Processing and Applications of Ceramics

Ceramics are compounds between metallic and non metallic elements for which the inter-atomic bonds are either ionic or predominantly ionic. The term ceramics comes from a Greek word which means ‘burnt stuff.

Based on their composition, ceramics are classified as: Oxides, Carbides, Nitrides, Sulfides, Fluorides, etc. The other important classification of ceramics is based on their application, such as: Glasses, Clay products, Refractory, Abrasives, Cements, Advanced ceramics. Ceramic materials used for engineering applications can be divided into two groups: traditional ceramics, and the engineering ceramics).

Traditional ceramics are made from three basic components: clay, silica (flint) and feldspar. For example bricks, tiles and porcelain articles. However, engineering ceramics consist of highly pure compounds of aluminium oxide (Al_2O_3), silicon carbide (SiC) and silicon nitride, Si_3N_4.

Glasses are – containers, windows, mirrors, lenses, etc. They are non-crystalline silicates containing other oxides, usually CaO, Na_2O, K_2O and Al_2O_3which influence the glass properties and its color. Typical property of glasses that is important in engineering applications is its response to heating. There is no definite temperature at which the liquid transforms to a solid as with crystalline materials. A specific temperature, known as glass transition temperature is defined based on viscosity above which material is named as super cooled liquid or liquid, and below it is termed as glass.

Clay is the most widely used ceramic raw material. It is abundant and popular. Clay products are mainly two kinds – structural products (bricks, tiles, sewer pipes) and white-wares (porcelain, chinaware, pottery, etc.).

Refractories are described by their capacity to withstand high temperatures without melting or decomposing; and their inertness in severe environments. Used for thermal insulation.

Abrasive ceramics are used to grind, wear, or cut away other materials. Thus the prime requisite for this group of materials is hardness or wear resistance in addition to high toughness. They need to exhibit some refractoriness. Diamond, silicon carbide, tungsten carbide, silica sand, are some typical examples.

Cements -cement, plaster of paris and lime come under this group of ceramics. The characteristic property of these materials is that when they are mixed with water, they form slurry which sets subsequently and hardens finally. Thus it is possible to form virtually any shape. They are also used as bonding phase, for example between construction bricks.

Advanced ceramics are newly developed and manufactured in limited range for specific applications. Typical applications are heat engines, ceramic armours, electronic packaging, etc.

Aluminium oxide / Alumina(Al_2O_3) is the most commonly used ceramic material. It is used in many applications such as to contain molten metal, where material is operated at very high temperatures under heavy loads, as insulators in spark plugs, and in some unique applications such as dental and medical use. Chromium doped alumina is used for making lasers.

Aluminium nitride(A l N) has good electrical insulation but high thermal conductivity properties hence, it is used in electrical circuits operating at a high frequency. It is also suitable for integrated circuits. Other electronic ceramics include – barium titanate ($BaTiO_3$) and Cordierite ($2MgO\text{-}2Al_2O_3\text{-}5SiO_2$).

Diamond is the hardest material known in nature. It has many applications such as industrial abrasives, cutting tools, abrasion resistant coatings, etc., in jewellery.

Lead zirconium titanate (PZT)is the most widely used piezoelectric material, and is used as gas igniters, ultrasound imaging, in underwater detectors.

Silica,(SiO_2) is an essential ingredient in many engineering ceramics and the most widely used ceramic material. They are used in thermal insulation, abrasives, laboratory glassware, etc. It is an integral part of optical fibers. Fine particles of silica are used in tires, paints, etc.

Silicon carbide,(SiC) is the best ceramic material for very high temperature applications. Used as coatings for protection against extreme temperatures. Also used as abrasive material. It is used as reinforcement in many metallic and ceramic based composites. It is a semiconductor and often used in high temperature electronics.

Silicon nitride (Si_3N_4) has properties similar to those of SiC but is somewhat lower, and found applications in such as automotive and gas turbine engines.

Titanium oxide,(TiO2): is mostly used as pigment in paints. It also forms part of certain glass ceramics. It is used in making other ceramics like $BaTiO_3$

Zirconia, (ZrO2) is used in producing many other ceramic materials. It is also used in making oxygen gas sensors, as additive in many electronic ceramics. Its single crystals are part of jewellry.

Uranium oxide, (UO2) is mainly used as nuclear reactor fuel. The products of fission process are well accommodated within its crystal structure.

Fabrication and processing of ceramics

Ceramics melt at high temperatures and are brittle Thus cannot be processed by the usual melting, casting and thermo-mechanical processing routes. Most ceramic products are made from ceramic powders. However, post forming shrinkage is much higher in ceramics processing because of the large differential between the final density and the as-formed density.

Glasses, however, are produced by heating the raw materials to an elevated temperature above which melting occurs. Most commercial glasses are of the silica-soda-lime variety.

Silica is in the form of common quartz sand, soda (Na_2O) in form of soda ash (Na_2CO_3) while the lime (CaO) is supplied in form of limestone ($CaCO_3$). Different forming methods- pressing, blowing, drawing and fiber forming- are widely used in practice to fabricate glass products. Thick glass objects such as plates and dishes are produced by pressing, while the blowing is used to produce objects like jars, bottles and light bulbs. Drawing is used to form long objects like tubes, rods, fibres etc.

Ceramic processing consists of powder production by milling, followed by fabrication of green product, which is then consolidated to obtain the final piece.

Powder is a collection of fine particles. Production of powder involves grinding/milling as-mined raw materials in which particle size is reduced to physically 'liberate' the minerals of interest from the rest of the 'gangue' material blending different powders, drying to form soft agglomerates. Different techniques such as compaction, tape casting, slip casting, injection moulding and extrusion are then used to convert processed powders into a desired shape known as green ceramic. The green ceramic is then consolidated further by heat treatment known as sintering or firing. Wet milling is much more common with ceramic materials than with metals.

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.The combination of dry powders with a liquid such as water is called slurry. Dispersants are added to ease the wet milling operation in a ball-vibratory mill in order to further reduce the particle sizes of the materials.

Ceramic powders/slurry prepared are shaped using number of techniques, such as casting, compaction, extrusion/hydro-plastic forming, injection moulding. Tape casting, also known as doctor blade process, is used for the production of thin ceramic tapes. In this technique slurry containing ceramic particles, solvent, plasticizers, and binders is then made to flow under a blade and onto a plastic substrate.

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The shear thinning slurry spreads under the blade. The tape is then dried using clean hot air. Later-on the tape is subjected to binder burnout and sintering operations. Tape thickness normally range between 0.1 and 2 mm. Commercially important electronic packages based on alumina substrates and barium titanate capacitors are made using this technique.

Slip casting is another technique which uses aqueous slurry, also known as slip, of ceramic powder. The slip is poured into a plaster of Paris ($CaSO_4:2H_2O$) mould. As the water from slurry begins to move out by capillary action, a thick mass builds along the mould wall.

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When sufficient product thickness is built, the rest of the slurry is poured out (drain casting). It is also possible to continue to pour more slurry in to form a solid piece (solid casting)

Extrusion and injection moulding techniques are used to make products like tubes, bricks, tiles etc The basis for extrusion process is a viscous mixture of ceramic particles, binder and other additives is fed through an extruder where a continuous shape of green ceramic is produced. The product is cut to required lengths and then dried and sintered.

Injection moulding of ceramics is similar to that of polymers.

Ceramic powder is mixed with a plasticizer, a thermoplastic polymer, and additives. Then the mixture is injected into a die with use of an extruder. The polymer is then burnt off and the rest of the ceramic shape is sintered at suitable high temperatures. Ceramic injection moulding is suitable for producing complex shapes.

A popular technique in ceramics to produce simple shapes in large numbers is the combined use of compaction and sintering. E.g electronic ceramics, magnetic ceramics, cutting tools. Compaction is used to make green ceramics with respectable strength and can be handled and machined.

Time for compaction varies and depends on the complexity and size of the product. compaction involves applying equal pressure in all directions to a mixture ceramic powder to increase its density. Cold iso-static pressing (CIP) involves application of pressure using oil/fluid at room temperature. The green ceramic is then sintered with or without pressure. . In some instances, compaction and sintering are conducted under pressure at elevated temperatures. This is hot iso-static pressing (HIP), and is used for refractory and covalently bonded ceramics that do not show good bonding characteristics under CIP. HIP is also used when close to none porosity is the requirement.

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Sintering is the firing process applied to green ceramics to increase its strength. It is carried out below the melting temperature thus there is no liquid phase present. During sintering, the green ceramic product shrinks with a reduction in porosity. This leads to an improvement in its mechanical integrity. After pressing, ceramic particles touch one another. During initial stages of sintering, necks form along the contact regions between adjacent particles thus every interstice between particles becomes a pore. The pore channels in the compact grow in size, resulting in a significant increase in strength.

With increase in sintering time, pores become smaller in size. The driving force for sintering process is the reduction in total particle surface area, and thus the reduction in total surface energy. During sintering, composition, impurity control and oxidation protection are provided by the use of vacuum conditions or inert gas atmospheres.

1. The word ‘ceramic’ meant for ___

(a) soft material (b) hard material (c) burnt material (d) dry material. 2. Not a characteristic property of ceramic material (a) high temperature stability (b) high mechanical strength (c) low elongation (d) low hardness

3. Major ingredients of traditional ceramics

(a)silica (b) clay (c) feldspar (d) all

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4. Not a major contributor of engineering ceramics (a) SiC (b) SiO2(c) SN4(d) Al2O3
5. The following ceramic product is mostly used as pigment in paints (a) TiO2(b) SiO2(c) UO2(d) ZrO2
6. Most commercial glasses consist of (a) lime (b) soda (c) silica (d) all
7. Hot isostatic pressing is not a viable option if the chief criterion is (a) strength without grain growth (b) lost cost (c) zero porosity (d) processing refractory ceramics
8. During sintering densification is not due to (a) atomic diffusion (b) surface diffusion (c) bulk diffusion (d) grain growth