INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
NPTEL
NPTEL ONLINE CERTIFICATION COURSE
Structural Analysis of Nanomaterials
LECTURE – 08
Basic Properties: Ceramics
With
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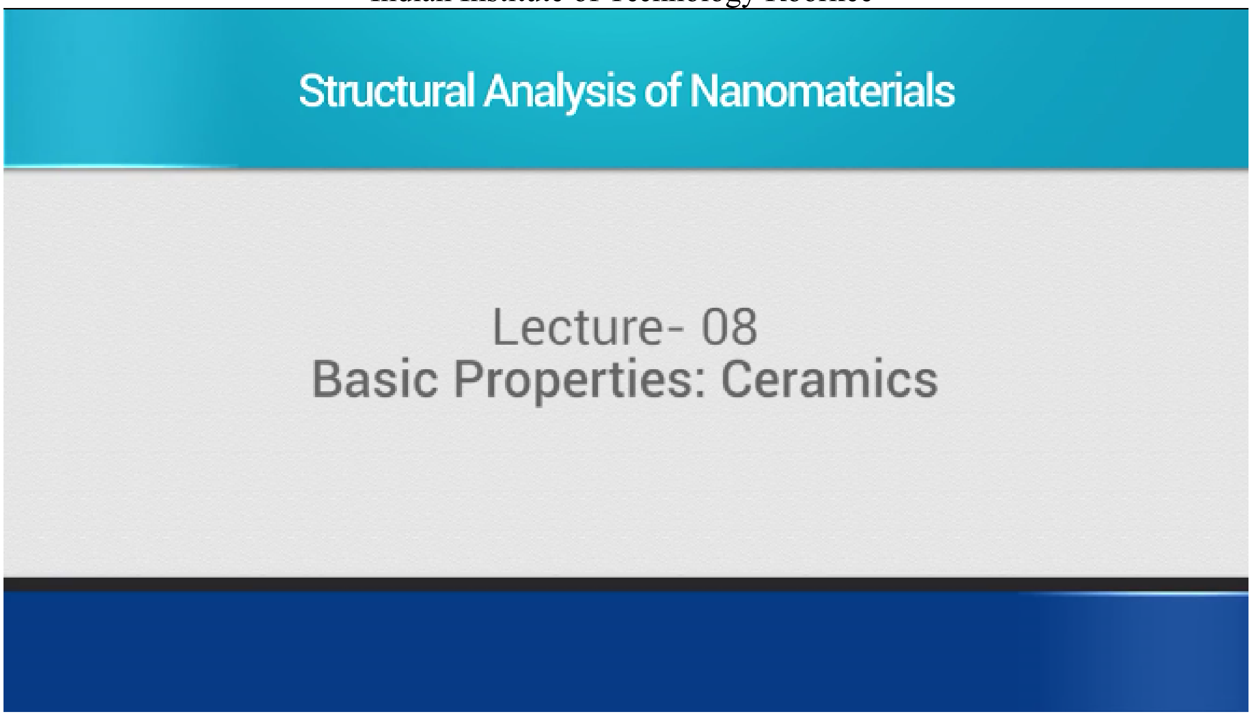
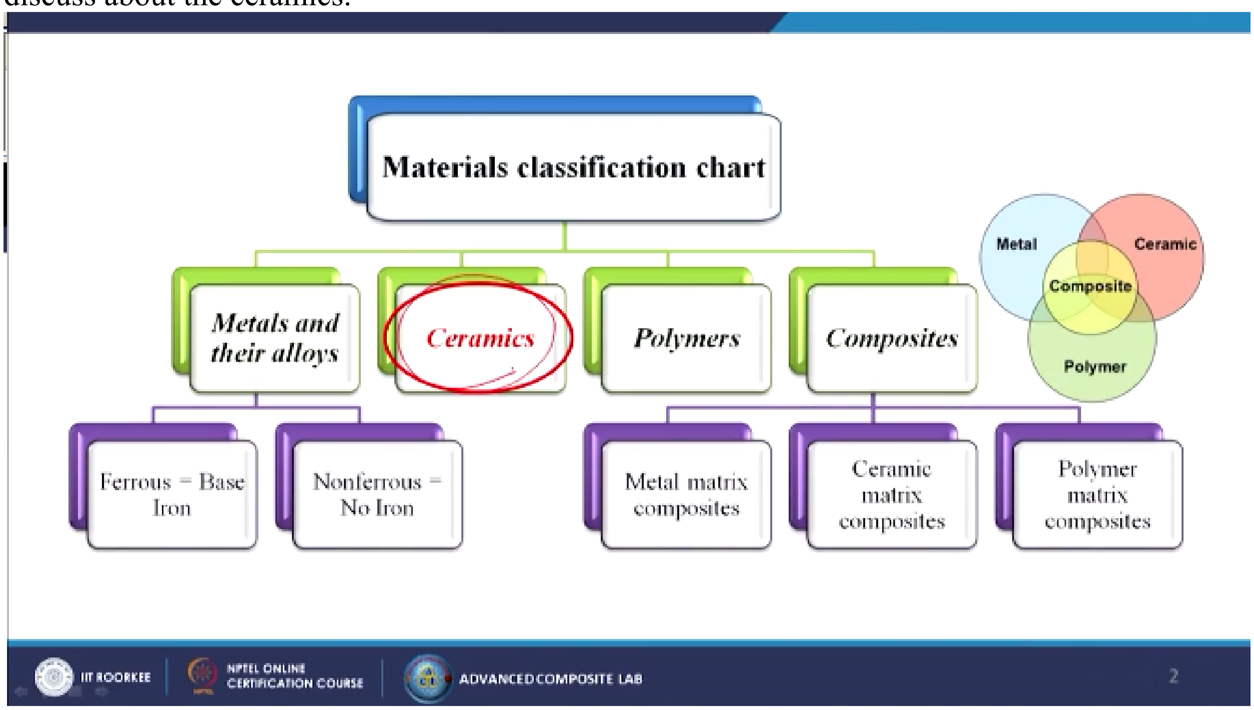


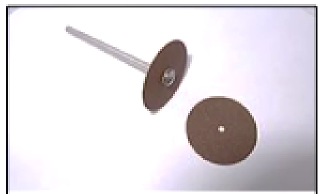
Hello, in our previous lectures we have discussed about the metals, in this lecture we are going to discuss about the ceramics.



So this is the same materials classification chart which I have already shown in the metal part, so now in this particular case we are going to discuss about the ceramics materials. So before going

Ceramics:

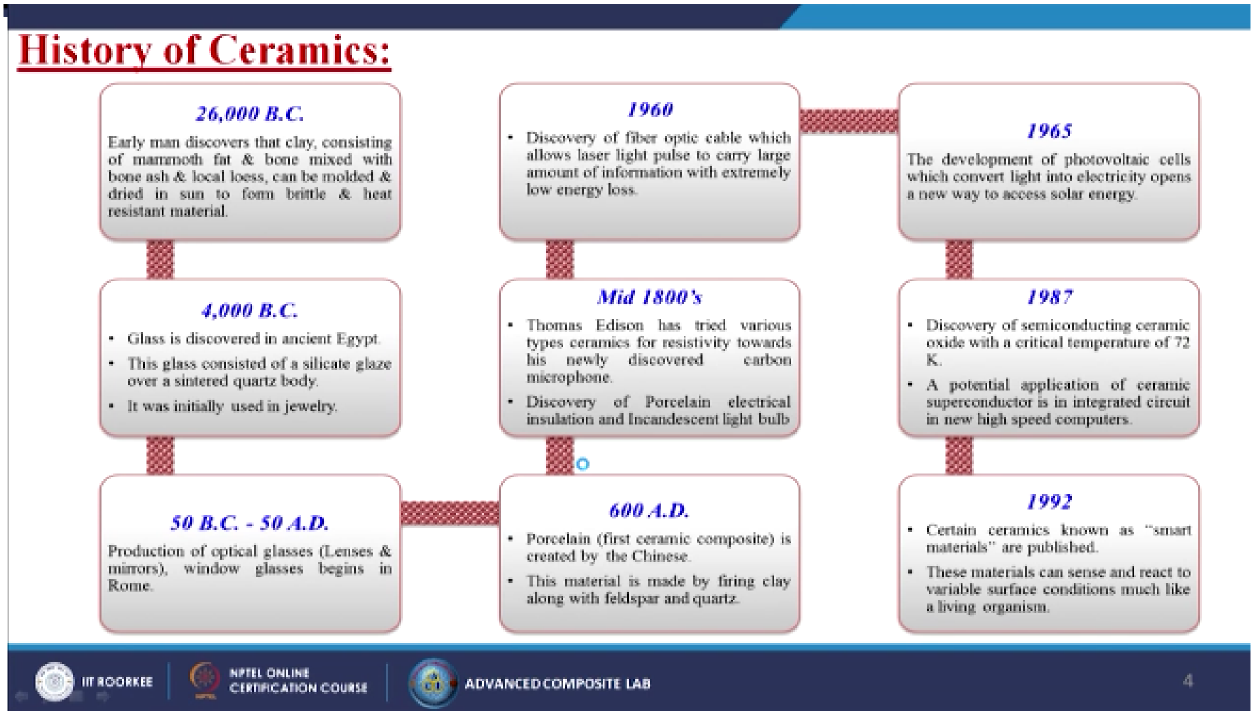
- The term "ceramics" comes from Greek word keramikos, which means "burnt stuff or drinking vessel".
- Ceramic material are inorganic, non-metallic material and things made from them.
- Most ceramics are compounds between metallic and non-metallic elements for which the interatomic bonds are either totally ionic bond or predominantly ionic but having same covalent character.
- They may be crystalline or partly crystalline.
- They are formed by the action of heat and subsequently cooling.


Cutting disc made of silicon carbide


Carbon ceramic disk brake


Spherical hanging ornament

to start just let us know about the definitions of the ceramics, the term ceramics comes from the Greek word keramikos which means the burnt stuff or drinking vessel. Ceramic materials are inorganic in nature, nonmetallic materials and things made from them. Most ceramics are compounds between metallic and nonmetallic elements for which the interatomic bonds are either totally ionic bond or predominantly ionic but having same covalent character. They may be crystalline or maybe partially crystalline. They are formed by the action of heat and subsequent cooling, so right hand side you can see some kind of ceramic materials like generally we are using the silicon carbide for the cutting disk, carbon ceramics for the disk brakes, nowadays we are using the disk breaks for all the vehicles and some spherical hanging arrangements from some aesthetics or maybe the aesthetic view or maybe some kind of home products.



Now we are going to discuss about the history of the ceramics, it has been started very long back, in 26,000 BC early man discovers that clay consisting of mammoth fat and bone mixed with bone action and local loess can be molded and dried in sun to form brittle and heat resistant materials, so that you can understand that from when the ceramics materials means working on the ceramics materials has been started.

Now it has come to 4,000 BC glass is discovered in ancient Egypt, this glass consisted of a silicate glaze over a sintered quartz body, it has initially used in jewelry purpose.

Then from 50 BC to 50 AD, production of optical glasses, lenses, and mirrors, window glasses begins in Rome, Italy.

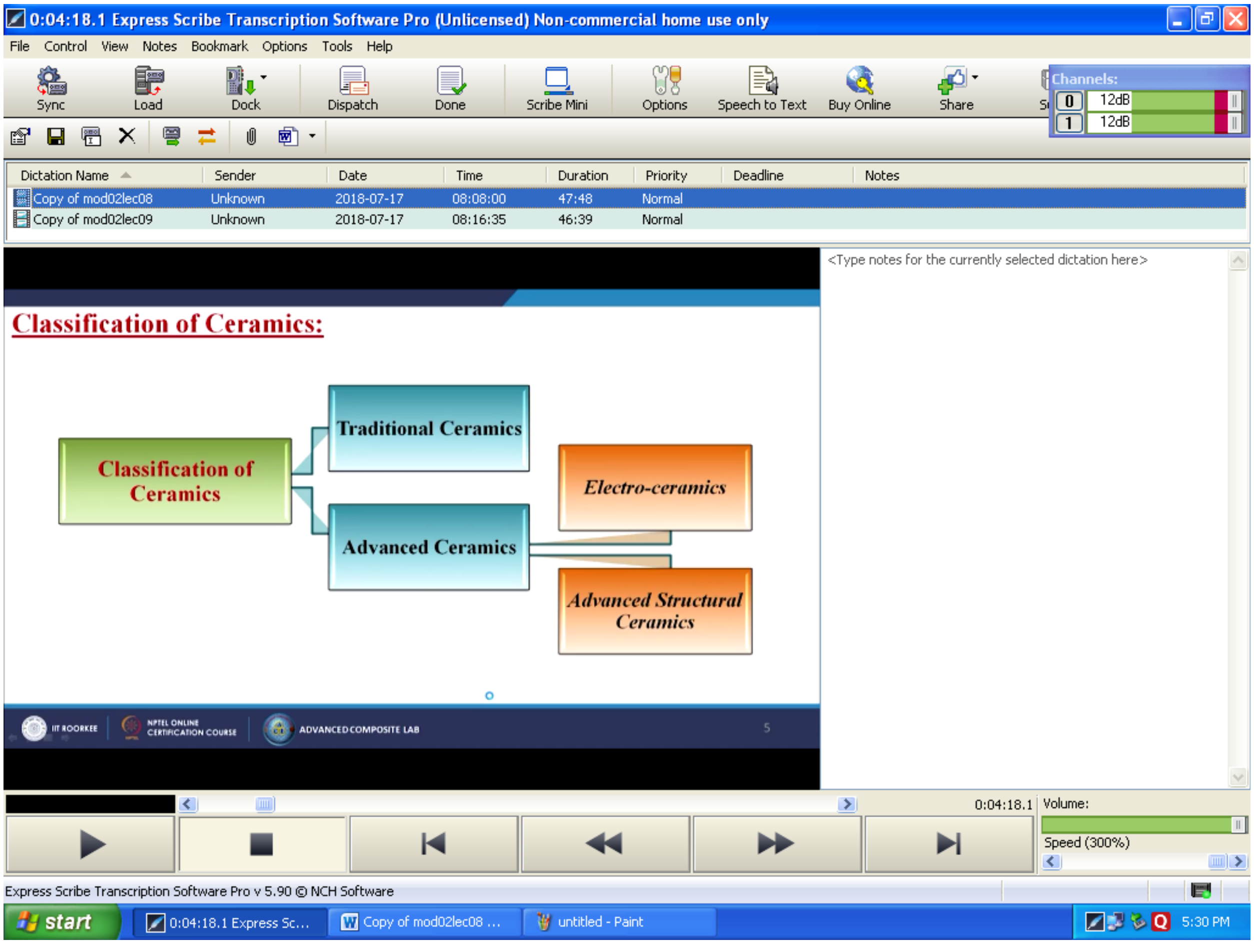
In 1960, discovery of 50 AD then it will come to 600 AD. Porcelain first ceramic composite is created by the Chinese. This material is made by firing clay along with feldspar and quartz.

Then we are moving to mid-1800's, Thomas Edison has tried various type ceramics for resistivity towards his newly discovered carbon microphone, discovery of porcelain electrical insulations and incandescent light bulb.

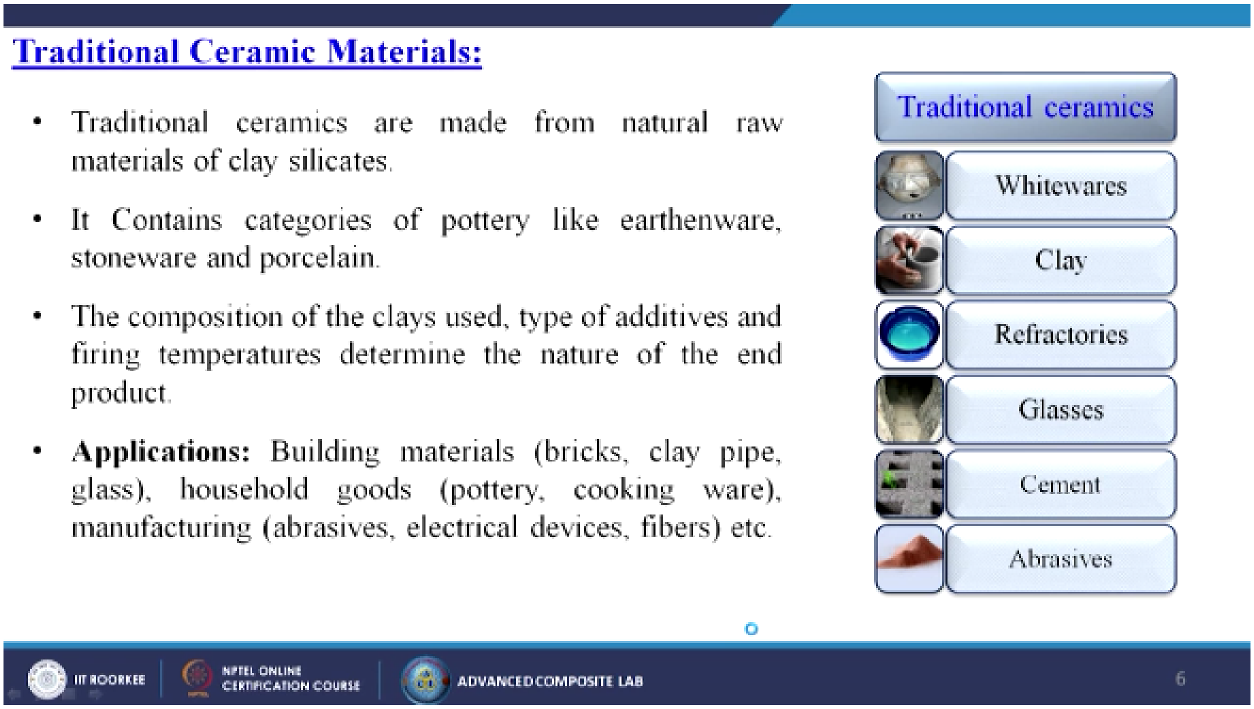
In 1960, discovery of fiber optic cable which allows laser light pulse to carry large amount of information with extremely low energy loss. Then we are moving to 1965, the development of photovoltaic cells which convert light into electricity opens a new way to access the solar energy.

In 1987, discovery of semiconducting ceramic oxide with a critical temperature of 72 kelvin, a potential application of ceramic superconductor is in integrated circuit, in new high speed computers.

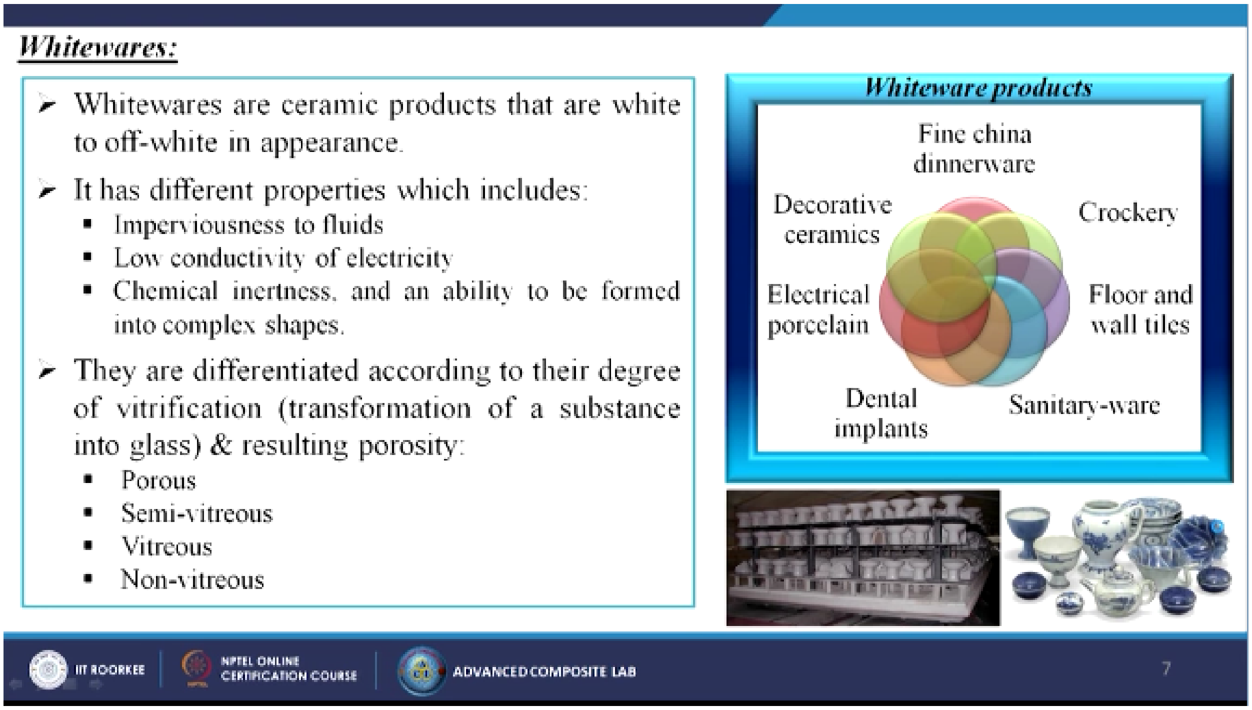
In 1992, certain ceramics known as smart materials are published, these materials can sense and react to variables surface conditions much like a living organism, and till today whatever the ceramics has been discovered for advance applications, everything will cover in this particular lecture.



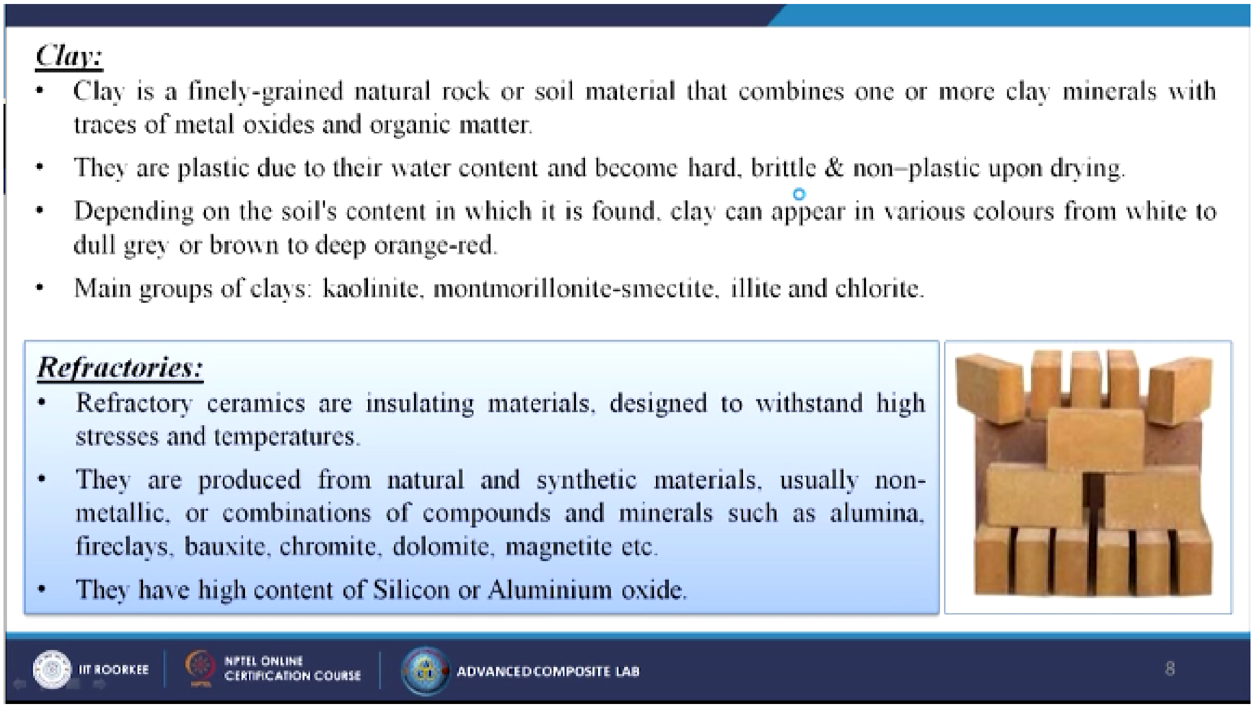
Now classification of the ceramics, so generally it is two types, one is known as the traditional ceramics, another one is known as the advanced ceramics. Advanced ceramics also has been divided into two sub categories, one is called the electro ceramics, another one is called the advanced structural ceramics.



So first we will discuss about the traditional ceramic materials, so traditional ceramics are made from natural raw materials which generally we are getting from the environment of clay or maybe clay silicates, it contains categories of pottery like earthenware, stoneware, and the porcelain. The composition of the clays used type of additives and firing temperatures determine the nature of the end product, generally applications, building materials like as we know that bricks we are using for making the buildings, clay pipe, glass, household goods like pottery, cooking ware, manufacturing like abrasives materials, electrical devices, fibers, etcetera. So right hand side you can find the traditional ceramics generally the whitewares, clay, refractories, glasses, cements, and the abrasives.

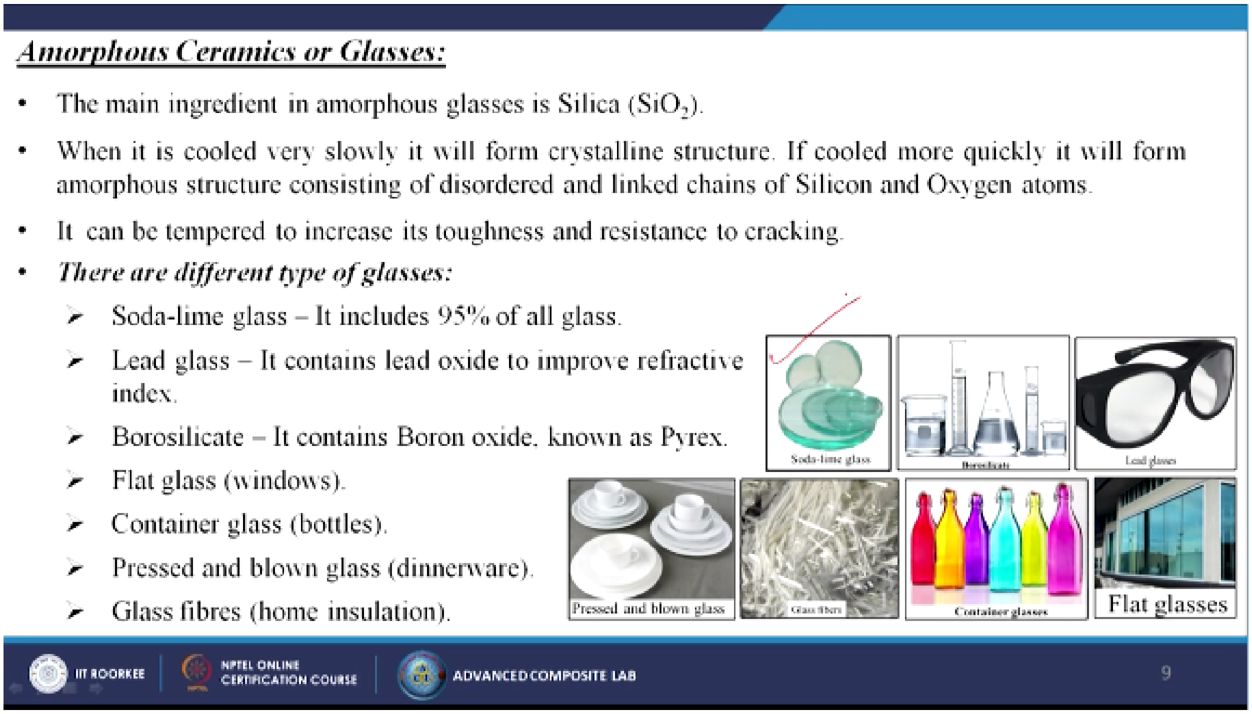


Now we'll discuss about the whitewares, whitewares are ceramic products that are white to off-white in appearances, it has different properties which includes imperviousness to fluids, low conductivity of electricity, chemical inertness and an ability to be formed into complex shapes. They are differentiated according to their degree of vitrifications, what is the meaning of vitrifications? Transformation of a substance into glass, and the resulting porosity, so the properties generally porous, semi-vitreous, vitreous and the non-vitreous, so when we are talking about the whiteware products you can find generally we are using it for the fine china dinnerware, crockery set, floor and wall tiles, sanitary ware, dental implants, electrical porcelain and the decorative ceramics, so bottom you can find that some kind of ceramics or maybe the whiteware products generally we are using in our day to day life.



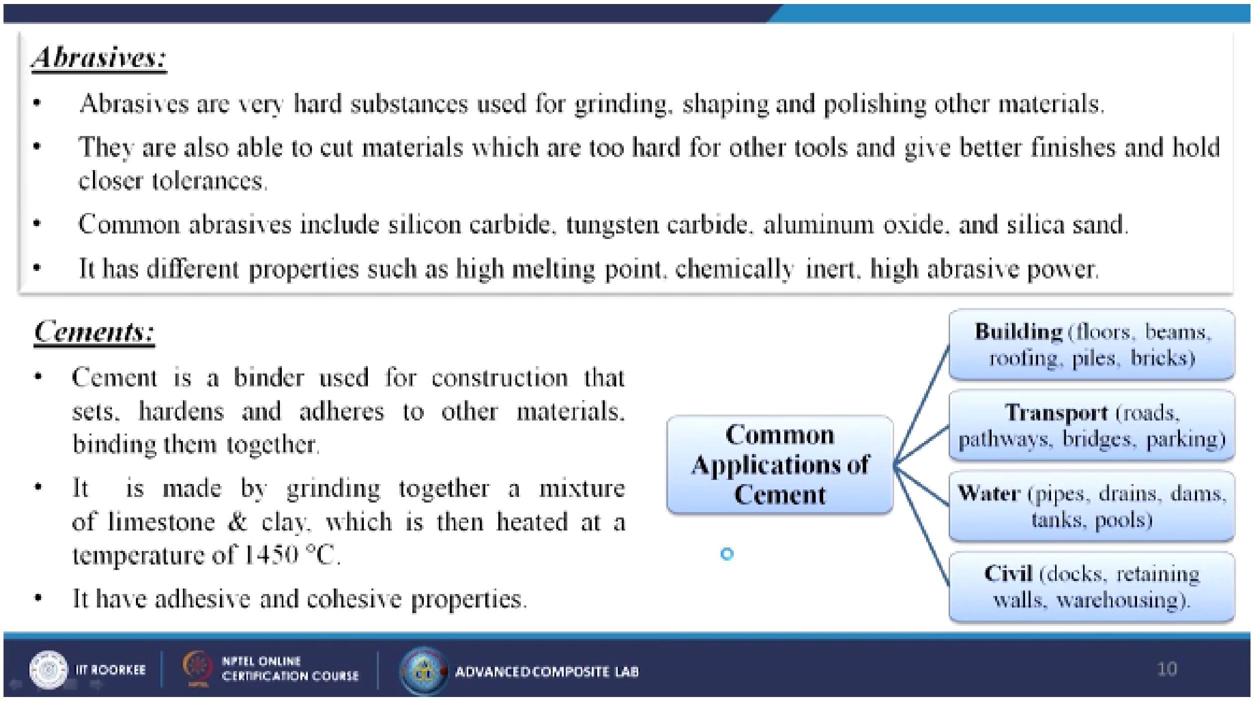
Now we'll discuss about the clay, so clay is a finely grained natural rock or soil material that combines one or more clay minerals with traces of metal oxides and the organic matter. They are plastic due to their water content and become hard brittle and non-plastic upon drying. Depending on the soils content in which it is found, clay can appear in various colours from white to dull grey or brown to deep orange red. Main groups of clays are kaolinite, montmorillonite-smectite, illite and chlorite.

Now we are going to discuss about the refractories, so generally the brick or maybe any kind of high temperature materials generally we are making it from the ceramics, so refractories ceramics are insulating materials, design to withstand high stresses and the temperature. They are produced from natural and synthetic materials usual in nonmetallic or combinations of compounds and minerals such as aluminum, fire clays, bauxite, chromite, dolomite, magnetite etcetera. They have high content of silicon, or aluminum oxide.



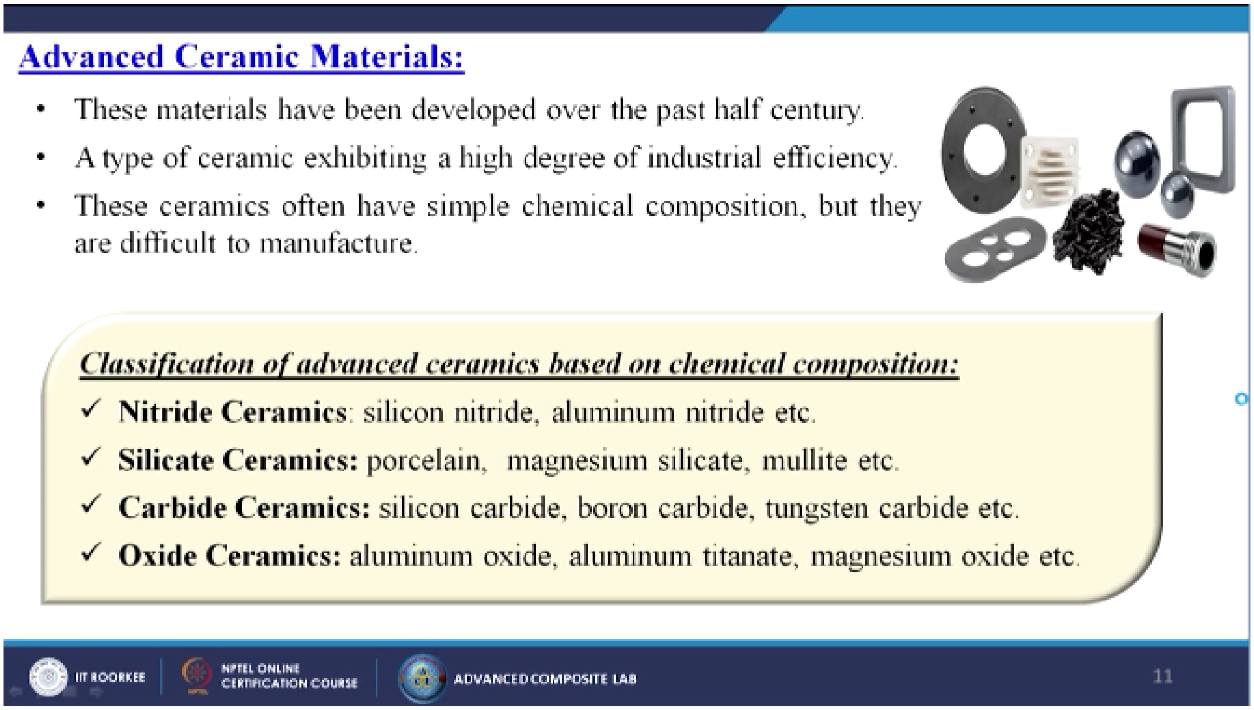
Now we are going to discuss about the amorphous ceramics or the glasses, the main ingredient in amorphous glasses is called the silica SiO2, when it is cooled very slowly it will form crystalline structure, if cooled more quickly it will form amorphous structure consisting of disordered and linked chains of silicon and the oxygen atoms. It can be tempered to increase its toughness and resistance to cracking, its depends upon your applications, so generally for the car wind shield we are using the tempered glasses or maybe some glasses where we are using for the high temperature applications we are using the tempered glasses, so it's varies from application to application. There are different types of glasses, generally soda-lime glasses, it includes 95% of all glass, so this is the pictorial view of soda-lime glass, then lead glass it contains lead oxide to improve the refractive index, borosilicate it contains the boron oxide known as the pyrex, so generally all our chemical, petri dish or maybe the pipette or burette, generally we are making it from the boron silicate.

Next we are discussing about the flat glasses, generally we are using for the windows for our household purposes, container glasses, bottles, then pressed and blown glasses generally dinner ware and the glass fibers for the home insulations for generally for the high temperature resistance we are using this kind of glass wools or maybe the glass fibers.

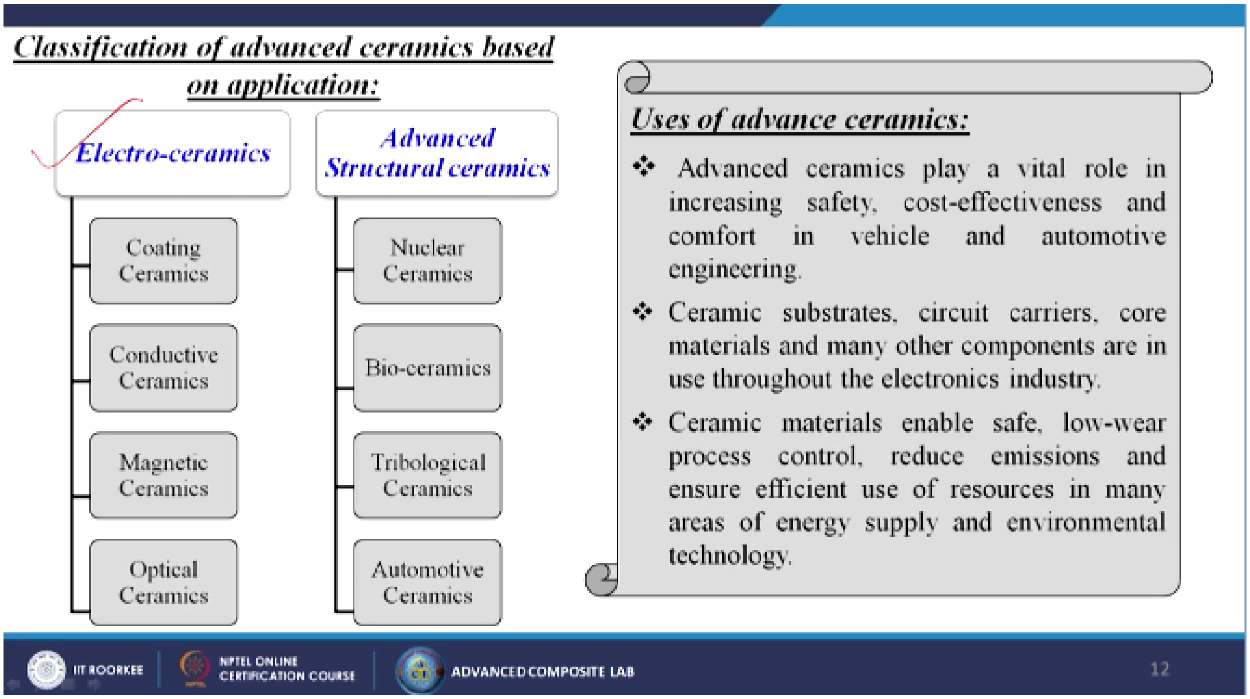


Now we are going to discuss about the abrasives, abrasives are very hard substances used for grinding, shaping or polishing the other materials, generally the emery paper or maybe for any kind of polishing or maybe the lapping or for the hunting methods generally we are using this kind of abrasive materials. They are also able to cut materials which are too hard, for other tools and give better finishes and hold the closer tolerance, so generally we are using this kind of abrasive particles to give the final shape of any products, common abrasives include silicon carbide, tungsten carbide, aluminum oxide and the silica sand. It has different properties such as high melting point, chemically inert and high abrasive power.

Now we are going to discuss about the cements, it is also one kind of ceramics, cement is a binder used for construction that sets hardens and adheres to other materials binding them together, generally for the building operations or maybe the structure applications we are using this cements, it is made by grinding together a mixture of limestone and clay, which is then heated at a temperature of 1450 degree centigrade, it has adhesives and cohesive properties, so common application of cements, generally as I already told we are using it for the buildings like floor, beams, roofing, piles and bricks. Transport for making the roads, pathways, bridges, parking. Water generally for the pipes, drains, dams, tanks and pools. Civil works like docks, retaining walls, warehousing, it is a very limited number of applications, but cement is having a very versatile applications.



Now we are going to discuss about the advanced ceramic materials, this materials have been developed over the past half century, because these all are the generally the research based or maybe the application based ceramic materials, the type of ceramic exhibiting a high degree of industrial efficiency, this ceramics often have simple chemical compositions but they are difficult to manufacture, so this classifications of the advanced ceramics based on chemical compositions, first it will come the nitrate ceramics, generally the silicon nitrate or maybe the aluminum nitrate, silicate ceramics like porcelain, magnesium silicate, mullite etcetera, carbide ceramics like silicon carbide, boron carbide, tungsten carbide, generally this kind of carbides we are using for cutting tool materials, oxides ceramics like aluminum oxide, aluminum, titanate, magnesium oxide, sometimes we are using this kind of materials for enhancing the strength of that particular material also.



Classification of advanced ceramics based on applications, so generally we are dividing into two parts, one is known as the electro ceramics, another is known as the advanced structural ceramics, when you are talking about the electro ceramics, first it will come the coating ceramics, then conducting ceramics, magnetic ceramics, and the optical ceramics, and when we are talking about the advanced structural ceramics first will come the nuclear ceramics, bio ceramics, tribological ceramics and the automotive ceramics, actually its totally depends upon the applications, if you are going to use it for some biotechnology side or maybe wear and aberrations or maybe some automobile parts, based on that you are giving the nomenclature for different types of ceramics.

What is the use of advanced ceramic? Advanced ceramics plays a vital role in increasing the safety, cost-effectiveness and comfort in vehicle and automotive engineering, as I told already as per our requirement, as per our own desire we are making this kind of ceramics as per our own requirement. Ceramics substrates, circuit carriers, core materials and many other components are in use throughout the electronics industries. Nowadays we are using this ceramics in a versatile manner for the electronics applications. Ceramic materials enables safe, low wear process control, reduce emissions and ensure efficient use of resource in many areas of energy supply and the environmental technology, this applications is also very, very limited. Ceramics nowadays we are using for means it’s a, for our day to day life it is fully joint with us.

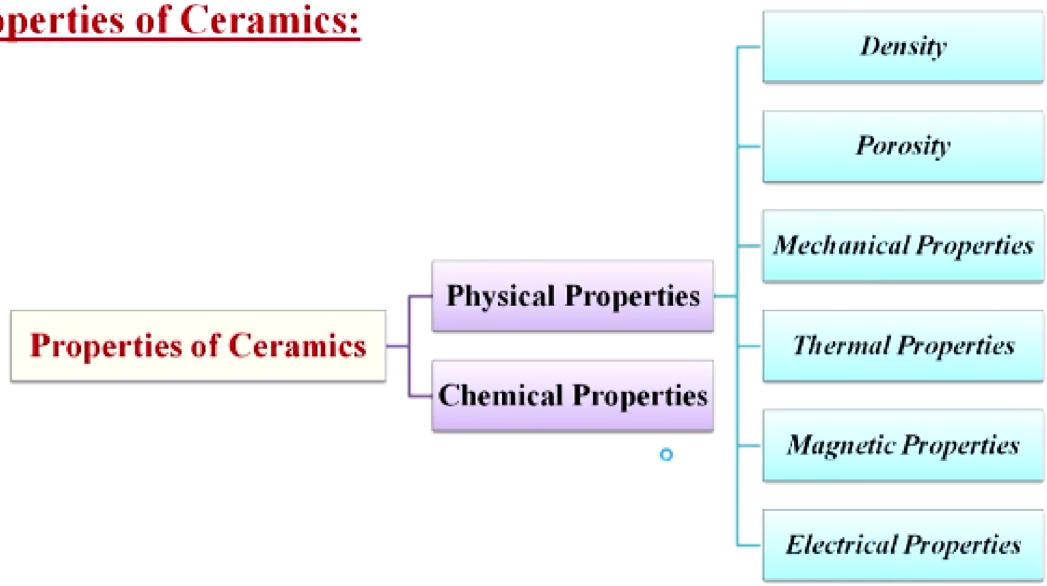
Preparation of advance and traditional ceramics:

Processes	Traditional Ceramics	Advanced Ceramics
Raw Materials Preparation	Raw mineral: Clay and Silica	Powders prepared by Chemical precipitation, Spray drying, Freeze drying, Vapour phase, Sol-gel
Forming	Potters wheel, Slip casting, Pressing	Slip casting, Injection molding, Sol-gel, Hot pressing
High temperature processing	Flame kiln	Electric furnace, Hot press, Reaction sintering, Plasma spraying, Microwave furnace
Finishing	Erosion, Glazing	Erosion, Laser machining, Plasma spraying, Ion-implantation, Coating
Characterization	Visible examination, Light microscopy	Light microscopy, XRD, Electron microscopy, Scanned probe microscopy, Neutron diffraction, Surface analytical methods

Now we will discuss about the preparations of advanced and the traditional ceramics, so first raw material preparations for that traditional ceramics, generally we are using the raw material as a clay and silica, when you are talking about the advanced ceramics we are using the powders generally prepared by the chemical precipitation methods, spray drying, freeze drying, vapour phase, or maybe by the sol-gel method. When you are talking about the forming process generally for the traditional ceramics we are using the potters wheel, slip casting, pressing. And for the advanced ceramics we are using the slip casting, injection moldings, sol-gel method, hot pressing. When you are talking about the high temperature processing, generally for the traditional ceramics we are using the flame kiln, but when you are talking about the advanced ceramics generally we are using the electric furnace, hot press, reaction sintering, plasma spraying and microwave furnace. Finishing products, generally for the traditional ceramics we are doing by it erosions or maybe the glazing methods, advanced ceramics we are using the erosions, laser machining, plasma spraying, ion-implantation which is the latest technology or maybe the coating technology.

When you are doing the characterizations for the traditional ceramics we are using the visible examinations or maybe simple the light microscopy, for advanced ceramics we are using for light microscopy XRD electron microscopy, scanning probe microscopy, neutron defractions, surface analytical methods, so from this particular table you can easily understand that for advanced ceramics we are using all kind of advanced technology to characterize or maybe to prepare this kind of ceramic materials.

Properties of Ceramics:



Now we are going to discuss about the properties of ceramics, so generally as we know the properties of ceramics has been divided into two parts, one is called the physical properties, another one is known as the chemical properties, so when we are talking about the physical properties generally the density, porosity, mechanical properties, thermal properties, magnetic properties and electrical properties, these all sub properties is coming under the physical properties, and rest one is known as the chemical properties.

Physical Properties:

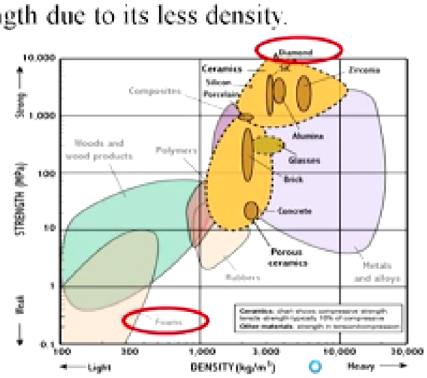
1. Density:

- Most of ceramics are lighter (20 and 70% of density of steel) than metals but heavier than polymers, ranging from 2-6 gm/cm^3.
- As the strength of ceramics increased the density become heavy and vice versa. For example: diamond has more strength due to high density whereas foam has less strength due to its less density.
- Calculation of ceramic density (ρ):

$$\rho = \frac{n' \left(\sum A_c + \sum A_A\right)}{V_c\, N_A}$$

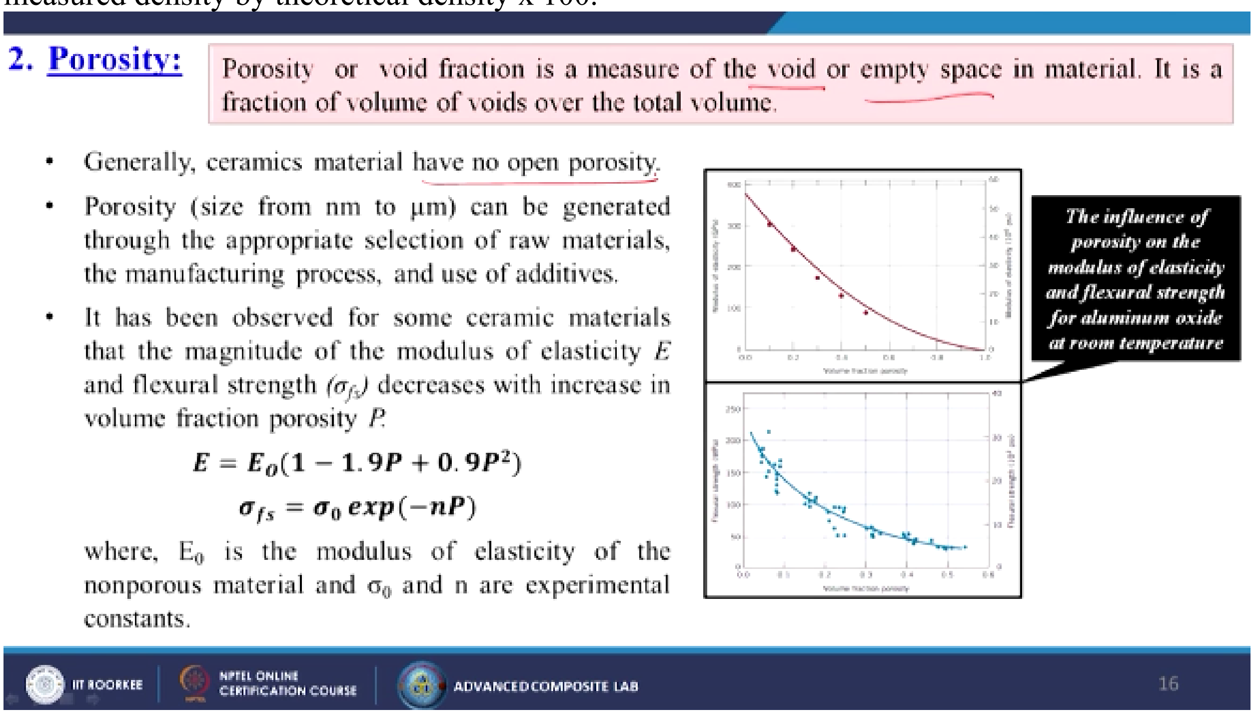
where, n' is no. of formula units' within the unit cell,
$\sum A_c$ & $\sum A_A$ are the sum of the atomic weights of all cations and anions in the formula unit,
V_C is the unit cell volume, N_A is Avogadro's number (6.023 X 10^{23} formula units per mol).

- % Theoretical density=$\frac{Measured\ density}{Theoretical\ density}$*100



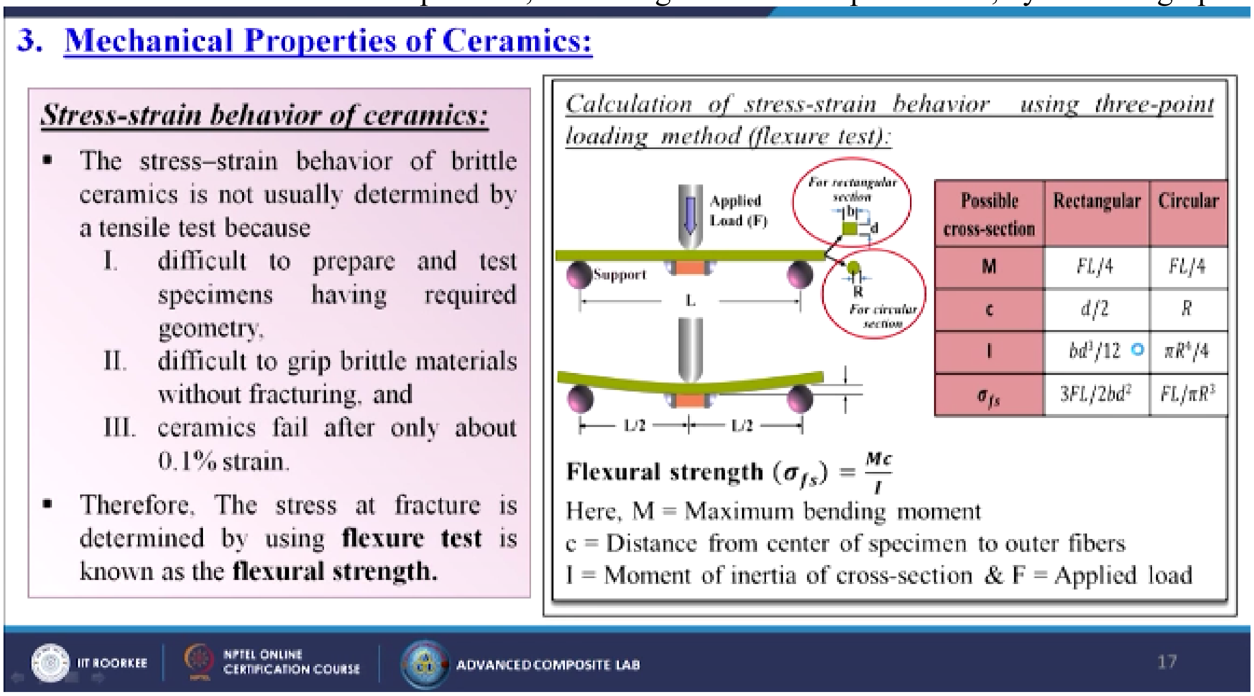
What is physical properties? First, physical properties is coming to our mind is known as the density, most of ceramics are lighter, generally 20 to 70% of density of the steel than metals but heavier than the polymers, ranging from 2 to 6 gram per centimeter cube, so this is the general basic density ranging of the ceramics, but maybe some advanced ceramics is having more than that or maybe that less than that of this particular value. As the strength of ceramics increased the density become heavy and vise-versa, for example diamond has more strength due to the high density whereas foam has less strength due to its less density, so from this particular image you can find that if the density of the foam is lighter, so automatically its strength is also less, but when we are talking about the diamond, so diamond the density is also too high and due to that its strength is also too high.

So now calculations of the ceramic density, generally it is denoted by the row is equal to N prime, then summation over AC + summation over AA by VC and NA, so where N prime is number of formula units within the units cell, summation over AC and summation over AA are the sum of the atomic weight of all cations and anions in the formula unit, VC is the unit cell volume, NA is the Avogadro's number generally it is 6.023 x 10 to the power 23, formula units per mole, and if we are going to calculate the percentage theoretical density, so generally it is measured density by theoretical density x 100.



Now we are going to discuss about the porosity of the ceramics, porosity or white fractions is a measure of the void or empty spaces in a material, it is a fraction of volume of voids over the total volume, so generally ceramic materials have no open porosity, porosity size from nanometer to micrometer can be generated through the appropriate selection of raw materials, the manufacturing process and the use of the additives, actually that is totally controllable, it has been observed for some ceramic material that the magnitude of the modulus of elasticity E and flexural strength sigma FS decrease with increase in volume fraction porosity P.

So generally E = E0 x 1 – 1.9P + 0.9 P square, sigma FS = sigma 0 exponential to the power – NP, where E0 is the modulus of elasticity of the nonporous materials and sigma 0 and N are the experimental constants, so from this right hand side graph you can easily find out that when the modulus of elasticity is going to be decreased, so automatically the volume fraction porosity is going to be increased, and same thing is happening for the flexural strength also, the flexural strength is also going to be decreased and the volume fraction of porosity is going to be increased, that means the influence of porosity on the modulus of elasticity and flexural strength for aluminum oxide at room temperature, we have given the examples of this, by this two graph.



Now we are going to discuss about the mechanical properties of ceramics, so first stress strain behavior of the ceramics, the stress strain behavior of brittle in ceramics is not usually determined by a tensile test because difficult to prepare an test specimens having required geometry, difficult to grip brittle materials without fracturing, because when you are going to give the press by the clip itself the material will break. And then third one is that ceramics fell after only about 0.1% of strain, so that's why generally we are not going to do any kind of tensile testing for ceramic materials, therefore the stress at fracture is determined by using the flexure test is known as the flexural strength which we are thinking that is equivalent to the tensile strength of that particular ceramic material.

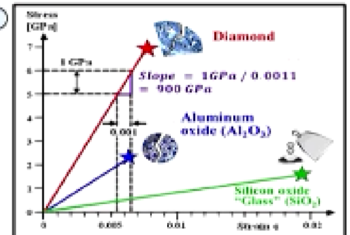
So how we are going to calculate? So calculation of stress strain behavior using 3 point loading methods we have shown into this particular image, so in this particular image you can find for rectangular sections the thickness of that materials is D, and the width is B, and if it is the circular one the radius of that particular material is known as the R, capital R.

So now how we are going to calculate? So far possible cross section we are calculating, when we are calculating the M, what is M? M is nothing but the maximum bending moment, so when we are calculating the maximum bending moment for the rectangular material, it is known as the FL/4, and for the circular also it is known as the FL/4. When we are going to calculate the distance from center of specimen to outer fibers, so generally for the rectangular materials it is D/2, and for the circular one it is only the capital R, and when you are talking about the moment of inertia cross sections capital I which is nothing but the small b, small d cube/12 for the rectangular one, and for circular one pi capital R to the power 4/4.

Now we are going to measure the flexural strength, what is the formula of that flexural strength? Sigma FS, it's nothing but the MC/I, so sigma FS for the rectangular material is 3FL/2bd square, and for the circular capital FL/pi capital R cube, so by using this formula you can easily calculate the flexural strength of any ceramic materials.

Elastic behavior:

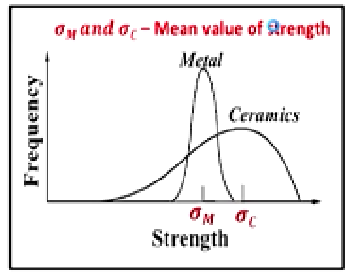
- Elastic stress–strain behavior for ceramic materials using flexure tests is similar to the tensile test results for metals.
- Elastic modulus (slope) of ceramics is usually higher than for metals, because ceramics are bonded either covalently or ionically.
- Range of elastic modulus for ceramic is about 70 and 500 GPa.



Elastic stress-strain curve of diamond, aluminum oxide and glass

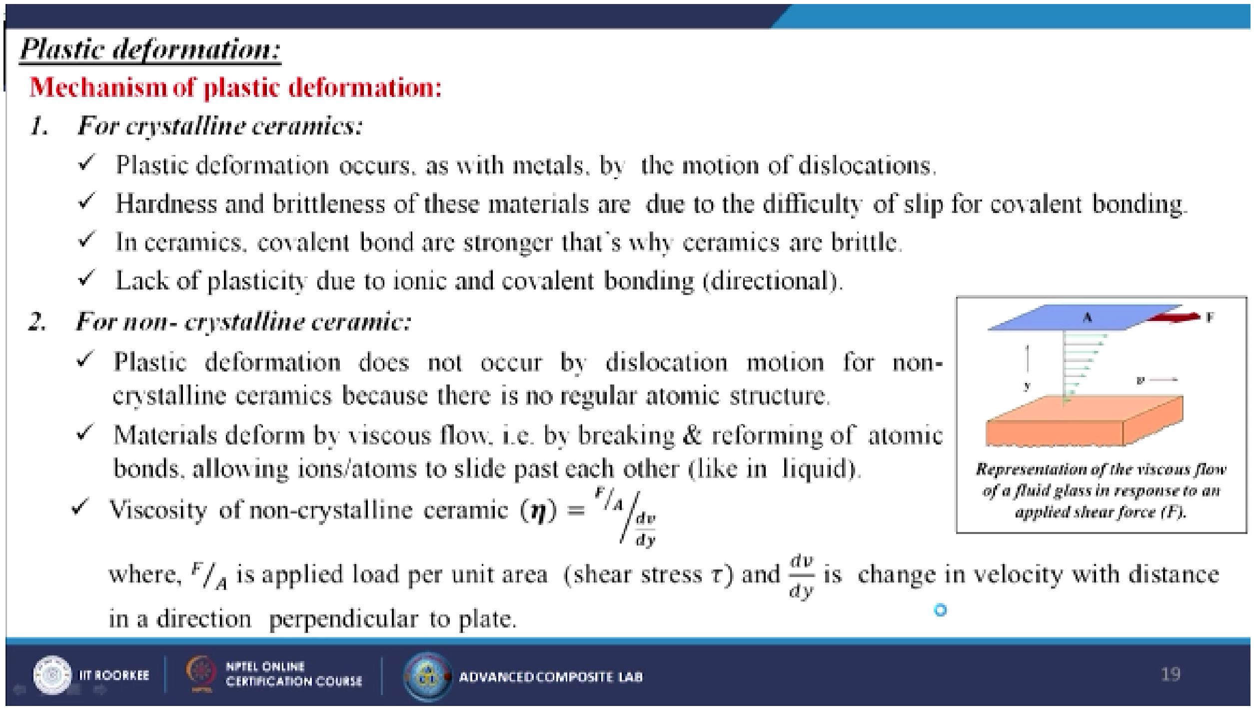
Strength of ceramics:

- Ceramics have compressive strengths about ten times higher than their tensile strength.
- The tensile strength of ceramics is low because the existing flaws giving stress concentration.
- Ceramics are usually used in applications where load are compressive.
- It depends on the material composition, production condition, manufacturing process, grain size of initial material and their additives.



Now we are going to discuss about the elastic behavior of ceramic materials, generally elastic stress strain behavior for ceramic materials using flexural test is similar to the tensile test results for the metals which I have already told. Elastic modulus slope of ceramics is usually higher than for metals, because ceramics are bonded either covalently or ionically and always it is much higher than the metallic bonds of any metals, range of elastic modulus for ceramic is about 70 to 500 gigapascal, so from this particular curve you can understand that the diamond generally it is coming around 900 GPA, but for aluminum oxide it is lesser and for silicon dioxide it is more lesser.

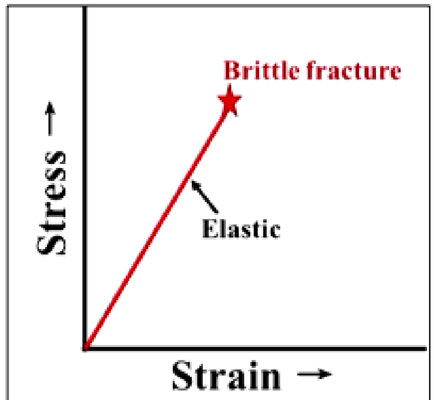
Strength of ceramics, ceramics have compressive strengths about 10 times higher than their tensile strength, the tensile strength of ceramics is low because the existing flaws giving the stress concentrations of that particular materials, ceramics are usually used in applications where load or compressive in nature, it depends on the material compositions, production conditions, manufacturing process, grain size of initial materials and their additives, so this is the common graphs generally we are showing that strength of the ceramics is automatically more or less than the metals.



Now we are going to discuss about the plastic deformations of ceramics, so first we have to know that what is the mechanism of the plastic deformations, so for crystalline ceramics plastic deformation occurs as with metals by the motion of dislocations, hardness and brittleness of this materials are due to the difficulty of slip for covalent bonding, because covalent bonding or maybe the ionic bonding is very, very strong bonding, so at slip is not possible in this particular case. In ceramics, covalent bonds are stronger that's why the ceramics are brittle in nature, lack of plasticity due to ionic and covalent bonding direction, which is in directional in nature, but when you are talking about the, for the non-crystalline ceramics plastic deformation does not occur by dislocation motion for non-crystalline ceramics because there is no regular atomic structure, materials deformed by viscous flow that is by breaking and reforming of atomic bonds allowing ions and atoms to slide past each other like in liquid, so the slipping mechanism is taking place, so in this particular case here the AF, you can see the AF is known as the shear force, A is the area, and V is the velocity, and Y is the distance in between, so in this case particular case viscosity of the non-crystalline ceramic eta = F/A / DV/DY where F/A is the applied load per unit area or which is known as the shear stress or maybe the tau, and DV/DY is the change in velocity with distance in a direction perpendicular to the plate itself.

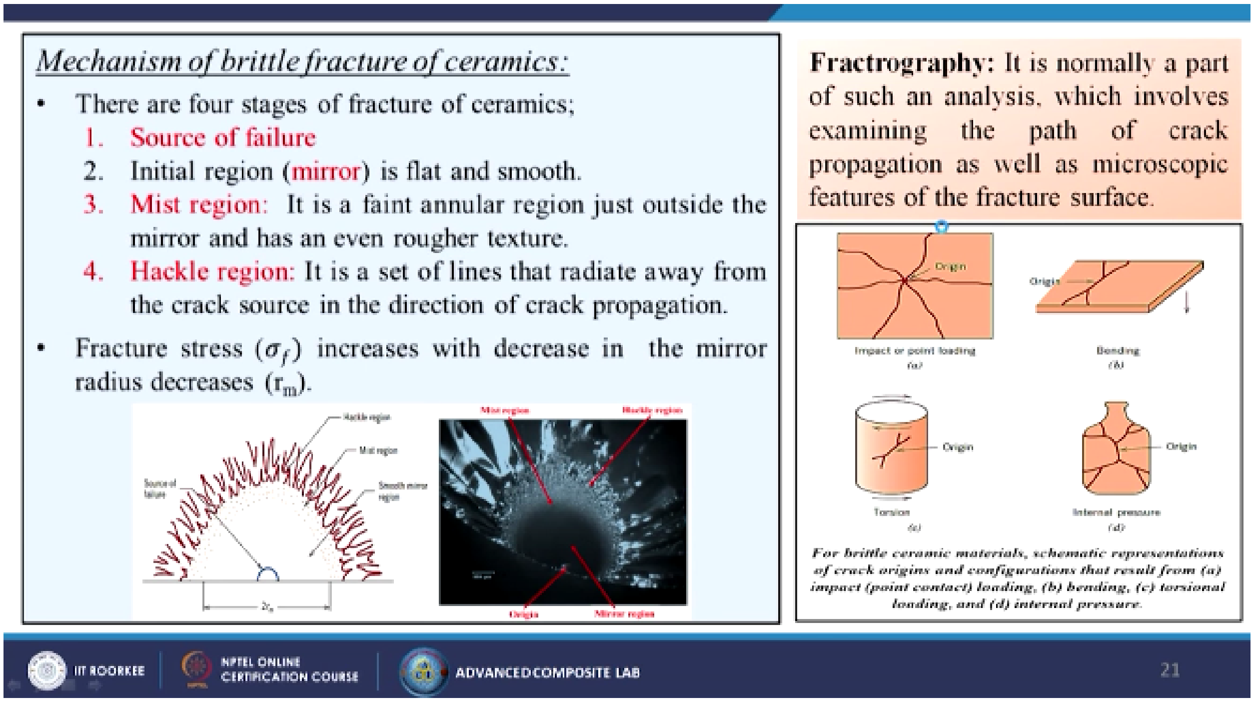
Brittle fracture of ceramics:

- At room temperature, both crystalline and non-crystalline ceramics shows fracture before any plastic deformation in response to an applied tensile load.
- Brittle fracture process consists of the formation and propagation of cracks through the cross section of material in direction perpendicular to the applied load.
- Crack growth in crystalline ceramics may be either trans-granular (through the grains) or inter-granular (along grain boundaries).



Stress- strain curve of ceramic material

Now we are going to discuss about the brittle fracture of ceramics, so at room temperature both crystalline and non-crystalline ceramics shows fracture before any plastic deformation in response to an applied tensile load. Brittle fracture processes consist of the formation and propagation of cracks through the cross section of material in direction perpendicular to the applied load, this is the very, very important parameters, so generally the crack formation is taking place for the ceramic materials. Crack growth in crystalline ceramics maybe either trans-granular through the grains or maybe the inter-granular along grain boundaries, so in this particular this is simple the stress strain curve and this is the elastic limit and you can get the brittle fracture in this particular point for a ceramic, so what is the mechanism of brittle fracture



in ceramics? There are four stages of fracture ceramics because if I give an example of an breaking of a glass you can better understand that how the fracture is taking place for the ceramics materials, so source of failure first one, second is the initial region, mirror is very, very flat and smooth as we already know.

Next is called the mist region and last one is called the hackle region, so now I'll tell you one by one, so suppose this is your glass, so this is your source of failure, and then there is some initial area or maybe the initial region, so generally the initial region is this zone actually.

Next is called the mist region, so this zone is called that, all that data side is called the mist zone, it is faint annular region just outside the mirror and has an even rougher texture.

Next hackle region, it is a set of lines you can find that there is a cracks lines generally we are calling it, that radiate away from the crack source in the direction of crack propagations, so fracture stress sigma F increases with decrease in the mirror radius decreases R subscript M, so right hand side is the real image of cracking of any mirror, so this is known as the origin, then this is known as the mirror region and then this zone is known as the mist region, and then last one is known as the hackle region.

So what do you mean by fractrography? It is normally a part of such an analysis which involves examining the part of a crack propagations as well as microscopic features of the fracture surface, so here you can see this is the origin and then after that the crack is propagating into different directions, so this is, crack is propagating into the different directions, here the bending the crack originating is taking place and then crack is propagating into this all directions, for the torsions and internal pressure say suppose you are having any glass bottles or maybe some ceramic material bottle, and internally you are giving a high pressure, so how the crack propagation is taking place in this particular ceramic materials.

Hardness:

- One beneficial mechanical property of ceramics is their hardness, which is often utilized when an abrasive or grinding action is required.
- Ceramics materials are considered as the hardest material.
- For ceramics hardness is defined at the resistance to elastic deformation of the surface.
- Hardness is affected from porosity in the surface, the grain size of the microstructure and the effects of grain boundary phases.
- The high hardness of technical ceramics results in favorable wear resistance, ceramics are thus good for tribological applications.
- Test procedures of determining the hardness of ceramic materials according to Knoop, Vickers, Rockwell as shown in table. (Already discussed in lecture-6)

Material class	Vickers hardness (GPa)
Glasses	5 – 10
Zirconia, Aluminium nitrides	10 – 14
Alumina, Silicon nitrides	15 – 20
Silicon carbides, Boron carbides	20 – 30
Cubic boron nitrides	40 – 50
Diamond	60 – 70 >

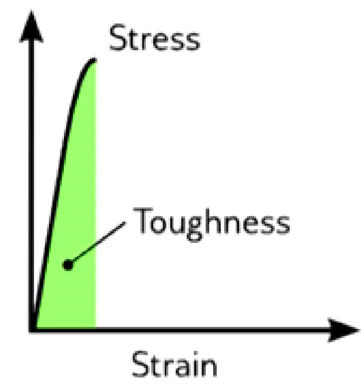
Now we are going to discuss about the hardness, so one beneficial mechanical property of ceramics is their hardness which is often utilized when an abrasive or grinding action is required, yes, because when we are going to grind any material so we are going to choose that abrasive particles which is more harder than the walk piece material, so ceramics materials are considered as the hardest material, so for ceramics hardness is defined at the resistance to elastic deformations of the surface, hardness is affected from porosity in the surface, the grain size of the microstructure and the effects of grain boundary phases.

The high hardness of technical ceramics results in favorable wear resistance, ceramics are thus good for tribological applications means for any kind of friction or maybe the wear mechanisms.

Test procedures of determining the hardness of ceramic materials according to Knoop, Vickers, Rockwell as all shown in this particular table. So if you see that material class here left hand side all are the different type of ceramic materials and we are going to give the example of the weaker hardness of those in the gigapascal, so for glasses it is 5 to 10, for zirconia aluminum nitrides its 10 to 14, for alumina silicon nitrides it is 15 to 20, silicon carbides and boron carbides is generally 20 to 30, cubic boron nitrides which is also one kind of hardest material which we are synthesizing in our laboratory, it’s known as 40 to 50 gigapascals, and for diamond it is 60 to 70 or more than that.

Toughness:

- Both ceramics and glasses, at room temperature will undergo fast fracture in a tensile test before any plastic deformation has occurred.
- They have a fracture toughness about fifty times less than metals, even though their bonding forces are higher.
- Using hot pressing, reaction bonding to improve toughness.



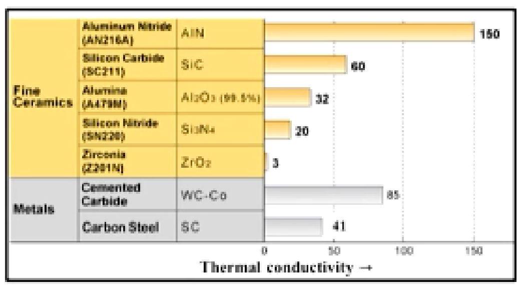
Toughness graph (Tensile stress vs Tensile strain curve)

Now we are going to discuss about the toughness of ceramic materials, so both ceramics and glasses at room temperature will undergo the first fracture, in a tensile test before any plastic deformations has occurred, they have a fracture toughness about 50 times lesser than the metals, even though their bonding forces are higher, yes, because as I already told they're possessing the covalent or maybe the ionic bonding which is much harder than the metallic bonding. Using hot pressing reaction bonding to improve toughness, so this is the simple stress strain curve and we have already gone through these graphs into the metal parts so this is simply giving you the toughness of that particular ceramic material.

4. Thermal Properties of Ceramics:

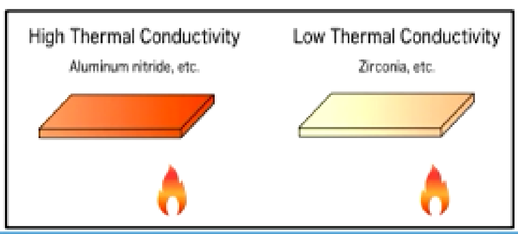
Thermal conductivity:

- It is the property of a material that indicate its ability to conduct heat.
- Ceramic have low thermal conductivity due to ionic-covalent bonding which does not have free electron opposite to metals.
- Ceramic materials are used for thermal insulation due to their low thermal conductivity (except silicon carbide, aluminium nitride).



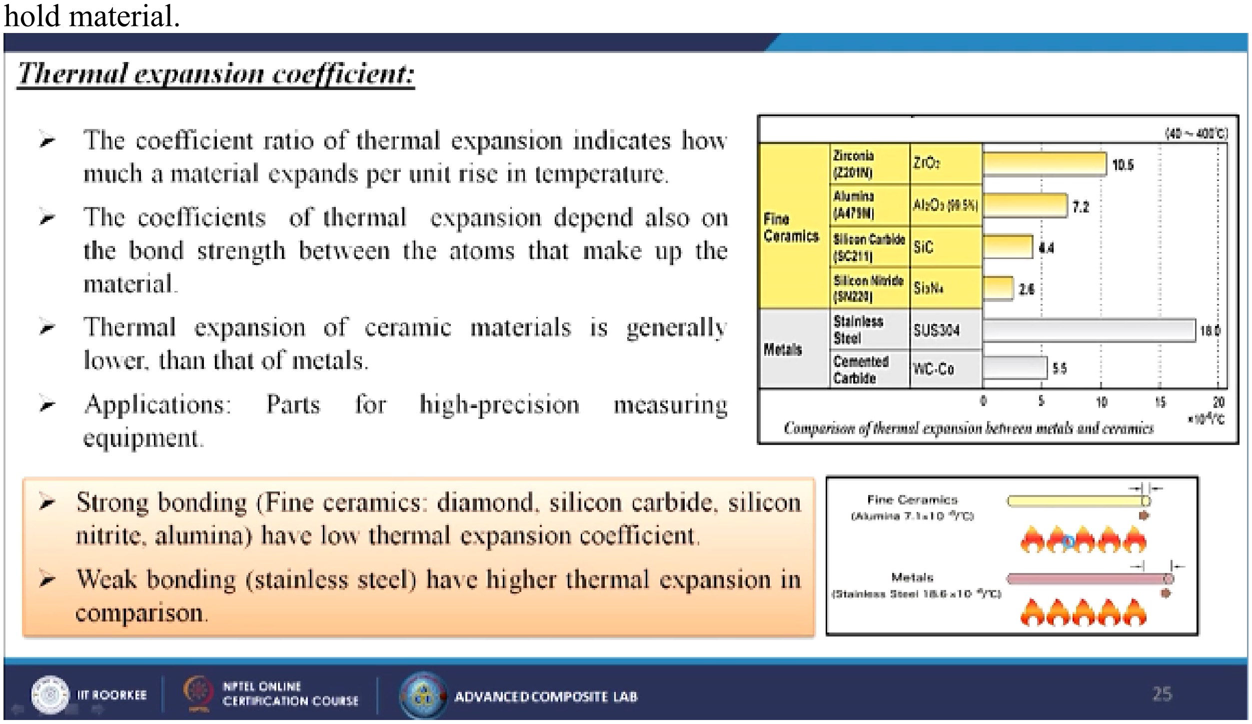
Applications:

- ✓ Aluminum nitride is used in IC packages for semiconductors that emit high volumes of heat.
- ✓ Zirconia blocks heat effectively and its coefficient of thermal conductivity is low. It is used for kiln walls, which are exposed to high temperatures.

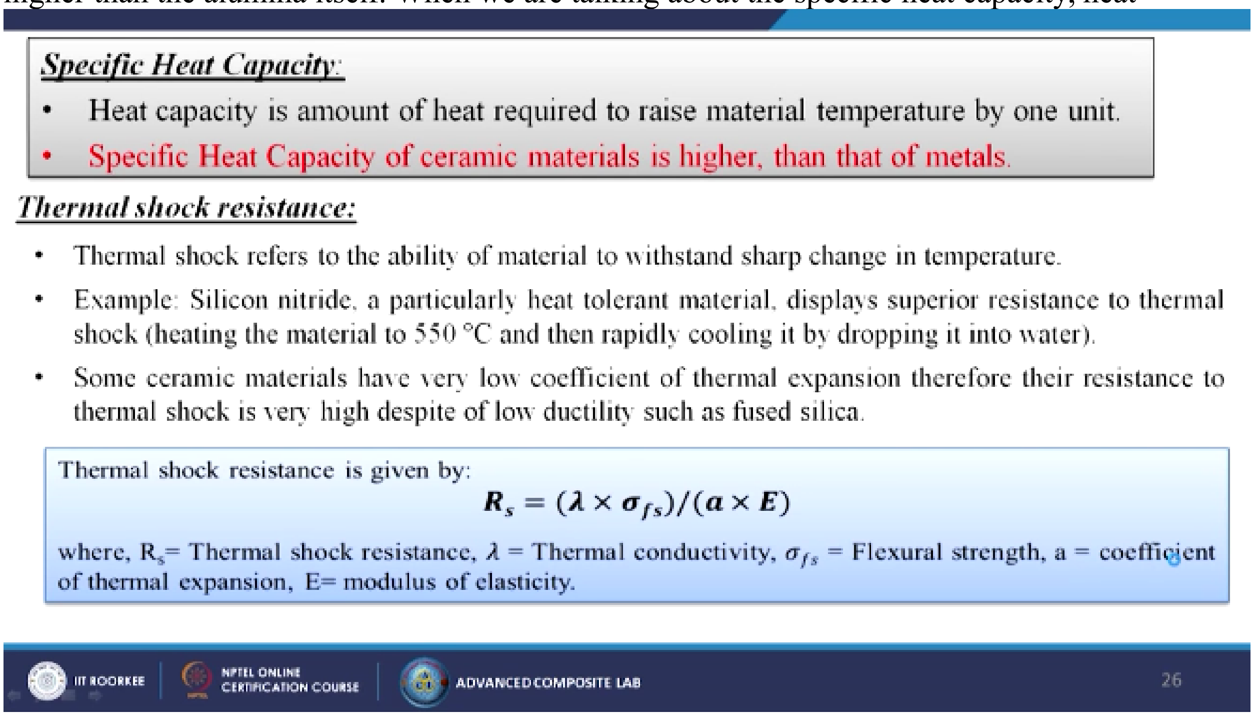


Now we are going to discuss about the thermal properties of ceramics, so first it comes in our mind is known as the thermal conductivity, it is the property of a material that indicates its ability to conduct the heat so that heat can easily flow from one point to another point, ceramic have low thermal conductivity due to ionic covalent bonding which does not have free electron opposite to metals, means metals is having more free electrons than the ceramics that's why the thermal conductivity of metals is much higher than the ceramic materials.

Ceramic materials are used for thermal insulations due to their low thermal conductivity except silicon carbide, aluminum nitride, these all are the exceptional ceramic materials, what are the applications? Aluminum nitride is used in IC packages so generally for the electronic purposes for semiconductors that emit high volume of heat. Zirconia blocks heat effectively and it's coefficient of thermal conductivity is low, it is used for kiln walls which are exposed to high temperature, generally we are using this zirconia blocks for the furnace or maybe oven, or maybe the high temperature obligations, so in this particular case you can find the thermal conductivity of different materials, when you are talking about the fine ceramics zirconia is only 3, but whereas aluminum nitride is 150, same thing you can find for the metals like cemented carbide, it's tungsten carbide with cobalt it is having 85 and carbon steel it is having SC is 41, and alumina and silicon carbide and silicon nitride they are much lesser than the metals one. So high thermal conductivity like aluminum nitrides so if you give the temperature, the temperature will go from one point to another point that means the temperature will be homogeneously dispersed throughout the material, but when you are talking about the zirconia from the colour itself when you are giving the temperature at a particular point the temperature is not flowing smoothly to hold material.

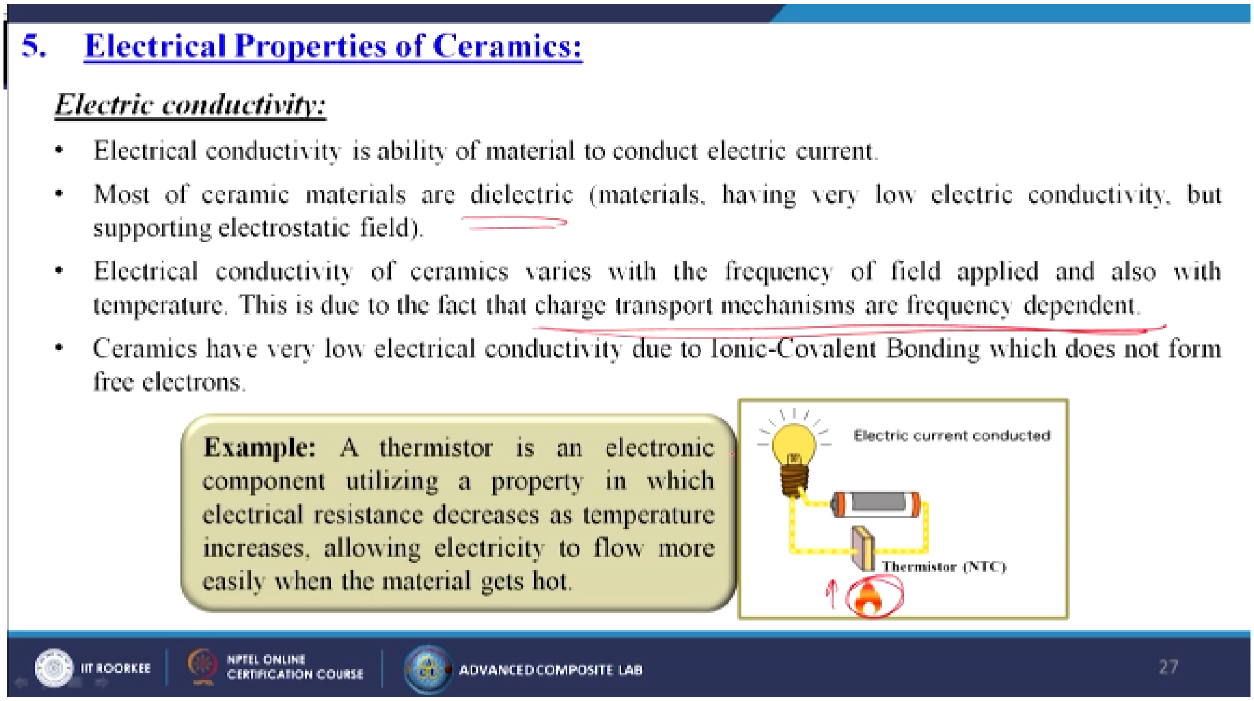


Now we are going to discuss about the thermal expansion coefficient, the coefficient ratio of thermal expansion indicates how much a material expands per unit raise in temperature, say suppose we are going to raise a degree of temperature so how much the material will elongate, the coefficient of thermal expansion depends also on the bond strength between the atoms that make up the material, thermal expansion of ceramic materials is generally lower than that of metals, applications parts for high-precision measuring equipment generally we are using this kind of materials, what are the reasons? Strong bonding, fine ceramics like diamonds, silicon carbides, silicon nitride and alumina have low thermal expansion coefficient, weak bonding like stainless steel have higher thermal expansion in comparison, so here from this particular graph also or maybe the data table you can find the value, say suppose for silicon nitride its 2.6, but when we are talking about the zirconia oxide it is about 10.5, but it is for stainless steel it is 18, 18 x 10 to the power -6 per degree centigrade, and it is for cemented carbide it is generally 5.5, so for fine ceramics you can see that a very negligible amount of expansion has been taken place due to the temperature, and thus its value is only 7.1 x 10 to the power -6 per degree centigrade, for alumina but simultaneously when we are talking about the metals you can find for stainless steel it is 18.6 x 10 to the power -6 per degree centigrade, so the thermal expansion here is much higher than the alumina itself. When we are talking about the specific heat capacity, heat



capacity is amount of heat required to raise the material temperature by 1 unit, specific heat capacity of ceramic materials is higher than that of metals.

Now we are going to discuss about the thermal shock resistance, thermal shock refers to the ability of material to withstand the sharp changes in temperature that means if we are going to change the temperature the material shape and size is not going to change so rapidly, so like example silicon nitride, a particularly heat tolerant material displays superior resistance to thermal shock, when we are raising the temperature of that silicon nitride up to 550 degree centigrade and suddenly we are dipping that materials into the water, no material shape has been changed or maybe the material properties is not going to be changed, some ceramic materials have very low coefficient of thermal expansion therefore their resistance to thermal shock is very high, despite of low ductility such as fused silica. So there is certain formula to measure the thermal shock resistance which is denoted by the capital R subscript S = lambda x sigma FS/small a x capital E, whereas capital R subscript, S is known as the thermal shock resistance, lambda is thermal conductivity of that particular materials sigma FS is the flexural strength, small a is the coefficient of the thermal expansion, and E is the modulus of elasticity.



Now we are going to discuss about the electrical properties of ceramics, so first electrical conductivity, so electrical conductivity is the ability of material to conduct the electric current, most of ceramic materials are dielectric in nature, what is dielectric? The materials having very low electrical conductivity but supporting the electrostatic field, electrical conductivity of ceramics varies with the frequency of field applied and also with temperature, thus is due to the fact that charge transport mechanisms are frequency dependent that is the important one. Ceramics have very low electrical conductivity due to ionic covalent bonding which does not form the free electrons, so that's why the electrical conductivity for metals is more higher than the ceramics.

Here we are going to give an example of an thermistor, so thermistor its an electronic component utilizing a property in which the electrical resistance decrease as temperature increases, actually here we are going to give the temperature, as the temperature is increasing so the resistance of this particular ceramic material is going to be decreased, that's why the flow of electricity is more and that's why the light is glowing, so that is one kind of examples of the electrical conductivity of ceramic material.

Superconductivity:

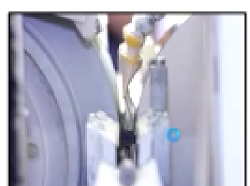
- Superconductors can transport electric current without any resistance and thus without any losses whatsoever.
- Despite of very low electrical conductivity of most of the ceramic materials, there are ceramics, possessing superconductivity properties (near-to-zero electric resistivity).
- Lanthanum (yttrium)- barium- copper oxide ceramic may be superconducting at temperature as high as 138 K. This critical temperature is much higher, than superconductivity critical temperature of other superconductor (up to 30 K).

There is one another interesting parameters which is known as super conductivity of ceramics, so super conductors can transport electric current without any resistance and thus without any losses whatsoever. Despite of very low electrical conductivity of most of the ceramic materials there are ceramics, possessing the super conductivity properties, near to zero electric resistivity. An example, lanthanum, yttrium, barium, copper oxide ceramic maybe super conducting at temperature as high as 138 kelvin, this critical temperature is much higher than superconductivity critical temperature of some other superconductors up to 30 kelvin only.

Piezoelectric property:

- Piezoelectric property of ceramics can be defined by piezoelectric effect. Piezoelectric effect can be defined as:
  - ✓ **Generating piezoelectric effect**: Mechanical stress, applied between two surfaces of a solid dielectric part, generates voltage between the surfaces.
  - ✓ **Motor piezoelectric effect:** Voltage, applied between two surfaces of a solid dielectric part, results in contracting (or expanding) of the part.
- Some ceramics (lead zirconate titanate, barium titanate, bismuth titanate, lead magnesium niobate) have piezoelectric properties.

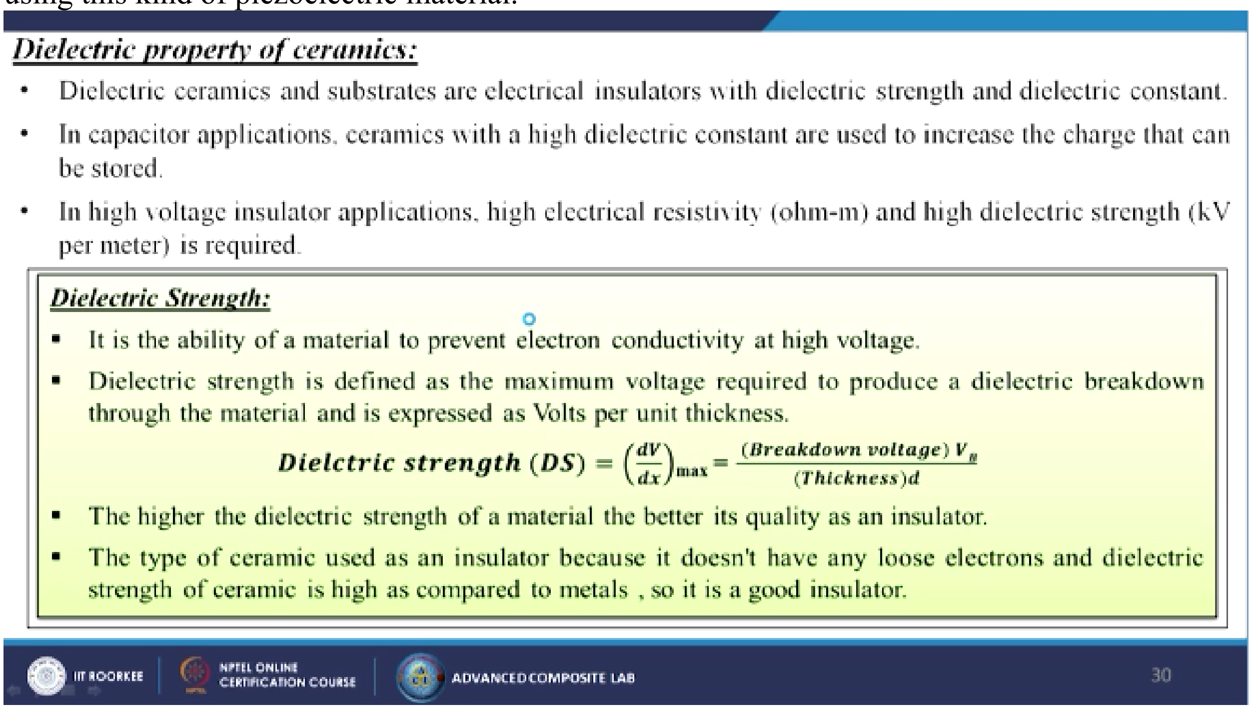
Applications: Piezoelectric ceramics are used for manufacturing various transducers, actuators and sensors like hydrophones, sonar, strain gauges, medical ultrasound equipment.



Piezoelectric actuator

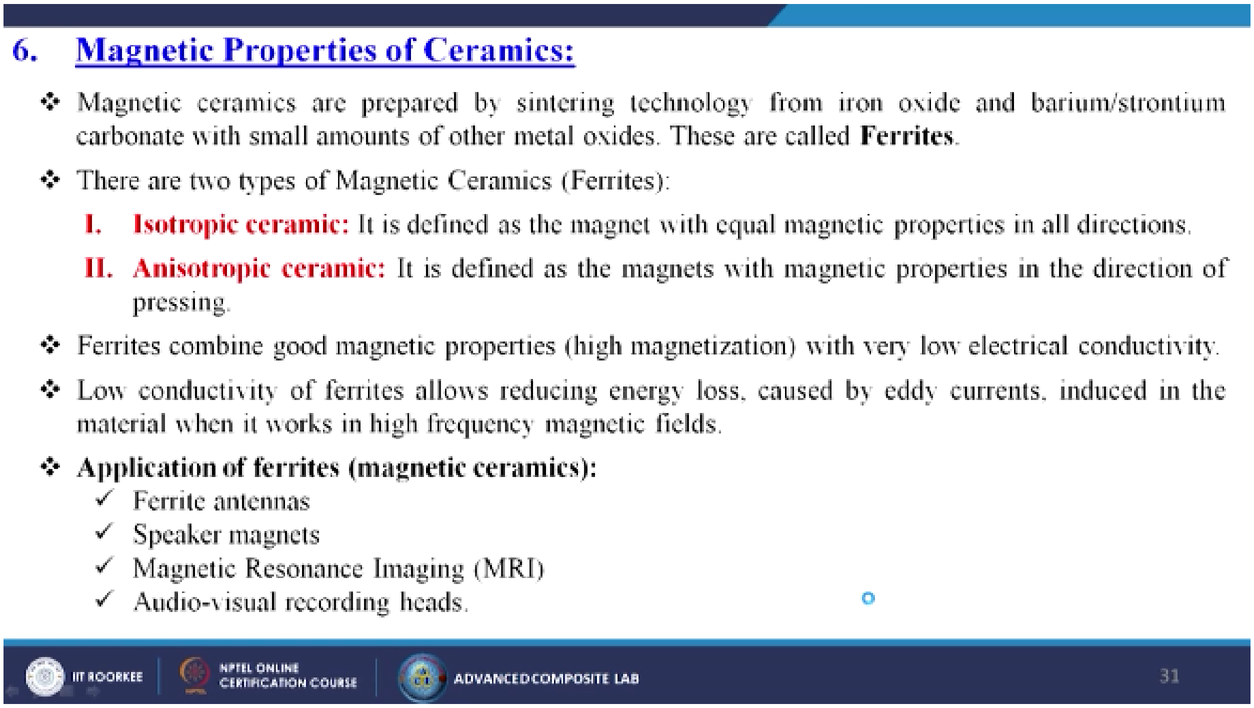
Piezoelectric property, piezoelectric property of ceramic can be defined by piezoelectric effect, piezoelectric effect can be defined as generating the piezoelectric effect by some mechanical stress. Here the basic thing I am telling you generally the piezoelectric properties is nothing, there is certain kind of materials so if you heat that materials generally they are going to generate the electricity and its vise-versa also, and if you give some kind of electricity to them, they are going to give some kind of mechanical vibrations, contracting or maybe the expanding actions of that particular materials.

So first one is the generating piezoelectric effect, means mechanical strengths applied between two surface of a solid dielectric part generates the voltage between the surfaces, motor piezoelectric effect voltage applied between two surface of a solid dielectric part result in contracting or expanding of the parts, some ceramics lead, zirconate, titanate, barium titanate, bismuth titanate, lead magnesium niobate have piezoelectric properties. So what are the applications? Piezoelectric ceramics are used for manufacturing various transducers, actuators and sensors like hydrophones, sonar, strain gauges, medical ultrasound equipment, so we are using this kind of piezoelectric material.



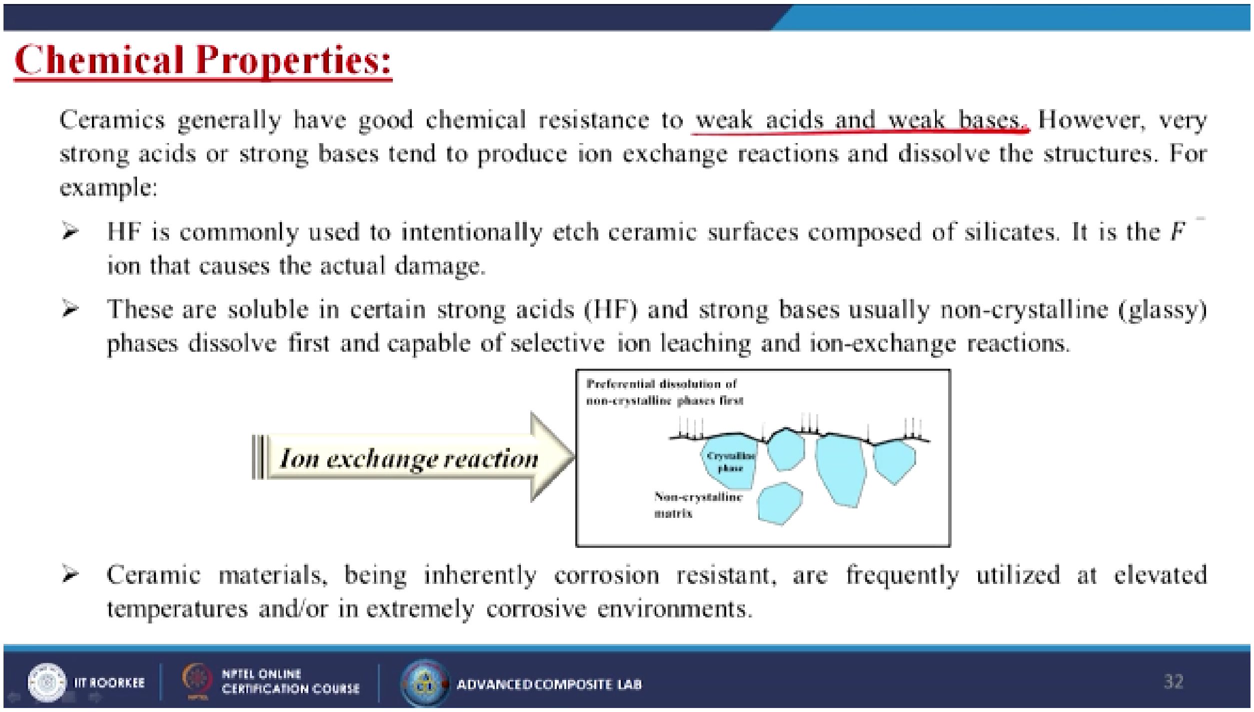
Now we are going to discuss about the dielectric property of ceramics, so dielectric ceramics and substrates are electrical insulators with dielectrics strength and dielectric constant, in capacitor applications ceramics with high dielectric constants are used to increase the charge that can be stored, in high voltage insulator applications high electrical resistivity ohmmeter and high dielectric strength kilovolt per meter is required.

What do you mean by dielectric strength? It is the ability of a material to prevent electrical conductivity at high voltage, what is dielectric strength? Dielectric strength is defined as the maximum voltage required to produce a dielectric breakdown through the material and is expressed as volts per unit thickness, so dielectric strength DS = DV/DS max = breakdown voltage x VB/ thickness D, the higher the dielectric strength of a material the better its quality as an insulator, the type of ceramic used as an insulator because it doesn’t have any loose electrons and dielectric strength of ceramic is high as compared to metals, so it is a good insulating material.

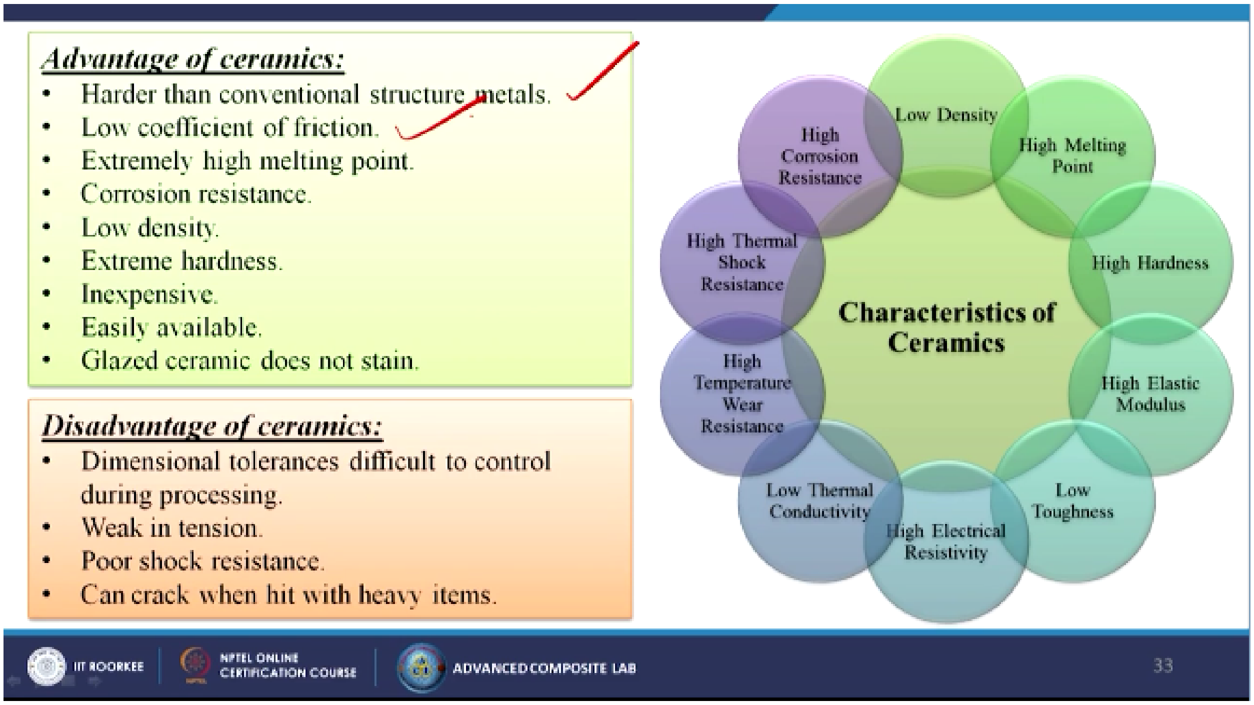


Now we are going to discuss about the magnetic properties of ceramics, magnetic ceramics are prepared by sintering technology from iron oxide and barium strontium carbonate with small amounts of other metal oxides, these are called the ferrites, there are two types of magnetic ceramics, first one is known as the isotropic ceramics and second one is known as the anisotropic ceramics, so what is isotropic ceramics? It is defined as the magnet with equal magnetic properties in all directions, and what is anisotropic ceramic? It is defined as the magnet with magnetic properties in the directions of pressing, ferrite combines good magnetic properties means high magnetizations with very low electrical conductivity, low conductivity of ferrites allows reducing energy loss caused by eddy currents induced in the material when it works in high frequency magnetic fields.

What are the applications of ferrites? Magnetic ceramics, ferrite antennas, speaker magnets, magnetic resonance imaging for the biomedical applications generally we are doing it for our bone cracks or maybe some other things, MRI, audio visual recording heads.



Now we are going to discuss about the chemical properties of ceramics, so ceramics are generally have good chemical resistance to weak acids and weak base. However, very strong acids or strong bases tends to produce ion exchange reactions and dissolve the structures, for example HF is commonly used to intentionally each ceramic surfaces composed of silicates, if – ion that causes the actual damage to that ceramic materials, this are soluble in certain strong acids and strong bases usually non-crystalline glassy phases dissolve first and capable of selective ion leaching and ion-exchange reactions, so here in this particular figure you can see the ion-exchange reactions, so first the preferential dissolutions of the non-crystalline phases first, and then it is going into the crystalline phases over there, so generally the ceramic materials being inherently corrosion resistance or frequently utilized at elevated temperatures and in extremely corrosive environments.



What are the advantages of ceramics? First it is harder than the conventional structure metals, low coefficient of friction, extremely high melting point, corrosion resistance, low density, extreme hardness, inexpensive, easily available, glazed ceramic does not stain, of course there is certain disadvantages also, first is called the dimensional tolerances difficult to control during processing, weak in tension, poor shock resistance can crack when hit with heavy items because they are very brittle in nature.

What are the characteristics of ceramics? First one it is the low density, high melting point, high hardness, high elastic modulus, low toughness, high electrical resistivity, low thermal conductivity, high temperature wear resistance, high thermal shock resistance and the high corrosion resistance.

Application of Ceramics:

Material	Application
Aluminum oxide / Alumina	Chromium doped alumina is used for making lasers.
Aluminum nitride (AlN)	Used in many electronic applications such as in electrical circuits operating at a high frequency.
Diamond (C)	Used in industrial abrasives, cutting tools, abrasion resistant coatings, etc.
Lead zirconium titanate (PZT)	Widely used piezoelectric material.
Silicon carbide (SiC)	Used as coatings on other material for protection from extreme temperatures.
Titanium boride	Great toughness property and hence found applications in armor production.
Zirconia	Used in making oxygen gas sensors, as additive in many electronic ceramics.

Now we are going to discuss about the application of various ceramics, so say let us take the aluminum oxide which is also known as alumina, generally application is chromium doped alumina is used for making the lasers, when you are talking about the aluminum nitride, used in many electronic applications such as in electrical circuits operating at high frequency, when you are talking about the diamond, used in industrial abrasives, cutting tools, abrasion resistant coatings etcetera. When you are talking about the lead zirconium titanate, widely used for the piezoelectric material, when you are talking about the silicon carbide, used as coating on other material for protection from extreme temperature because it can withstand the high temperature, titanium boride, great toughness property and hence found application in armor productions, generally for the defense applications we are using this materials. Zirconia used in making oxygen gas sensors as additive in many electronic ceramics.

Summary:

- Ceramic materials have covalent and ionic bonding.
- There are basically two types of ceramics;
  1. Traditional Ceramics
  2. Advanced Ceramics
- At room temperature, Mechanical response is elastic, but fracture is brittle, with negligible deformation.
- Due to desirable characteristics such as high hardness, wear resistance, chemical stability and high temperature strength, ceramics become selected as preferred material for many applications.
- So, this lecture will introduce about advanced ceramic materials, various ceramic properties and their applications.

So now we have come to the, at the last slide of this particular lecture, so now we have to conclude this particular lecture so just I'll tell you that the summary of this particular lecture, so first ceramic materials have covalent and ionic bonding, and they don't have any free electrons over there, there are basically two types of ceramics, one is called the traditional ceramics, and another one is called the advanced ceramics, at room temperature mechanical response is elastic but fracture is brittle with negligible deformations, due to desirable characteristics such as high hardness wear resistance, chemical stability, and high temperature strength, ceramics become selected as preferred material for many, many applications. So this lecture will introduce you about the advanced ceramic materials, various ceramic properties and their applications, but whatever the examples I have given to you here is the very limited one, this ceramic materials is widely used for several applications in our day to day life and also for some advanced applications. Thank you.

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