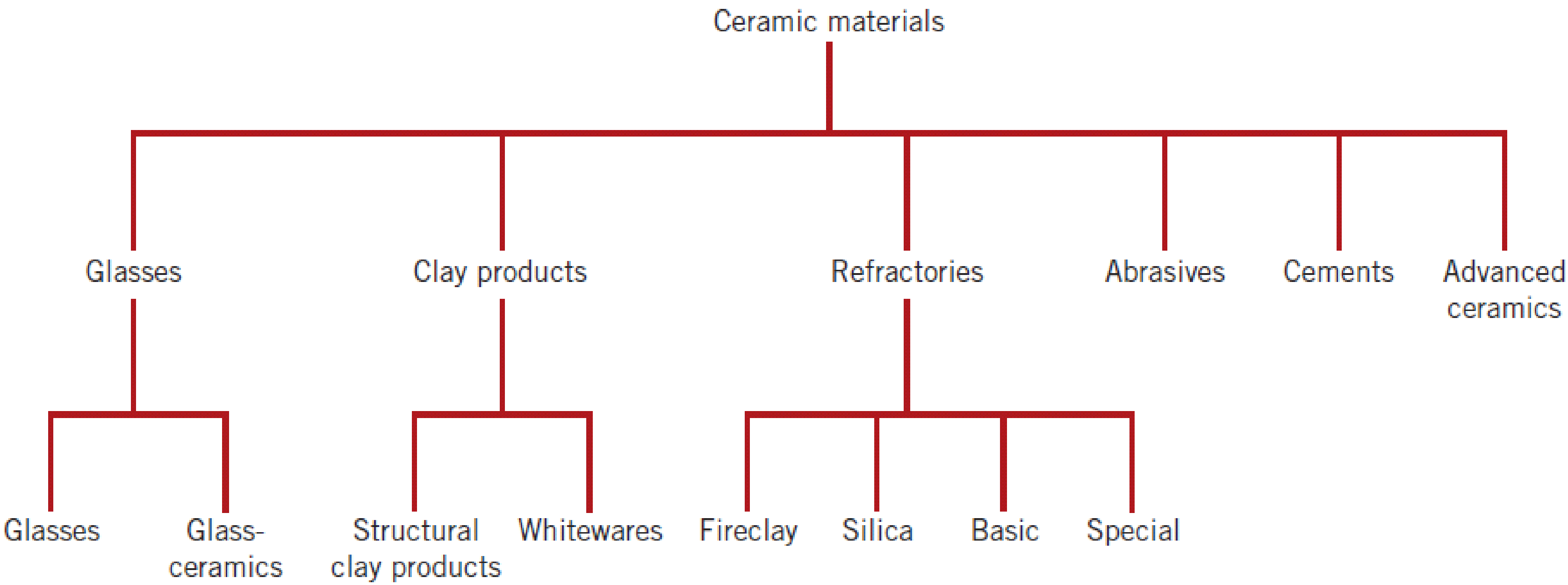
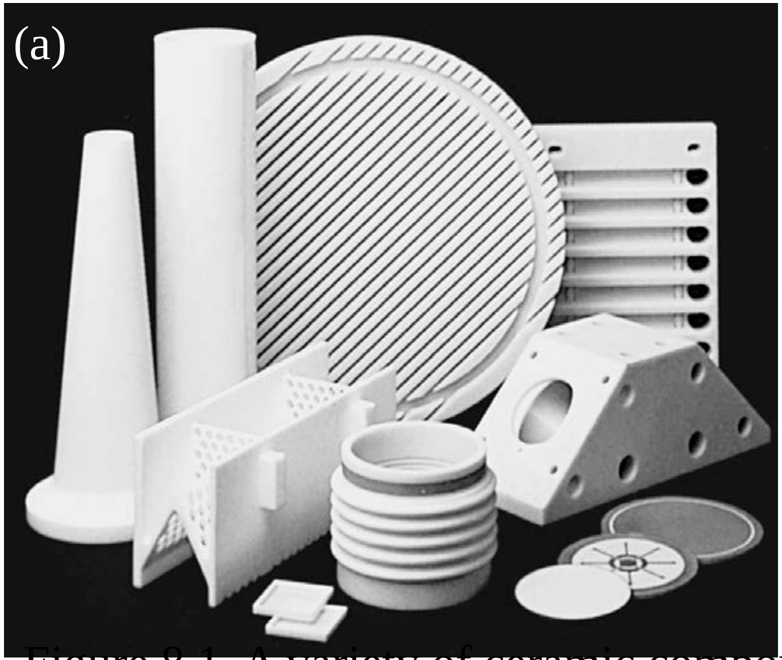
Lect 9 ceramics

Ceramics, Graphite, and Diamond: Structure, General Properties, and Applications

Classification of ceramic materials on the basis of application



Examples of Ceramics



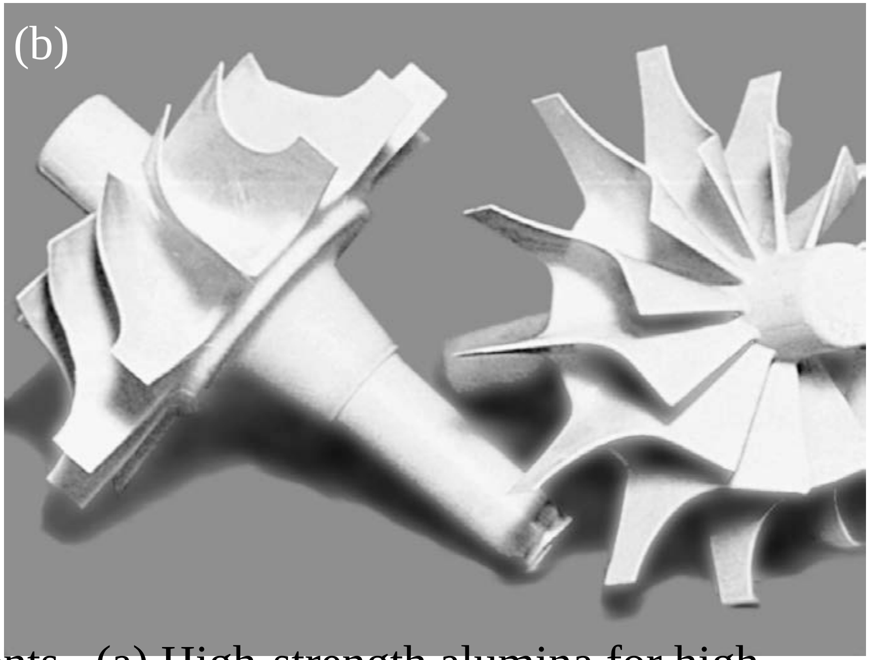


Figure 8.1 A variety of ceramic components. (a) High-strength alumina for high-temperature applications. (b) Gas-turbine rotors made of silicon nitride. *Source*: Wesgo Div., GTE.

Types and General Characteristics of Ceramics

TABLE 8.1

Type	General Characteristics
Oxide ceramics	
Alumina	High hardness, moderate strength; most widely used ceramic; cutting tools, abrasives, electrical and thermal insulation.
Zirconia	High strength and toughness; thermal expansion close to cast iron; suitable for heat engine components.
Carbides	
Tungsten carbide	Hardness, strength, and wear resistance depend on cobalt binder content; commonly used for dies and cutting tools.
Titanium carbide	Not as tough as tungsten carbide; has nickel and molybdenum as the binder; used as cutting tools.
Silicon carbide	High-temperature strength and wear resistance; used for heat engines and as abrasives.
Nitrides	
Cubic boron nitride	Second-hardest substance known, after diamond; used as abrasives and cutting tools.
Titanium nitride	Gold in color; used as coatings because of low frictional characteristics.
Silicon nitride	High resistance to creep and thermal shock; used in heat engines.
Sialon	Consists of silicon nitrides and other oxides and carbides; used as cutting tools.
Cermets	Consist of oxides, carbides, and nitrides; used in high-temperature applications.
Silica	High temperature resistance; quartz exhibits piezoelectric effect; silicates containing various oxides are used in high-temperature nonstructural applications.
Glasses	Contain at least 50 percent silica; amorphous structures; several types available with a range of mechanical and physical properties.
Glass ceramics	Have a high crystalline component to their structure; good thermal-shock resistance and strong.
Graphite	Crystalline form of carbon; high electrical and thermal conductivity; good thermal shock resistance.
Diamond	Hardest substance known; available as single crystal or polycrystalline form; used as cutting tools and abrasives and as dies for fine wire drawing.

Properties of Various Ceramics at Room Temperature

TABLE 8.2

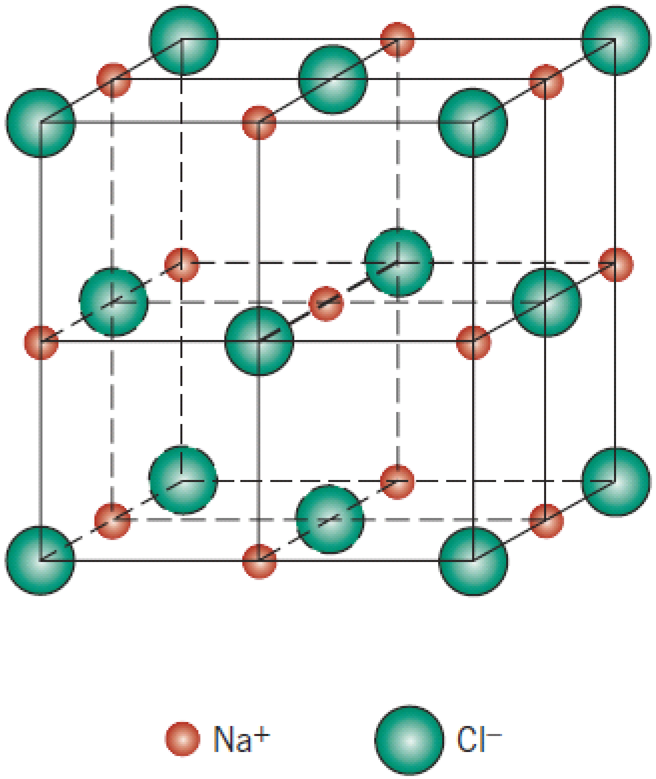
Material	Symbol	Transverse rupture strength (MPa)	Compressive strength (MPa)	Elastic modulus (GPa)	Hardness (HK)	Poisson's ratio (ν)	Density (kg/m^3)
Aluminum oxide	Al_2O_3	140–240	1000–2900	310–410	2000–3000	0.26	4000–4500
Cubic boron nitride	CBN	725	7000	850	4000–5000	—	3480
Diamond	—	1400	7000	830–1000	7000–8000	—	3500
Silica, fused	SiO_2	—	1300	70	550	0.25	—
Silicon carbide	SiC	100–750	700–3500	240–480	2100–3000	0.14	3100
Silicon nitride	Si_3N_4	480–600	—	300–310	2000–2500	0.24	3300
Titanium carbide	TiC	1400–1900	3100–3850	310–410	1800–3200	—	5500–5800
Tungsten carbide	WC	1030–2600	4100–5900	520–700	1800–2400	—	10,000–15,000
Partially stabilized zirconia	PSZ	620	—	200	1100	0.30	5800

Note: These properties vary widely depending on the condition of the material.

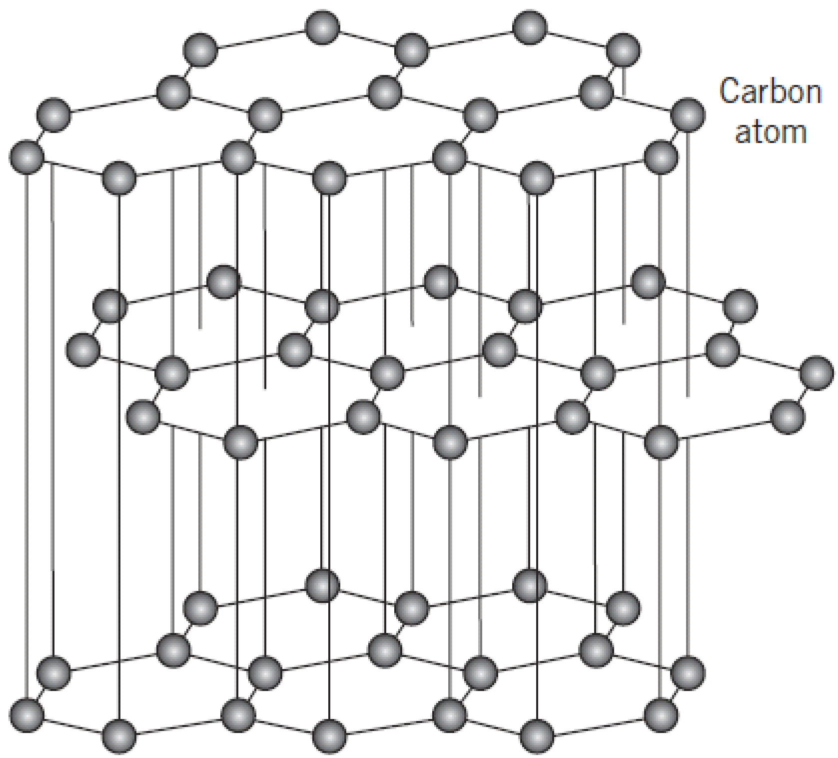
Ceramic Structures

- Because ceramics are composed of at least two elements, and often more.
- Their crystal structures are generally more complex than those for metals.
- The atomic bonding in these materials ranges from purely ionic to totally covalent.
- Many ceramics exhibit a combination of these two bonding types.

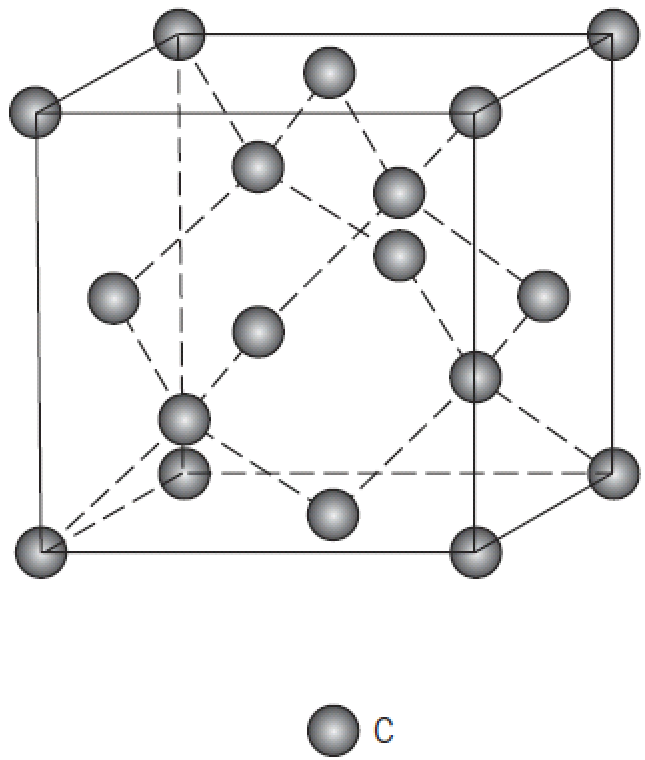
A unit cell for the rock salt, or sodium chloride (NaCl), crystal structure.



The structure of graphite



A unit cell for the diamond cubic crystal structure



Graphite Components

Figure 8.2 Various engineering components made of graphite. *Source*: Poco Graphite, Inc., a Unocal Co.

GLASSES

- The glasses are a familiar group of ceramics;
- containers, lenses, and fiberglass represent typical applications.
- They are noncrystalline silicates containing other oxides, notably CaO, Na_2O, K_2O, and Al_2O_3, which influence the glass properties.
- A typical soda–lime glass consists of approximately 70 wt% SiO_2, the balance being mainly Na_2O (soda) and CaO (lime).
- Possibly the two prime assets of these materials are their optical transparency and the relative ease with which they may be fabricated.

Glass

- Glass products
  - window glass
  - containers
  - light bulb glass
  - laboratory glass
  - glass fibers
  - optical glass
- Glass ceramics - polycrystalline structure

Properties of Various Glasses

TABLE 8.3

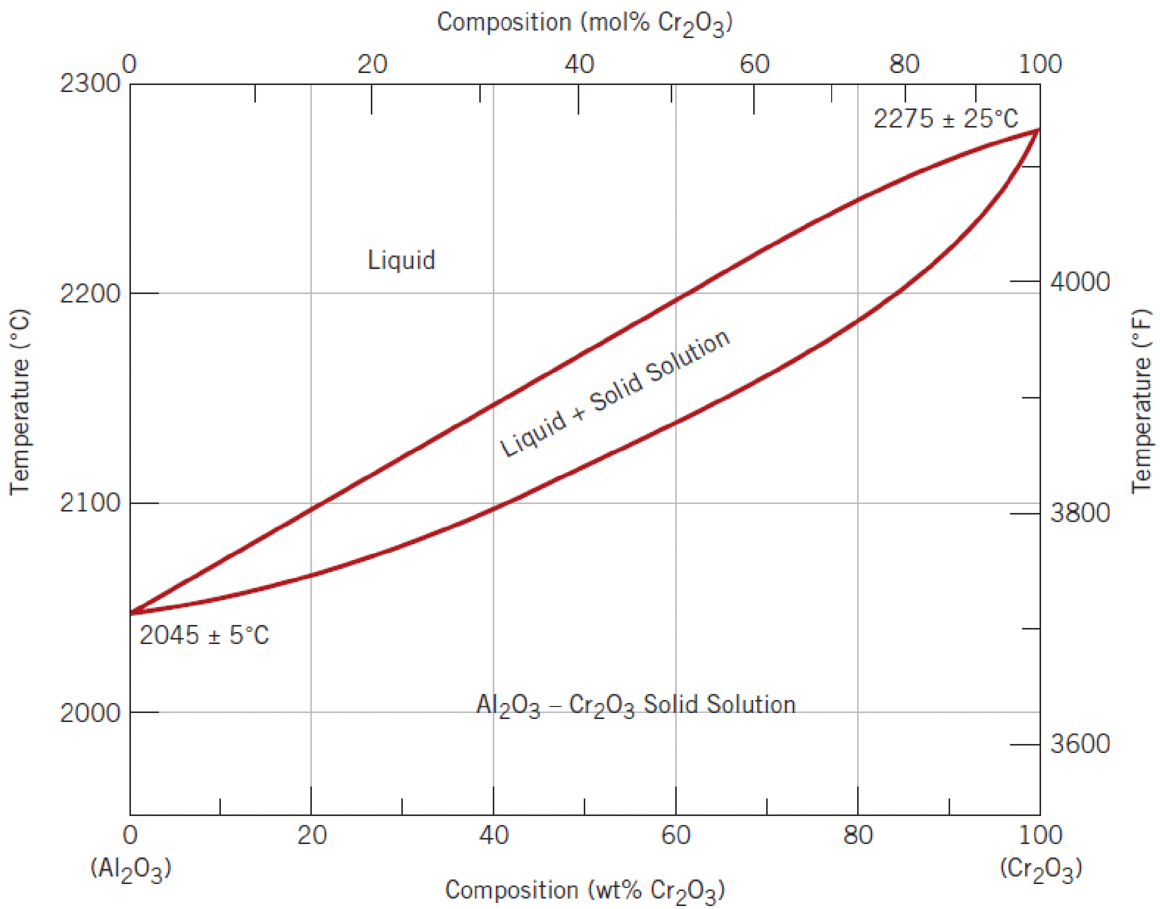
	Soda-lime glass	Lead glass	Borosilicate glass	96 Percent silica	Fused silica
Density	High	Highest	Medium	Low	Lowest
Strength	Low	Low	Moderate	High	Highest
Resistance to thermal shock	Low	Low	Good	Better	Best
Electrical resistivity	Moderate	Best	Good	Good	Good
Hot workability	Good	Best	Fair	Poor	Poorest
Heat treatability	Good	Good	Poor	None	None
Chemical resistance	Poor	Fair	Good	Better	Best
Impact-abrasion resistance	Fair	Poor	Good	Good	Best
Ultraviolet-light transmission	Poor	Poor	Fair	Good	Good
Relative cost	Lowest	Low	Medium	High	Highest

Several Common Glass Materials

Table 13.1 Compositions and Characteristics of Some of the Common Commercial Glasses

	Composition (wt%)						
Glass Type	SiO_2	Na_2O	CaO	Al_2O_3	B_2O_3	***Other***	***Characteristics and Applications***
Fused silica	>99.5						High melting temperature, very low coefficient of expansion (thermally shock resistant)
96% Silica (Vycor™)	96				4		Thermally shock and chemically resistant—laboratory ware
Borosilicate (Pyrex™)	81	3.5		2.5	13		Thermally shock and chemically resistant—ovenware
Container (soda–lime)	74	16	5	1		4MgO	Low melting temperature, easily worked, also durable
Fiberglass	55		16	15	10	4MgO	Easily drawn into fibers—glass–resin composites
Optical flint	54	1				37PbO, $8K_2O$	High density and high index of refraction—optical lenses
Glass–ceramic (Pyroceram™)	43.5	14		30	5.5	$6.5TiO_2$, $0.5As_2O_3$	Easily fabricated; strong; resists thermal shock—ovenware

The aluminum oxide– chromium oxide phase diagram. (Adapted from E. N. Bunting, “Phase Equilibria in the System *Bur. Standards J. Research*, ***6, 1931,*** p. 948.)

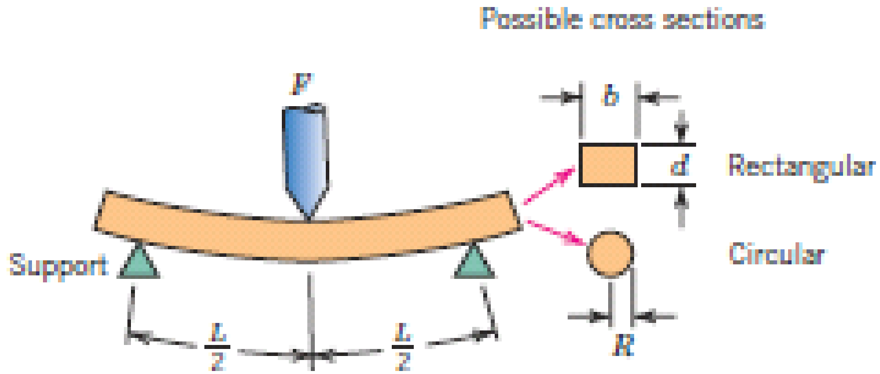


Mechanical Properties

BRITTLE FRACTURE OF CERAMICS

- At room temperature, both crystalline and noncrystalline ceramics almost always fracture before any plastic deformation can occur in response to an applied tensile load.

STRESS–STRAIN BEHAVIOR
Flexural Strength



$$\sigma = \text{stress} = \frac{Mc}{I}$$

where M = maximum bending moment

c = distance from center of specimen to outer fibers

I = moment of inertia of cross section

F = applied load

	M	c	I	σ
Rectangular	$\frac{FL}{4}$	$\frac{d}{2}$	$\frac{bd^3}{12}$	$\frac{3FL}{2bd^2}$
Circular	$\frac{FL}{4}$	R	$\frac{\pi R^4}{4}$	$\frac{FL}{\pi R^3}$

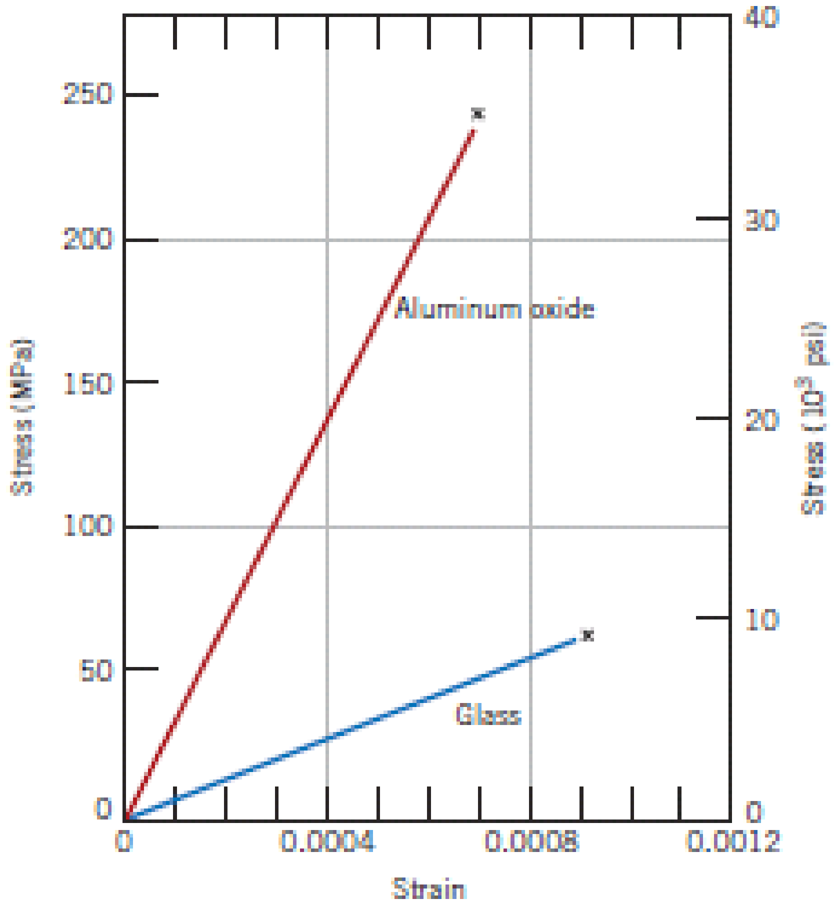
Table 12.5 Tabulation of Flexural Strength (Modulus of Rupture) and Modulus of Elasticity for Ten Common Ceramic Materials

Material	*Flexural Strength*		*Modulus of Elasticity*	
	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

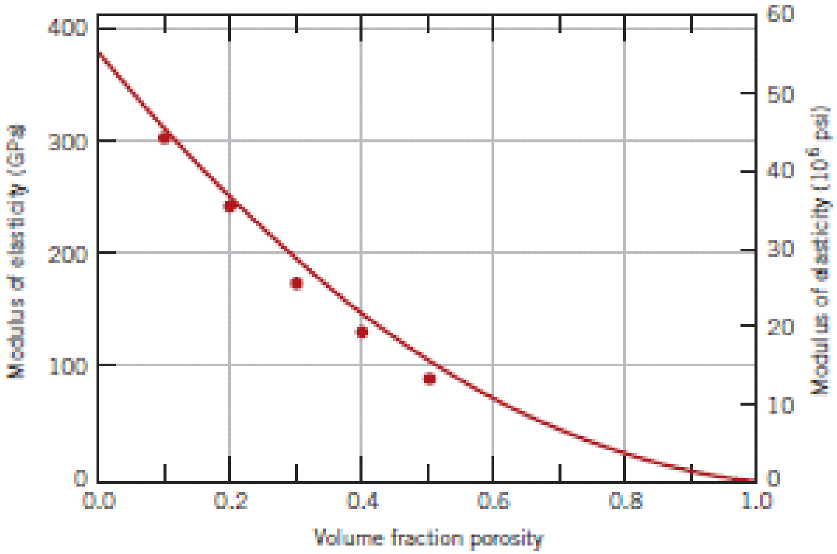
[a] Partially stabilized with 3 mol% Y_2O_3.

[b] Sintered and containing approximately 5% porosity.

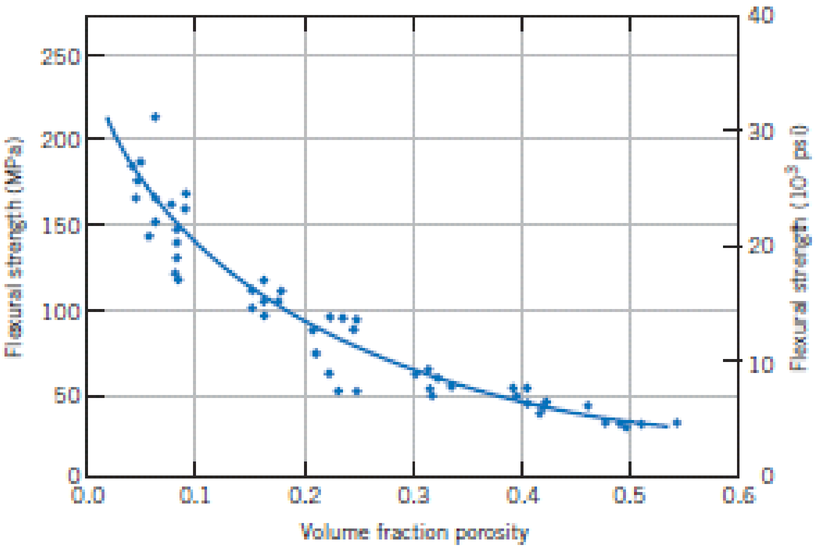
Elastic Behavior



The influence of porosity



The influence of porosity on the modulus of elasticity for aluminum oxide at room temperature.



The influence of porosity on the flexural strength for aluminum oxide at room temperature.

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

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