Processing of Non-Metals

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Module - 3
Ceramics: Properties and processing
Lecture - 1
Ceramics

A warm welcome to all of you in this module on ceramics. As you well aware that we have been discussing our course on processing of non-metals, which has been divided into seven different modules. We have completed two modules - in which, we have seen the different aspects of material, we have seen manufacturing aspects of engineering materials. And we have seen the second module, we have seen the glasses. As the title of the course is processing of non-metals our focus is two important aspects that is the non-metals and they processing techniques. And in this particular course, the processing of non-metals we would be covering different types of non-metals, such as we are today going to start our discussion on ceramics. And at a later stage in the module number six we would be covering ceramics matrix composite, which would be and advanced stage of basics ceramics or monolithic ceramics, where the materials has been modified in order to take advantage of the properties of the ceramics.

And in order to overcome the limitations of the ceramics, so that is a late at later stage that is in module number six, and we are going to cover the polymers and well as the polymer matrix composites. So, now, we are at a stage where we are going to start module number three, in module number four our focus will be on polymers; in module number five, our focus will be on polymer matrix composites; and in module number six, again we will discuss about the ceramic matrix composites. And finally, in module number seven, our focus would be on the secondary processing aspects of this composite materials or advance materials or non-metals or non-metallic materials.

So, today we are going to start a new module that is ceramics. In ceramics, our focus will primarily be to understand the basic aspects of ceramics that what are ceramics, how the ceramics can be classified, what are the various criteria on the basics of which ceramics can be classified, what are the distinct features of ceramics, what type of bonding exists in ceramics, what are the different types of ceramics raw materials, and finally, we are

going to see what are the application of ceramics. So, this is something related to the materials aspects of ceramics that is the materials science aspects of ceramics.

Then we would shift our focus from the materials aspects of ceramics towards the processing aspects of ceramics. In which, we would be seen different process which are used for processing of ceramics like powder processing technique is there slip casting is there. They are number of techniques, which are used for processing of ceramics. So, we will see one by one all the techniques which are used for processing of ceramics. But in the first two lectures, that is lecture number one and lecture number two, our focus is primarily to understand the basics aspects of ceramics. So, we would be covering this fundamentals aspects in two lectures, that is ceramics one and that is ceramics two.

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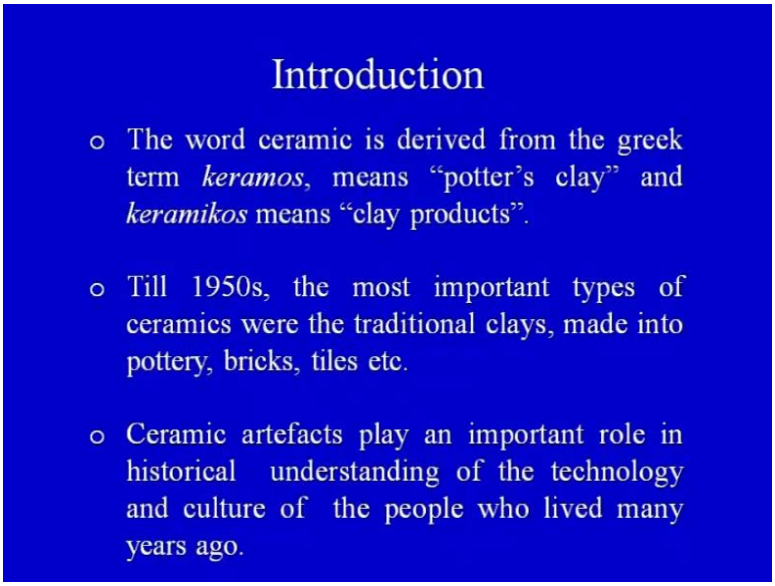

So, today we are going to start our decision in module three, that is ceramics. And we are going to start the discussion with basics aspects of ceramics. So, with this introduction, let us start our discussion on the basic aspects of ceramics. So, this is the introduction to the word ceramics the word ceramics is derived from Greek term Keramos which means potters clay, and Keramikos which means clay products. So, basically they are two important points that are coming in this particular words that is ceramic that is potters clay and clay products. So, basically the traditional used for ceramics started with the use of clay and converting this raw materials that is clay into some tangible product that is pottery and some other products of made up of clay.

So, basically, the word ceramic is very clearly mentioned it is derived from Greek work keramos, which means potters clay. Basically it is the concept of or science and engineering of ceramics started with the potters clay, and the clay products. So, basically ceramics deals with the name of the process also as well as the product also. So, the product also product is also a ceramic and the ceramic making it also a process. So, basically first important point is to understand the origin from where this particular branch of science and engineering is started. This important aspects of material science started that is from potters clay, when the raw materials clay was converted into the final useable tangible product.

Then from the historical point of view till 1950, the most important types of ceramics was traditional clays, made into pottery, bricks, tiles etcetera. So, the application aspects are also given and the raw material aspect is also given. If you also have a look the raw material or the traditional clays, so clay is material and the product is pottery the different type of pottery items bricks, tiles, etcetera. So, traditionally, the clays were classified into the ceramics category, but later on different types of ceramics have been invented that would be seen in the application of ceramics like bio-ceramics, ceramics for electronics industries, and they are ceramics for space shutter application. So, these days, we have different sophisticated advance ceramics available which are used for specific design requirements, but traditionally the ceramics that were used in engineering application or in house hold application were made from traditional clay.

Next point, ceramics artefacts that is the products made by ceramics play an important role in historical understanding of the technology and culture of the people who lived many years ago. If you remember during the excavation many times pottery shreds are found out, some ceramics products are found out. Then from the kind of we can say the art work done on those ceramics product, the culture is estimated that what was the culture or what type of people used to live and what was the cultural we can say the heritage related to that particular era. So, important point to note here is that, this is an important type of material which not only have engineering relevance, but also has historical relevance. And it is we can say house hold items which dictates or which helps us to understand the culture has well as the historical developments of a particular civilization or of a particular time domain.

So, basically this particular slide highlights the important aspects of ceramics that somebody whose listening to this word ceramics for the very first time, should be able to understand that what is a ceramics from where it has got is origin, and what are the traditional application of this particular material and what is his relevance in society. So, this particular points give us a idea that is an important material which is in use for a long long time. And particularly now gained substantial application spectrum in different engineering application that we are going to study in our subsequent slides. So, basically the focus is on the word ceramic and we are going to understand the basic fundamental aspects of ceramics, and then we will see what are the latest application of these materials.

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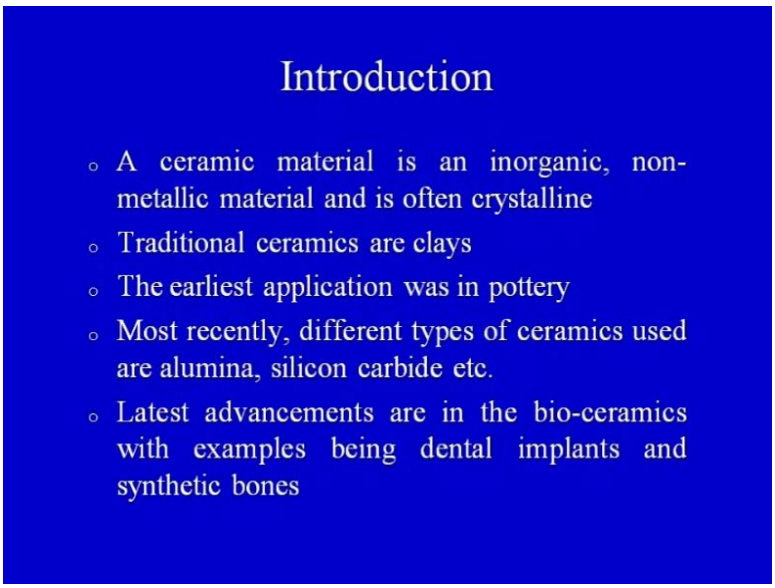

A ceramic material is an inorganic, non-metallic material and is often crystalline. So, this important point highlights three important aspects of ceramics that is a ceramics is inorganic - that is point number one; it is non metallic is point number two, and is often crystalline. In our previous model, if you remember we have discussed upon glasses and we have seen that glasses are usually amorphous. So, ceramics materials is a crystalline material and we have also seen the distinguish between the crystalline material and the amorphous material.

So, ceramic material is inorganic, it is non-metallic, and it is often crystalline. Second important point is very important that is non-metallic, because now we have discussing

the course on processing of non-metals. So, ceramics is one of the important non-metals and we should know the tools and techniques for high quality good cost effective processing of ceramic material. So, basically again I am high lighting and revising, because it is a simple definition of a ceramic material and anybody who is attending to this particular discussion should be able to remember that what actually a ceramic a ceramic is a inorganic material a non metallic material.

Moreover the most of the ceramic is mostly crystalline second traditional ceramics are clays as we are already understood in the very first slide that the very basic origin of the word ceramic is from potters clay. So, basically the traditional ceramics are clay the earliest application was in pottery that we have also seen in the previous slide most recently different types of ceramics are used are alumina silicon carbide extra.

So, this are just two examples of the latest use of ceramic material, they are different types of ceramics ceramics is a very huge family and they are large number of material which fall under this category and are used in different engineering application. So, just to make the things simple and easily under stable, I have taken two very simple example of the latest materials which fall under the category of ceramics. Most recently different types of ceramics have been used that is alumina and silicon carbide. So, the latest advancements are now, these are two examples of the ceramics then the latest advancements are in the fields of bio ceramics that is sometimes bio-medical implants are being made up of ceramic materials and dental implants as well as synthetic bones.

So, basically now we are trying to understand that what basically a ceramic is, what is the historical perspective of the ceramic material, and we are trying to understand the application point of view of the ceramic material that what are the latest application like in the last point. We can see artificial bones or synthetic bones dental implants as well as the bio ceramics. These are some of the applications of ceramics in today's scenario and to examples of ceramic material latest ceramics that we have seen that is alumina and silicon carbide. We would been seen a large number of we can say applications of the ceramic material in today's lecture and in the subsequent lectures.

So, by now if we have, if we revise what we have covered, we have just seen what basically a ceramic is it is an inorganic non-metallic material which are mostly crystalline, then we have seen two important examples of an ceramic material that is

alumina and silicon carbide. Then we have seen some of the latest applications of the ceramic materials like the bio medical implants, the dental implants or the synthetic bones. So, now, we will carry forward our discussion and have a comparative analysis of the ceramics with the other important engineering materials like metals and polymers.

Basically, the purpose of showing this particular slide is that we want to compare the ceramic with the metal basically our focus core focus is on processing of non-metals. So, polymers and ceramics both are non-metals. So, we have to compare the characteristics of these two particular materials in reference to the properties of the metals, because these properties only would dictate the processing techniques for these materials. So, one by one we can try to understand the difference that what are the good properties of ceramics which are not present in the metals or what are the danger area or limitations in ceramics where metals have got an edge.

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Property	Ceramic	Metal	Polymer
Density	Low	High	Lowest
Hardness	Highest	Low	Lowest
Ductility	Low	High	High
Wear resistance	High	Low	Low
Corrosion resistance	High	Low	Low
Thermal conductivity	Mostly low	High	Low
Electrical conductivity	Mostly low	High	Low

So, first important property on your screen is density. So, density, you can see ceramics have the low density; metals have high density, and polymers have lowest density. Now from the density point of view, if we take the application spectrum that what type of applications are relevant to the density then we can say low weight applications are particularly relevant to the density of the material. So, metals have high density therefore, the use of metals for light weight applications is not usually feasible or is not usually advisable. Whereas, in case of ceramics, the density is low; in case of polymers

the density is lowest therefore for light weight for light applications there are large variety of materials which have been developed using ceramics and polymers and are been used for light weight applications specifically in aerospace industries, in marine industries, in sports goods and equipments. There are large number of applications where light weight is the prime design criteria and in those cases ceramics and polymers have an edge over the metals. So, the first important property that the ceramics have an edge is the light weight characteristics that is the density of ceramics is less as compared to that of metals.

Property numbers two that is hardness. Ceramics have high hardness that is the highest hardness metals have low hardness and polymers have the lowest hardness. So, if we compare the metals with ceramics the hardness of ceramics is much much higher compared to most of the metals. So, the hardness is an important property where we are focusing the use of wear resistance materials. So, when we want to have the wear resistance, we tried we tend to increase the hardness. So, hardness is good for ceramics; it is higher for ceramics, but for metals it is lower. So, hardness also if high hardness is required ceramics have an edge ductility which is another important property, it is low for ceramics and it is high for metals. So, plastic deformation or bending or any other process to give a shape to the metal it is easier in case of metals, but in case of ceramics it is difficult, because they do not have the property of ductility.

So, ceramics the ductility is low; whereas, in metals the ductility is high therefore, the metals can be drawn into thin wires metals can be plastically deformed whereas ceramics cannot be drawn into thin wires even if possible then very very precise control over the processing parameters is required. So, therefore, the ductility of the ceramics is lower as compared to that of metals. The next property as I have already highlighted along with point number two that is hardness is wear resistance. So, wear resistance in case of ceramics is high; whereas, in case of metals is low. So, we can say whereever we want to have an application of a particular material where wear resistance is a design requirement there we would advocate the use of ceramic materials as compared to the metals because the wear resistance of ceramics is higher as compared to that of metals.

Coming on to the corrosion resistance. So, corrosion resistance is also higher for ceramics as compared to that for metals. Thermal conductivity is mostly low for ceramics in most of the cases, although there can be some ceramics which may have a

temperature dependent conductivity and may go into superconductivity range at an elevated temperature. But those are specific examples or exceptional cases, but in most of the ceramics we will see that the thermal conductivity would be low as compared to that of metals and the electrical conductivity would also be low as compared to that for metals. So, we have seen in this particular table, the comparison between the ceramics and the metals. The other comparison between the metals and the polymers we will see. When we will start discussing the module on polymers, but if we compare the two important class of materials that is the metal and the ceramic we can see that for lightweight application, for high temperature applications, for wear resistance corrosion resistance applications. Where wear resistance and corrosion resistance is desired we should certainly use the ceramic material, but whereever we want high electrical conductivity or we want a good thermal conductivity in those cases we should go for metals as our alternative.

So, basically ceramics have got certain advantages and metals have got got their own advantages, but apart from the advantages that the ceramics have there are few limitations also, because ceramics have the major advantage of high temperature suitability for high temperature applications ceramics can be used. Then they have good corrosion resistance also, therefore, in some applications we may love to advocate the use of ceramics where high temperature is there corrosion resistance is also there. So, we may be initiated or we may be motivated to advocate the use of ceramics, but one of the important points to note is the brittle nature of the ceramics.

So, whenever we are going to advocate the use of ceramics for a particular engineering application, we should take into account the type of loads that are going to come on that particular component. So, if impact load is going to come then we should not advocate or we should not initiate the use of ceramic material for that particular application. So, although ceramic materials have got a wide variety of properties like high hardness, we can say low density. So, for light weight applications high hardness for weir resistance we can say low density. So, for light weight applications high hardness for weir resistance applications, corrosion resistance applications we may be tempted to promote the ceramic materials, but one of the major limitations is the brittle nature. So, that particular aspect has to be addressed and that we will try to address when we will study our module on ceramic matrix composites.

Where the ceramic matrix is reinforced with the reinforcing phase and some of the properties of ceramics which are lacking are improved with the help of reinforcing phase, although the advantageous properties of ceramics are taken care of. They are usually adopted in to the ceramic matrix composite, but the limiting properties of ceramics are addressed by the reinforcing phase and we get a good quality material which over comes the limitations of the monolithic ceramics. So, the important point in this particular slide is to have a comparative analysis of the metals and the ceramics, and we should be able to understand that what is the application spectrum as an engineer we should know that whenever we are designing a product. We have to specify the material, we would be used to fabricate or process that final product.

So, basically we before advocating the use of a particular material, we should know that what are the strengths of that material and what are the weaknesses of that material and this particular slide gives us overview of the comparison between the metals and the ceramics. And we have been able to understand that what are the properties, which are good for ceramics as compared to metals, and what are the important challenges for ceramics which have to be overcome with the blending of other phases or other materials with the ceramic materials.

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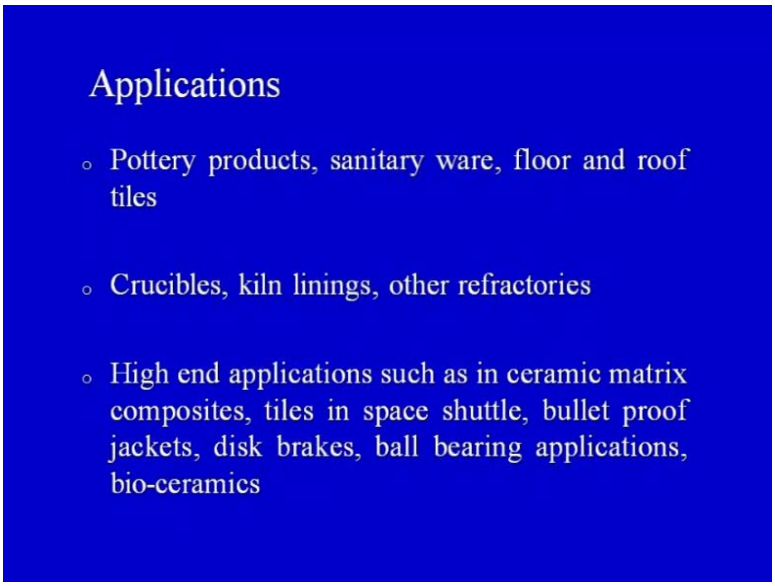

Let us see what are the important applications we can have pottery products, sanitary ware floor, and roof tiles. It is one spectrum of applications then crucibles kiln linings

and other refractory. Refractory means high temperature application then high end applications are there. So, we started from the very basic application or household applications like pottery products or sanitary ware which is weir in very household floor and roof tiles also. So, we are starting from the consumer goods then slightly high end applications like the crucibles kiln linings and other refractories that are high temperature applications then high end application such as ceramic matrix composite.

So, ceramic matrix composites, we are going to cover in our module number six. We will see that what are the various types of toughening mechanism, we will try to understand that what are the various types of manufacturing processing or processing techniques which are used for ceramic matrix composites. So, this is another class of materials, which is finding substantial application in various engineering requirements then the tiles in space shuttle this is also high-end application bulletproof jackets, disk brakes, ball bearing applications bio ceramics. So, these are some of the latest applications of the ceramic materials. So, starting from the very basic application household applications, we can see the ceramics have now graduated into a very important class of engineering material, and is finding diverse applications in the fields ranging from aerospace to bio ceramics.

Now, till now what we have discussed, let us just have brief overview of what we have tried to understand till now. Now we have tried to understand the brief origin of the ceramic materials, the ceramic clays which have been used for a long long time that initially the ceramic materials were used as clays. Then we have tried to understand the basic concept of the ceramics, we have tried to compare the ceramics with the metals and then we have seen what are the various applications of ceramic materials. So, having this introduction that what do we mean by a ceramic, how the ceramic materials compared with the metallic materials, and finally, the applications where we can see the ceramics around us because all of us, can see the ceramic materials all around us. We can see the roof tiles, we can see some decorative pottery items which are usually kept in the houses. So, basically, we can till now, we can just visualize that what are the various applications of ceramic materials.

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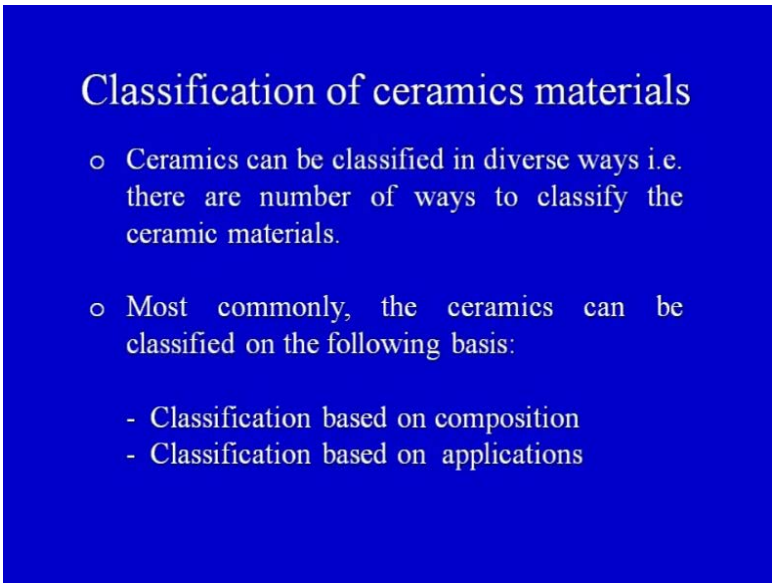

Now, let us see how the ceramic materials can be classified. So, the classification can be based on two important criteria. So, the ceramics can be classified in a large number of ways we can we can choose different types of criteria for classifying the ceramic materials, but broadly there two important criteria that have been widely accepted as the classifying criteria. So, mostly the ceramics can be classified by the following basis. So, two important classifying criteria are classification based on the composition of the ceramic materials and the classification based on applications of the ceramic materials that is why in the previous slide we have seen that starting from the very basic application from household application the applications of ceramics may range to bio ceramics and the bullet proof armour.

So, on the basis of the applications the ceramics can be classified as well as the ceramics can be classified on the basis of composition of the base material. So, the composition in this particular ceramic, we will see in our subsequent lecture that that the ceramics is made up of two or three elements. And therefore, the structure of the ceramics is also very very complex as compared to the metallic materials, but that we will come to at a later stage, but let us first see the broad classification of the ceramic materials.

Now, classification of ceramic materials on the basis of composition, we can broadly classify them into four categories silicate ceramics which is one of the most commonly used ceramic material. Oxide ceramic like a lumina one example, I have given. We will

just see some other examples of the oxide ceramics also in the subsequent slides, non oxide ceramics and the glass ceramics. So, glass ceramics is also a very very important class of ceramic material which is finding a wide variety of applications in today's engineering world.

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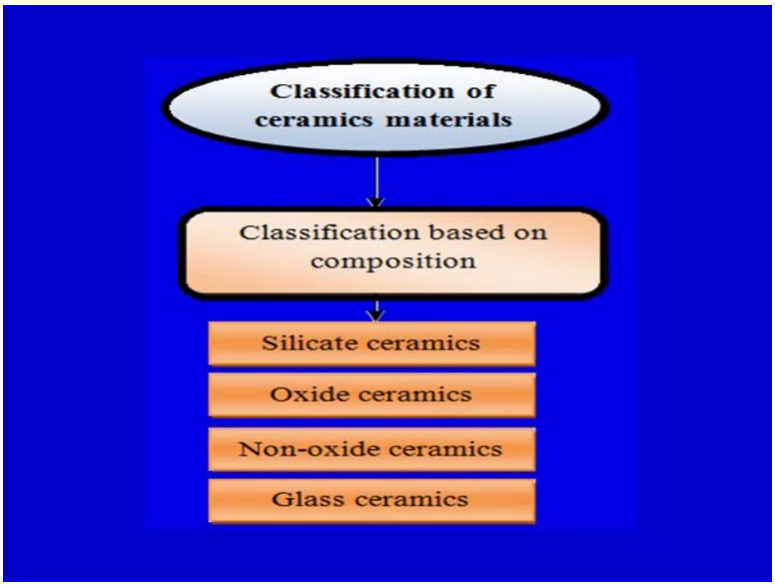

So, basically on the basis of composition we can classify the ceramics into four categories. So, all the four categories have been highlighted on your screen and one by one, we will try to see that which particular type of ceramics falls under which categories. So, again we can see that in this particular diagram, we have been able to classify the ceramics into four broad categories, there is based on the composition. Now one by one, we will try to understand that silicate ceramics, oxide ceramics, non-oxide ceramics and glass ceramics.

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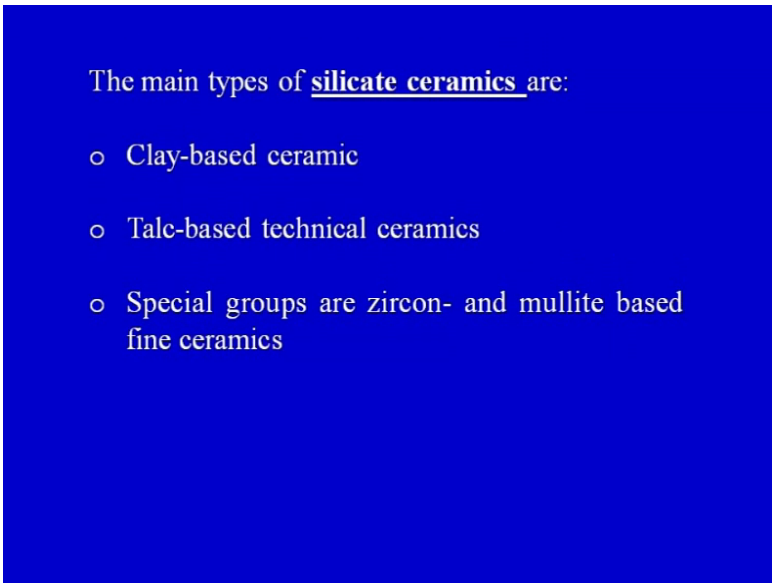

The main types of silicate ceramics are these are the most commonly used type of ceramic materials. They are clay based ceramics, talc based technical ceramics, special groups such as zircon and mullite based fine ceramics, but we can try to understand here that one of the broad categories based on the composition of the material is the silicate ceramic. So, major type of this ceramic products are made by the silicate ceramics and they can further be sub divided into clay based ceramics talc based technical ceramics as well as special groups or fine ceramics. So, basically first important category on the basis of the composition is the silicate ceramics. We should try to remember that on the basis of composition, there are four types of categories of ceramics or four types of we can say sub divisions of the ceramic materials on the basis of composition that is first one silicate ceramics, which is most widely used second is the oxide ceramics non oxide ceramics and the glass ceramics. So, the first one is the silicate ceramics different types is already mentioned on your screen.

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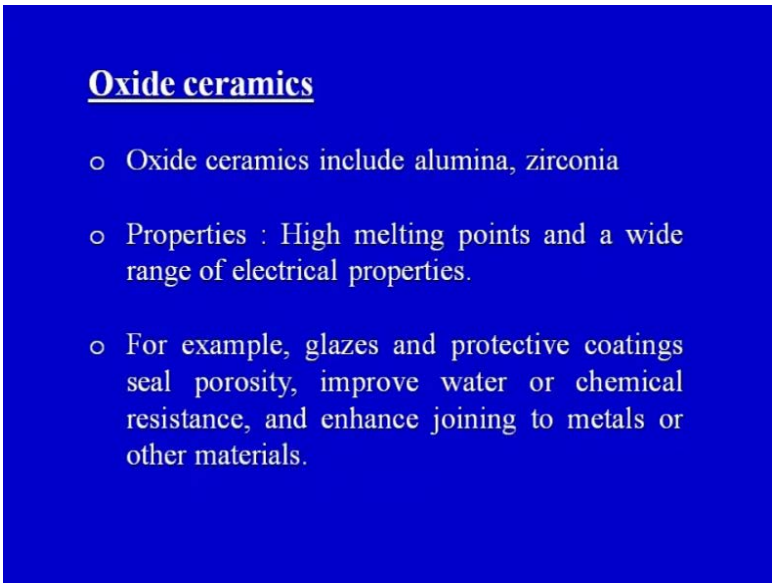

Next is the oxide ceramics. So, coming on to the oxide ceramics the oxide ceramics basically include alumina zirconia and their other types of oxide ceramics also. Now, what are the important properties of the oxide ceramics we can have a high melting point, and a wide range of wide variety of electrical properties now there are different examples like glazes and protective coatings seal porosity improve water or chemical resistance and enhance joining to metals or other materials. So, the we can say the application areas of oxide ceramics are also given. So, we have seen the two examples of oxide ceramics since two specific properties of oxide ceramics and we have seen the application that they can be used for glazes and protective coatings for sealing the porosity as we have seen and we can say important application ceramics are porous in nature.

So, sometimes we need to reduce or seal the porosity. So, there the oxide ceramics can be used improve water or chemical resistance, it is also very very important as we know that corrosion resistance and chemical resistance of oxide ceramics is good and they can enhance joining to the metals or other materials. So, oxide ceramics is one category on the basis of composition which is falling under the ceramics category.

Then non-oxide ceramics, there are large number of we can say material related problems and difficulties and limitations. As we know that whatever properties, we desire from a particular material, all those properties we cannot achieve with one specific

materials. For example, for a very high temperature application at that particular application we require high strength of the material also the mechanical properties should not diorite at an elevated temperature. So, this is just one example of a very specific requirements. So, there are very diverse requirements from the engineering materials in today's day, in today's world.

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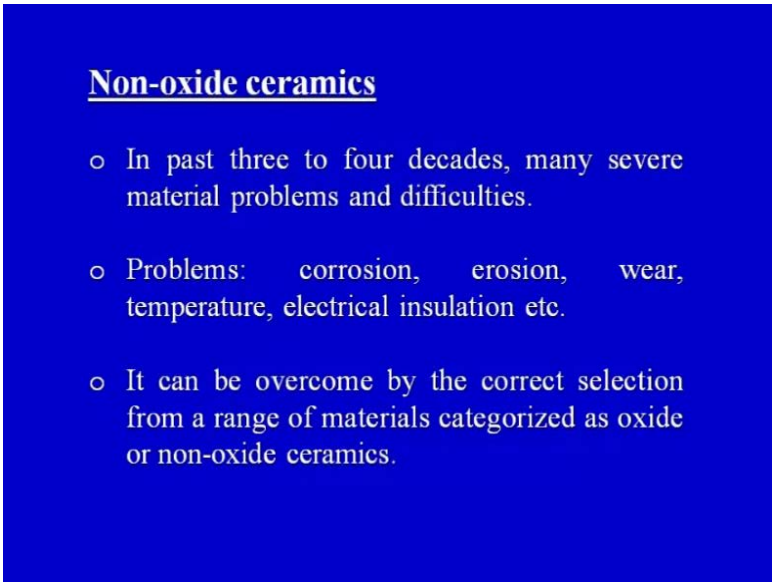

So, basically in past three to four decades, many severe problems and difficulties are there. So, problem such as corrosion erosion wear temperature electrical insulation etcetera. These are some of the problems that exists. So, these can be overcome by the correct selection of range of materials categorized as oxide and non-oxide ceramics. So, non-oxide ceramics, this is just giving you an highlight that in which particular application spectrum the non oxide ceramics can be used, but what are the exactly non oxide ceramics that also we should try to understand.

In oxide ceramics, we have seen two important examples are alumina and zirconia. So, in case of non oxide ceramics we can have carbides we can have nitrites. So, carbides nitrites fall under the category of non-oxide ceramics, and within carbides we can have silicon carbides we can have titanium carbide tungsten carbide. So, we can have different types of carbides we can have different types of nitrites and these will fall under non-oxide ceramics. So, carbides and nitrites will fall under non-oxide ceramics, alumina zirconia are the oxide ceramics. Till now on the basis of the composition of the basic

material, we can classify the ceramics into four categories - that is first one is the silicates; second is the oxide ceramics, and the third one is the non oxide ceramics and the fourth category is the glass ceramics. But before going to the glass ceramics, let us see the examples of non oxide ceramics, I have already told non-oxide ceramics basically are carbides and nitrites, and they have got their own specific set of applications.

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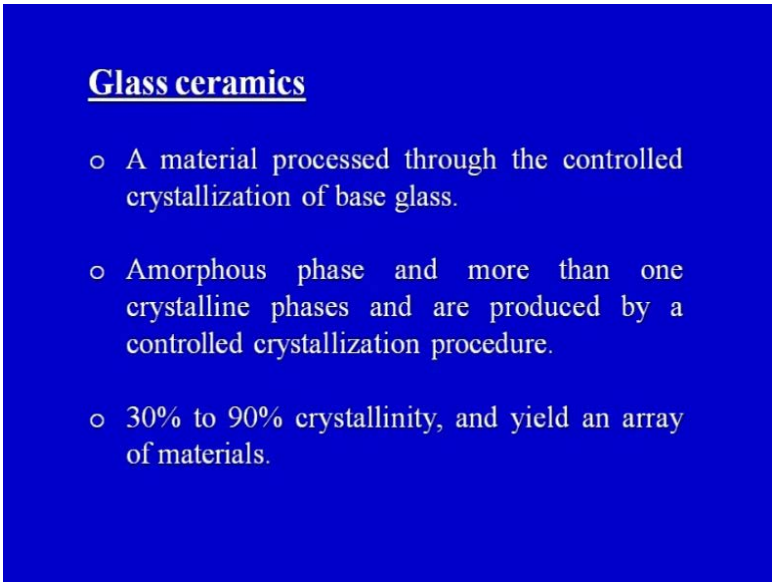

Now, coming on to the glass ceramics, a material processed through the controlled crystallization of the base glass. So, we have seen in our previous module that was on glass that what is difference between amorphous and crystalline material. So, glass is basically amorphous material, but a glass ceramic is a material which is processed through the controlled crystallization of the glass. So, we will have certain degree of crystalline and that would add a specific dimension to the material and would make it applicable in certain application areas. So, amorphous phase and more than one crystalline phase is and are produced by a controlled crystallization procedure. So, the glass ceramic exist in amorphous phase and more than one crystalline phases, and how it will be processed by the controlled crystallization.

We know that we have to undertake this much amount of crystallization. So, 30 to 90 percent crystalline, and an yield array of materials. So, we will get different types of materials. So, basically glass ceramics are we will process the glass, and later on add

certain degree of crystalline nature into that base glass, and we will get a glass ceramic why do we need to do this let us try to understand this.

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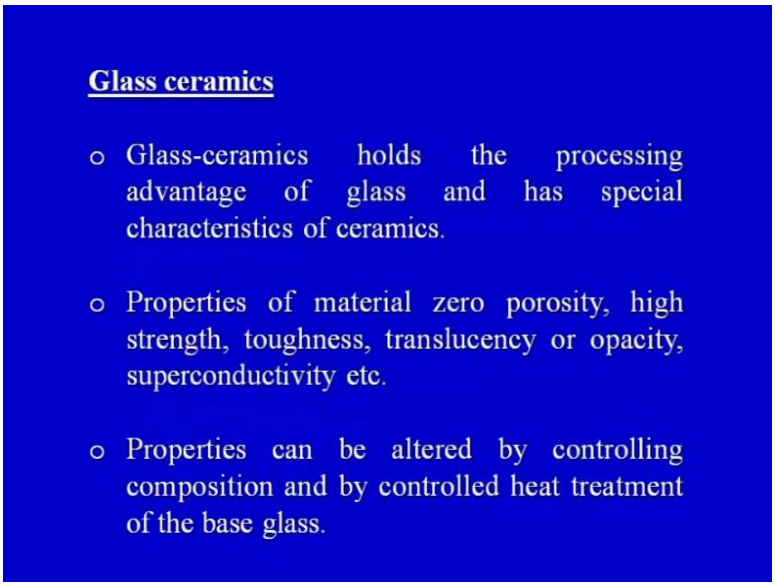

Glass ceramics hold the processing advantage of glass and has special characteristics of ceramics. So, basically a question can be asked that what is the need, when we have a glass has an engineering material and ceramics is another category of engineering material, what is the need to blend this two characteristics together or blend this two materials together. So, first important point is on your screen, you can see the glass ceramics. They hold the processing advantage of glass, because it is easier to process glass as compared to ceramics and has a special characteristics of the ceramics.

So, ceramics have got certain specific properties that we have already understood in one of the previous slides where we have paired the ceramics with the metals. We want to take the advantages of those properties take advantages of processing is of the glass then we combine this two important characteristics together. The processing characteristics of glass and the other properties of ceramics and we get a glass ceramic. So, that is one of the important points why we want to blend the two together properties of material zero porosity, may be this properties of the material that glass ceramics what type of properties they process possess zero porosity porosity is very less high strength. So, strength is improved toughness is good translucency or opacity we can have whatever we want or design accordingly and superconductivity.

So, basically glass ceramics have got certain special characteristics. Now what are those special characteristics that is mentioned on your screen. Again we want to revise the porosity is less strength, is good toughness, is good, we can have a range from translucency to opacity and the superconductivity. So, we can see that although ceramics are poor conductors of electricity, but glass ceramics can be made superconductive at specific operating conditions. So, basically when we blend the two things together that this particular concept we are also going to see in case of polymer matrix composite and ceramic matrix composite in later modules of this particular of this course. But here also we have combined the characteristics of two things together or two materials together glasses and ceramics and we have been able to make a resultant material which is giving a certain special characteristics as mentioned.

On your screen, you can see porosity, low porosity, high strength, toughness and super conductivity properties can be altered by controlling composition and by controlled heat treatment of the base glass. So, this is not, these are not the only properties or this is not the only characteristics that these materials possess. There are other types properties which can be achieved with the controlled heat treatment or by controlling the composition of the material that we are forming. So, just take a revision of what we have seen in the classification of the ceramics, we have seen on the basis of composition. We can classify the ceramics into four broad categories that first one is the silicate, second one is the oxide ceramics, third one is the non-oxide ceramics, and the forth one is the special category of glass ceramics.

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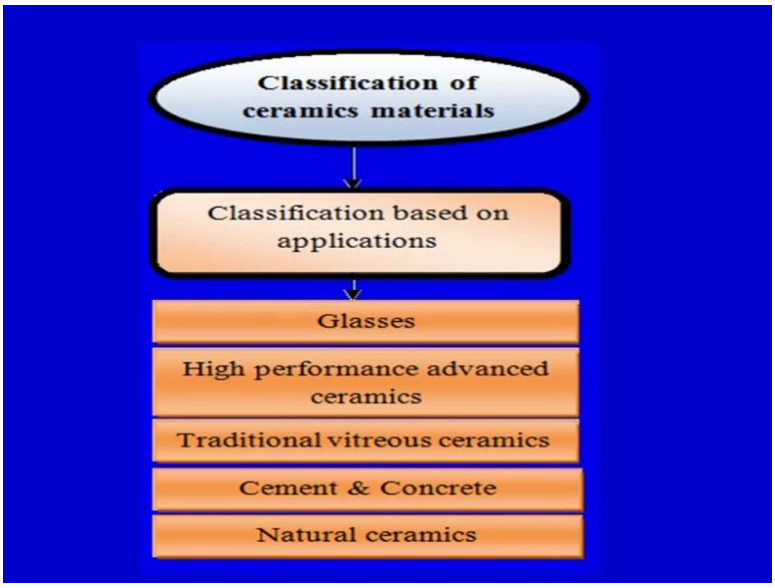

Now, second characterization or second classification is on the basis of applications. So, we have seen that although there are number of ways to classify the ceramic materials, but we are basically focusing on two important criteria that is on the basis of composition of the materials. And on the basis of the application of the materials, so on the basis of the composition, we have already seen that there are four subcategory in case in case of applications. Now we can see, we can have glasses, high performance advanced ceramics such as bio ceramics or for ceramic tiles for space shuttles, traditional vitreous ceramics, that is the most commonly used clays cement and concrete. And finally, the naturally occurring ceramics such as our bones.

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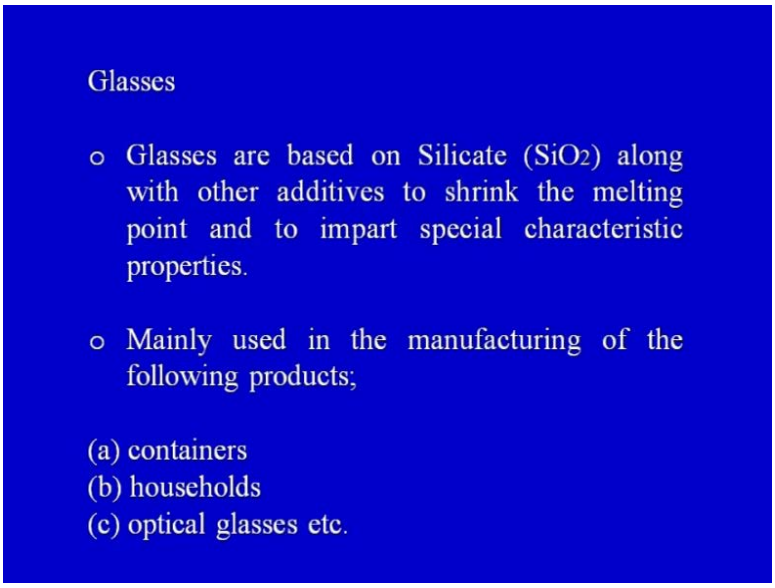

Now, glasses, glasses are based on silicate along with other additives to shrink the melting point and the impart special characteristic properties. We just give revision of what we have already covered in our module number two mainly used in the manufacturing of following products like containers household equipments and optical glasses as we have seen. There are number of other applications of glasses for the detailed discussion on glasses, you can refer to the discussions on module two or discussions held in module two in which we have seen the different types of glasses.

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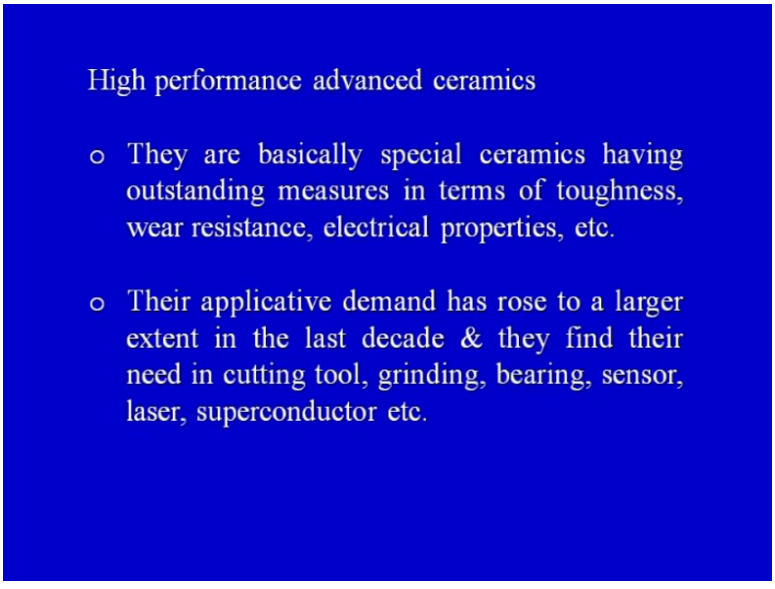

High performance advanced ceramics that is the next category on the basis of the application. They are usually special ceramics having outstanding measures in terms of toughness, wear resistance and electrical properties. Their applicative demand has to the large extent in the last decade and they find their need in cutting tools like wigs sometimes we use carbide tools for machining purpose. So, we can have different types of hard tools which can be used for machining grinding, bearing, ball bearing applications also are the latest applications of ceramics they have used for sensors also lasers superconductors. So, we can see that high performance applications for ceramics also are there and the ceramics can be classified into category where they have used for high performance applications. Some of the applications which are not mentioned here in case of bio ceramics or in space shuttles or or our body armour, bulletproof body armour. So, we can see high performance advanced ceramics is one category although few examples are listed on your screen there are other examples as well.

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Traditional vitreous ceramics you can see all the clay-based products within ceramics comes under this category. So, clay based ceramics usually are traditional ceramics applications are easily noticeable in porcelain, sanitary ware, tiles. Bricks, refractories which we have already seen covered in this lecture. Only in the very beginning, we have seen that what are the typical applications of ceramic materials. Now we are classifying the ceramic material into different categories on the basis of the applications.

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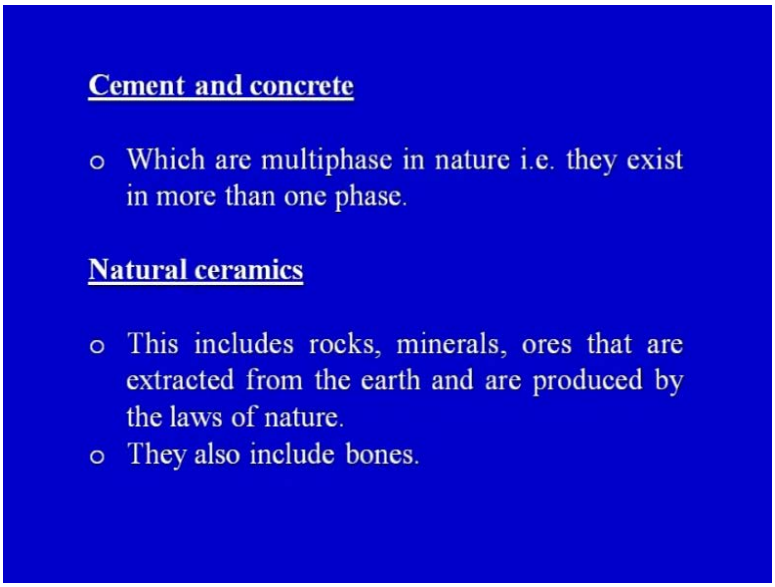

Then cement and concrete is another, we can say sub category of the ceramics based on the application. These are multiphase in nature. They exist in more than one phase multiphase means they exist in more than one phase concrete and cement is well known commodity. I think all engineers know about this natural ceramics, this include rocks minerals ores that are extracted from the earth and are produced by the laws of nature they also include the bones. So, basically there are natural ceramics also which can be used for certain application, there are we can say cement and concrete category for the ceramics on the basis of the application. Then are high performance ceramics then there are traditional then there are clays etcetera. Glasses, glass ceramics on the basis of the application also we have got a wide variety of ceramic materials. So, whatever we have discussed.

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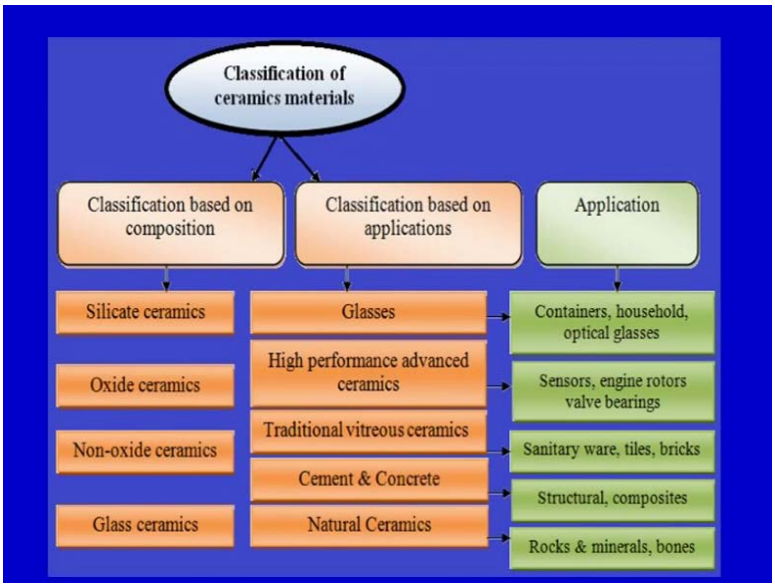

Let us now try to highlight or try to summarize with the help of this diagram. Classification of ceramic materials, classification based on composition. We can have silicate ceramics, oxide ceramics, non-oxide ceramics, and glass ceramics. We have seen the examples of all four types of these classification based on application. We can have glasses high performance advanced ceramics traditional vitreous ceramics, cement and concrete and natural ceramics and the examples we have seen in each and every case. So, with this, we come to the end of lecture number one in our module three that is ceramics.

In our subsequent lectures, our focus would be to further investigate or further study the basic aspects of ceramic to understand what is the type of bonding that exists in ceramics and how that bonding affects the properties. And finally seen what are the mechanical properties of the different types of ceramic materials and then we will shift our attention to the major focus of this particular course that is the processing of nonmetals. So, then our subsequent lectures would be focusing on the processing aspects of ceramics. In our next lecture, our focus would be on the basic aspects of ceramics.

Thank you