Introduction

Ceramics can be defined as solid compounds that are formed by the application of heat, and sometimes heat and pressure. Ceramics are compounds between metallic and nonmetallic elements and are associated with covalent and ionic bonding.

They are frequently oxides, nitrides, and carbides. For example, the most common ceramic materials known as engineering ceramics include aluminum oxide (alumina, Al_2O_3), silica (SiO_2), silicon carbide (SiC), and silicon nitride (Si_3N_4).

In addition, what some refer to as traditional ceramics are those composed of clay minerals (i.e., porcelain), as well as cement and

glass.

With regard to mechanical behavior, ceramic materials are typically stiff, strong, very hard and exhibit extreme brittleness (lack of ductility), and are highly susceptible to fracture. Ceramic can be classified into:

1. Domestic ceramics (porcelain, china ware, and cement).

2. Natural ceramics (stones and rocks).

3. Engineering ceramics (oxides, nitrides, and carbides).

4. Glasses (glass and glass-ceramic).

5. Electronic ceramics (ferrites and semiconductors).

6. Smart ceramics (piezoelectric ceramics, ferroelectric ceramics).

Ceramics Microstructure

Crystalline solids exist as either single crystals or polycrystalline solids. A single crystal is a solid in which the periodic and repeated arrangement of the atoms is perfect and extends throughout the entirety of the specimen without interruption.

A polycrystalline solid, fig. 1, is comprised of a collection of many single crystals, termed the grains, separated from one another by areas of disorder known as the grain boundaries.

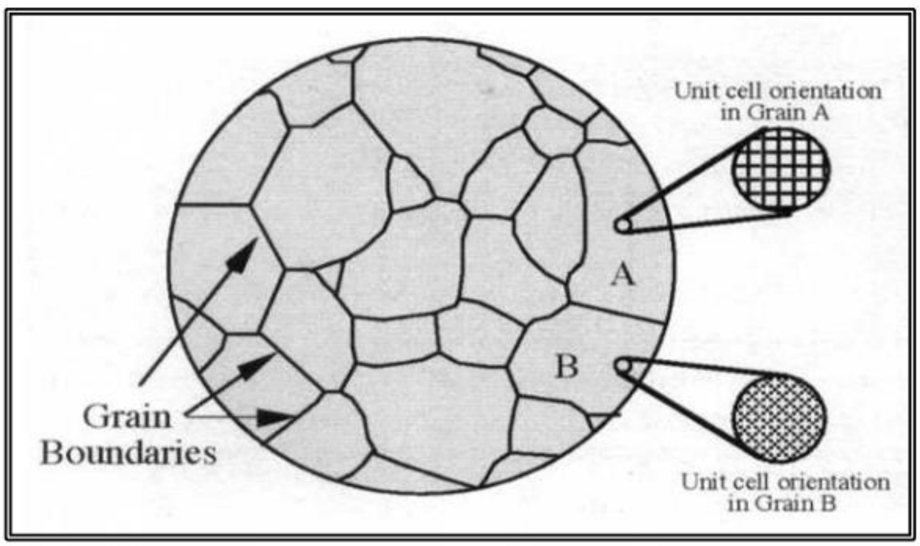

Fig (1): Polycrystalline ceramics.

Typically, in ceramics, the grains are in the range of 1 to 50 µm and are visible only under a microscope. The shape and size of grains, together with the presence of porosity, the second phases, and their distribution describe what is termed the microstructure. Many of the properties of ceramics are microstructure-dependent.

In most ceramics, more than one phase is present, with each phase having its own structure, composition, and properties. Control of the type, size, distribution, and amount of these phases within a material provides a means to control properties.

The microstructure of a ceramic is often a result of the way it was processed, for example, hot-pressed ceramics often have very few pores. This may not be the case in sintered materials.

The Main Properties of Ceramics

1- Brittleness, which results from the strong atomic bonding. At high temperatures, the glass no longer behaves in a brittle manner; it behaves as a viscous liquid. That is why it is easy to form glass into intricate shapes. So, what we can say is that most ceramics are brittle at room temperature but not necessarily at elevated temperatures.

2- Medium density.

3- Poor electrical and thermal conduction. The valence electrons are tied up in bonds, and are not free as they are in metals. Ceramics can also have high electrical conductivity: Such as oxide ceramic, ReO_2, has an electrical conductivity at room temperature similar to that of (Cu).

4- Wear and corrosion resistance.

5- Difficult to form (machine).

6- Working at high temperatures.

7- Compressive strength. Ceramics are stronger in compression than in tension, whereas metals have comparable tensile and compressive strengths. It is necessary to consider the stress distributions in the ceramic to ensure that they are compressive. An important example is in the design of concrete bridges; the concrete must be kept in compression. Ceramic materials usually have low fracture toughness, although combining them in the composite can dramatically improve this property.

8- Chemical insensitivity. A large number of ceramics are stable in both harsh chemical and thermal environments. Pyrex glass is used widely in chemistry laboratories specifically because it is very resistant to many corrosive chemicals, stable at high temperatures, and resistant to thermal shock because of its low coefficient of thermal expansion. It is also widely used in bakeware.

9- Optical characteristics, ceramics may be transparent, translucent, or opaque, and some of the oxide ceramics (e.g., $Fe3O4$ exhibit magnetic behavior.

Mechanical Behavior of Ceramics

Ceramics are materials that are very strong and hard, but they are also very brittle. They have strong ionic and covalent bonds, which make them stiff and resistant to deformation, but these same bonds prevent the atoms from sliding past each other. Because of this, ceramics do not show plastic deformation like metals; instead, they break suddenly when the stress becomes too high.

The mechanical strength of a ceramic depends mainly on the flaws inside it, such as tiny cracks or pores. Even very small defects can cause failure because they concentrate stress. This makes ceramics much weaker in tension, where cracks open easily, and much stronger in compression, where cracks are closed.

Ceramics also have low fracture toughness, meaning cracks can grow quickly once they start. They can withstand very high temperatures without deforming, but they are sensitive to rapid temperature changes, which can cause thermal shock and cracking.

Defects in Ceramics

Point defects are the common type of defects that exist in ceramic materials. This type involving host atoms may exist in ceramic compounds. As in metals, both vacancies and interstitials are possible; however, because the ceramic materials contain ions of at least two kinds, defects for each ion type may occur.

It is highly unlikely that there would be appreciable concentrations of anion interstitials. The anion is relatively large, and to fit into a small interstitial position, substantial strains on surrounding ions must be introduced. Anion and cation vacancies and a cation interstitial are represented in fig 2.

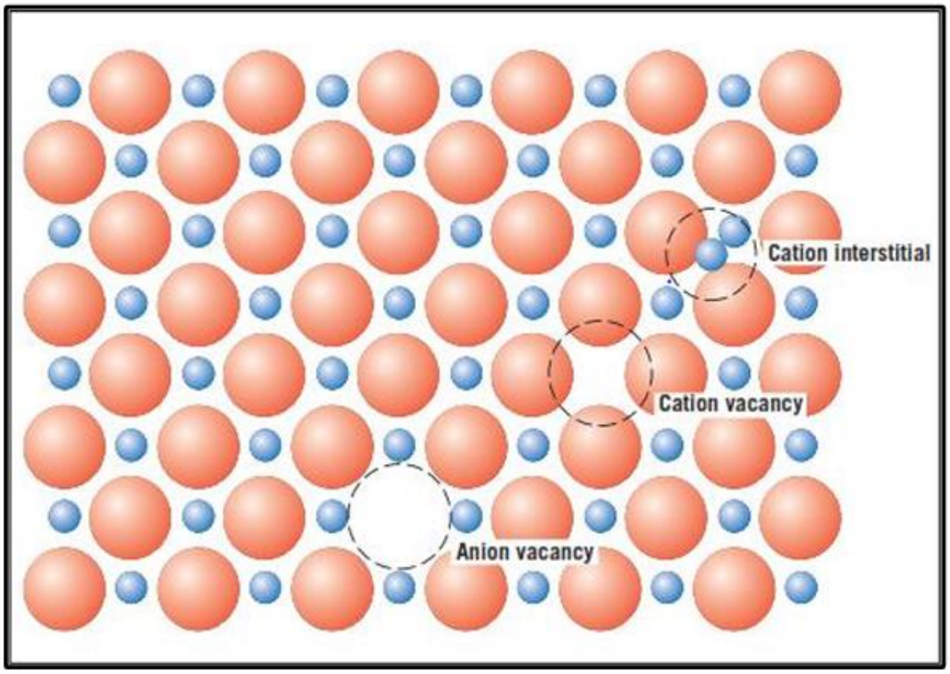

Fig (2): Schematic representations of cation and anion vacancies and a cation interstitial.

One such category of the defect involves a (cation–vacancy) and a (cation–interstitial) pair. This is called a Frenkel defect (fig 2). It might be thought of as being formed by a cation leaving its normal position and moving into an interstitial site. Another type of defect found in the ceramic materials is a cation vacancy–anion vacancy pair known as a Schottky defect, shown in fig 3.

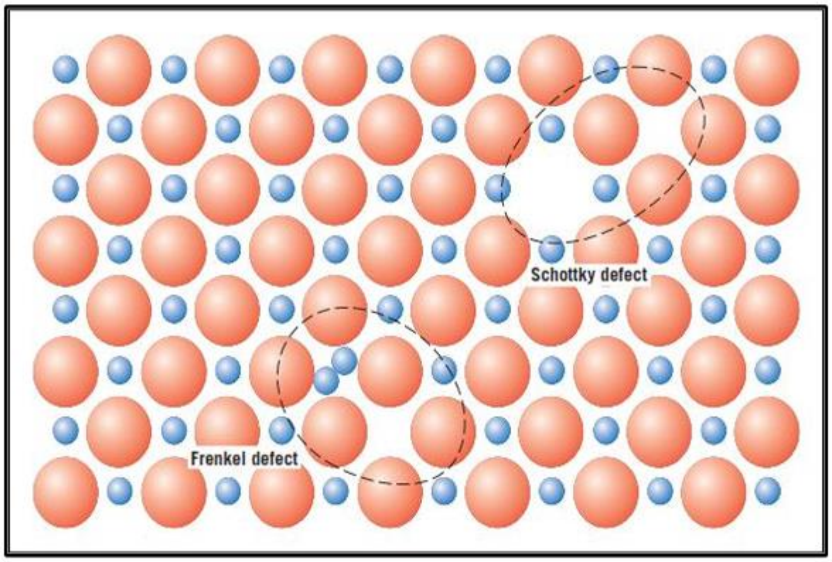

Fig (3): Frenkel and Schottky defects in ionic solids.

Classification of Ceramics on the Basis of its Application

1. Structural Ceramics – Used for mechanical strength and wear resistance. Examples: Alumina, Silicon Nitride, Silicon Carbide. Applications: Bearings, cutting tools, engine parts, armor.

2. Functional Ceramics – Used for their electrical, magnetic, optical, or thermal properties. Examples: Piezoelectric ceramics (PZT), dielectric ceramics ($BaTiO_3$), magnetic ferrites, ionic conductors (YSZ). Applications: Sensors, capacitors, transformers, fuel cells.

3. Refractory Ceramics – Can withstand very high temperatures. Examples: Fireclay, silica, magnesia. Applications: Furnace linings,

kilns, metallurgical equipment.

4. Bioceramics – Compatible with the human body. Examples: Hydroxyapatite, Zirconia. Applications: Dental implants, joint replacements, bone repair.

5. Glass and Glass-Ceramics – Transparent or partially crystalline. Examples: Silicate glass, borosilicate, glass-ceramics. Applications: Windows, cookware, optical fibers.

6. Abrasive Ceramics – Extremely hard materials for cutting and polishing. Examples: Silicon Carbide, Alumina, Diamond. Applications: Grinding wheels, cutting tools, polishing surfaces.