Ceramics

Introduction:

Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides.

For example, some of the common ceramic materials include aluminum oxide (or alumina,Al_2O_3), silicon dioxide (or *silica*, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, in addition, what some refer to as the

traditional ceramics those composed of clay minerals (i.e., porcelain), as well as cement, and glass.
the most important materials in this class were termed the "traditional ceramics," those for which the primary raw material is clay; products considered to be traditional ceramics are china, porcelain, bricks, tiles, and, in addition, glasses and high-temperature ceramics.

Consequently, a new generation of these materials has evolved, term "ceramic" has taken on a much broader meaning. To one degree or another, these new materials have a rather dramatic effect on our lives; electronic, computer, communication, aerospace, and a host of other industries rely on their use.

mechanical behavior of ceramic materials are relatively stiff and strong stiffnesses and strengths are comparable to those of the metals.
In addition, ceramics are typically very hard. On the other hand, they are extremely brittle (lack ductility), and are highly susceptible to fracture .

These materials are typically insulate to the passage of heat and electricity , and are more resistant to high temperatures and harsh environments than metals and polymers. Several common ceramic objects are shown in the photograph of Figure 1.

Figure 1. Common objects that are made of ceramic materials: scissors, a china tea cup, a building brick, a floor tile, and a glass vase.

Definition of Ceramics: Inorganic Materials made from Metals and Non Metals united by ionic and/or covalent bonds

Can be: crystalline, amorphous or mixture of both

General Properties of Ceramics:-

1- **Brittleness**

Mixed covalent and ionic bonding, brittle at RT but not necessary at HT

2- **High Compressive strength**

3- **High Young's Modulus and high melting points**

4- **Limited electrical and thermal conductivity**

Absence of electronic cloud (directional bond)

5- **Low thermal shock resistance**
Coefficients of thermal expansion and thermal conductivity are low
6- **Refractory**
Stability at high temperature (NO CREEP)
7- **Resistance to oxidation/corrosion**
Chemical stability

CLASSIFICATION

Glasses

Based on SiO_2 + additives for $\downarrow T_f$

Traditional Ceramics (clay products)

- Porous ceramics (bricks, pottery, china)
- Compact ceramics (porcelain, earthware)
- Refractory ceramics

Clay: $Al_2O_3 \cdot SiO_2 \cdot H_2O$
Silica: SiO_2
Feldspar: $K_2O \cdot Al_2O_3$ $6SiO_2$

Egineering Ceramics or Advanced Ceramics :

- Refractory ceramics (SiC, Al_2O_3, ZrO_2, BeO, MgO).
- Piezoelectrics and Ferroelectrics: $BaTiO_3$, $SrTiO_3$
- Electro-optics: $LiNbO_3$
- Abrasive ceramics: nitrides and carbides Si_3N_4 , SiC
- Molecular membranes
- Superconductive ceramics ($YBa_2Cu_3O_7$)
- Biomaterials : Hydroxyapatite

Ceramic Phase Diagrams:

Phase diagrams have been experimentally determined for a large number of ceramic systems. For binary or two-component phase diagrams, it is frequently the case that the two components are compounds that share a common element, often oxygen. These diagrams may have configurations similar to metal–metal systems, and they are interpreted in the same way.

As an example, one of the relatively simple ceramic phase diagrams is that found for the aluminum oxide–chromium oxide system,

Figure 2.This diagram has the same form as the copper–nickel phase diagram,

consisting of single liquid and single solid phase regions separated by a two-phase solid–liquid region having the shape of a blade. The solid solution is a substitutional one in which substitutes for and vice versa. It exists for all compositions below the melting point of inasmuch as both aluminum and chromium ions have the same charge as well as similar radii (0.053 and 0.062 nm, respectively). Furthermore, both Al2O3 and Cr2O3 have the same crystal structure.

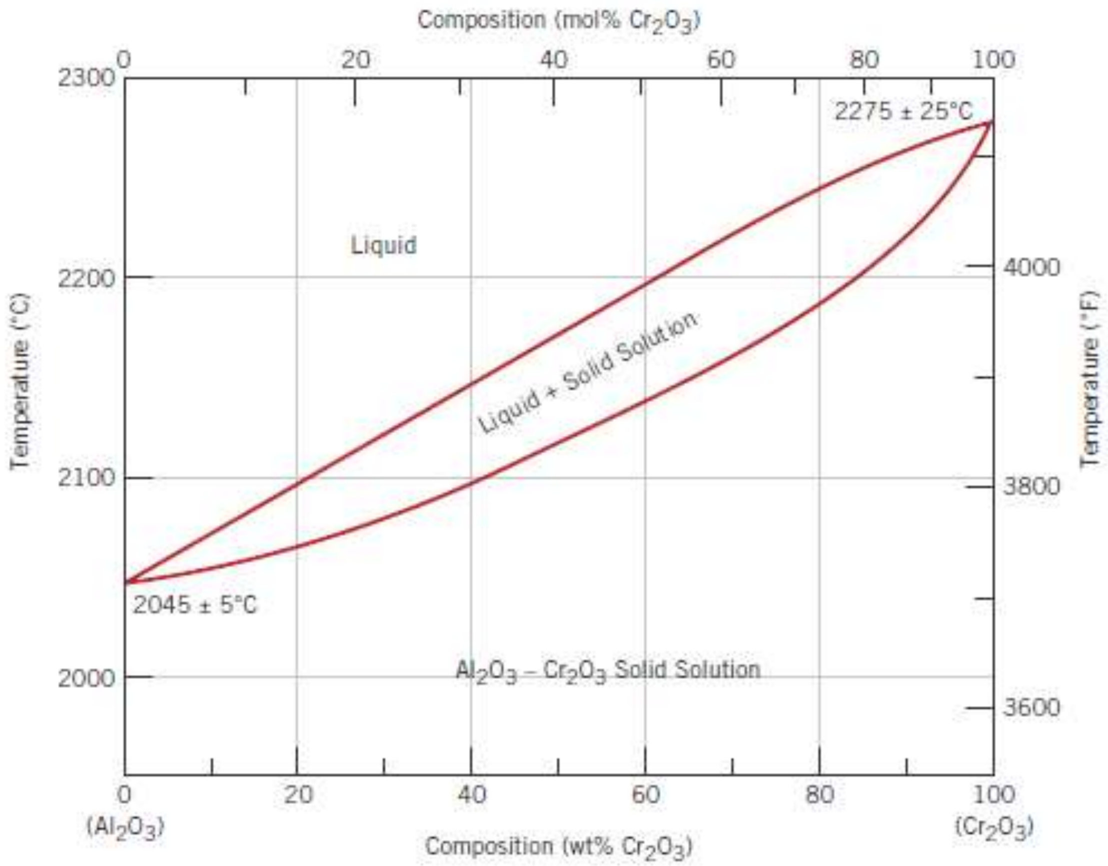


Figure 2. The aluminum oxide – chromium oxide phase diagram.

Mechanical Properties :
Ceramic materials are somewhat limited in applicability by their mechanical properties, which in many respects are inferior to those of metals.

1- **Brittle Fracture of Ceramics:**
The brittle fracture process consists of the formation and propagation of cracks through the cross section of material in a direction perpendicular to the applied load. Crack growth in crystalline ceramics may be either trans granular (i.e., through the grains) or intergranular (i.e., along grain boundaries); for transgranular fracture, cracks propagate along specific crystallographic (or cleavage) planes, planes of high atomic density.

2- **Stress–Strain Behavior:**
At room temperature, virtually all ceramics are brittle. Micro cracks, the presence of which is very difficult to control, result in amplification of applied tensile stresses and account for relatively low fracture strengths . This amplification does not occur with compressive loads, and, consequently, ceramics are stronger in compression.

The stress at fracture is known *modulus of rupture, fracture strength*, or the *bend strength,* an important mechanical parameter for brittle ceramics.

3- **Hardness**
One beneficial mechanical property of ceramics is their hardness, which is often utilized when an abrasive or grinding action is required; in fact, the hardest known materials are ceramics.

4- **Creep**
Often ceramic materials experience creep deformation as a result of exposure to stresses (usually compressive) at elevated temperatures. In general, the time deformation creep behavior of ceramics is similar to that of metals; however, creep occurs at higher temperatures in ceramics. High temperature compressive creep tests are conducted on ceramic materials to ascertain creep deformation as a function of temperature and stress level.

Types and Applications of Ceramics:

Most ceramic materials fall into an application-classification scheme that includes the following groups: glasses, structural clay products, white wares, refractories, abrasives, cements, and the newly developed advanced ceramics as shown in Figure 3.

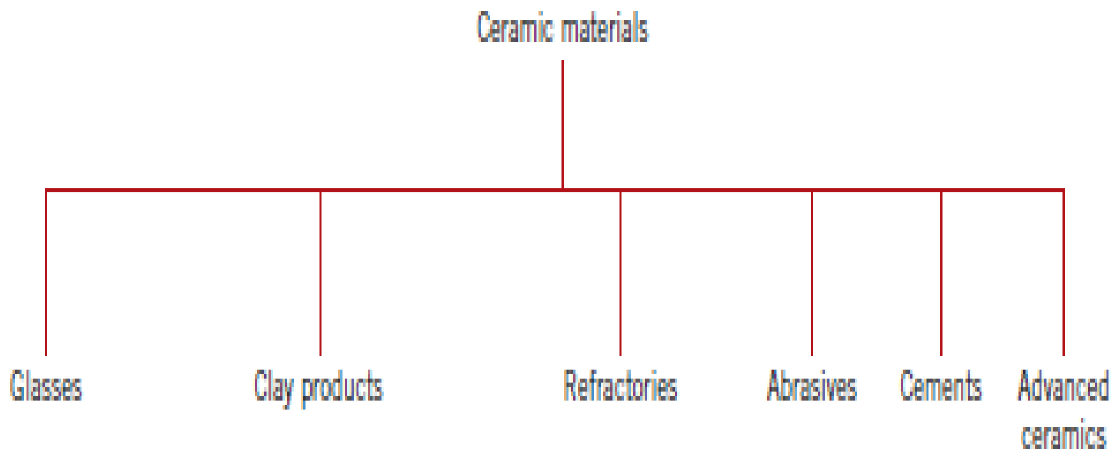


Figure 3. Classification of ceramic materials on the basis of application.

1) Glasses

The glasses are a familiar group of ceramics; containers, lenses, and fiberglass represent typical applications**.**

Most inorganic glasses can be made to transform from a noncrystalline state to one hat is crystalline by the proper high-temperature heat treatment. This process is called **crystallization,** and the product is a fine-grained polycrystalline material which is often called a **glass–ceramic.**

Glass-ceramic materials have been designed to have the following characteristics:

1- relatively high mechanical strengths;
2- low coefficients of thermal expansion (to avoid thermal shock);
3- relatively high temperature capabilities; good dielectric properties .

4- good biological compatibility.

2) Clay Products

One of the most widely used ceramic raw materials is clay. This inexpensive ingredient, found naturally in great abundance, often is used as mined without any upgrading of quality.
Another reason for its popularity lies in the ease with which clay

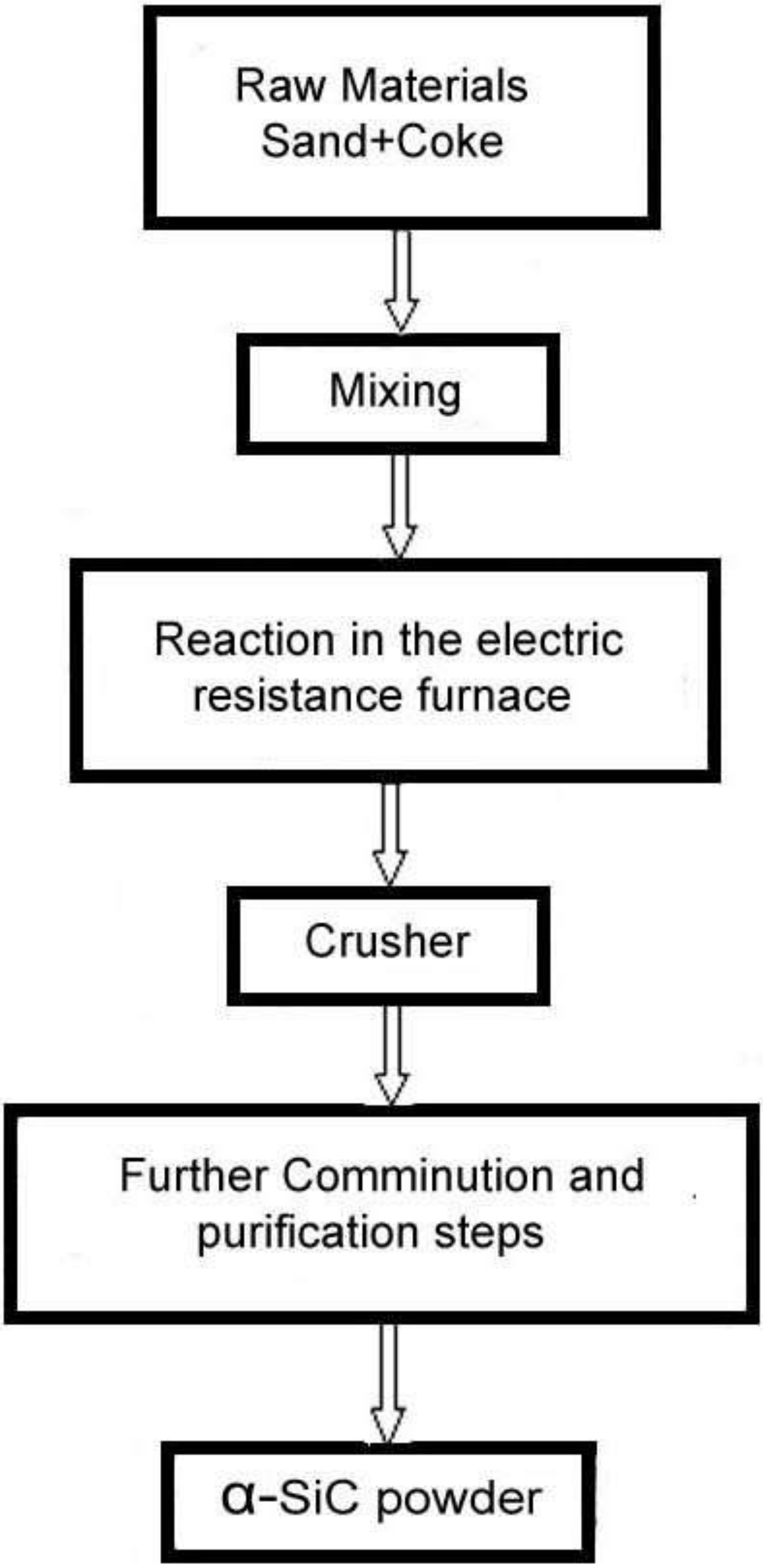
products may be formed; when mixed in the proper proportions, clay and water form a plastic mass that is very amenable to shaping. The formed piece is dried to remove some of the moisture, after which it is fired at an elevated temperature to improve its mechanical strength.

3) Refractories

Another important class of ceramics that are utilized in large tonnages is the **refractory ceramics.** The salient properties of these materials include the capacity to withstand high temperatures without melting or decomposing, and the capacity to remain unreactive and inert when exposed to severe environments. In addition, the ability to provide thermal insulation is often an important consideration.

Refractory materials are marketed in a variety of forms, but bricks are the most common. Typical applications include furnace linings for metal refining, glass manufacturing, metallurgical heat treatment, and power generation.

Of course, the performance of a refractory ceramic, to a large degree, depends on its composition. On this basis, there are several classifications namely, fireclay, silica, basic, and special refractories.
For example SiC production as below:-



SiC Production

4) Abrasives

Abrasive ceramics are used to wear, grind, or cut away other material, which necessarily is softer. Therefore, the prime requisite for this group of materials is hardness or wear resistance; in addition, a high degree of toughness is essential to ensure that the abrasive particles do not easily fracture. Furthermore, high temperatures may be produced from abrasive frictional forces, so some refractoriness is also desirable. Diamonds, both natural and synthetic, are utilized as abrasives; however, they are relatively expensive. The more common ceramic abrasives include silicon carbide, tungsten carbide (WC), aluminum oxide (or corundum), and silica sand.

5) Cements

Several familiar ceramic materials are classified as inorganic **cements:** cement, plaster , and lime, which, as a group, are produced in extremely large quantities. The characteristic feature of these materials is that when mixed with water, they form a paste that subsequently sets and hardens. This trait is especially useful in that solid and rigid structures having just about any shape may be expeditiously formed. Also, some of these materials act as a bonding phase that chemically binds particulate aggregates into a single cohesive structure. Under these circumstances, the role of the cement is similar to that of the glassy bonding phase that forms when clay products and some refractory bricks are fired. One important difference, however, is that the cementitious bond develops at room temperature.

6) Advanced Ceramics

Many of our modern technologies utilize and will continue to utilize advanced ceramics because of their unique mechanical, chemical, electrical, magnetic, and optical properties and property combinations.

Engineering Ceramics

Ceramic		Applications
Alumina	Al_2O_3	Cutting tools, dies, wear resistant parts and coatings, oxidation barriers, bearing surfaces, high temperature components, turbine parts, hip implants, body armour, radiation shielding.
Silicon Carbide	SiC	
Silicon Nitride	Si_3N_4	
Zirconia	ZrO_2	
Boron Nitride	BN	