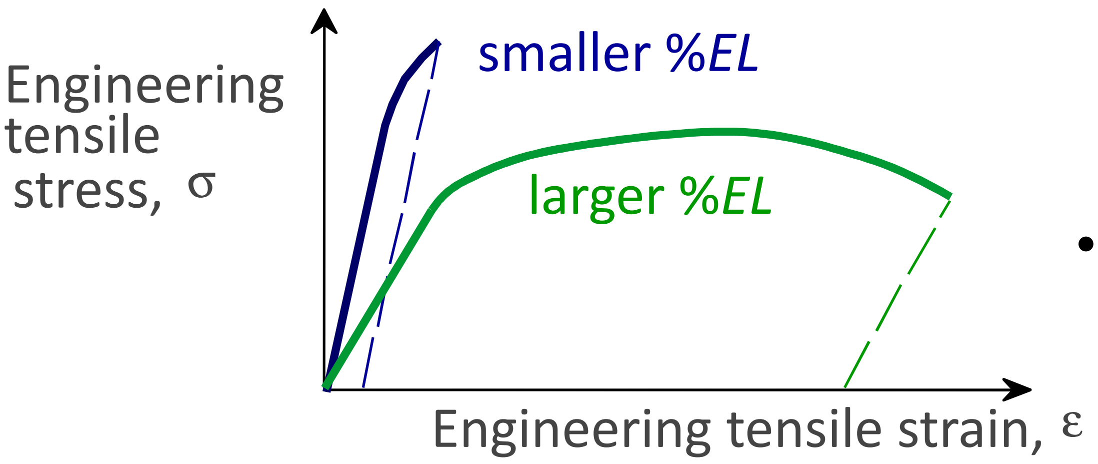
12.43 A circular specimen of MgO is loaded using a three-point bending mode. Compute the minimum possible radius of the specimen without fracture, given that the applied load is 425 N (95.5 lb_f), the flexural strength is 105 MPa (15,000 psi), and the separation between load points is 50 mm (2.0 in.).

12.45 **(a)** A three-point transverse bending test is conducted on a cylindrical specimen of aluminum oxide having a reported flexural strength of 390 MPa (56,600 psi). If the specimen radius is 2.5 mm (0.10 in.) and the support point separation distance is 30 mm (1.2 in.), predict whether you would expect the specimen to fracture when a load of 620 N (140 lb_f) is applied. Justify your prediction.

Ductility

- It is the ability of a material to undergo plastic deformation without fracture. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area.





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

- **Another ductility measure:**

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

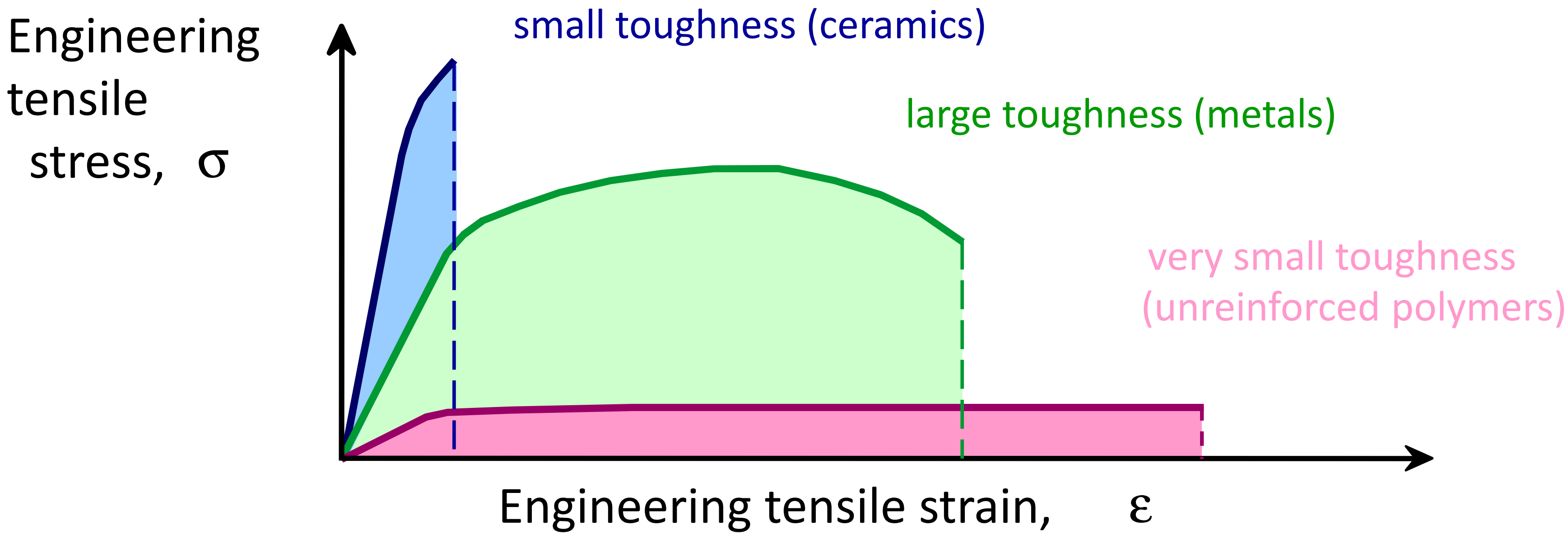
Toughness

- **Toughness = the ability to absorb energy up to fracture =the total area under the strain-stress curve up to fracture**

Units: the energy per unit volume, e.g. J/m

Can be measured by an **impact test**

- Tough materials exhibit **strength and ductility**.



Brittle fracture: elastic energy

Ductile fracture: elastic + plastic energy

HARDNESS OF CERAMICS

Technical ceramic components are therefore characterized by their stiffness and dimensional stability.

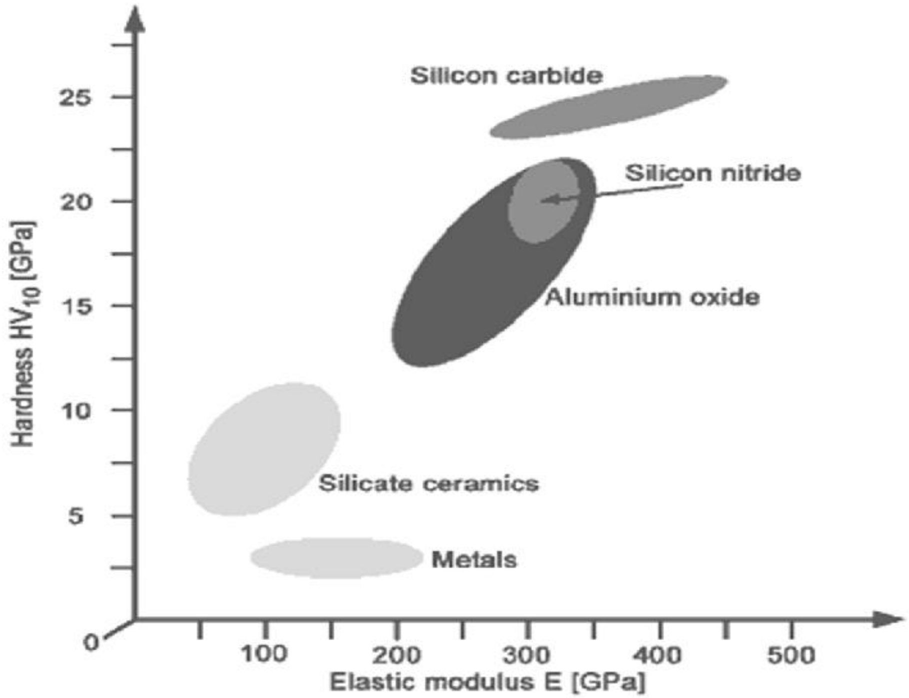
Hardness is affected from porosity in the surface, the grain size of the microstructure and the effects of grain boundary phases.

the hardness measured by **Vickers, Knoop and Rockwell.**

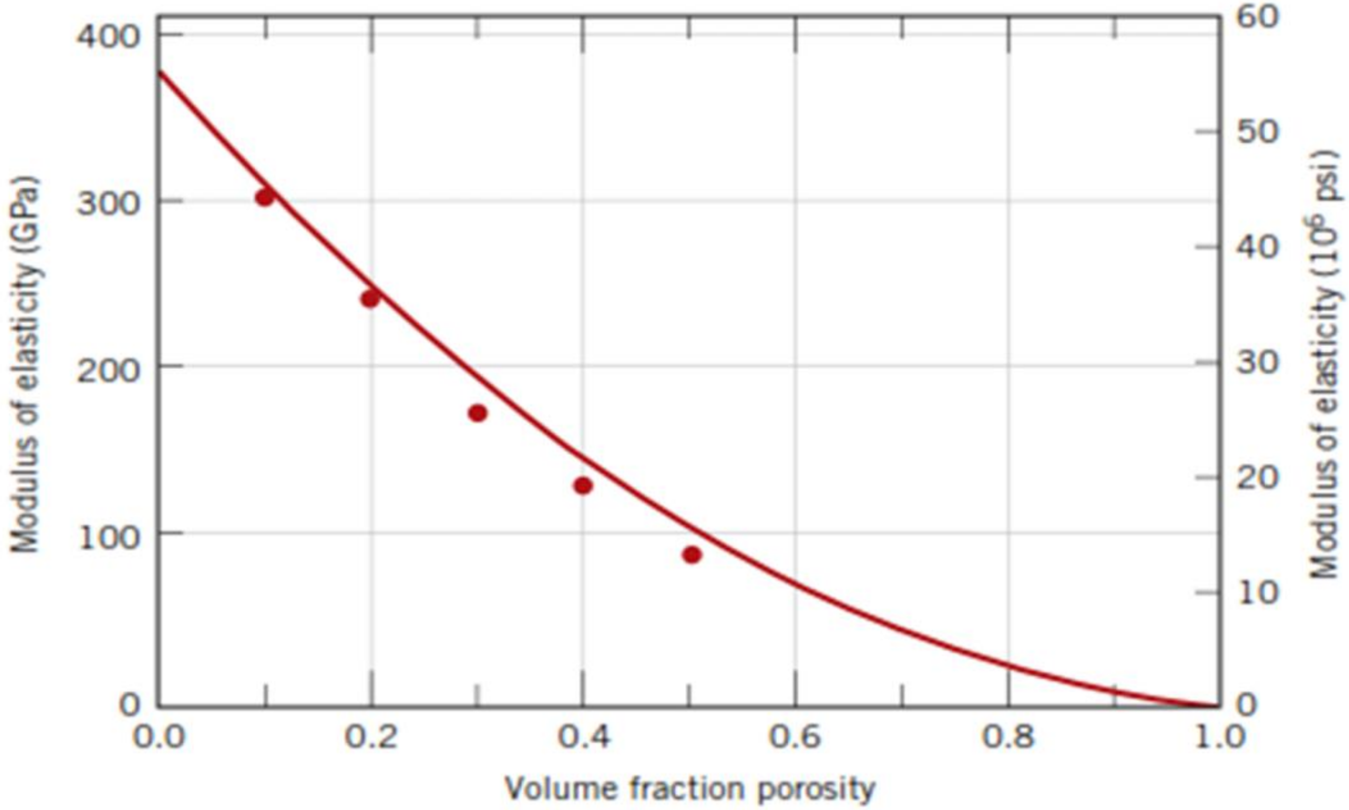
The **high hardness** of technical ceramics results in favourable wear resistance. Ceramics are thus good for tribological applications.

Some typical hardness values for ceramic materials are provided below:

Material Class	Vickers Hardness (HV) GPa
Glasses	5 – 10
Zirconias, Aluminium Nitrides	10 - 14
Silicon Carbides, Boron Carbides	20 - 30



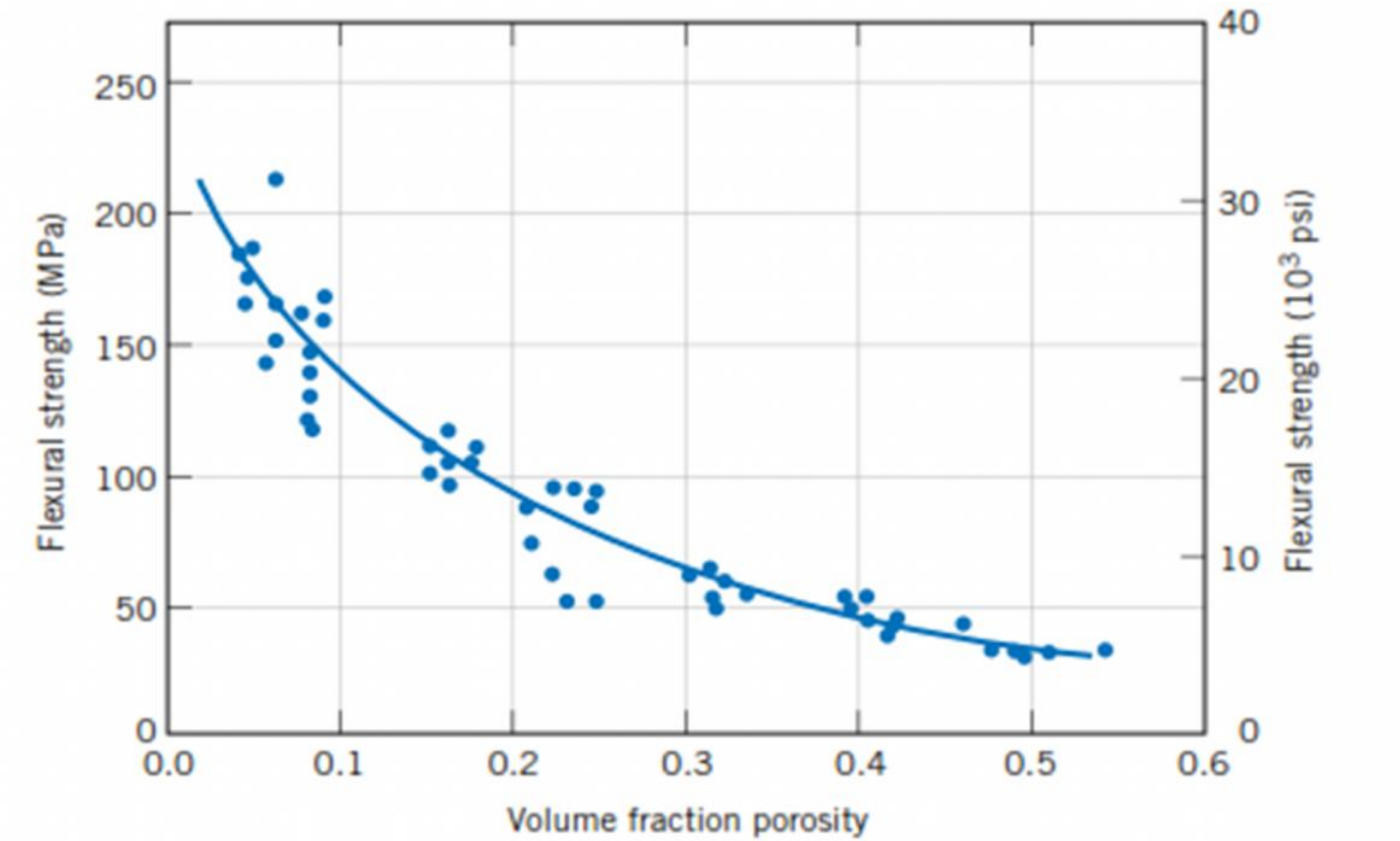
Effect of Porosity on Stiffness



$$E = E_0(1 - 1.9P + 0.9P^2)$$

where E_0 is the modulus of elasticity of the nonporous material.

Effect of Porosity on Strength



$$\sigma_{fs} = \sigma_0 \exp(-nP)$$

where n constants

Homework

12.49 The modulus of elasticity for spinel ($MgAl_2O_4$) having 5 vol% porosity is 240 GPa (35×10^6 psi).

(a) Compute the modulus of elasticity for the nonporous material.

(b) Compute the modulus of elasticity for 15 vol% porosity.

12.50 The modulus of elasticity for titanium carbide (TiC) having 5 vol% porosity is 310 GPa (45×10^6 psi).

(a) Compute the modulus of elasticity for the nonporous material.

(b) At what volume percent porosity will the modulus of elasticity be 240 GPa (35×10^6 psi)?

12.51 Using the data in Table 12.5, do the following:

(a) Determine the flexural strength for nonporous MgO, assuming a value of 3.75 for n in Equation 12.10.

(b) Compute the volume fraction porosity at which the flexural strength for MgO is 74 MPa (10,700 psi).

12.52 The flexural strength and associated volume fraction porosity for two specimens of the same ceramic material are as follows:

$\sigma_{fs}(MPa)$	P
70	0.10
60	0.15

(a) Compute the flexural strength for a completely nonporous specimen of this material.

(b) Compute the flexural strength for a 0.20 volume fraction porosity.

Table 12.5 Tabulation of Flexural Strength (Modulus of Rupture) and Modulus of Elasticity for Ten Common Ceramic Materials

	Flexural Strength		*Modulus of Elasticity*	
Material	*MPa*	*ksi*	*GPa*	*10^6 psi*
Silicon nitride (Si_3N_4)	250–1000	35–145	304	44
Zirconia[a] (ZrO_2)	800–1500	115–215	205	30
Silicon carbide (SiC)	100–820	15–120	345	50
Aluminum oxide (Al_2O_3)	275–700	40–100	393	57
Glass-ceramic (Pyroceram)	247	36	120	17
Mullite ($3Al_2O_3$–$2SiO_2$)	185	27	145	21
Spinel ($MgAl_2O_4$)	110–245	16–35.5	260	38
Magnesium oxide (MgO)	105[b]	15[b]	225	33
Fused silica (SiO_2)	110	16	73	11
Soda-lime glass	69	10	69	10

[a] Partially stabilized with 3 mol% Y_2O_3.

[b] Sintered and containing approximately 5% porosity.

Methods to Strengthen Ceramic Materials

- Make starting materials more uniform
- Decrease grain size in polycrystalline ceramic products
- Minimize porosity
- Introduce compressive surface stresses
- Use fiber reinforcement
- Heat treat

Physical Properties of Ceramics

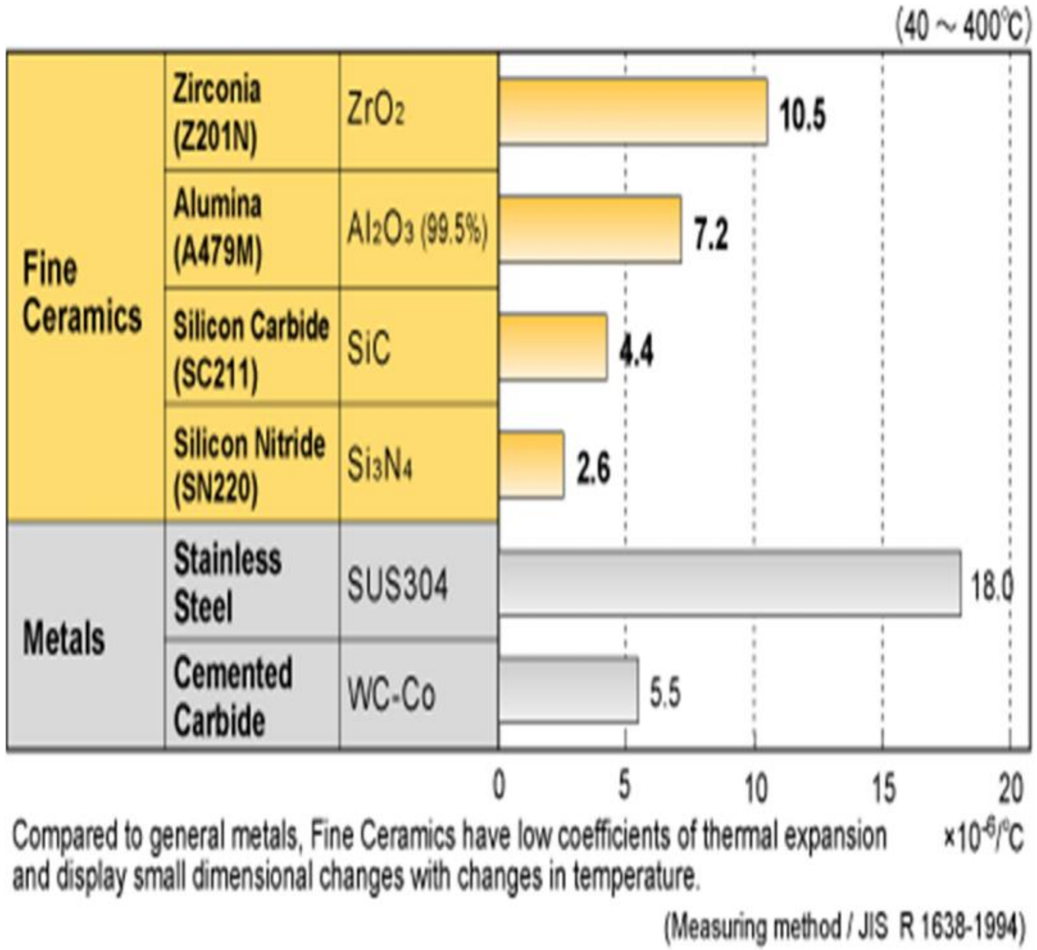
- **Density –** most ceramics are lighter than metals but heavier than polymers
- **Melting temperatures -** higher than for most metals
- **Electrical and thermal conductivities -** lower than for metals
- **Thermal expansion -** somewhat less than for metals, but effects are more damaging because of brittleness

Thermal properties

1)Thermal expansion

- The coefficients of thermal expansion depend on the bond strength between the atoms that make up the materials.
- **Strong bonding** (diamond, silicon carbide, silicon nitrite) → low thermal expansion coefficient
- **Weak bonding** (stainless steel) → higher thermal expansion coefficient in comparison with fine ceramics

Comparison of thermal expansion coefficient between metals and fine



Thermal properties

2)Thermal conductivity

- generally less than that of metals such as steel or copper
- ceramic materials, in contrast, are used for thermal insulation due to their low thermal conductivity

3)Thermal shock resistance

- **Thermal shock resistance:** the name given to cracking as a result of rapid temperature change
- A large number of ceramic materials are sensitive to thermal shock
- Some ceramic materials → very high resistance to thermal shock is despite of low ductility (**e.g. fused silica, Aluminium titanate)**

Electrical properties of ceramic

- Most of ceramic materials are **dielectric**. (materials, having very low electric conductivity).
- **Dielectric ceramics** are used for manufacturing capacitors, insulators and resistors.