Processing of Non-Metals

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Module - 3
Ceramics: Properties and Processing
Lecture - 2
Ceramics: II

A warm welcome to all of you, in the second lecture on module 3 - that is ceramics. If you remember in module number 1, we have focussed on the very basic aspects of ceramics, from where the ceramic word has been derived. We have seen some of the important applications of ceramics; and our focus primarily was to classify the ceramic materials into different categories. The ceramic was classified into two broad categories on the basis of the composition of the material and on the basis of the applications. If you remember, on the basis of the applications, we have seen that there are traditional vitreous ceramics, we have seen there are advanced ceramics or for advance performing ceramics for advance applications.

Then we have seen that there are cement and concrete, there are glasses. On the basis of applications, there were four to five categories of the ceramic materials. On the basis of the composition of the material, there were the silicates, then there were oxide ceramics, non oxide ceramics and the glass ceramics. So, broadly we have classified the ceramic materials into two broad categories, on the basis of the compositions into silicates oxide ceramics, non oxide ceramics and glass ceramics. And on the basis of applications in two categories such as glasses, traditional vitreous ceramics, advance performance ceramics and the cement and concrete.

So, broadly we can have different types of ceramic materials. So, we cannot discuss each and every category of the ceramic materials or we cannot discuss the structure or the chemical composition of each category of the ceramic material, as we have seen in the previous lecture that there are wide variety of ceramic materials, which are being used. So, our focus would be to limit our discussion to the basic fundamentals or the general aspects of the ceramic materials, as we have seen in our lecture 1 of this particular module.

Now, our focus would be to understand, that what is the type of the bonding that exists, in case of ceramic materials and how that bonding influences the mechanical properties of the ceramics? How these properties are important for the processing aspects of ceramics? Our focus primarily is to understand the processing routes or processing techniques for ceramics. But before going to the processing techniques, our focus is to understand the fundamental or the basic aspects of the ceramic materials. What are the important properties of ceramics? Because, these properties would only help us to understand the various processing techniques of ceramics.

And in order to, will also help us to find out the, what are the specific requirements, which have to be met during the processing of ceramic materials. For that we need to understand that what are the specific properties, which are relevant in case of ceramic materials? As in case of metals, we have seen that the melting point, the hardness are important properties from the point of view of manufacturing of metals or processing of metals. So, in case of ceramics also we will see the hardness is important property, melting point is also an important property, ductility also an important property, whether we can make the ceramics into long wires or not?

So, these are the properties related to the materials that we should know, before actually processing the material. So, for that purpose and for that thing in our mind with that we can say, introduction required for the processing of ceramic material we are undertaking or we are discussing these important fundamental or basic aspects of ceramic materials. So, before going towards the types of bonding available or the types of bonding that is found in case of ceramics and how are this bonding affects, which properties are affective and what are the important properties of the ceramic materials? Before going into that, let us just have a brief overview of the ceramics which we have covered in the last class.

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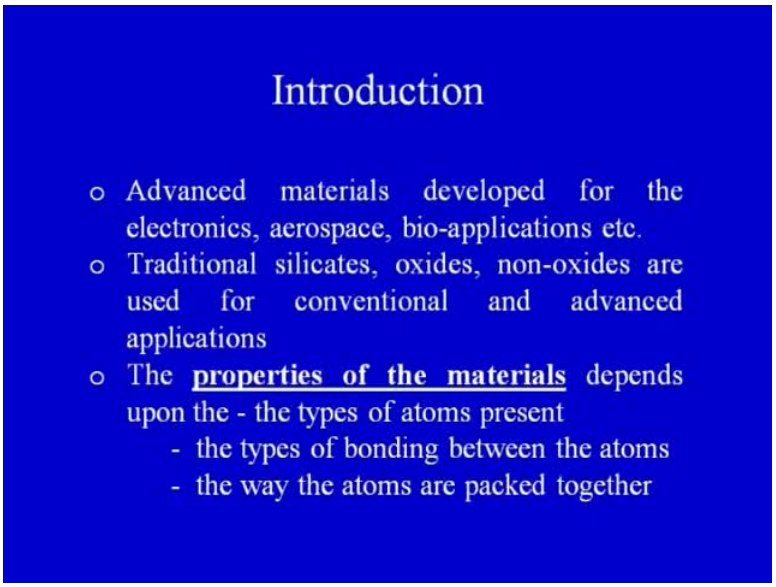

Advanced ceramics are developed for electronics aerospace and bio applications. So, in the previous class, we have seen that there is a, we can say specific applications spectrum for ceramic materials. New and new materials are being developed for new and new applications of ceramics, which traditionally were are used for pottery and clay products only. These days are finding applications in aerospace electronics and as bio ceramics. So, wide the applications spectrum has been increased in manifold for the ceramics, it is because of some of the important properties that the ceramics possess.

Such as, they are corrosion resistants, they are wear resistants, and they have high hardness, so these some of the properties they have low density means light weight applications, can be there for ceramics. Because of these important properties that the ceramics possess, the application spectrum of ceramics has increased in the manifold in the past few decades. This is just to highlight the application spectrum of ceramic materials. The point number one, gives us an idea that where the ceramics are being used.

So, on your screen you can just have a look, that ceramics are being used for electronics industries, in aerospace applications as well as in space shuttle applications, as well as they are used as bio ceramics in bio medical implants, in dental implants or sometimes in case of synthetic bonds also. The variety of application of ceramic materials is increasing Point number two, traditional silicates oxides non oxides are used for conventional and

advanced applications. So, this highlights the categorization or the classifications of the ceramics, which we have covered in lecture number 1.

That is on the basis of the compositions, the ceramics can be classified into four broad categories. That is, first one is the first one are the silicates, second are the oxide non oxide ceramics and finally, the glass ceramics. So, these types of materials or these type of ceramics can be used for both conventional applications as well as unconventional applications. In lecture number 1 we have seen, the applications of silicates, we have seen the applications of oxide, non oxide as well as of glass ceramics. Now, the important point that is we can say some part of today's lecture we will focussing on the third aspect that is there on the screen.

The properties of the materials, properties means, the mechanical properties, the physical properties, the chemical properties. So, the properties of the materials depend upon the types of the atoms present. That is one important criteria, which would dictate the properties of a material. Properties of the materials will depend upon, that is first criteria is the types of the atoms present. Second, the types of bonding between the atoms and the third the way the atoms are packed together. So, basically these important we can say points will justify or would dictate the properties of the particular material. Those properties would further used for the processing of that particular material.

So, the properties are dependent on a number or parameters that are there on your screen and these parameters would further dictate the properties or would be responsible for a specific set of properties, for a specific materials, and those properties would be further used. For example, hardness, electrical conductivity, thermal conductivity, toughness. So, all these properties may be in a way one way or the other related to these important points that have been highlighted on your screen.

Though the types of atoms presents the packing as well as the bonding, so all these would dictate the properties. Now, what are the properties that are being dictated by these, that we would see in the subsequent slides. So, the major purpose of this particular slide was to just have a revision of we have covered in lecture 1 and to introduce that would we are going to study today.

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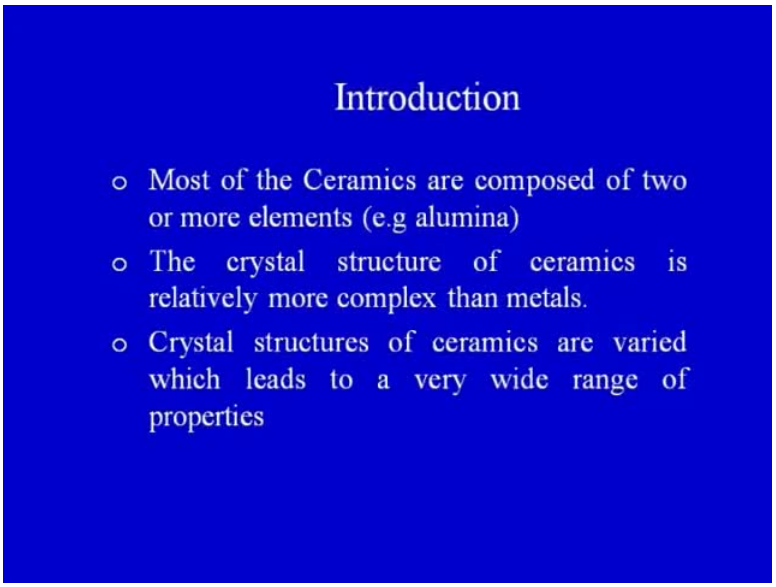

Now, most of the ceramics are composed of two or more elements. For example, alumina we have aluminium and oxygen. So, most of the ceramics are composed of two or more elements. Therefore, the structure of ceramic is quite complex as compared to that of metals. Therefore, the second point is written already highlighted, I have already told, crystal structure of ceramics is relatively more complex as compared to that of metals because of the presence of two or more elements in the ceramic. Crystal structure of ceramics are varied, which leads to a very wide range of properties.

So, the properties that we can expect from a wide variety of ceramics are comparatively different. So, a large versatility or a large variety of properties can be achieved with ceramics. Why? Because the crystal structures are quite different, so the crystal structure ceramics are vary. So, we can have different types of crystal structures in case of different types of ceramics and the properties attained and properties achievable for a specific class of ceramics would be different.

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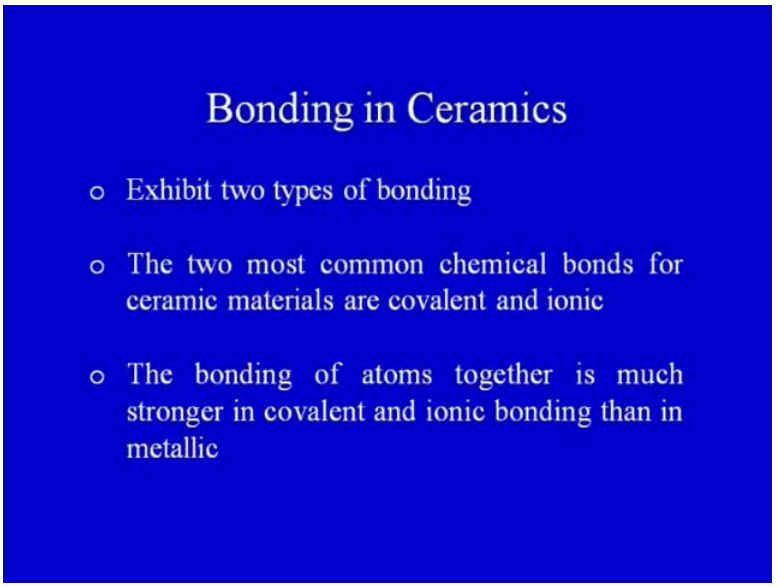

Now, bonding in ceramics; that is one of the important points that we want to highlight today; so the bonding in ceramics is, two types of bonding usually exist that is the ionic and the covalent bonding. So, the two most common chemical bonds were ceramic materials are covenant and ionic bond. So, the bonding of atoms together is much stronger in covalent and ionic bonding and than in the metallic bonding. So, third point is really important. Point number one and two highlight that there are two types of bonding ionic and covenant and combination of both.

But it is stronger than the metallic bonding, so we can see that when we have ionic and covalent bonds, so we have a strong bonding in case of ceramics. Therefore, we cannot plastically deform the ceramic materials, whereas the metallic bonding is weaker as compared to the ionic and covalent bonding. Therefore, in case of metals, we can plastically deform them to give them desired shapes. So, depending upon the nature of the bonding the type of manufacturing process is that can be applied to a particular material would be different.

So, the type of processing techniques that would be applied for processing a particular material, would be quite dependent upon the type of bonding that is existing in the material. So, metallic bonding is weaker than the ionic and the covalent bonding, ceramics are the ionic and covalent bonding and therefore, they have brittle in nature they cannot be plastically deformed.

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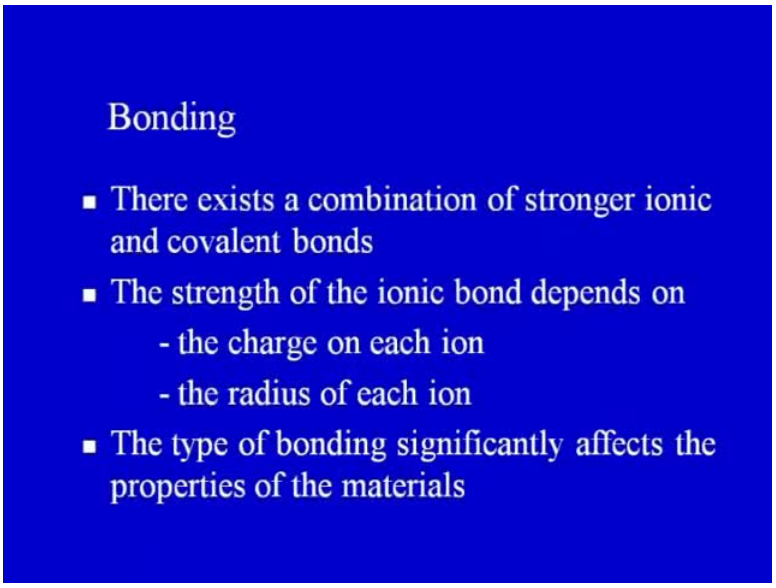

There exists a combination of stronger ionic and covalent bonds in the ceramics, which has been already highlighted. It has been related to the processing aspects also. The strength of the ionic bonds depends upon the charge on each ion and the radius of each ion. So, these are the two important parameters that would dictate the strength of the ionic bond. The type of bonding significantly affects the properties of the materials. So, which i have already highlighted.

So, the type of bonding would significantly affect the properties of the material. Now, one important we can say aspect we have already seen; that is it is easier to deform the metals whereas, it is very difficult or we can say nearly impossible to deform a ceramic material. So, ceramic will undergo a brittle structure whereas, the metals can plastically deformed. Now, why that is possible? That is possible because of the basic nature of the bonding that is there or that is present in the metal as well as that is present in ceramics.

So, depending upon the bonding as we have already seen, metals have metallic bonding and in case of ceramics we have ionic or covalent bonding. So, depending upon the bonding we will have different types of properties. So, the type of bonding would significantly affect the properties of the material. Now, what are the properties that would be affected? Let us see.

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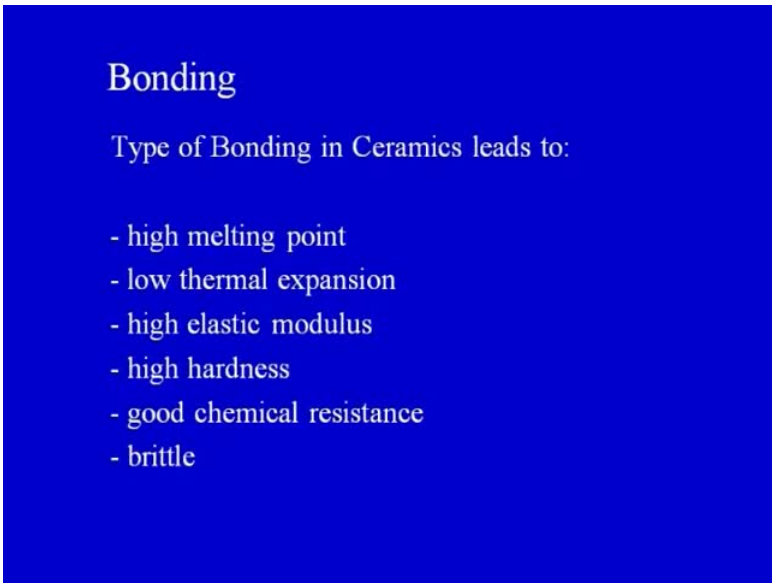

Type of bonding in ceramics leads to different types of properties; it would lead to, this is not specifically related to ceramics, but the type of bonding that is there in the material would subsequently, would lead to a certain set of properties for that particular material. So, the important point to highlight in the previous slide was that the type of bonding would significantly affects the properties of any material. If you take a metal, in case of metals also the type of bonding would affect the properties, in case of polymer also the nature of bonding would affects the properties. In case of ceramic also the nature type of bonding would affects the properties.

So, any type of material the bonding would affects the properties of the material. So, in case of specifically, now let us come to the ceramics. Specifically in case of ceramics we can see that these are the properties which are being affected by the bonding. So, the type of bonding in ceramics leads to, we can say it leads to high melting point, low thermal expansion, high elastic modulus, high hardness, good chemical resistance and it also makes the ceramics brittle. So, we can see there are many properties which are quite useful and there are many properties which would be causing a problem, when we would try to process the ceramic materials into a product.

So, you can see high melting point that is one important properties. So, it is very difficult to process materials which have very high melting points because we need to melt them, in many cases to give them a desired shape. They have to be processed in the solid form

only without melting. So, this particular property high melting point is advantageous from the application point of view. We have seen that, ceramics can be used for high temperature applications. So, they have (( )) market for high temperature applications and most of the ceramics products specifically the refractoriness are used for high temperature applications. In that case or those applications the high melting point of ceramic is very, very advantageous.

But in case of the processing aspects sometimes this may cause a little bit of a problem also. So, high melting point is because of the bonding that exists in the ceramics. Low thermal expansions can be advantageous in many cases. High elastic modulus also advantageous in many cases, high hardness as we have already seen in our previous lecture, that the ceramic materials are used for wear resistance. So, there the hardness comes in to the picture. So, high hardness is also we can say after effect of the type of bonding that exists in the ceramic materials. Good chemical resistance and finally, the brittle.

So, because the ceramic materials are brittle, therefore in many applications they are discarded. For example, we take a component for engine application. In engine application all of us know the temperature would be very high. So, for a specific engine assembly components, the temperature would be high, very first point in your screen you see that ceramics have high melting point. So, for high temperature application we can very easily advocate the use of ceramics materials. Sometimes, some oil etc may be there that is coming in contact with this component, so corrosion may take place. In case of ceramics we have good chemical resistance corrosion resistance, so that also is satisfied.

So, we can we have a material, which is good at high temperature, which has very high melting point, which can be used for elevated temperature applications. It has good corrosion resistance, there is the we can say moment of the material or it is rubbing against the moving material, wear is there. This particular material has good wear résistance also, that is ceramics have good wear resistance, they have good chemical or corrosion resistance, they have high temperature applications capabilities, but because of the brittle nature the application is discarded. Therefore, now-a-days there is a focus on improving on this important aspect of ceramic materials. In our module 6 we will see, the ceramic matrix composites in which this particular aspect brittleness or the fracture toughness aspect of the ceramics has been addressed properly.

So, there we will see that monolithic ceramics are reinforced with the reinforcing phase. The reinforcing phase can be in terms of continuous fibres or it can be in terms of particulates which are added into the ceramics in order to improve certain characteristic of the ceramic material. So, I have taken an example just to explain that all other criteria is being met, high temperature application criteria is met, wear resistance criteria is met, corrosion resistance criteria is met, chemical inertness criteria is met, but the mechanical load that is coming on the component may be a kind of impact load and ceramic material is not so advisable in case of impact loads because of the brittle nature of the ceramic material.

So, apart from, apart from satisfying all the criteria because of only one limitation, the application of ceramic for that particular application could not be materialized or could not be finally, found feasible. So, the problem area has to be addressed and all these properties from where they are coming? They are coming from the very basic bonding mechanism or very basic type of bonding that is found in case of most of the ceramics. So, bonding is one of the important point that has to be taken care of. Bonding that is existing it is already existing, so it is cannot modify the we can say bonding in most of the cases.

So, already whatever materials are available, whatever bonding is there it is already there, properties are already known to us. Now, these properties we have to take care when we are going to process ceramics into a desired shape. So, before addressing the processing aspects of ceramics, we should try to understand that what are the important properties of the ceramic materials. Now, on your screen, you can see some of the important properties of the ceramic materials. These properties we will further see. In today's lecture also we will see the comparison between the metals and the ceramics because from the processing aspect of view, we have to from the processing point of view.

We have to see that, which are the important processing techniques, which are well established for metals? But specifically in case of ceramics, can we apply those techniques? Then we will see that what can be the specific techniques or dedicated mechanisms or dedicated techniques for processing of ceramics. So, till now we have seen the brief review about what we have covered in the previous discussion. Today we have seen that there is ionic and covalent bonding, that is present in the most of the

ceramic materials and this type of bonds are stronger than the metallic bonds.

And because of this type of bonding present in the ceramics, these are the mechanical properties or physical and thermal properties, which are highlighted on your screen. So, these are the properties that are present in the most of the ceramic materials and these properties would be used by the engineers to design and develop the processing techniques for ceramics.

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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

Again coming to the same diagram, which we have seen in the lecture 1 also. Let us now see this diagram from the processing point of view. Now, density of the ceramic is less, for metals it is high, hardness for ceramics is high. So, we cannot think of machine in the ceramic material because diamond is also a kind of ceramic, so difficult to machine the hardest substance known. So, basically hardness is an important criteria, which has to be taken care of.

So, metals have low hardness as compared to the ceramics. Therefore, they can be processed easily, one metal can be used to cut another metal only condition is the hardness of the cutting tool should be greater than the hardness of the work piece material. So, metals can be machined, but machining of ceramics is bit difficult because of the very high hardness of the ceramic materials. Coming on to the ductility; now ductility is an important property of the material, which makes it amenable to be drawn into long wires.

So, ceramics cannot be drawn into long wires because the ductility of the ceramics is low. Whereas, the metals have very high ductility and therefore, they can be drawn into thin wires. All of us have seen the wires made up of metals, so the ductility is an important criteria, which is low for ceramics. Therefore, if you want to make wire of a ceramic materials, we have to think of the process, which can we used for making a wire of ceramic materials because of low ductility of the ceramic material. Similarly, we can see electrical conductivity of ceramics is low.

Whereas, in case of metals it is high, we have many unconventional manufacturing or processing techniques, like most of the engineers know about the electro discharge of machining, EDM process. Now, for a material which has low electrical conductivity, it is difficult to process the electric discharge machining. Whereas, this metals have high electrical conductivity they can be easily processed by the electrical discharge machine process.

So, all these properties on your screen is one way or the other way related to the processing of the materials. So, whatever the property is there, it will have the direct bearing or the indirect bearing on the processing of that particular material or for a processing of a particular material. So, we can see hardness, ductility, density, thermal conductivity, electrical conductivity, all these properties will have affect on the processing of the materials. So, we have seen that it is difficult to make wires of the ceramics.

It is difficult to process ceramics, where the high conductivity is desired in the work piece materials because the electrical conductivity is low for ceramics. It is difficult to melt the ceramics also because the melting point of the ceramics is also very, very high. So, these properties we have to understand before subjecting the ceramic material to be converted into a particular product or before subjecting a ceramic material to any of the processing techniques. So, here we have just try to understand the same diagram, but from a slightly different perspective, that is from the point of view of the processing aspects of the materials. And the materials we have compared are the metals and the ceramics.

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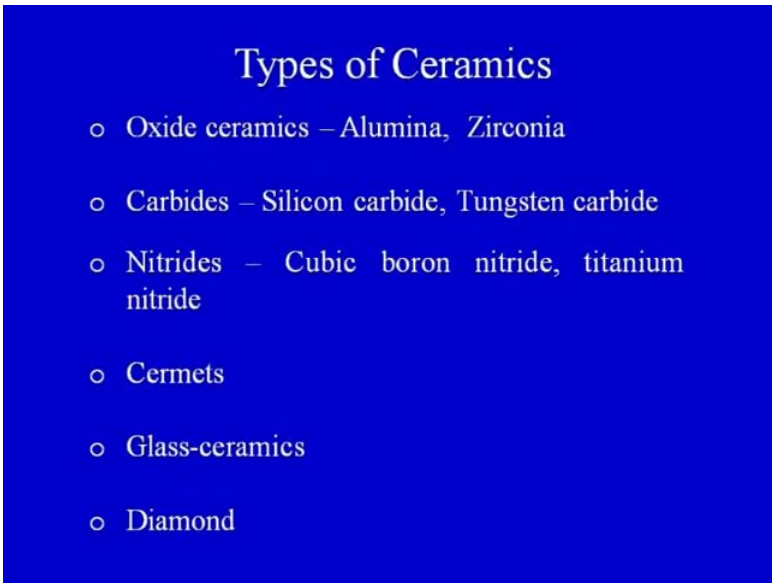

Now, what are the various types of ceramic materials? Let us see, although we have classified the ceramics, but now we want to see different types of ceramic materials that are available. Oxide ceramics like alumina zirconia, carbides like silicon carbide tungsten carbide. Now, silicon carbides, let me give you the example used as a reinforcing material in may metals matrices. As we will see in our subsequent classes, there either new class of materials which have been developed some two three decades back, that is the composite materials.

The composite materials have been designed and developed, in order to meet some specific design requirements of many applications of where single material cannot meet the demand. So, basically two micro constituents have to be combined together to make a third material, which has the best properties of material one and material two. So, we are combining the two materials and making a third material. Third material has the properties of both but possess certain special characteristics or special properties, which are not achievable by any one of these taken alone.

So, those composite materials we are going to study, specifically the polymer matrix composites and the ceramic matrix composites. Silicon carbide is used as one of the reinforcing materials, in case of metal matrix composites in which matrix is the metal and the reinforce is ceramic that is silicon carbide. We get a material, which is having very good hardness, which is having good wear resistance and which is used for many

engineering applications. Silicon carbides can be used as a reinforcement material in the metallic matrix.

Next are the nitrides, cubic boron nitride, titanium nitride. So, we can see the cubic boron nitrides, CBN, most commonly used, it is a very high hardness material which is used as a tool material in many cases or a coating on the tool. It has got high hardness that I have already told and as got good we can say temperature resistibility resistance. That is at elevated temperature when the tool is in contact with the work piece, it will hold its mechanical properties. So, cubic boron nitrate is the material which is being used in cutting tool applications. Then there is titanium nitrate, which is used as a coating material on the cutting tool and has got good frictional properties or good frictional characteristics.

So, nitrate is another class of ceramic material, carbide is another class of ceramic material, oxide ceramic examples are there, alumina or zirconia. Alumina s is also used as a reinforcing material in the metal matrix composites. Then we have surmates, surmates basically are the combinations of the ceramics and the metals. So, metals provide the toughness and the ceramics provide distinct characteristics of high temperature application, good wear resistance. We have seen a number of good properties or usable properties of the ceramics.

Ceramics and metals are combined together and they are taking advantage of the best properties of the two and coming in the form of a third material, which possesses the special characteristic of the ceramics as well as the important characteristic of the metals. So, cermets is another category in which we have the ceramic materials. Then glass ceramics we have seen that basically glass ceramic possesses special advantages that they have combined the easy processabilty of the glass, with distinct characteristic of the ceramics.

So, glass ceramic is another type of ceramic, which is being used. It has an enhanced toughness, it has good strength and sometimes it can be made superconductive also. Glass ceramics have got there own characteristics, then we have the hardest of strength known as that is diamond. Diamond is also used as cutting tools, it can exist as pcd poly crystalline diamond. Diamond grid is sometimes coated on the cutting tool in order to improve the hardness of the cutting tool.

So, basically types of ceramics the important point of ceramics highlighting this particular slide is to give application spectrum of the ceramics and to give and revise the classification of the ceramics. We have oxide ceramics, in case of non oxide we have carbides and nitrides. Then we have a special combination of metals and ceramics that is cermets, then we have combination of glasses and ceramics, that is glass ceramics. Finally, we have diamond which is the hardest substance known. So, there can be different types and this list is not an exhaustive list of the types of ceramics, there can be other additions also in this list. But this is just to give an overview to that what are the important types of ceramic materials which we have using in our day to day life.

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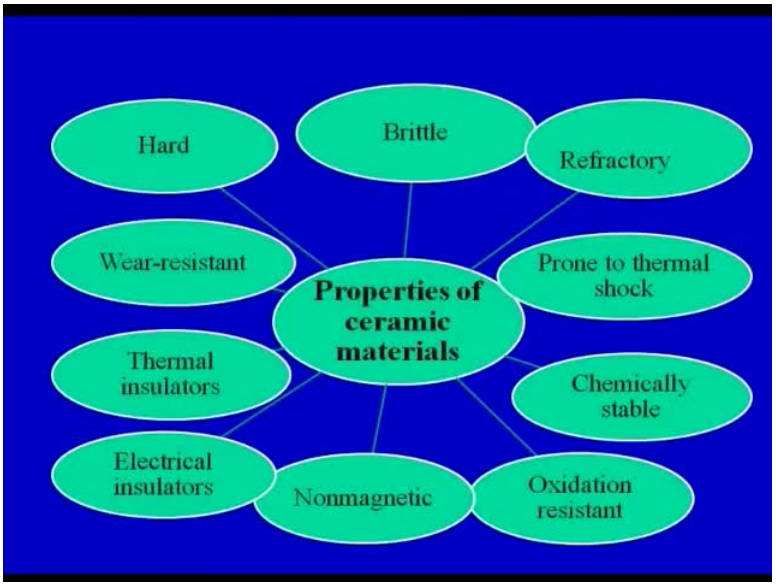

Now, this is we can say very busy slide so in this busy slide we can see at the centre we have the properties of the ceramic materials. So, this is just giving a summary before jumping on to the processing aspects of ceramics. Now, this is a summary of we can say the properties that are present in case of ceramics. It is not only the advantage or the disadvantage, but the properties that the ceramics possesses. So, we can see the properties of the ceramics. Let us starts from here, they are hard, that is they have high hardness, brittle in nature.

This we will try to understand with the help of a stress strain diagram, in which how the brittle fracture takes place in case of ceramics. Refractoriness means, they can used for high temperature applications like linings in the kilns or they can be used for crucible

applications. So, there can be different refractory applications, so important point is that most of the ceramics are used for high temperature applications. They are prone to thermal shock, so that is we can say properties that has to be taken care of in case of some of the ceramics.

Chemically they are stable, that is they are we can say corrosion resistance, they are not prone to chemical attack means, they are we can say chemical resistance is good, corrosion resistance is good, so they are chemically stable. Oxidation resistant, so oxidation of ceramics is we can say not an easy task. Nonmagnetic in nature, electrical insulator in many electrical engineering applications we see ceramics being used as electrical insulators. Then they are also sometimes used as thermal insulators also, because they have poor thermal conductivity, poor electrical conductivity.

Then they are wear resistant and these two properties are we can say related to one another. They are wear resistant, so we can see that many properties are there for ceramics. So, they are all versatile materials and they possess wide variety of properties. Some of these properties make them amenable to processing and some of these properties acts as an hindrance for the processing of ceramics. So, these are the properties which gives rise to a large number of applications for the ceramic materials. So, we can foresee a large number of applications for ceramic because they possess so many diverse properties.

So, just to have a revision of the properties that the ceramics possesses, let us just revise that they are hard, brittle, wear resistant, thermally they can they are insulators, electrically they are insulators, non magnetic, chemically stable, refractory properties, they are oxidation resistance, thermal shock, so basically a wide variety of properties are there for the ceramic materials. We can see out of these, if you say let us choose four important properties and try to find out the applications of based on those four properties.

Let us take the example of hardness; they are hard, therefore they are used for watch making. In watches sometimes they are used for making the cases or scratch free or scratch resistant cases in case of watches. So, that is one important properties that is or hardness. Then on the basis of we can say electrical insulators because they have electrical insulation properties, they are poor conductor of electricity. Therefore, they can be used as electrical insulators for electrical engineering applications.

They are chemically stable, so they can be used for making the laboratories, crusicles of laboratory equipments because they will not react with the chemicals that has being used in the laboratory. Then we can say refractory is another properties of the ceramic materials on the basis of refractory, refractoriness they can be used for brick linings or they can be used for, in the we can say in the furnace as the covering material. They can be used for high temperature applications for example, in space shuttles such as ceramic tiles.

So, high temperature applications refractory properties, scratch resistant applications hardness, insulation thermal and electrical large number of applications are there, wear resistant applications are there. So, we can see that the ceramic material possess a wide variety of properties and these particular properties make them very upcoming or we can say very promising engineering materials. But there are few limitations such as the brittle behaviour or the fracture toughness. So, fracture toughness and brittle nature of the we can say ceramics have to be addressed, if we want to further increase the application spectrum of ceramic materials.

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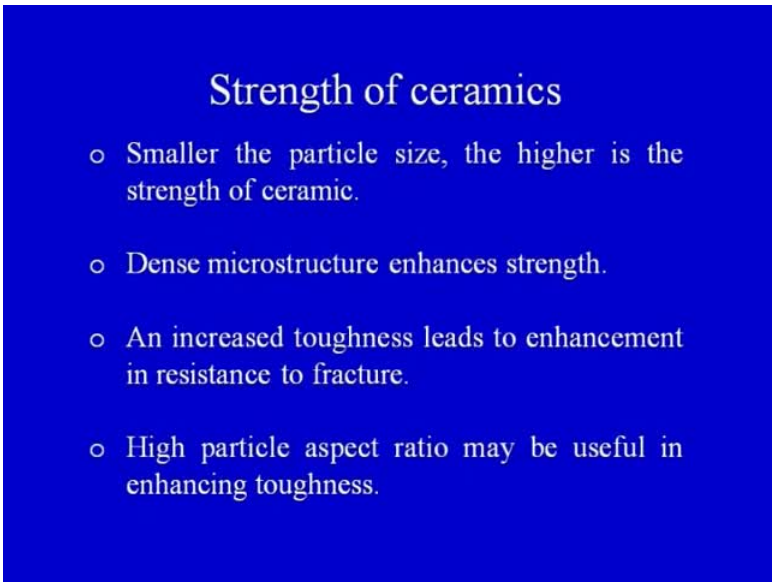

Now, coming on to the strength of ceramics. Let us see, this is just strength is the we can say very common word which has been highlighted here. So, strength can be compressive strength, shear strength. So, let us see we can say the strength of ceramics basically is dependant on the smaller the particles size, the higher is the strength of the

ceramics. So, different particles make up the ceramics because we will see the powder processing techniques for processing of ceramics. There we will see, how we will blend powder together to make a ceramic product.

So, basically there we will address the size of the particles would affect the properties or the mechanical properties of the ceramic products. So, when we will make the ceramic from the powder, properties of the powder would affect the mechanical properties of the compo ceramic product. Dense microstructure enhances strength, hence the porosity is less we will get better mechanical properties. Increased toughness leads to enhancement in resistance to fracture. So, basically we want resistance to fracture, we want good fracture toughness.

So, an increased toughness would help us to improve the fracture toughness aspect of the ceramics. High particle aspect ratio may be useful in enhancing the toughness. So, basically the materials that we are using, that is the particle that we are using for making a ceramic product would affect the properties of the final products. So, two important points are highlighting that aspect, that is the size that is point number one and the aspect ratio that is point number four. So, these two important points would be discussed when we will see the powder processing technique of ceramic fabrications or ceramic products fabrication. So, let us see try to understand an important aspect of ceramics that is the stress strain behaviour of the ceramic products or the ceramic materials.

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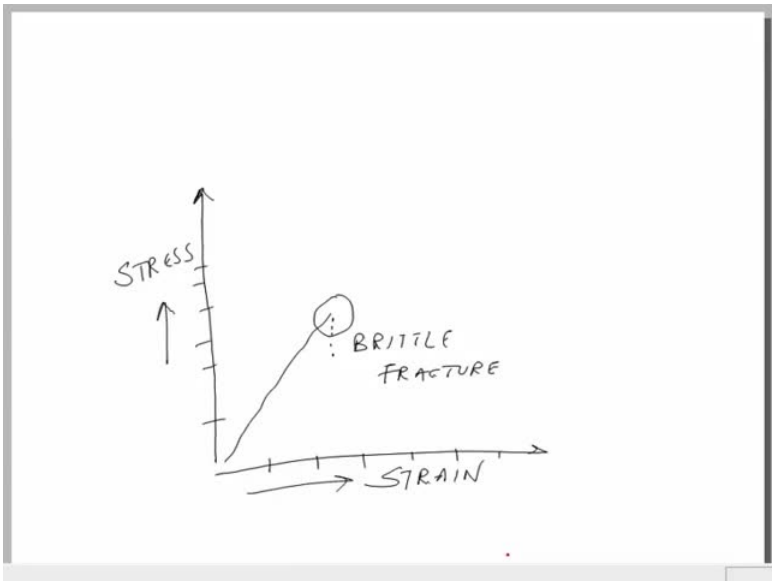

On your screen you can see, that if we plot a stress strain curve for a ceramic material, it will be something like this. Then the load would come down, that is brittle fracture would takes place. Whereas, in case of metals we will see that, when we are loading it under tensile load, we will see that necking will be take place. Finally, we will get a different type of stress strain curve. I think this is the very common stress strain curve for metals, which is taught in almost all the engineering colleges and all the engineering curriculum.

So, that we are not, I am not going to draw here, that what is the stress strain curve? But I think everybody should be able to distinguish the stress strain curve between a metal and a ceramics. In case of ceramics we can see that there is no elongations taking place, there is a brittle fracture that is taking place. Similarly, the tensile and compressive behaviour of ceramic would also be different. Under tensile load we will see that the ceramics would fail at a fearly at less stress level. Whereas, in compressive the kind of loading the ceramics can take more load to failure as compare to the tensile loading conditions.

So, basically we can see the stress strain behaviour of ceramics is different from the stress strain behaviour of metals. Therefore, the processing techniques that we can used for processing of ceramics should be different from the techniques, that are used for processing of metals. Now, coming back to our discussion, we have seen there the mechanical properties of ceramic are different than the mechanical properties of the metals. Therefore, the processing techniques for ceramics would be different from the processing techniques that we have developed for metals.

So, we have try to understand the stress strain behaviour also, that the brittle fracture takes place in case of ceramics. Whereas, the necking takes place in case of metals and finally, the failure takes place. So, because of the difference in the mechanical properties of the two materials that is the ceramics and the metals, the processing techniques that would be used for processing of ceramics and there for that for metals also be entirely different, so that is an important point to note. Because whatever processing techniques we would be seeing in the subsequent lectures would be different from the techniques that are used for metals.

Now, coming on to the electrical properties of ceramics, the last slide just highlighted that the mechanical properties of the ceramics are different from the mechanical

properties of the metals. One important aspect that has just come to my mind that is, one of the applications of ceramics is, if you remember in our previous lecture that is lecture number 1, we have classified the ceramic materials into two broad categories or two broad classifications. That is one was based on the nature of the compositions of the materials, that is based on the composition of the different types of ceramics. The second one was based on the applications of different types of ceramics.

So, on in the applications side if you remember have seen, that cement and concrete is also a ceramic material. If you remember if you have this information with you that concrete is very good in compression, but is very poor in tension. Similarly, we are seeing a general behaviour of the ceramics, that when we applied compressive load they are able to take more load to failure, whereas in case of tensile loading, the failure stress is less or the failure load is less. So, under tensile applications ceramics should not be advocated or the use of ceramics should not be advocated, where the tensile loads are come on the components.

But certainly in comparison to the tensile loading they are able to sustain higher compressive loading. So, here we can draw one to one analogy between a difficult ceramic and concrete, which is also a type of ceramic. So, we can we have seen in our applications, that the cement and concrete also are the types of ceramics based on the applications point of view.

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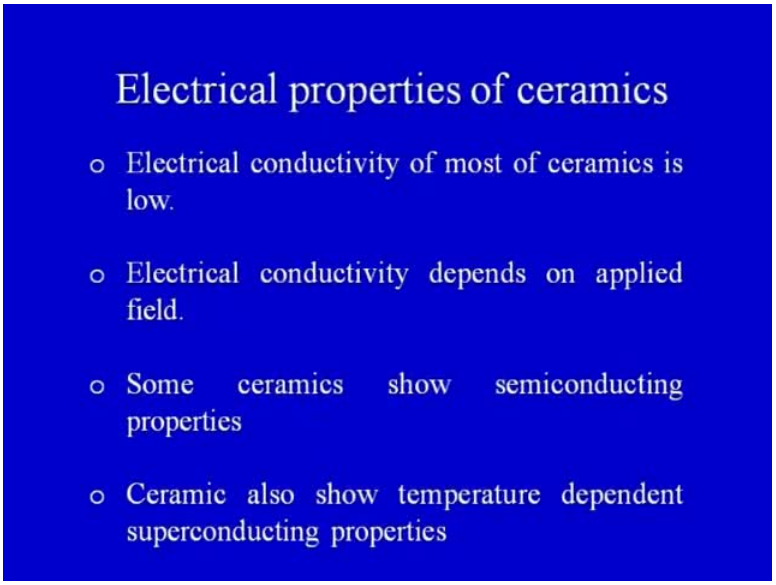

Now, leaving the mechanical aspects now coming on to the electrical properties of ceramics, we can see on your screen electrical conductivity of the most of the ceramics is low and therefore, they are used for electrical as electrical insulators for electrical insulation. So, the electrical conductivity of the most of the ceramics is low. Therefore, they are used for electrical insulation purposes. Electrical conductivity depends on the applied field which is common, depending upon the applied field the conductivity would be it is dependent on the applied field. Some ceramic shows, this is an important point some ceramics show semiconducting properties.

So, we have seen that there is a wide variety of ceramics, one or two elements combined together to make a single ceramic material. There are large families of ceramic materials as we have seen, when we have seen in lecture 1 the classification based on the compositions we have seen silicates, non oxides, oxides and glass ceramics, within each we have large number of further categories of ceramics. So some of the ceramics show semiconducting properties and ceramics also shows temperature dependant superconducting properties also. In general we can say that the electrical conductivity of most of the ceramics is low.

Therefore, they are used for electrical insulation purposes, but some of the ceramics do process semiconducting or superconducting properties at elevated temperature. One of the point that is highlighted here is, that the conductivity will depend upon the applied field. So with these we can come to the end of lecture number 2 in module 6. But before leaving the lecture we will just see just revise the applications of ceramics, so that as an audience you have in your mind that whatever or what are the important or typical applications of ceramics?

So, that whenever you see any ceramics application around you just have an idea, that this is a ceramic product, this might be having this type of bonding this particular product might be having this type of properties. As we have seen that it is, good wear resistance properties, good we can say thermal insulation properties, good electrical insulation properties, so it may be having high melting point. So, just by looking at a ceramic product you can have an idea that these are the properties that this particular product should possess. So, just before leaving the lecture, let us just end the lecture with this typical application.

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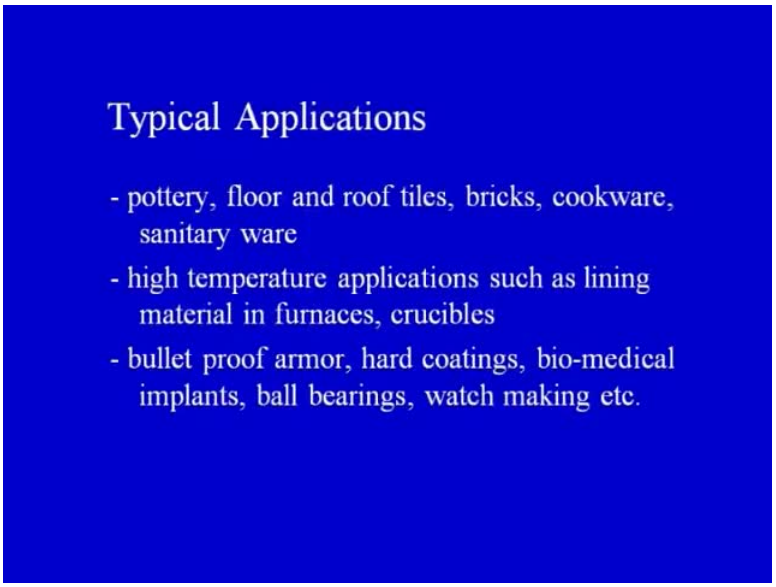

On your screen you can see pottery, floor and roof tiles, because all of us see floor and road tiles. Bricks, cookware, sanitary ware, so these are some of the ceramic applications starting from our household applications. Then high temperature applications such as lining, crucibles, so lining basically the lining material in the furnaces. We can have crucibles as high temperatures or refractory applications of ceramics. Then we have high temperature we can say high performance applications of ceramics that is bullet proof armour, hard coatings on metallic materials, biomedical implants, ball bearings. As I have already discussed in today's lecture only the watch making, the cases of the watch can be made scratch resistant with the help of ceramic materials.

So, this is just the applications all around us, and looking at these applications we can have frame in our mind that yes this is the ceramic material. This particular product should be possessing these type of properties. So, that was the basic idea of having these two lectures that is ceramics 1 and ceramics 2. And with this brief overview about the ceramics now, we would start our discussion in the subsequent lecture on the processing techniques of ceramics.

Thank you.