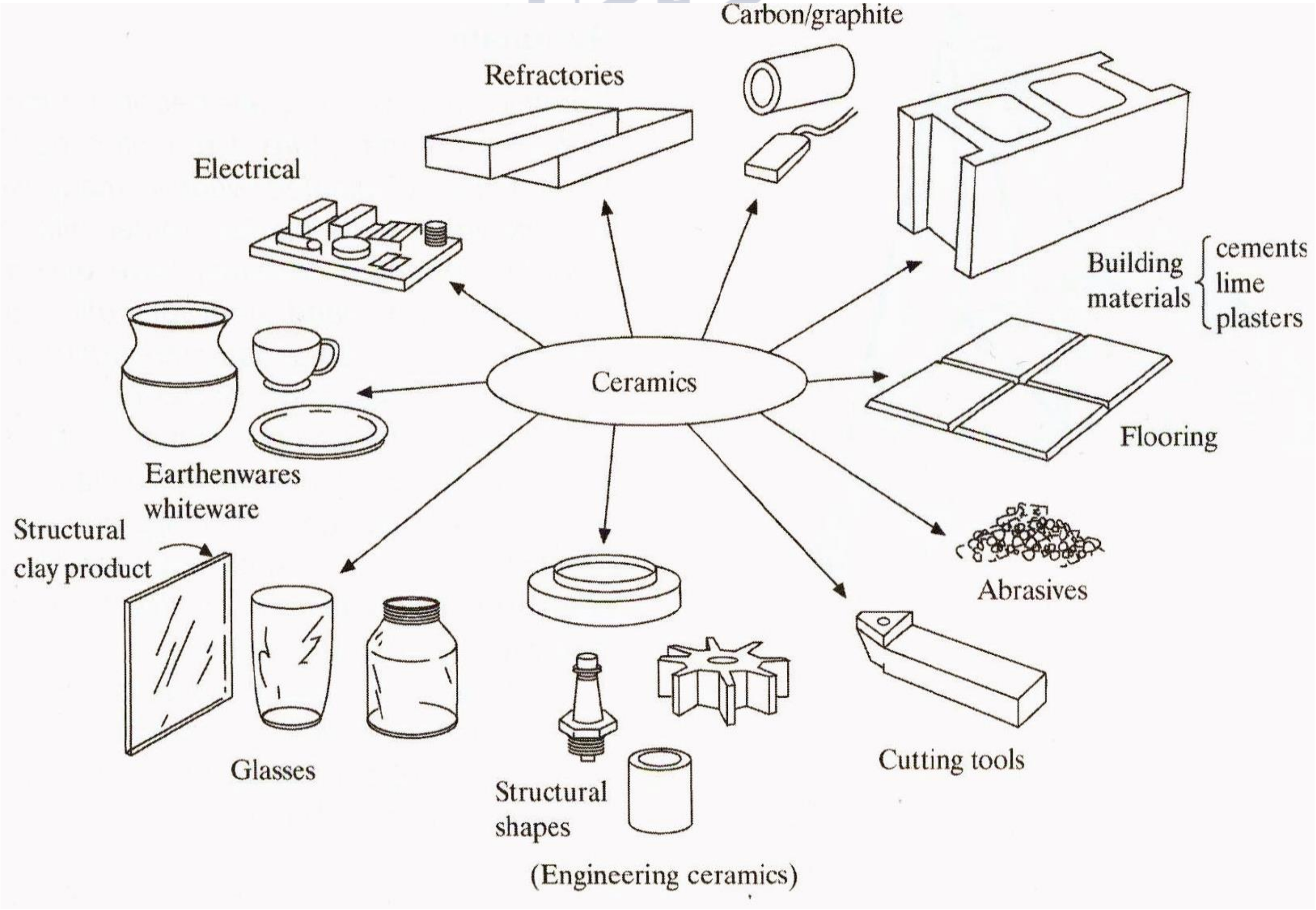
Unit 3

Ceramic Materials

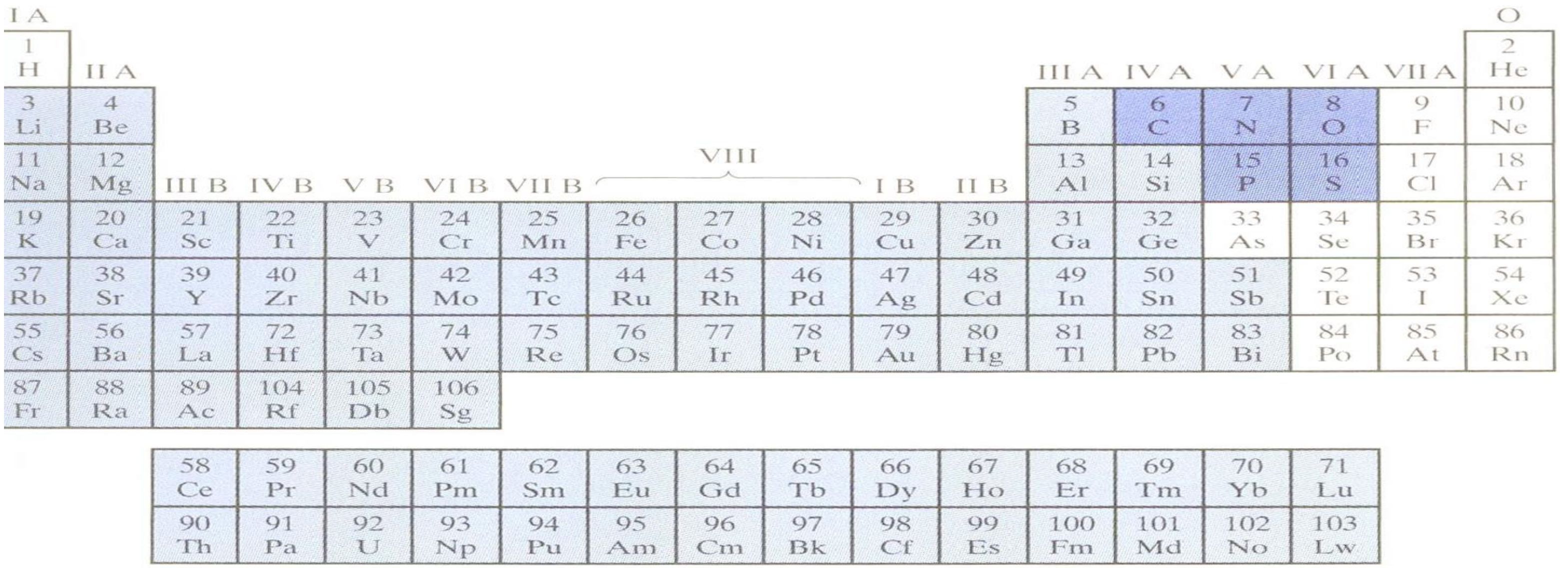
SPECTRUM OF CERAMICS USES



CERAMIC INTRODUCTION

- The word ceramic comes from the Greece word keramicos, which means burnt stuff, indicating that the desirable properties are achieved through high temperature heat treatment process called firing.
- The ceramic materials consist of compounds of metallic and nonmetallic elements (like oxides, nitrides, borides, silicides and carbides), interatomic bonds are either totally ionic or predominantly ionic but having some covalent character.
- Ceramics include a wide variety of substance such as brick, stone, concrete, glass, abrasives, cement, dielectric insulator, non metallic materials and high temperature refractories.

What Are Ceramics?



- Periodic table with *ceramics compounds* indicated by a combination of one or more metallic elements (in light color) with one or more nonmetallic elements (in dark color).

Ceramic and Non ceramic phases

- A comparison between ceramics and non-ceramic materials has been made as under;

✓ Like metals, ceramic materials have crystal structure, but this structure is more complex than metals. Due to this complex structure, the **ceramic reactions are slow and sluggish**.

✓ As compared with metals, ceramics contain **lesser number of free electrons and that is why ceramic materials are poor conductors of heat and electricity.** But at very high temp they can conduct small amount of electricity.

- ✓ Ceramic materials **are more stable** because of their primary bonds, covalent bonds or ionic bonds. Therefore they have **high melting point** and high chemical resistance. **Their hardness and strength** are much more as compared to metals and organic materials.
- ✓ Some semi-metallic element such as graphite, SiC, WC, Zirconium nitrate have both metallic and covalent bonds. They are considered as ceramic materials because they have specific ceramic properties such as high melting point, high hardness and strength, high resistance to oxidation etc.
- ✓ Like metals such as Fe, Co, some ceramic materials such as ferrites, granites etc. have **magnetic properties**.
- ✓ Deformation occurs by slip, slip occurs more easily in case of pure metal, in case of ceramic more force is required because of ionic bond present in ceramic. **Therefore ceramics are more brittle in nature**.

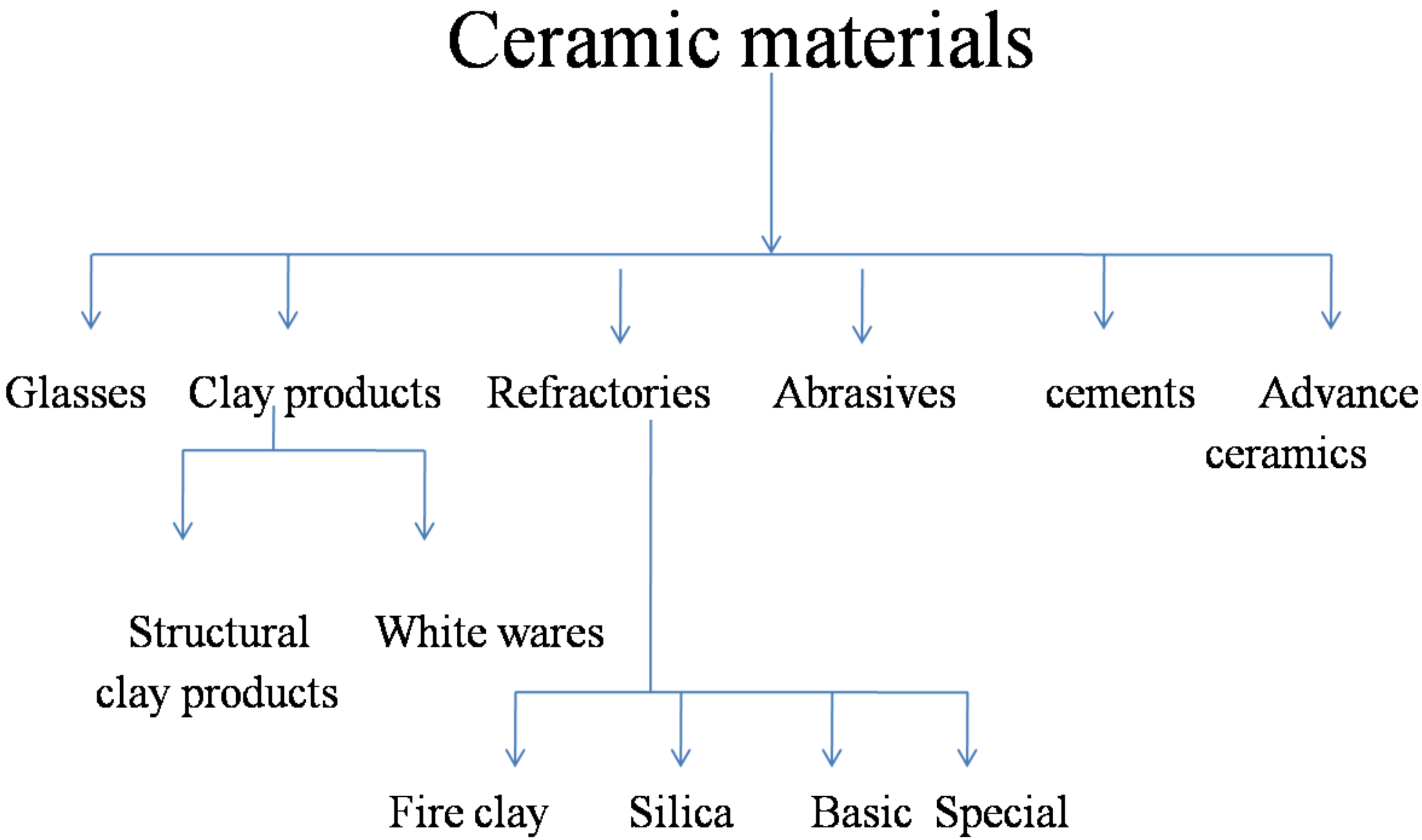
In briefly the properties of ceramics are

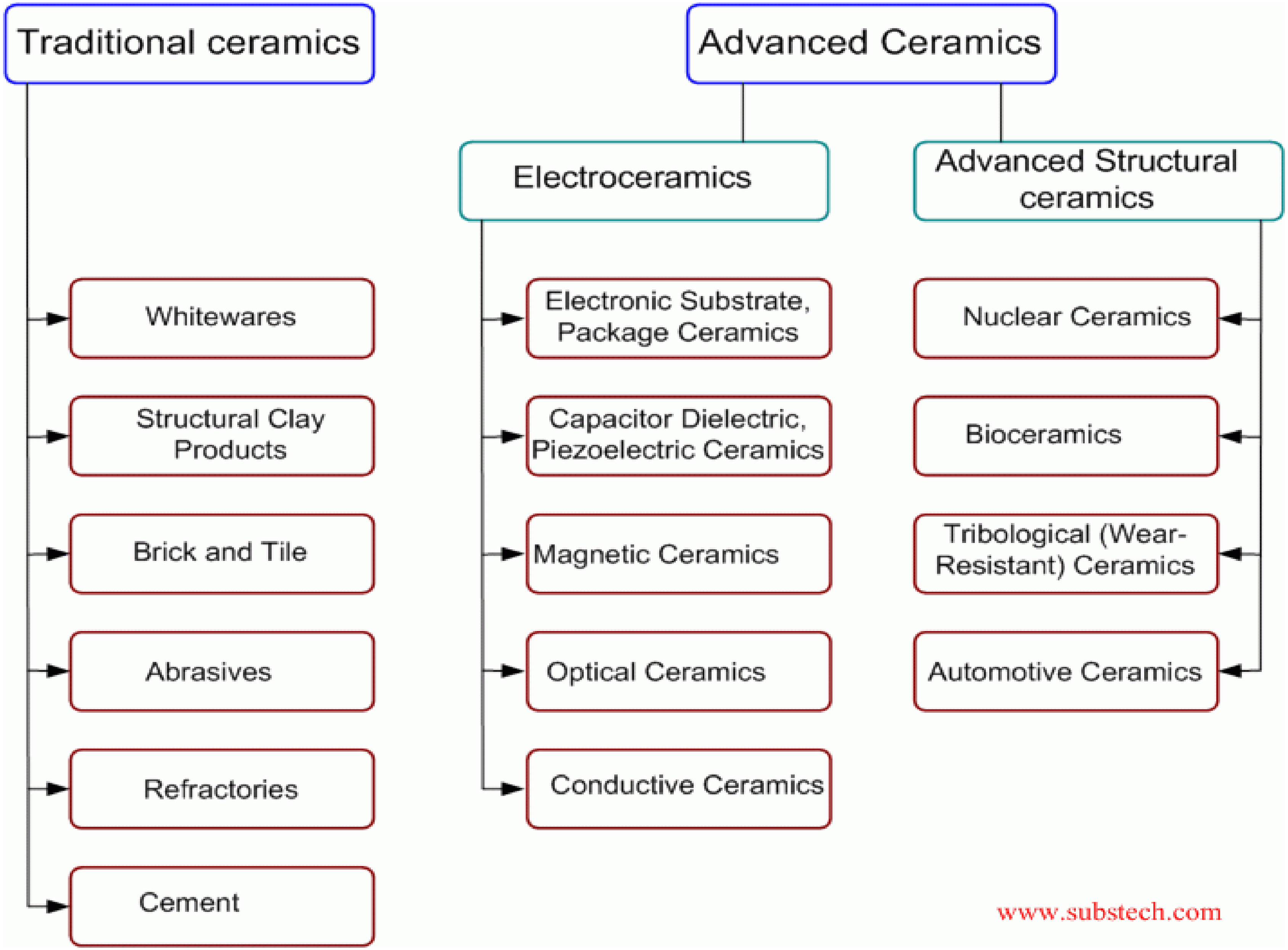
- The ceramic have high compressive strength but are weak in tension.
- They have good oxidation and corrosion resistance.
- Ceramics exhibit useful properties like good strength and hardness, high melting temperatures, chemical resistance and low thermal and electrical conductivity and brittleness.

Three Basic Categories of Ceramics

- Traditional ceramics - clay products such as pottery and bricks, common abrasives, and cement
- New ceramics/Advance ceramics - more recently developed ceramics based on oxides, carbides, etc., and generally possessing mechanical or physical properties superior or unique compared to traditional ceramics
- Glasses - based primarily on silica and distinguished by their noncrystalline structure
  - In addition, glass ceramics - glasses transformed into a largely crystalline structure by heat treatment

CLASSIFICATION OF CERAMICS




Traditional ceramics
Whitewares
Structural Clay Products
Brick and Tile
Abrasives
Refractories
Cement
Advanced Ceramics
Electroceramics
Electronic Substrate, Package Ceramics
Capacitor Dielectric, Piezoelectric Ceramics
Magnetic Ceramics
Optical Ceramics
Conductive Ceramics
Advanced Structural ceramics
Nuclear Ceramics
Bioceramics
Tribological (Wear-Resistant) Ceramics
Automotive Ceramics
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TRADITIONAL CERAMICS

- Traditional ceramics are highly crystalline in nature. Raw materials for these type of ceramic are natural occurring such as clay, sand etc.
- Generally, produced from unrefined clay and silicates
- In which the clay content exceeds 20 percent.

Traditional Ceramics

- The general classifications of traditional ceramics are described below.

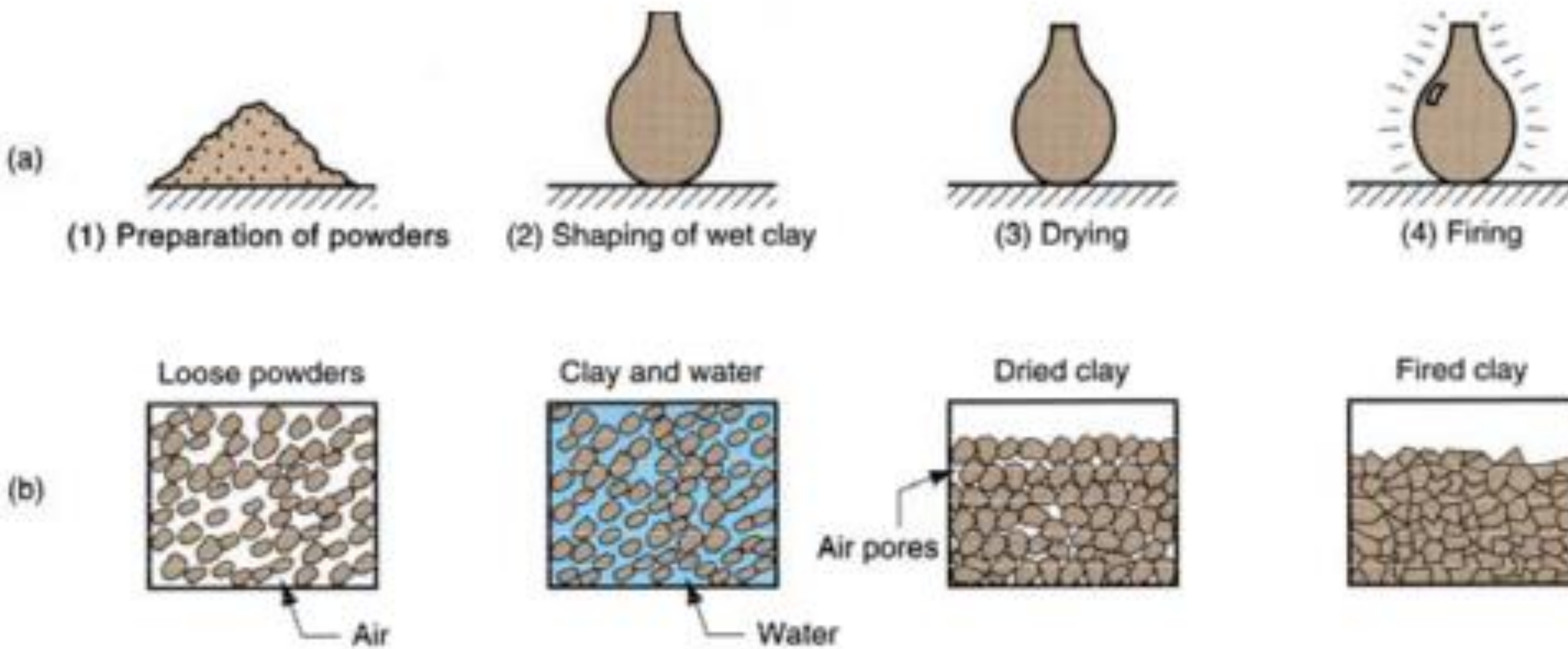
1. Clay Product:

- Most widely used ceramics raw materials is clay.
- 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 elevated temperature to improve its mechanical strength.

Traditional Ceramic Processing

- Processing sequence
  - Preparing powders
  - Shaping of wet clay
  - Drying
  - Firing

The more water in the mixture, the easier to form. But cracking during drying and sintering.



- Clay-based products classified as, structural clay products and whitewares.
- Structural clay products include building bricks, tiles and sewer pipes etc.
- The whiteware ceramics become white after the high-temperature firing. It is further classified as stoneware, chinaware, porcelain, pottery and tableware.
- Most ceramic products are clay-based and are made from a single clay or one or more clays mixed with mineral modifiers such as quartz and feldspar. The types of commercial clays used for ceramics are primarily kaolin and ball clay.

2. Refractories:

- The ceramic materials capable of withstanding high temperatures without appreciable deformation and without melting and decomposing under service conditions are called refractory materials.
- In addition , the ability to remain unreactive and inert when exposed to severe environments and ability to provide thermal insulation.
- Typical applications include furnace lining for metal refining, glass manufacturing, metallurgical heat treatment and powder generation.

Classification

- **Refractories can be classified**
- -on the basis of chemical composition
- -method of manufacture
- -according to their refractoriness.

On the basis of chemical composition

Acidic refractories

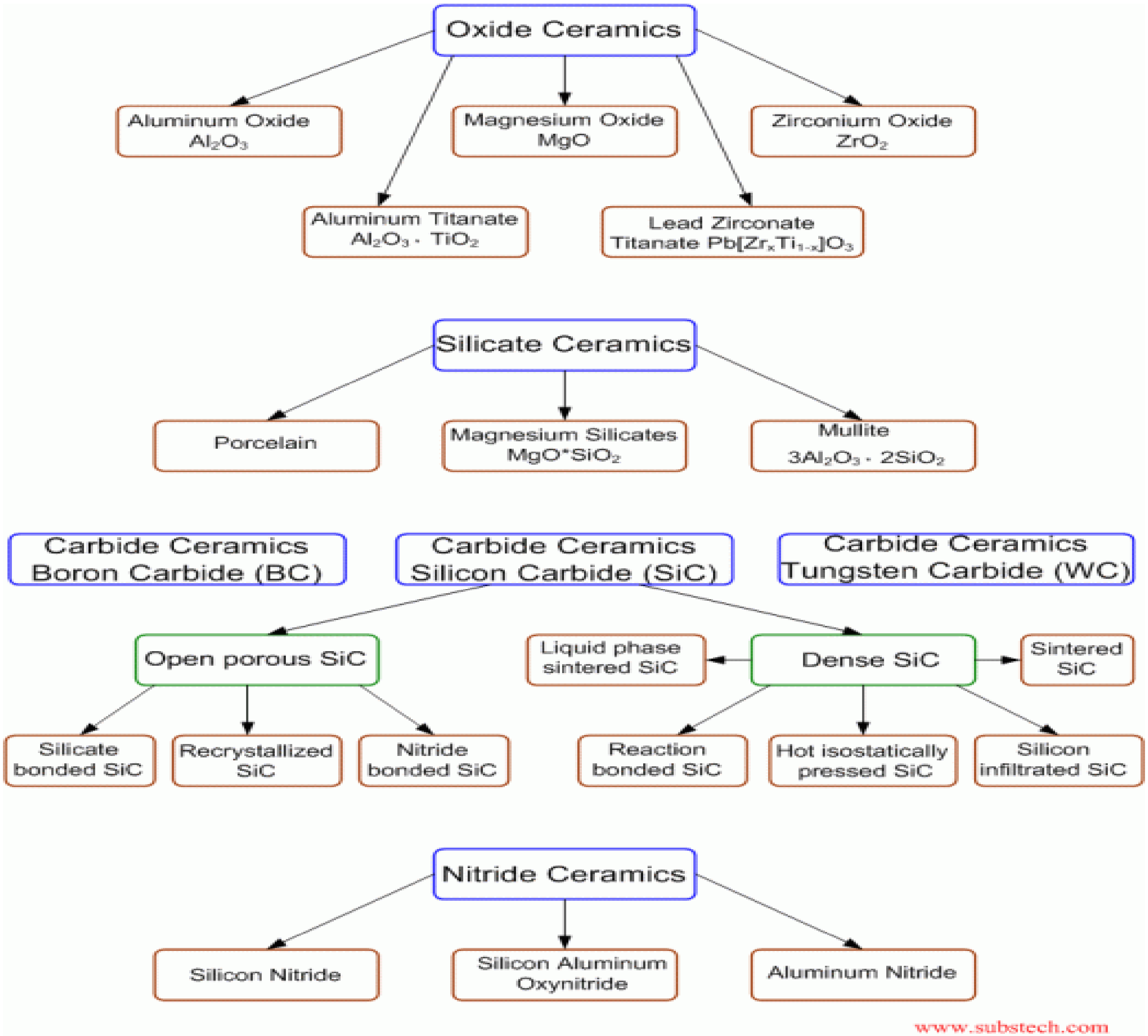
- These are used in areas where slag and atmosphere are acidic.
- They are stable to acids but attacked by alkalis.
- e.g. fire clay, silica, Quartz, Zirconia.

Basic refractories

- These are used on areas where slags and atmosphere are basic,
- stable to alkaline materials but reacts with acids.
- e.g. Magnesia , Alumina, Dolomite.

Neutral refractories

- These are used in areas where the atmosphere is
- either acidic or basic and are chemically stable to both acids and bases.
- e.g. Chromite, Carbide, Mullite.


Oxide Ceramics
Aluminum Oxide Al_2O_3
Magnesium Oxide MgO
Zirconium Oxide ZrO_2
Aluminum Titanate $Al_2O_3 \cdot TiO_2$
Lead Zirconate Titanate $Pb[Zr_xTi_{1-x}]O_3$
Silicate Ceramics
Porcelain
Magnesium Silicates $MgO*SiO_2$
Mullite $3Al_2O_3 \cdot 2SiO_2$
Carbide Ceramics Boron Carbide (BC)
Carbide Ceramics Silicon Carbide (SiC)
Carbide Ceramics Tungsten Carbide (WC)
Open porous SiC
Liquid phase sintered SiC
Dense SiC
Sintered SiC
Silicate bonded SiC
Recrystallized SiC
Nitride bonded SiC
Reaction bonded SiC
Hot isostatically pressed SiC
Silicon infiltrated SiC
Nitride Ceramics
Silicon Nitride
Silicon Aluminum Oxynitride
Aluminum Nitride
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Based on refractoriness

1. Low heat duty refractories

- For low temperature environment i.e. 1520 —1630 ºC

2. Medium heat duty refractories

- For temperature ranging from 1630—1670 ºC

3. High heat duty refractories

- For temperature ranging from 1670—1730 ºC

4. Super duty refractories

- For temperature above 1730 ºC

On basis of Manufacture

- Dry pressed
- Fused Cast
- Hand molded
- Formed
- Unformed

Properties of Refractories

- It should be able to withstand high temperature generated in the furnace.
- It should be able to withstand sudden alternating heating and cooling.
- Its contraction and expansion due to the inevitable temperature variation should be minimum.
- It should be able to withstand fluxing action of the slags and the corrosive action of gases.
- It should have good insulating properties.
- It should be chemically inactive at elevated temperature.
- If used in electrical furnaces, it must have low electrical conductivity.

3. Abrasives:

- Abrasive ceramics are used to wear, grind or cut away other material.
- Hence these materials have a very high hardness or wear resistance; in addition, a high degree of toughness is essential to ensure that the abrasive particle do not easily fracture.
- Diamonds, both natural and synthetic, are utilized as abrasives; however, they are relatively expensive. The more common ceramic abrasives include silicon carbide, tungsten carbide, aluminum oxide and silica sand.

Types of Abrasive

- Natural Abrasives

These abrasive are further classified as:

(i) Hard abrasives.
(ii) Siliceous Abrasives.
(iii) Soft Abrasives.

- Artificial Abrasives

Artificial abrasives include chiefly:

I. Silicon Carbide
II. Aluminium Oxide

Abrasives

4. Cement:

- Several familiar ceramic materials are classified as inorganic cements: cement, plaster of paris and lime.
- The characteristic feature of these materials is that when mixed with water, they form a paste that subsequently sets and hardens.
- These materials are used in construction work.
- Material for bonding solids together
- Ex. Portland cement
- Portland cement is used in construction
- Composition: SiO_2-15.5%, Fe_2O_3-2.0%, MgO-2.5%, Al_2O_3-2.5%, CaO-42%, Co_2-35.5

Porcelain

Stoneware

Pottery

China

Bricks

ADVANCE CERAMICS

- The new and emerging family of ceramics are referred to as advanced, new or fine ceramics.
- Utilize highly refined materials have mechanical or physical properties superior compared to traditional ceramics are referred to as advanced ceramics.
- The term also refers to improvements in processing techniques that provide greater control over structures and properties of ceramic materials

- New ceramics are usually oxides, carbides, nitrides, and borides. They are largely used as/in

✓ Refractories for industrial furnaces.

✓ Electrical and electronic industries- as insulators, semiconductors, transistors, thermoelectric, storage cells in memory systems and piezoelectric transducers

✓ Nuclear applications- as fuel elements, fuel containers, moderators, control rods and structure parts. Ceramics such as UO2,UC are employed for all these purposes.

✓ Electronic packaging

✓ Cutting tools

Examples of Advance ceramics

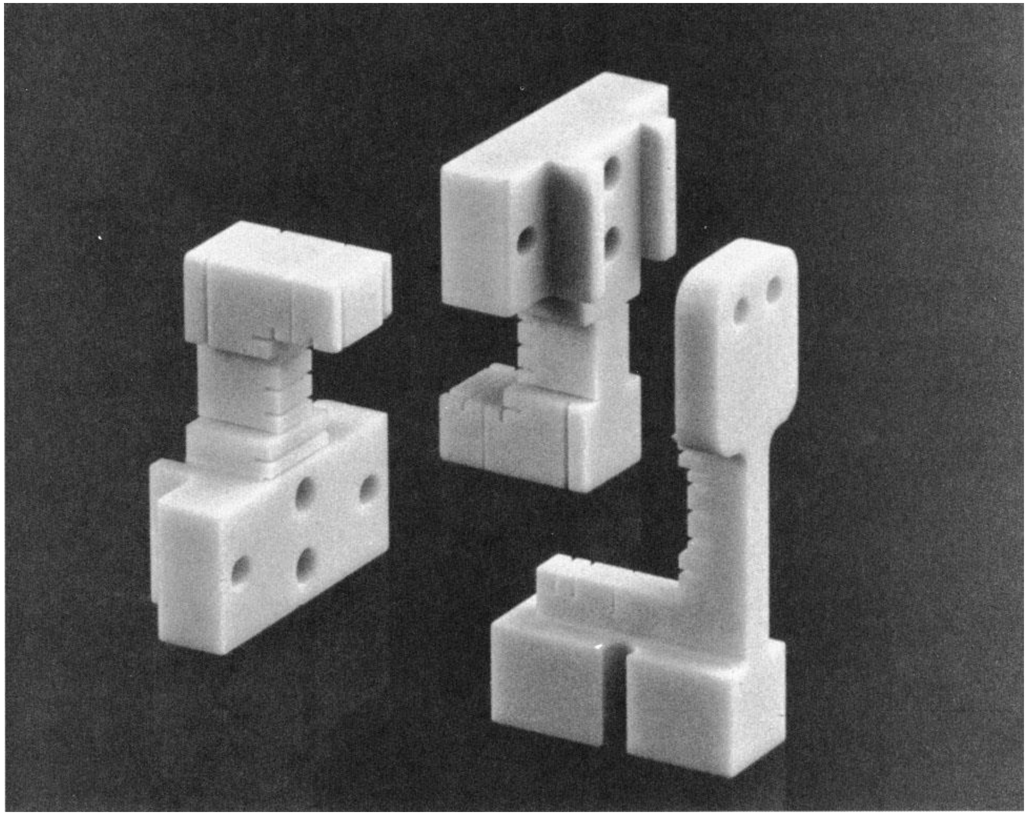
More recently developed ceramics based on oxides, carbides, etc.

- Silicon carbide (SiC),
- tungsten carbide (WC),
- titanium carbide (TiC),
- tantalum carbide (TaC),
- chromium carbide (Cr3C2)
- silicon nitride (Si_3N_4),
- boron nitride (BN),
- titanium nitride (TiN)

- The following is a brief summary of applications of some of the more widely used ceramic materials:

✓ Alumina(Al_2O_3) is used to contain molten metal or in applications where a material must operate at high temperatures and high strength also required, Alumina is also used as insulators in spark plugs.

✓ Titanium Dioxide (TiO_2) is used to make electronic ceramics such as $BaTiO_3$. The largest use is as a white pigment to make paints. Fine particles of TiO_2 are used to make suntan lotions that provide protection against UV rays.



Alumina ceramic components

- Diamond © is the hardest naturally occurring material. It is used as abrasives for grinding and polishing. It is also used as cutting tools.

- Silica (SiO_2) is probably the widely used ceramic material. Silica is an essential ingredient in glasses. Silica-based materials are used in thermal insulation, refractories, abrasives, as fiber-reinforced composites, laboratory glassware, etc.

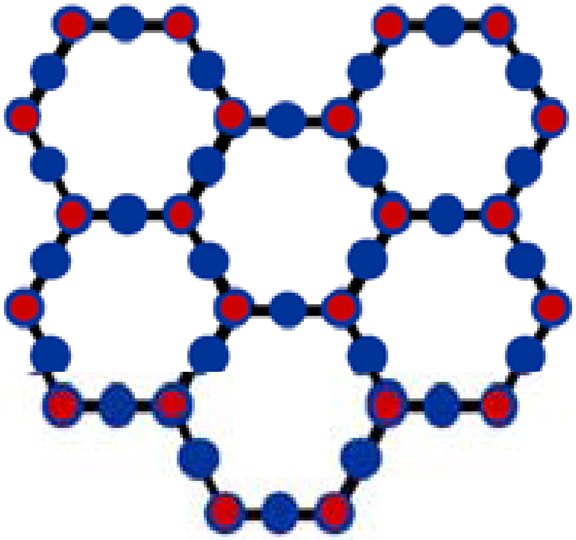
- In form of long continuous fibers, silica is used to make optical fibers for communications. Also powder form of silica is used in many other applications.

- Silicon carbide (SiC) provides outstanding oxidation resistance at temp. even above the melting point of steel. Sic often is used as a coating for metals, C-C composites, and other ceramics to provide protection at high temp. It is also used as an abrasive in grinding wheels and as a reinforcement in both metal matrix and ceramic matrix composites. Also used to make heating elements for furnaces. Sic is a semiconductor and is a very good candidate for high temp. electronics.
- Silicon nitride (Si_3N_4) has properties similar to those of SiC, although its oxidation resistance and high temp strength are somewhat lower.

Glass

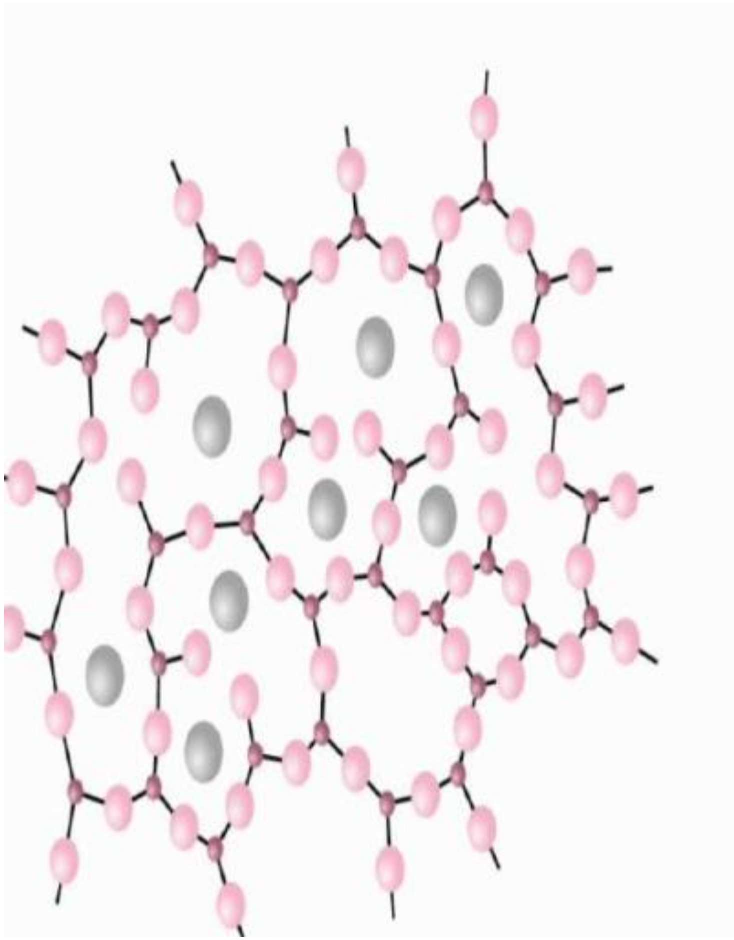
- Glass is substance or mixture of substances that has solidified from the liquid state without crystallization.
- As a type of ceramic, *glass* is an inorganic, nonmetallic compound (or mixture of compounds) that cools to a rigid condition without crystallizing
  - The glassy state occurs in a material when insufficient time is allowed during cooling from the molten state for the crystalline structure to form.
  - Glass may also be defined as a hard, brittle, transparent or translucent material chiefly compound of silica , combined with varying proportions of oxides of sodium, potassium, calcium, magnesia, iron and other minerals.

Structure of glass



The glass is a random arrangement of molecules, the great majority of which are oxygen ions bounded together with the network forming ions of silicon, boron or phosphorus.

Silica is an ideal glass-forming material: but because it has a very high melting point and cannot be melted alone within reasonable cost, it is **expensive to produce glass entirely from silica**. Also, a glass consisting of three-dimensional network would be too viscous to shape economically.



In order to reduce the temperature and to lower the viscosity, network-modifiers are added such as Na_2O, CaO, K_2O, which serve to open up partially the silica network.

Why So Much SiO_2 in Glass?

- Because SiO_2 is the best *glass former*
  - Silica is the main component in glass products, usually comprising 50% to 75% of total chemistry
  - It naturally transforms into a glassy state upon cooling from the liquid, whereas most ceramics crystallize upon solidification

Other Ingredients in Glass

- Sodium oxide (Na_2O), calcium oxide (CaO), aluminum oxide (Al_2O_3), magnesium oxide (MgO), potassium oxide (K_2O), lead oxide (PbO), and boron oxide (B_2O_3)
- Functions:
  - Act as flux (promoting fusion) during heating
  - Increase fluidity in molten glass for processing
  - Improve chemical resistance against attack by acids, basic substances, or water
  - Add color to the glass
  - Alter index of refraction for optical applications

Types of Glass

- Different modifiers are used to produce different types of glass with special characteristics required for their eventual use.

1. Pure silica glass: This type of glass is almost pure silica (99.6-99.9% SiO_4) made by fusing crushed quartz or glass sand, **without the addition of modifiers**, in a high frequency induction furnace.

   Silica glass has a very low rate of expansion and contraction with temperature change with the result that it can withstand severe thermal shocks without cracking, while its high fusion point also gives it stability over a wide range of temperature.

Its rigidity, thermal stability, make it valuable for use in mirrors and reflectors for telescopes and laser beams.

Its ability to transmit ultraviolet light, it use in prisms, solar-cell covers and other space-age applications.

2. Soda-lime glass: It is made from soda ash (Na_2CO_3), lime (CaO), and high-purity sand.

The modifiers used are calcium oxide and sodium oxide, which greatly lower the melting temperature and viscosity of the glass, making it easier to shape.

It **is cheapest** and most common of all glasses.

It is used for a common purposes such as windowpanes, plate glass, bottles, electric bulbs, and ordinary kitchenware, where high chemical stability and high temperature resistance are not required.

3. Lead glass: This type of glass, also called flint glass, usually contains as modifiers 15-30% of lead oxide and small amounts of alkaline oxides.

   Since lead glass has exceptional optical qualities, and is soft and easy to grind, it is widely used for optical purposes such as **lenses** in spectacles and in optical instruments.

   The high luster of lead glass makes it very useful for tableware, vases and art objects.

4. Borosilicate glass: alkali and other basic oxides of soda-lime glass are substituted by boron oxide and aluminum oxide.

   It has higher thermal shock resistance and higher chemical resistance, compared to soda-lime glass.

   Borosilicate glasses are used for laboratory ware and as piping and linings of equipment in food and chemical industries.

Glass Products

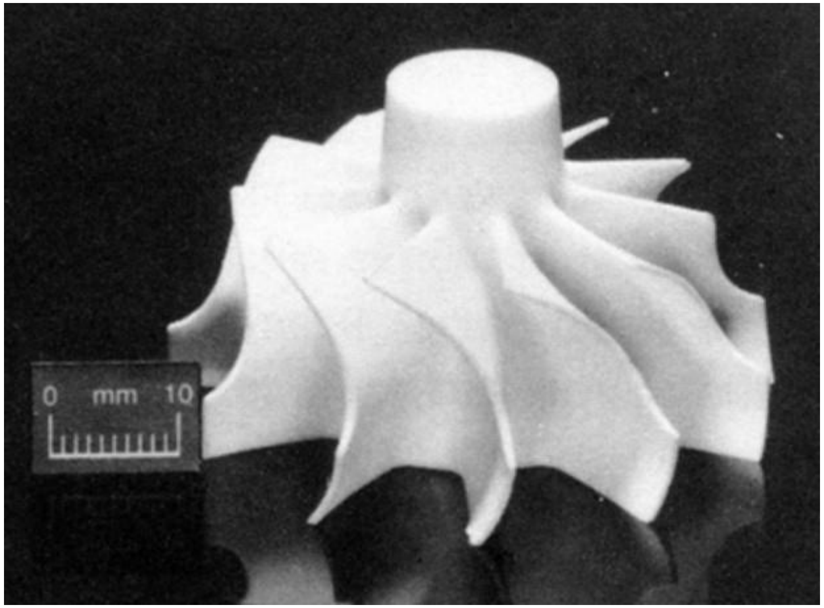
- Window glass
- Containers – cups, jars, bottles
- Light bulbs
- Laboratory glassware – flasks, beakers, glass tubing
- Glass fibers – insulation, fiber optics
- Optical glasses - lenses

Application of ceramics

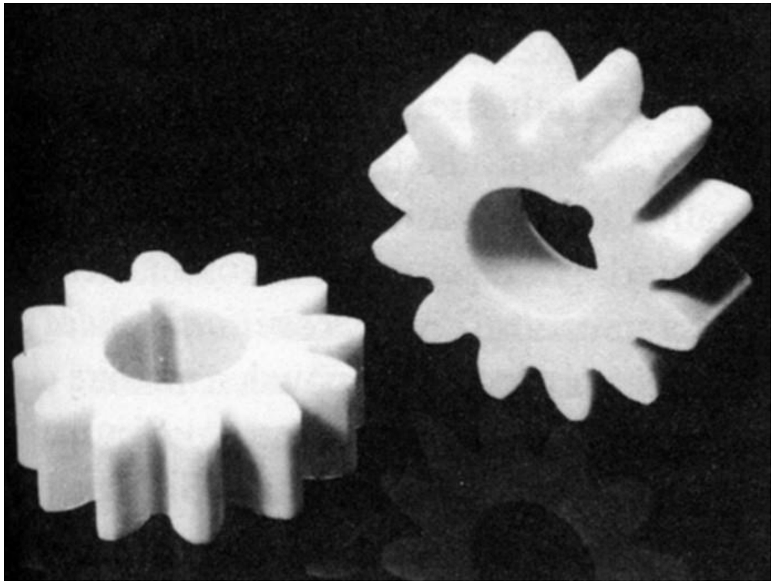
- Compressive strength makes ceramics good structural materials (e.g., bricks in houses, stone blocks in the pyramids)
- High voltage insulators and spark plugs are made from ceramics due to its electrical conductivity properties
- Good thermal insulation has ceramic tiles used in ovens and as exterior tiles on the Shuttle orbiter
- Some ceramics are transparent to radar and other electromagnetic waves and are used in radomes and transmitters.

- Chemical inertness makes ceramics ideal for biomedical applications like orthopedic prostheses and dental implants
- Glass-ceramics, due to their high temperature capabilities, leads to uses in optical equipment and fiber insulation

Engine Components



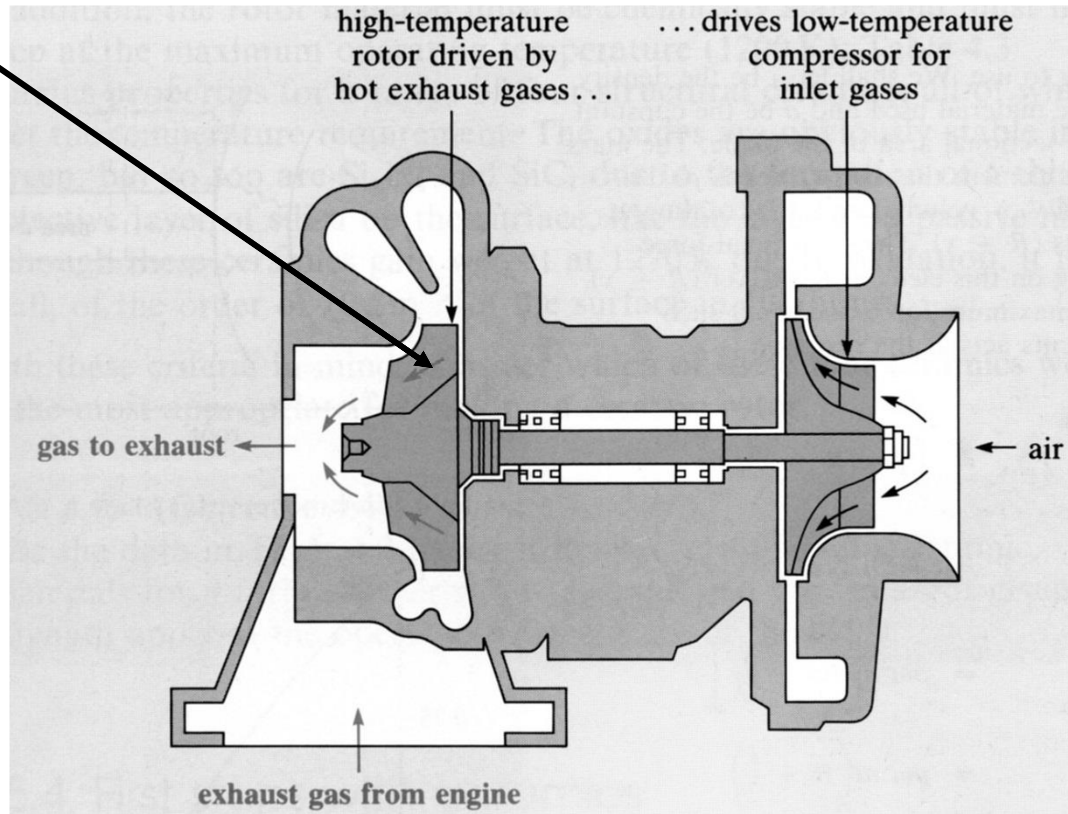
Rotor (Alumina)



Gears (Alumina)

Turbocharger

Ceramic Rotor



Ceramic Brake Discs

Assignment 5

DOS= 30^{th} March 2015

1. What are ceramic materials? Write the difference between Ceramics phase and Metals (Non-ceramic phases).

2. Give classification of ceramic materials. What are the general properties of ceramic materials?

3. Define glass materials. How does it different from other ceramic materials.

4. Write a short note on Glass.

5. Write a short note on: Clay products, Refractories, Abrasive.

6. What is advance ceramics? How it has superior properties than traditional ceramics. Give at least two common examples of advance ceramic.