Advanced Ceramics for Strategic Applications
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Lecture - 46
Structural Ceramic Materials

Welcome to today's lecture on structural ceramics materials, the emphasis this kind is on materials have been discussed the mechanical properties of ceramic materials, the fracture mechanisms and also various other mechanical property. In general, today we will be discussing or focusing our attention on the materials aspect, that the, what are the different materials we have introduced some of the materials earlier. But this particular lecture will primarily focusing on the materials used for different applications.

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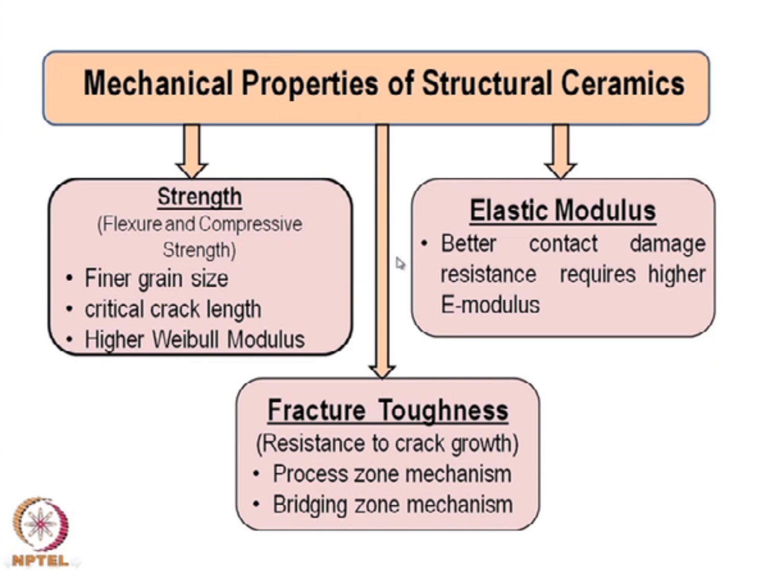

So, the topic as mentioned is structural of ceramic materials. Well this is what we have already discussed in our earlier lectures on mechanical properties. The summary of that discussion is we have looked into the strength elastic modulus and the fracture toughness in case of strength, we have also discussed about the flexure strength and comp compressive strength and their different aspects of strength of different materials then we have also included elastic modulus and fracture toughness. Here some of the parameters, we have discussed under strength is the finer grain size on strength or the dependence grain size on strength critical crack length. That is a particularly for brittle facture and then higher Weibull modulus, the basically the reliability, reliability of the measurement. So, you need, because of the brittle fracture, you need large number of measurements to arrive at a different arrive at elaborate. In case of elastic modulus better contact damage resistance requires higher e modulus that is why we need the understanding of the e modulus.

And then fracture toughness resistance is basically the resistance to crack growth and higher is the resistance, higher is the fracture toughness. And there all has in a attempt in ceramic materials to enhance the fracture toughness, because basically, intensically they have a very low fracture toughness. So, there are many extensic measures or extensic mechanisms by which one can improve the fracture toughness. So, that can be done only through understanding of the mechanism of fracture. So, there are process zone mechanisms and bridging zone mechanisms that we have already discussed in our earlier lectures.

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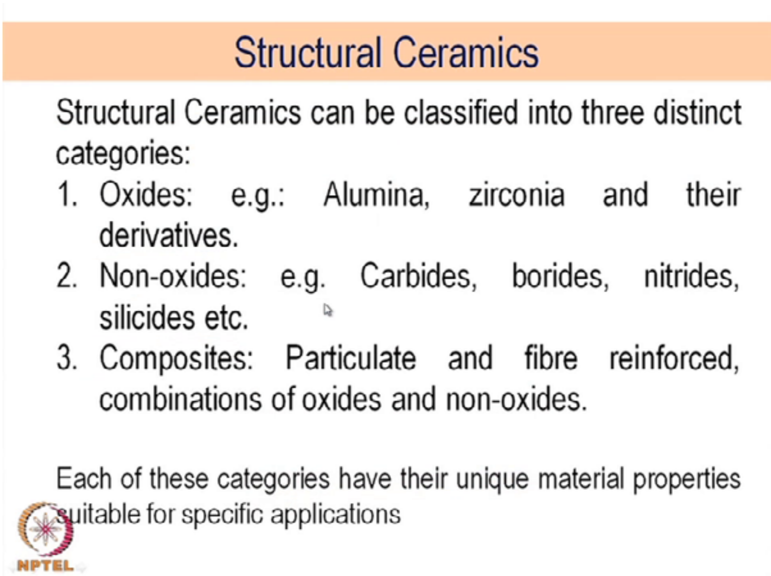

So, have been discuss that, as I mention couple minutes back our focus here is on structural ceramics, will ceramic materials used for different applications where the mechanical properties of different types are of relevance. So, there are three varieties of structure ceramics depending on what is the chemical composition, composition not chemical constituents, the nature of bonding mechanisms, the ionic bonds or the covalent bonds. So, the oxides, oxides ceramics among which, the alumina, zirconia and there derivatives that means, certain composites made of alumina, certain additives used in alumina or zirconia, we will discussed some of them later. So, basically they are alumina and zirconia best oxides, that is the metrics then we can have other pages present there to improved their properties that is the big group on structural ceramics that is non oxides, which do not having oxygen in them and there and they may be carbides, borides, nitrides, silicides and so on.

So, carbides I mean these non oxides play a very vital role. So, far as the structure ceramics concern primarily because they have a coherent character so far as the bonding is concerned, atomic bonds and ionic bonds are concerned. And then they have higher most of them higher melting points, very hard and so on. Although the fabrication and the synthesis of this compound are relatively difficult, and they may be little, they are not available as such in nature of like alumina and zirconia, but they are very important from the applications point view.

So, even if they are costly, they have use application potentiality. Third group of course, it is the composite's, it can be either particulate composite's and fiber reinforced composites, sometimes they refer to as ceramics matrix composites c m c as compared to m m c s which are basically metal matrix composites. So, here in metal matrix composite's also use ceramics, but ceramics are use as, a enforcing agents, particulates particularly fine particles of ceramics are using metal matrix composites, but in ceramic matrix composite's the matrix itself is ceramics.

And you have to add to, that the reinforcing agents of a different ceramics or different fibers or different compound, different other ceramics. So, these are the 3 different groups under which the whole structure ceramic materials can be classified, and each of these categories have their unique material properties and suitable for specific applications. So, we will look into some them it is a very, vast, subject as such and one can spend several lectures on this particular topic at the time is short. So, we try to finish it very briefly within this one hour lecture.

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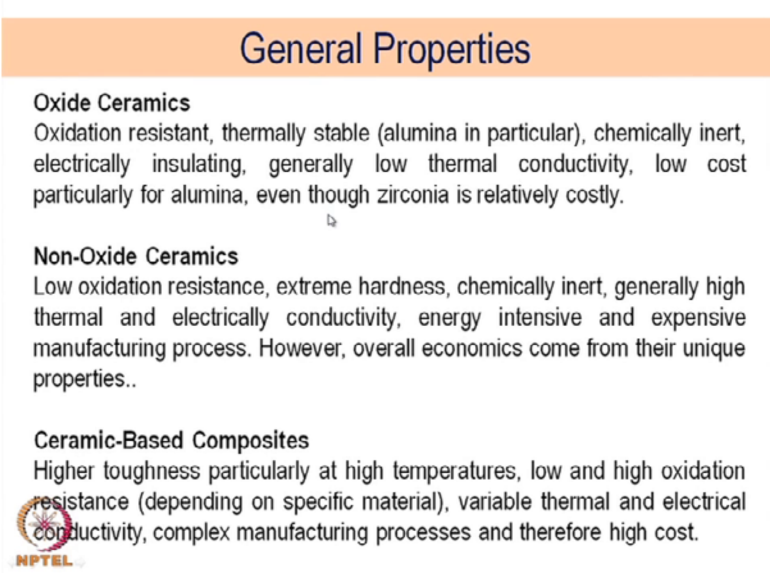

General properties by this time, it is already well-known of the oxides ceramics their oxidation resistance, thermally stable, particularly alumina and in particular zirconia may not have that much to thermal stability, but of course, the melting points is very high, but the phase transformation to take place and. So, from that point of view that may not that stable particularly high-temperature except the stabilize zircon which is used for fracture applications. Partially stabilized zirconia has certain limitations of, the values at relatively high-temperature, chemically inert the oxides; obviously, chemically inert, electrically insulating, most of them are electrically insulating particularly alumina, zirconia of course, has some higher some come electrical conductivity.

But that as we discussed earlier that is not electronic conductivity, that is basically ionic conductivity and they have its own application areas. But as a structures ceramic material electrical property not always that important, thermal properties are very important zirconia as a relatively low thermal conductivity. And therefore, it has a very important application as structural ceramics particularly as coatings, a low cost particularly for alumina even though zirconia is relatively costly so far non oxides are concerned. Low oxidation resistance, because they are non oxides either carbides, nitrites, silicides, they have a tendency to get oxidized at relatively high-temperature. But in fortunately for as in most cases particularly, silicon carbide for example, molybdenum silicide. So, in both this cases, you have silicon and that gets oxidized at form silicon dioxide.

And forms a glass layer, which is a protective layer, protects it protects the basic material from further oxidation. So, although they are prone to oxidation, but if silica is there, silicon is there, it gets oxides to silica and forms of glassy coating to reduce their oxidation that is an advantage, for some of these is oxygen be silicon bearing compounds. Generally high thermal or electrical conductivity, for example, both molybdenum silicide and silicon carbide fairly large have a good conductor, conductivity both electrical and thermal.

So, they can be use for the heat exchanges kind of applications at high-temperature, energy intensive and expensive manufacturing process, that fairly large, fairly high, melting point. And therefore, they need very high sintering temperature and also a controlled atmosphere, because oxygen should be, should not be allowed to come in contact and therefore, it needs control atmosphere sintering. So, therefore, costly however, overall economics comes from the unique properties. So, they have certain unique properties, which are not available in other materials. And therefore, you have always some economic advantage even then in a, their costly in an absolute sense ceramic based composite's higher toughness most of the composite's are actually designed for increasing the toughness.

So, they have a higher toughness particularly higher temperature also, and low and high oxidation resistance, low and high oxygen resistance depending on the specific material, sometimes low oxide, and high oxidation rate where or sometimes in some other material will be very low. So, depending on the application's one can design or choose the materials appropriately, variable thermal and electrical conductivity, variable thermal electrical conductivity and complex manufacturing process. And therefore, high cost so; obviously, for making a ceramic based composite's with right kind of phase distribution and it needs, a special techniques. And therefore, the cost is high, but that always compensates, with the kind of unique properties or the application potentiality on those materials.

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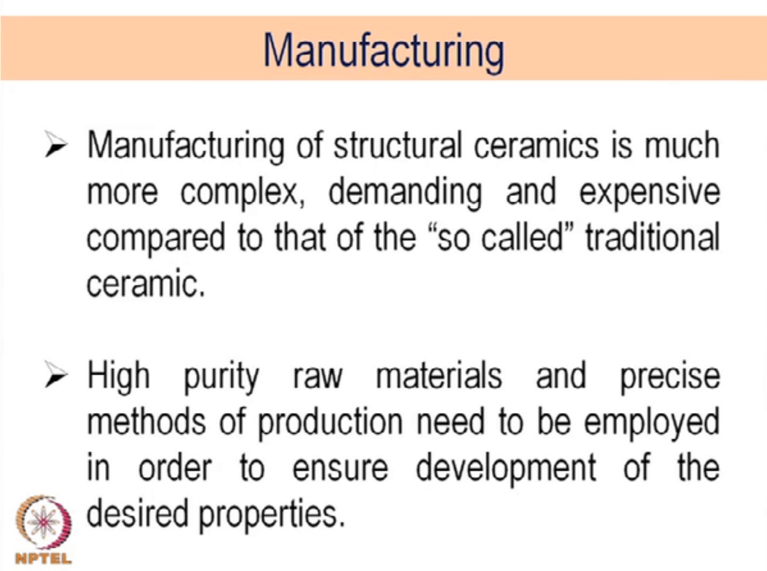

Manufacturing; how normal in general, how they manufacture? The manufacturing of structural ceramics is much more complex, demanding and expensive compared to that of the so called traditional ceramics. That we have already discussing other initial or introductory lectures that compared to traditional ceramics where the raw materials are naturally available with certain amount of purification and so on. So, they are little less expensive whereas when we talk about structural ceramics they are high purity materials, many a times synthesize materials, powders or starting materials.

Starting raw materials needs special attention for a synthesis there are different techniques for synthesis depending on what kind of chemical compound it is. And therefore, they are demanding an expense compared to so-called traditional ceramics. High purity raw materials, as just mentioned and precise methods of production need to be employed in order to ensure development of the desert properties. So, there more challenging, for any ceramic technologies to prepare them and of them the right kind of properties, by controlling the chemical purity the manufacturing process and also the environment.

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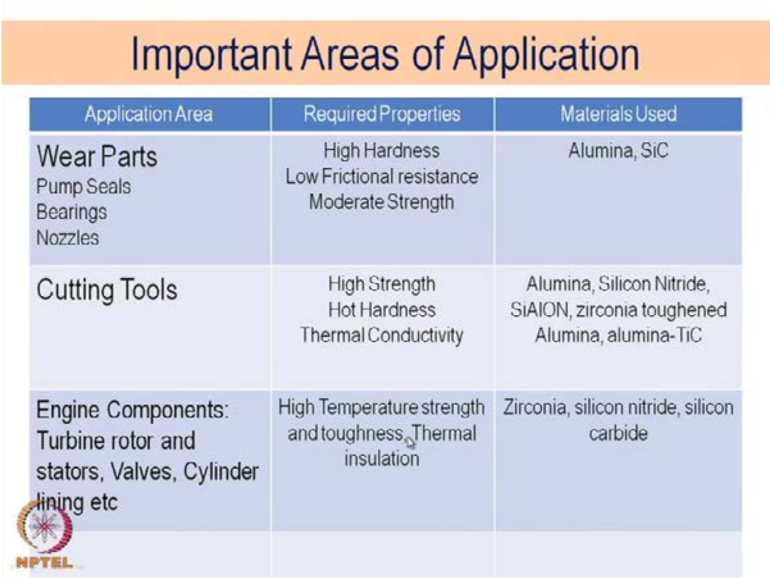

And these are some of the important areas or applications and the corresponding materials normally used, for such applications. For example, on the left we have the, the list of different application areas they have been subdivided in to 3 different classes. For example, wear parts where fiction is very, very important and as we know, ceramics are hard materials. And therefore, the, they have a wear resistance property and together it that you have fictional the coefficient of friction is also important. And therefore, for the wear parts not only you need high hardness, but low friction resistance and moderate strength. The strength is also important, but is not that important compared to the hardness and the low friction resistance. The specific components are like pump seals extensively used as pump seals particularly for to avoid leakage of the liquid through the soft or near the soft.

So, the pump seals is a very important application, and is a from the point of view of market share is a huge markets share, bearings is more or less the similar applications ceramic weariness even ceramic balls, total ball bearings are been in fracture these days and nozzles, nozzles for different applications. It can be for aggressive, to supply aggressive or to deliver aggressive, aggressive particles or sometimes at high temperature even avoiding all these. Ceramic nozzles are also used where it is supposed resistance high temperatures are also to high velocity of the gas.

So, these are some of the wear parts where height of high hardness, low faxing, frictional resistance and more strength and sometimes. Of course, the high-temperature resistance are very important and the 2 most important materials used for this kind of purpose is alumina, which is relatively less costly and then silicon carbide, silicon carbide also a is used for above all these applications. In fact, pump seals started with alumina, but these days, it is mostly use in silicon carbide, silica carbide.

Cutting tools is the another very important area of the applications of structure ceramics, because you need high speed cutting in many different advanced manufacturing workshops. So, need properties like high strength, hot hardness is very important, because the tip of the cutting tool, when it comes the metallic, jobs are the material to be cut there is high speed, the job rotates very high speed. And whenever there is a contact between the tip of the cutting tool and metallic materials you have a huge amount of heat is generated.

So, the tip temperature goes up more than thousand degree centigrade is of times and therefore, you need not only the material has to stand that high-temperature, but also it should not lose its hardness and the temperature. So, that is what we call the hot hardness. So, the hot hardness property of the particular material is very important and thermal conductivity, sometimes you need less thermal conductivity, but mostly higher thermal conductivity because the heat has to be disputed out. So, if there you just 2 insulating material, then there is heat dissipation is difficult, and we get high temperature's which reduce the or lower down the property particular the hot hardness. The materials used for this purpose is a once again alumina, silicon, nitride, sailon is basically sily silicon aluminum oxide nitride. So, it is a combination of silicon, nitride, aluminum and aluminum oxide.

So, it is a kind of composite it is little complex structure, but siolon is a very, very important material for, cutting tools in particular. Zirconia toughened alumina, not only pure alumina or high purity aluminum, but particular zirconia, alumina that addition of zirconium, introduce toughening trap transformation toughening, from the monocloinic titagna transformation and alumina titanium carbide. So, alumina is relatively insulating, where as titanium carbide is more conducting and a composite of alumina and titanium carbide particular composite is a very useful material so far is the cutting tool is concerned most of his cutting tools.

In fact, are coated with some kind of carbide's and nitrides. For example, titanium nitride and that provides a better performance, not only the, because the bulk of the material not only important. But the surface is another criteria, which determines the performance of the tool. So, many a times different kind of ceramics coatings, are added to this cutting tools. In engine components, one of the major areas of structural ceramics is in the different kind of engines, either the automotive engines or the aero engines, the turbines, the gas turbines and so on turbo charges and so on. So, all these applications require not only very high temperature, the material must be stand high temperature. So, higher is the temperature of operation of the engine, the higher is the efficiency, fuel efficiency is better and fuel consumption gets reduced.

So, there is a always a tendency for the all this engines, why that is automotive engines, or gas turbines for aero engines, all of them you know all this cases you have a desire to increase the temperature of operation. And for that we need right kind of materials, beyond the service temperature of most of the metals and alloys. So, ceramics plays an very, very important role there, and not only the overall engine block, engine block. Of course, it is very difficult to make out of ceramics, but there can be many different other components, where ceramics plays an important role.

So, the turbine rotors and stators valves, cylinder lining all these, can be made out of sili out of different ceramic materials, the properties which have more importance here high temperature, strength, and toughness, and thermal insulation. So, most cases thermal insulation, sometimes you need thermal conduction also, depending on the particular purpose or the function of that particular component. So, high temperature strength and toughness are the prime requirement, and then in addition to that thermal properties are also important.

The materials, which are of importance in this case is zirconia, silicon nitride, silicon carbide these are the basic materials. But then they have many different variations, either composites or toughening additives, additives to toughening the material or to enhance the other properties. So, zirconia, silicon nitride and silicon carbide these 3 are the basic materials, which are used for this purpose.

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Properties of a few Monolithic and Ceramic Matrix Composites

Materials	Fracture Toughness ($Mpa.m^{1/2}$)	Critical Flaw Size (micron)
Sintered SiC	3-3.5	20-25
Sintered Si_3N_4	4.0-6.0	30-70
Hot Pressed Si_3N_4	4.0-6.0	30-70
SiAlON	4.0-6.0	30-70
Particulate Dispersion		
Al_2O_3 – TiC		
SiC – TiB_2	4.0-4.5	35-40
Si_3N_4 –TiC		

While we have discussed earlier, some of the typical properties of structural ceramics materials while we are discussing mechanical properties. We just use capitalize the separate list the values may not exactly come match with what we have represented earlier, but just because we are discussing the different here. Let us have a look at, for the key properties ceramic materials, sinter silicon carbide, it is the fracture toughness about 3 to 3.5 and critical flaw size. We have discussed about the, while we discussed about the fracture mechanism fracture mechanism, we have introduce the concept of the critical flaw size. So, that is the critical flaw size of 20 to 25 micron which will grow if the flaw size is less than that, that is not going to grow under the application of the of the mechanical stress.

So, critical size and the idea of the critical flaw size is very important for all these materials, of course, they are just a, a harder magnitude values, they may not be exact. And the vary, the vary of the wide range depending on, what kind of micro structure, it has, what kind of grain size it has, what processing history it has? And of course, the chemical composition of the on the material, and the way it has been prepared. For example, you can see here, sintered silicon nitride and hot pressed silicon nitride, sintered means it’s a partial less entry, and a normal mostly pressure whereas, when we talk about hot pressed this situation is slightly different. Although, in this case you can see the properties are more or less comparable even SiAION as more or less comparable properties.

So, the, but in others context, will find that the processing history or the technique of processing, do have a effect or influence on the ultimate properties. These are the last 3 actually composites, alumina titanium carbide composites, silicon carbide composite, titanium boride composite, and silicon nitride titanium carbide composite. So, these are all particular composite. So, the particulates the dispersion is that of titanium carbide, titanium diborite and titanium carbide again, and different matrix; one is the oxide matrix like alumina carbide matrix and nitride matrix. Once again the fracture toughness is more or less into same order, and the critical flaw size again, very similar to the earlier values except silicon carbide. So, these are just an order on magnitude just to give an idea and these are the kind of materials have been different properties which have been used extensively in industry or in different high tech purposes.

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Properties of a few Monolithic and Ceramic Matrix Composites (Cont…)

Materials	Fracture Toughness (Mpa.m$^{1/2}$)	Critical Flaw Size (micron)
Transformation Toughened		
ZrO_2 – MgO	9-12	150-300
ZrO_2 – Y_2O_3	5-8	75-150
Whisker Dispersion		
Al_2O_3 – SiC	8-10	130-200
Fiber Reinforcement		
SiC in borosilicate glass	15-25	
SiC in Lithium Alumino Silicate	15-25	
SiC in CVD SiC	8-15	

This is the continuation of the same table, here is again different kind of few groups of materials, and the first group is a transformation toughened. Earlier, we have just the bulk materials, origin material kind of the origin materials, except this particulate dispersion composite. Here we have, another toughening mechanism, is transformation toughing, well one of the very exiting material in this area is zirconia, zirconia with M g O. So, it is a partially stabilized zirconia with M g O with partially stabilized with yttrium oxide, the two partially stabilized, zirconia matrix composites or matrix material, having the fracture toughness, the enhance fracture toughness of 9 to 12 and 5 to 8.

And then, the critical flaw size is of course, increased because fracture is difficult in this case the fracture had been the crack does not propagate so easily. So, the critical size is enhance, if you have a whisker dispersion alumina, silicon carbide for example, silicon carbide whiskers, are made or available in industry. Of course, whiskers the handling of whiskers is difficult or it is not that advisable, and even then alumina silicon carbide composite with silicon carbide whiskers has, a fairly large fracture toughness and the critical flaw size is also large.

Obviously, higher is the fracture toughness higher is the critical flaw size normally. Fiber re enforced, normally is a continuous or a checked 5 silicon in a boro silicate glass, well normally boro silicate glass cannot be used as a high temperature material. Of course, as such the borosilicate glass is a relatively high suffering point compare to total ion silica glass. But in some cases silicon carbide enhances the fracture toughness to 15 to 25. You can see these are some kind of although they cannot be use at a very high temperature, but for creatively low temperature they have very good fracture toughness.

Similarly, silicon carbide in lithium alumina silicate, which is basically a glass ceramics, lithium alumina silicate is one of the highest melting glasses and, it is basically a glass ceramics composition in, in which. So, as such better thermal better mechanical property, but in addition, if you re enforce it to silicon carbide, the fracture toughness enhances quite extensively, then you have silicon carbide in c v d silicon carbide. So, it is silicon carbide fibers, grown by the chemical representative techniques, within CVD. So, it’s a within silicon carbide, silicon carbide composite and that is again a fairly high very high temperature material, because silicon carbide is involved both metrics and the reinforcing agent and the fracture toughness is also enhance. So, these one of the costliest material, one can have a in for high temperature structural application.

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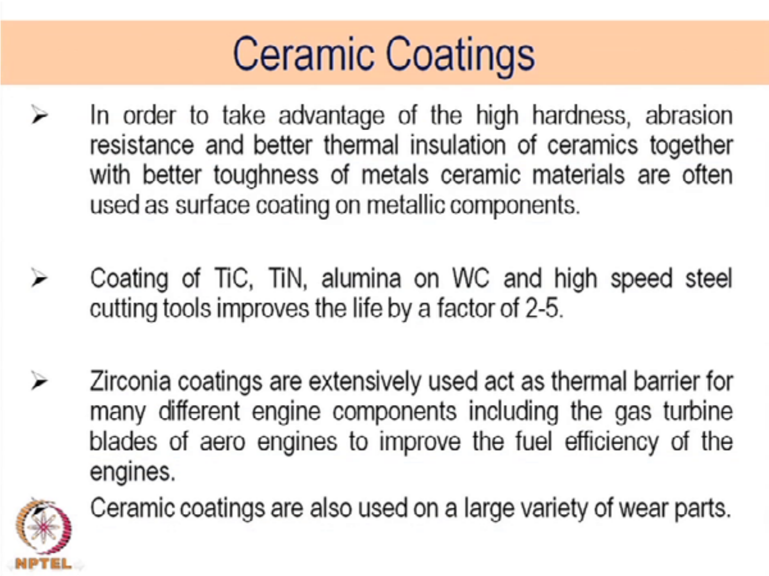

Ceramic coatings; those who have already discussed there all, basically used in the monolithic or the, it is not the monolithic in the bulk form, but ceramics many of the ceramics, are used extensively as ceramic coatings. Because ceramics being little, bulk material always have some limitations, but ceramic coatings can always be applied on a metal cinalise different kind of metal cinalise having the, were having a much greater fracture toughness. So, in order to take advantage of the high hardness, abrasion resistance and better thermal insulation of ceramics, together with better toughness, a metal ceramics material are often used as surface coating on metallic components. So, that is a very important area it is a some kind of a composite laid composite one can say a, but is basically a coated materials.

So, you can take advantage of the high abrasion resistance and thermal insulation of ceramic materials together with the good toughness and elastic modulus, of metals or the tensile properties in some cases. So, coating the different materials ceramic materials, which are normally used for coating purpose is titanium carbide, titanium nitride, alumina on a tungsten carbide, cutting tools. For example, I mentioned earlier that not only a ceramic cutting tools, but the conventional tank a tungsten carbide cutting tools are also coated with ceramics. So, that is another way of enhancing the property of the cutting tools, should the bulk is tungsten carbide, which has a much better fracture toughness. And one top of that, you coat that tungsten carbide particular tip with a much harder materials or conducting materials like titanium carbide, titanium nitride and alumina in some cases.

And as such coatings can also be used on more conventional high-speed steel's, not only carbide tip steels, tip tools, but a high-speed steel cutting tools, which improves their life by a factor of 2 to 2 to 5. So, 2 to 5 times of life enhancement is possible by just applying a good coating a adherent as well as sound coating on the cutting tools. Zirconia coating to the extensively used there is a mistake used as the zirconia coatings are extensively used as thermal barrier for many different engine components, including the gas turbine blades, of aero engines to improve the fuel efficiency of the engines. As I mentioned earlier, there is always a desire to operate the gas turbines, at higher and higher temperatures.

So, the metallic turbine blades have their own limitations. So, the performance of that metallic blade can be further improved by using a coating of zirconia, zirconia is relatively low thermal conductivity. So, the protects, it protects from the high temperature so and that is called thermal barrier coating. So, use a thermal barrier, to protect the surfaces of the turbine blades, and that is an very important and very exotic application of structural ceramics particularly zirconia. Ceramic coatings are also used, on a large variety of the wear parts. So, all wear parts, which you have mention earlier, either it can be a way a bulk material or metal's can be coated with ceramics. And you get the advantage of the ceramics, because it is a surface property which is more important in most of these wear parts.

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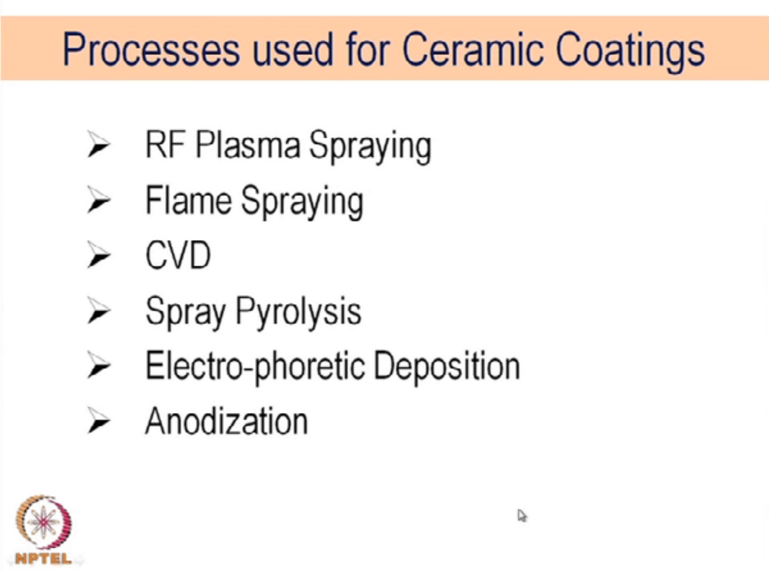

The process is useful ceramic coatings a there are many different process which can be used for making these coatings. Only the most common is RF plasma spraying radio frequency plasma are sometimes either in here or in vacuum flame spraying. That means, depending on the melting point of the oxide or the compound, you can just directly thermal spray not the plasma spraying research suggests that thermal spraying is also possible. A CVD chemical vapour deposition is another very important a technology or technique by which sound and good coatings can be applied on metallic points.

Spray pyrolysis once again is relatively low temperature process, where some of the soluble salts can be insitu paralyzed to form the oxides are mixture of oxides and deposited on the substrates. So, spray pyrolysis another technique electro phoretic deposition this some little different from electo lesis, electroplating. In electroplating, normally you are nice or in the materials to be use in iron form in the soluble form in a particular solvent. Whereas, in the electrophoretic, it is not in solution only the disportion of very fine particles, which are not dissolved in the part in the solution, but it just gets dispersed very fine disportion. Of course, you have to maintain the P H N, the suspension characteristics by the flankles is and so on and then apply.

So, oneself particles dispersed in a particular solvent, the have some surface charges and that surface charges can be used to move this particles by applying and external electric field. And it gets deposited on the substrate which is also charged, or it forms another electron, one of the electrons in the system.

So, a non soluble and insoluble fine particle can be deposited on a conducting or conducting surface. So, that is called the electrophoresis, the deposition and ceramics are being difficult to dissolve in any material. This is one of the techniques which are used for deform for coating ceramic materials particularly oxides not so much on carbides nitrites. Anodization is another technique, which is used in metallurgy quite extensively, but ultimately you get nearer revolutionary as you now you get a oxide coating on a metal. So, a insist to oxidation of a metal. So, you augment oxide forms, you can call you a ceramic coating on a metal surface. So, particularly aluminum and anodization is very common, the titanium also can be anodized and one can form titanium dioxide coating on titanium. So, these are different techniques by which ceramics can be coated on metal parts.

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Commonly used Processing Techniques for Structural ceramics

Processing Step	Processing Technique	Materials/ Components
Green Forming	Slip Casting Dry Pressing Extrusion Injection Molding	Combustors, Stators Cutting Tools Tubing, Honeycomb Turbocharger rotors
Densification	Pressure-less Sintering	$Al_2 O_3$
	Gas Pressure Sintering Reaction Bonding Hot Pressing Hot Iso-static Pressing	AlN, AlON, SiAlON Si_3N_4, SiC Si_3N_4, SiC, BN Si_3N_4, SiC, BN

These are commonly use processing techniques for structure ceramics those are coatings, but otherwise if you want to a make a bulk material. We have talked about the materials as such, but this is where you are talking about the different techniques by this materials are prepared. While all ceramics you know can be prepared by slip coasting particular oxides, then there are been classified in two or three different steps of formation. I think the next one is also there now. So, these are green forming and densification.

So, at room temperature, use this processing technique less trusting dry pressing which are per conventional and extrution, injection molding. So, these are a your particularly known oxides, wire slip coasting is not possible, but dry pressing is possible for all powders than extortion and injection molding are two important techniques by which the processing or the fabrication contact take place, a depending on what kind of shapes and sizes we are looking for.

For example, percip coasting combustibles and status can be used, can be fabricated dry facing cutting toolser are mostly dry paste tubing and honeycombs are normally done by extrusion and tahoe charges complicated setups. Most of the complicated steps like turbo charges a rotus for the gas turbines or turbo charging automotives, automotive engines, they are primarily made by injection molding, injection molding. Of course, you know you need a a flow able material, a viscous flow able material. A lot of polymorphs are actually I mixed with the ceramic particles, ceramic particulates. And then one can very easily slip coast a sorry an injection mould molding can be done as in case of plastics, but significant amount of plastic has to be used for this purpose.

And that has to be bont out at a later stage and that is a very critical stage a for bonding of the bankers with the quantity of the bonded is quite large. In this case, densification a pressure less sintering a that is very common and the alumina is one materials, which can be done quite easily and the sintering process alumina and the additives are quite well understood and standardized. There can be gas pressure sintering for some of the, it is not hot pressing as such or not is static pressing, it is a slightly lower pressure and in a different chamber. So that some of these oxi nitrites or nitrites can be a centre by this kind of gas pressure.

Normally, urban pressure up to 100 bars at a opposite high temperature, a aluminum nitride, aluminum oxide nitride, silicon aluminum oxide nitride all these things can be done. The one they can also be done by not isostatic pressing or hot pressure reaction bonding. Well, this is a technique will discuss little a bit of in connection with the silicon nitride, but silicon carbide reaction bonded, silicon carbide are also available or that is also very standard technique by which silicon carbide's can be haplicated. Hot pressing; I am sure all of you know, what is hot pressing, because you see only hot pressing is normally refers to uni accel hot pressing. And then hot isostatic pressing is once again, gas pressure are not high temperature high pressure. So, all the non oxides, non oxide ceramic silicon nitride, silicon carbide, boden nitrate in particular can be and prepare by both hot pressing and hottest iso static pressing.

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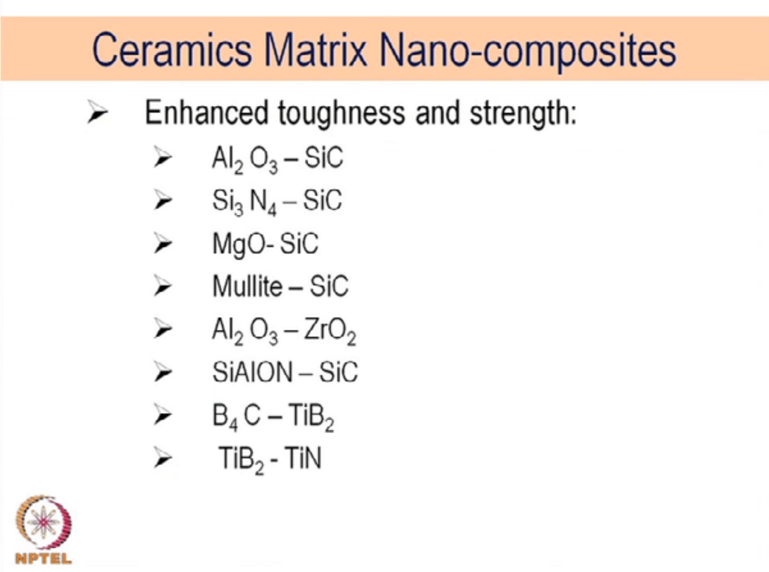

Ceramics matrix nano composite's; of course, you mentioned earlier about the composite's are is a new term in the nano composites, because this is another variation of the composites only thing the fineness of the issperside of the fineness of the particulates a much finer year. And therefore, they can be classified as nano composites and there are many different nano composites are being tried and being used to some extent for different purposes. Show some there are examples, enhance toughness and strength is a basic or driving force for making nano composites.

So, most of this is second phase is in the form of nano dispersion are there are many different morphology are available it can be intergrannual, it can be transgranuler. Then there are many ways, this dispersion can be controlled are designed to make this nano composites. So, somebody important to systems are listed here are ill to 3 silicon carbide, a silicon carbide, reinforced l 2 3 silicon carbide reinforcing silicon nitride, silicon carbide, reinforcement magnesium oxide ,even mulate.

Mulate is a good high temperature material and wants and relatively low cost wants disdain forsooth silicon carbide. It has a quite improve properties at high temperature. Zirconia, zirconia dispersion nano zirconia can be used particularly if the talking about a zirconium toughened alumina. Basically, there it is a nano dispersion of zirconia affairs are silicon carbide dispersed in salan. Salan is the matric place once again nano sized silicon carbide can be used for the reinforcement of salan to enhance ones, second the enhance property both high temperature property and the toughness are titanium diborade, de enforce boron carbide that is another material, nano composite which is been tried or different purposes are titanium nitrite, the reinforced titanium diborade. So, many different composite combinations can be tried and I have been used and developed for different purposes. So, some of the, some of them any oxide, some of them the metrics itself may be monoxide.

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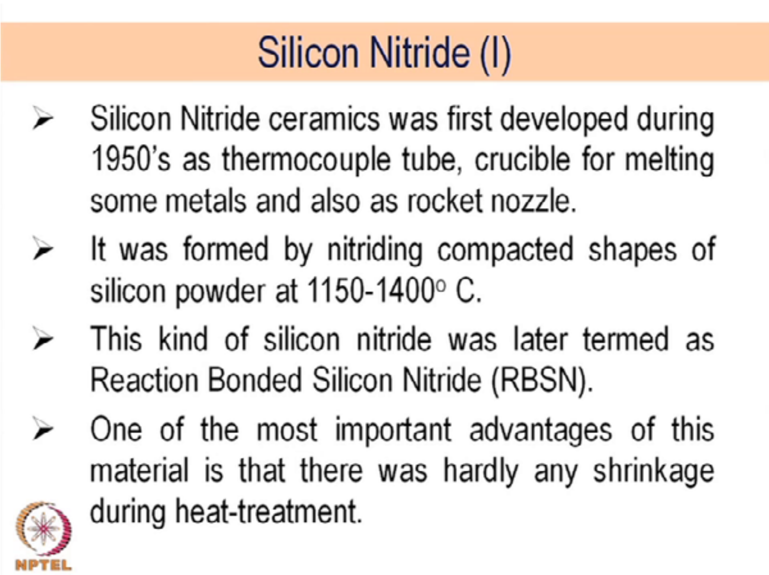

Now, there we have talked about a large number of different nitrides, (( )) carbides so on. It is difficult to within this short time term to discuss in details are what are the structures, what are there are a preparation techniques? One can go as I mention earlier is a very fast subject and expanding subject and one can discussed a lot about that. So, without going through all that, I have just picked up one particular compound to silicon nitride, which is been one of the earliest develop known oxides ceramics. And try to give some details about the silicon nitride, but similar discussion can also be taken for other are nano oxides ceramics as was.

So, silicon nitride ceramics was first developed during 1950s as a thermocouple tube and cristobal for melting some metals and also as rocked noises. So, this is a very high temperature material and one of the male apricot one of the main properties, not only the fracture toughness is creatively high, but also it is a non waiting characteristics, non waiting characteristic to different metal in molten metals. And therefore, silicon nitrite crucibles have been used a for melting soundly small, but the small quantities of metals, why you do not lose the metaled or metal is not getting contaminated with the contained material.

So, that was the first time in 50s, it was use for the purpose. It was form one of the interesting properties of or criteria for making silicon nitride is a it was formed by nitriding compacted shapes of silicon powder at 1150 to 1400 degree centigrade is one of the very easiest way of making a silicon carbide, silicon nitride sets take silicon nitride, silicon metallic silicon powders. And press it or give intercept just like any other cily and ceramic powder. And then nitriding heat it at high temperature 1150 to 1400 degree centigrade and nitrogen atmosphere when silicon powder gets convert silicon nitride and also gets into.

So, this kind of silicon nitride was later termed as reaction bonded silicon nitrite. So, it is automatically during the reaction of between silicon and nitrogen are the bonding is also takes place. So, it is a this reaction bonded reaction centre you can say. So, a this particular terminology has been used quite extensively in a structural ceramics, particular both for silicon carbide, silicon nitride and silicon carbide .Silicon can be a starting materials and then it can be a, it can be melted in presence of carbon. So, that silicon carbide form and gets syntems. So, that also silicon carbide reaction bonded silicon carbide. So, RBSN and RBSE only most important advantages of this material is that there was a disadvantages.

This is the advantage, in fact, one of the most important the advantage of this material is that there was hardly any shrinkage during the heat treatment. During this reaction, there is hardly any shrinkage the volume change from silicon to silicon nitride is very negligible. And therefore, you do not have any shrinkage whatever. So, it is a there is a net shape formation, net shape form reforming it is possible by this technique.

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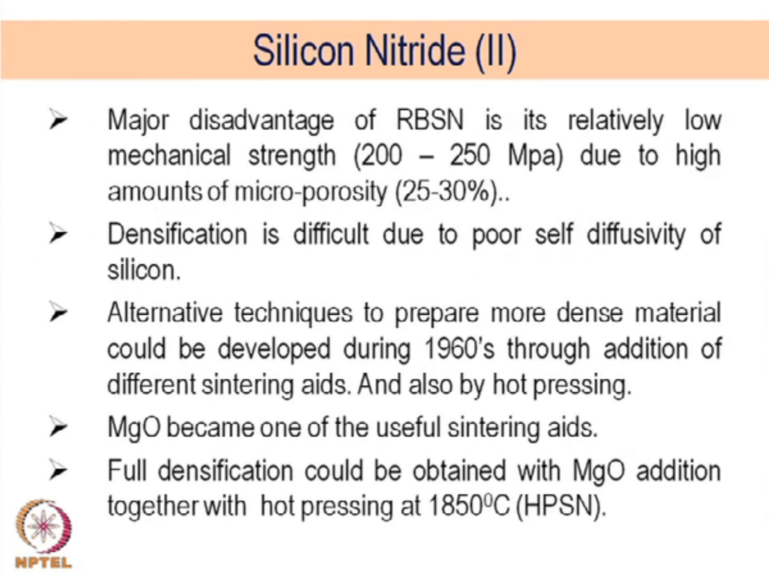

Major disadvantage, however for the RBSN or reaction bonded silicon nitride is relatively low mechanical strength, because of the high amount of microporousity. So, 22 to 30 percent microporous city and therefore, the strength relatively low. So, that was one of the major disadvantages. Densification is difficult due to poor self diffusivity of silicon. So, silicon in silicon nitride actually the diffusivity co efficient is very low. So, the sintering is relatively difficult and therefore, the microporousity. The alternate techniques to prepare more dense material could be developed during 1960s, electron through addition of different sintering aims and also by hot pressing.

So, electron a lot of researchers has gone in and densification could be the enhanced by addition of different additives and also by hot pressing. Magnesium oxide became one of the useful sintering agents; our full densification could be obtained with magnesium oxide, addition together with hot pressing about 1850 degree centigrade. So, that is hot pressed silicon nitride. So that is the terminology used for a different group of silicon nitride prepared by hot pressing and together with addition of magnesium oxide as the additive. So that is much more dense full densification almost 100 percent densification could be possible by the technique.

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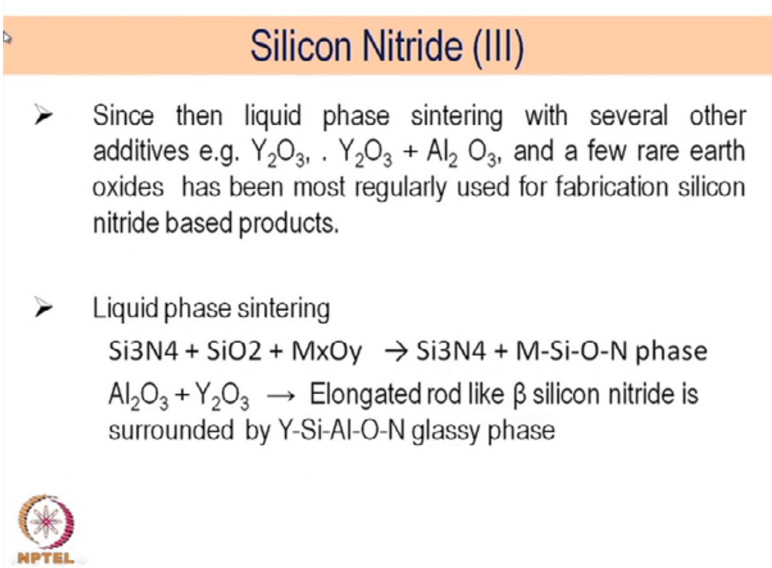

Since, then a liquid phase sintering has been more prevalent and several other additives like yttrium oxide or yttrium oxide together with aluminum oxide. And a few rare earth oxides has been most regularly used for fabrication of silicon nitride based products. So, to this silicon nitrite products are mostly a bare liquid phase sintered with additives like yttrium oxide, yttrium oxide and aluminum oxide and some of the rarer also are used. And during liquid phase sintering this is the kind of reactions, which takes place silicon nitride plus SiO2. And this is oxide which added, then it goes to silicon nitride and if is like this which is a kind of salon face, a metal is the oxide either yttrium or aluminum or yttrium aluminum a show A l 2 3 plus y 2 3.

This kind of a additive gives a liquid phase centre material very nicely are microstructure elongated rods like beta silicon carbide, silicon nitride is surrounded by a yttrium silicon aluminum oxygen glass phase. So, that is liquid phases forms and is a lower melting point and is nice crystal steps, a microstructures rejected. Mostly is beta, beta silicon nitride carbide there is an alpha variety also I will give you some of the difference between alpha and beta in a minute.

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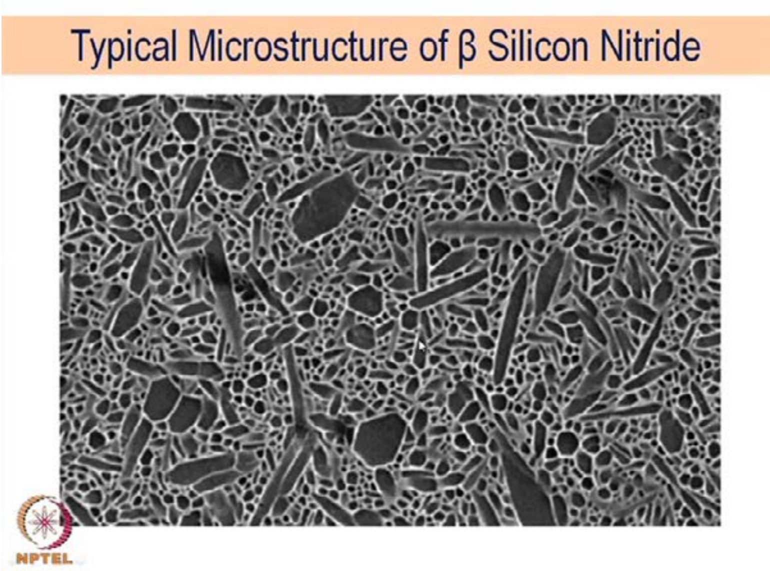

So, this is a typical microstructure of a beta silicon nitride. So, these are the black phases, where surrounded by glasses white phases and because of this elongated structure. It is a very nice, a very high strength and fracture toughness.

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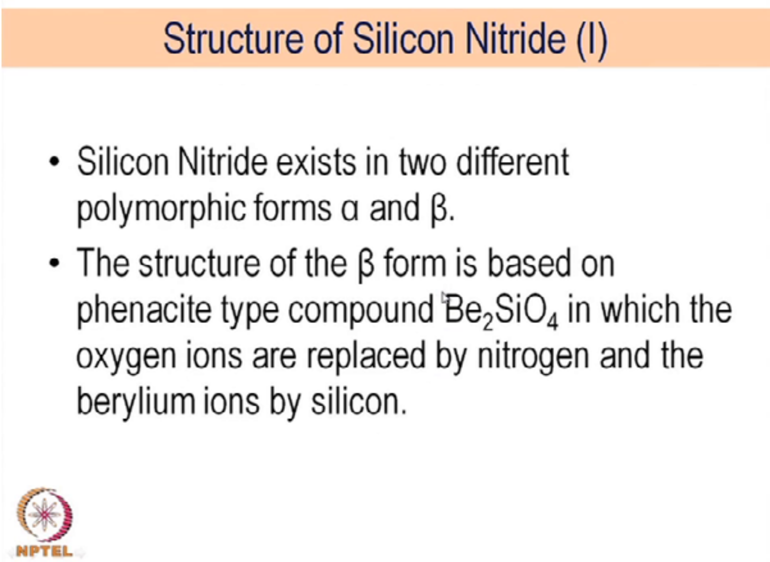

I will just give you in lip brief idea about the structure of silicon nitride and different polymorphic forms silicon nitride exist in 2 different polymorphic forms alpha and beta. Beta, beta is most, more common and mostly used, but there is in alpha variety also. The structural of the beta form is based on phenacite type are compound that beryllium silicon oxygen. This is the kind of silicate beryllium silicon oxygen a silicate in which the oxygen ions are replaced by nitrogen, oxygen is replaced by nitrogen, and beryllium, beryllium by silicon. So, that is out the, there are 2 varieties of silicon here, one of this, one of is that. So, the structure looks like this.

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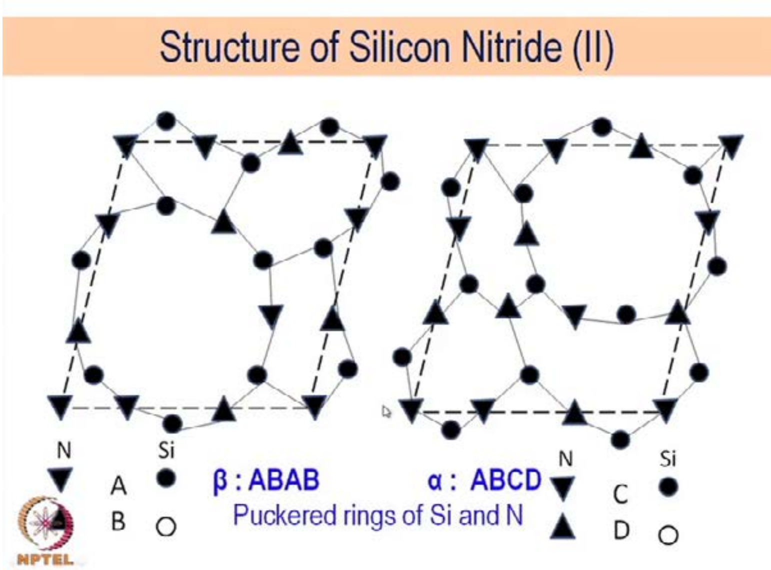

And this is the; this is the beta variety; this is the alpha variety. So, I do not have much time to go through details of that these basically puckered rings of silicon and oxygen and there are layer, as there are layers of silicon. This is a your A layer, A layer you have a this kind of layer and B layer is again, this is nitrogen and this is silicon are this kind of open circles are not shown here, but this are the different levels. So, this is one level a where nitrogen and silicon of their again the nitrogen silicon there is A B layer a at a different level. So, it can also be like this A B C D, there are different in practices stacking of different layers of what were seen.

So, in case of the basic difference between alpha and beta, one can see the stacking a beta layer, beta has a, A B A B stacking. Whereas, alpha has a A B C D stacking. So, these are the different notations used are. So, these are and the triangles are actually nitrogen and the circles are silicon and they are at different levels. So, that is what is the difference between alpha and beta and out of that beta is more stable. And this is the structure; this is the material which we normally use.

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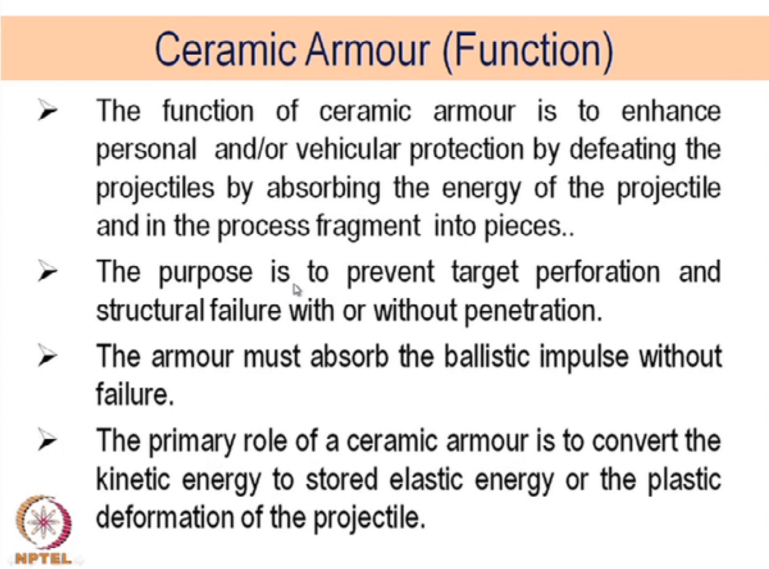

Last topic, I will just take cup of minutes very briefly, the function of ceramic armour a there is the one of the applications, which is coming up in a very large way is the armour application of ceramics. The function of the ceramic armour is to enhance a personal or vehicular protection by defeating the projectile, when we strike a bullet or some cells by absorbing the energy of the projectile and the process fragment into pieces. The purpose is to prevent target perforation and structural failure with or without penetration.

Basically, these armour, the purpose of these armorous to save the human beings, all the vehicles in the battlefield. So, the armour must absorb ballistic impulse without failure. The primary role of the ceramic armour is to convert the kinetic energy of this, to the stored elastic energy. So, higher the toughness higher is the hardness, if the hardness is high, the bullet gets blunted. And if the crack toughness is high bullet the energy of the kind energy of the bullet actually gets absorbed in the form elastic energy and that is how the force the velocity gets lost.

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Ceramic Armour (Materials)

Processing Technique	Material used
Pressure-less Sintering	Alumina of different purity (upto 99.5%) Sintered SiC
Reaction Bonding	SiC and B_4C
Hot Pressing	SiC, B_4C, TiB_2 and WC
At R&D Stage	AlN

So that is out you protect the human beings as well as the vehicles a in the battle field. So, that is one of the application which are strategy applications, which are coming up very big way a in the sense the last a decadeses. So, so the materials used alumina of different purity of 99.5 percent centre silicon carbide then reaction bonded silicon carbide and boron carbide. Hot pressed materials like silicon carbide, boron carbide, titanium dichloride, and tungsten carbide.

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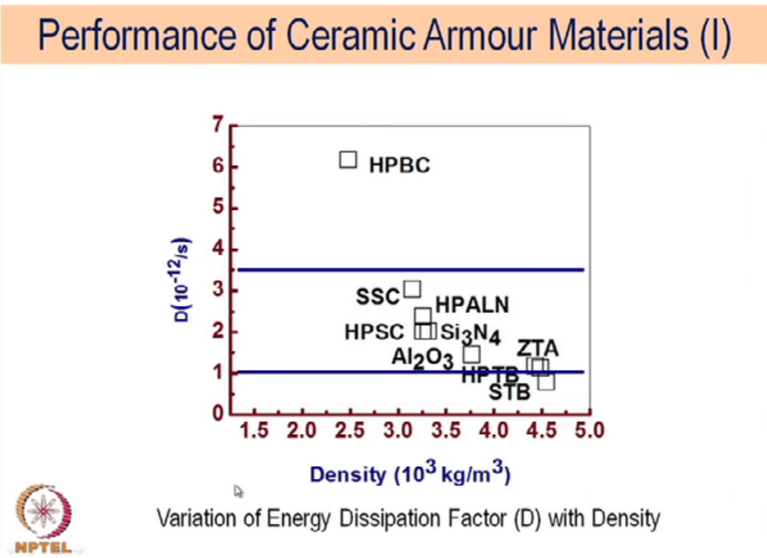

And at are in this stage is another material which is used for this purpose is aluminum nitride. And I will give you some this is the variation of energy dissipation factor as a function of different properties and even see hot press boron carbide is one of the preferred materials for all this. But there are many others as alumina hot pressed aluminum nitride that silicon nitride Al 2 O 3 a press silicon carbide and all of them with different properties ZTA, but this is always on the top. So, here is been plotted the facture toughness.

So, higher is the fracture toughness are the better is the dissipation factor, energy dissipation factor, but in all this case is even if you have load fracture toughness. Here is a combination of fracture toughness and hardness. And then hot press boron nitride always the highest dissipation factor. Here again the hardness again at higher hardness, we have a higher dispersion factor and so on. So, these are different materials a I do not have much time to discuss all them, you can always look at it.

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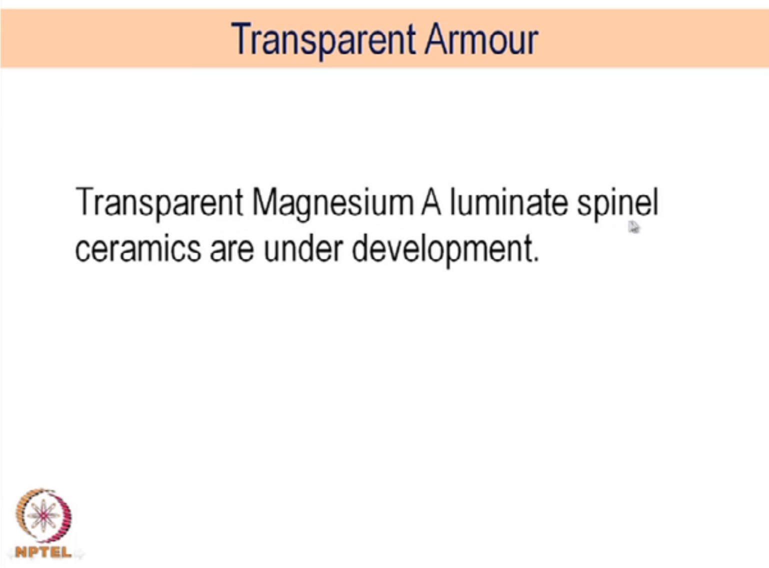

But the transparent armour, only very recent a development is in the area of transparent magnesium A luminate spinel ceramics, it is under development. And all these a earlier materials are basically opec materials, but sometimes you need transparent ceramics, which can also protect the human beings in particular are you have the windows of different battlefield vehicles. So, there you need transparency, as well as the armour property, the energy distribution property.

So with this, we come to the end of this lecture on structural ceramics, and also the end of the mechanical behavior of the materials they only one left I will take it up in the next class that is a bio ceramic. So, I will spend about a hour discussing about bio ceramics or the material ceramic material use in biotechnology. So, with this, we come to the end of this class and.

Thank you for your attention.