Manufacturing of Composites
Prof. J. Ramkumar
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

Lecture - 20
Ceramic Matrix Composites

Welcome to lecture number 20. In this lecture we will try to cover about ceramic matrix composites. Ceramic is one material, which has been used for centuries together. In fact, the earthen part is a very simple example for ceramic materials being used in the history.

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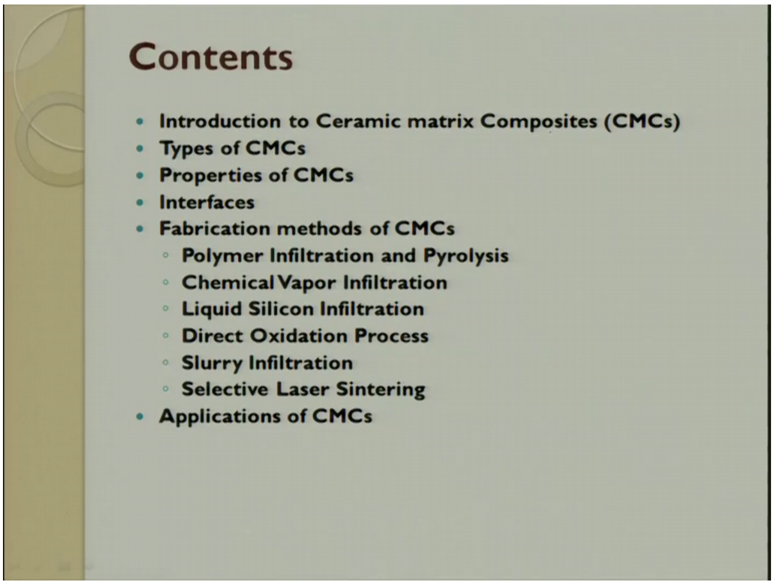

So, ceramic materials has its own advantage, and in the past itself; for example, in the previous century, self-people started using ceramics as a matrix, and then reinforced with some soft materials, and then they have. Now recently we have move to hard materials also. So, in this lecture, we will primary focus on introduction to ceramic matrix composites, what are different types of ceramic matrix composite, property of ceramic matrix composite, interfaces. Then we will go through some of the fabrication techniques, and finally, application of ceramic matrix composite

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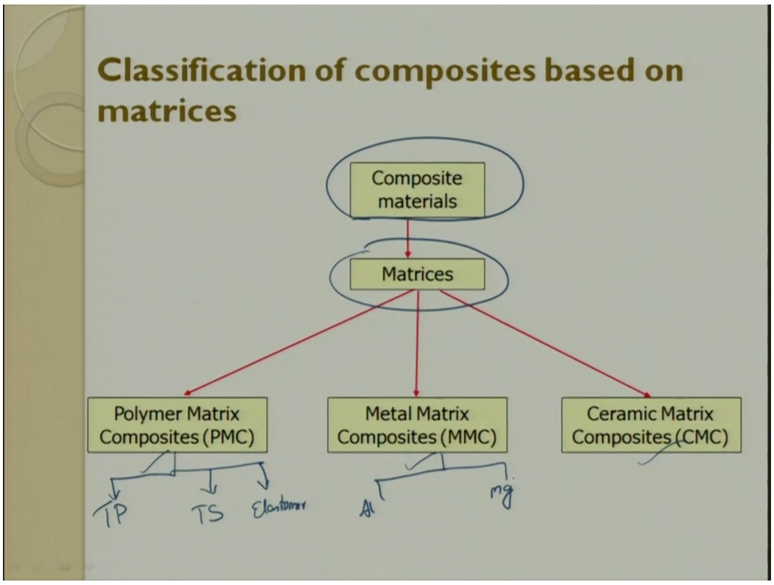

So, a recap till now whatever we have done, we have we have studied of manufacturing of composites. In manufacturing of composites, we had three matrices; one is polymer matrix composite, metal matrix composite and ceramic matrix composite. In polymer matrix composite we have seen thermoplast, thermoset, and to some extent we also have seen elastomer. Metal matrix composite, we have seen aluminium based, and then to some extent magnesium based composite materials right. So, now, we will focus on ceramic matrix composite.

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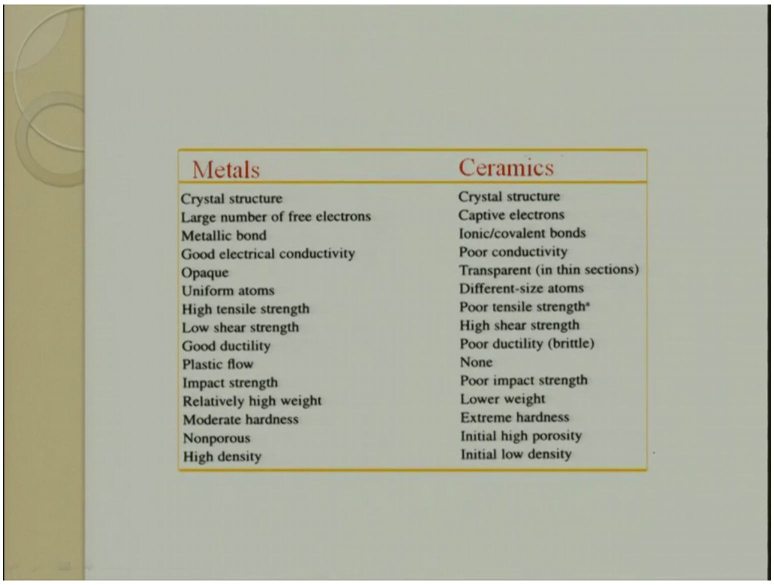

Metals	Ceramics
Crystal structure	Crystal structure
Large number of free electrons	Captive electrons
Metallic bond	Ionic/covalent bonds
Good electrical conductivity	Poor conductivity
Opaque	Transparent (in thin sections)
Uniform atoms	Different-size atoms
High tensile strength	Poor tensile strength*
Low shear strength	High shear strength
Good ductility	Poor ductility (brittle)
Plastic flow	None
Impact strength	Poor impact strength
Relatively high weight	Lower weight
Moderate hardness	Extreme hardness
Nonporous	Initial high porosity
High density	Initial low density

So, before getting into, little bit of fundamental what is the typical difference between a metal and the ceramic material metal are crystal structure ceramics are also of crystal structures in metals. You have large number of free electrons. So, that is why it is predominantly conducting material. Here it is captive. Electrons are there in metals we have metallic bond here. It is ionic or covalent bond; that means, to say it is very strong.

So, since it is metallic and it has free electrons, it is good conductor. Here ceramics are poor conductors. Majority of the metals are crystalline or polycrystalline in structure. So, they are opaque, and here you have amorphous material also in ceramic. So, that is why it is transparent and of course, you have crystalline, semi crystalline and amorphous ceramics all three, but if it amorphous is also one. So, amorphous we have transparent a simple example is your glass, then it has uniform atoms here, different size of atoms are there; that means, to say for semi crystalline materials can also be possible. So, it has a very high ductile strength here. It has very poor ductile strength; since its alcohol and bonded the bond is very strong. So, it is tensile strength, very high tensile strength, here it is very poor tensile strength.

So, here since they have free electrons, and this free electrons and metallic bond they give you some amount of ductility, here there is no ductility. So, that is why it has very poor tensile strength, it has very low shear strength, it has very high shear strength, it is good in ductility, it is poor, it can plastically flow here that property itself is not there. It is very good in impact strength, it has very poor in impact strength. So, that is why it is brittle, it is relatively, it has a high heavy weight or high weight, or it has a higher density. Here it is low weight or low density, hardness is moderate, hardness is extremely high. So, predominantly if you look at ceramics extreme high hardness, poor ductility, poor tensile strength. So, it is non-porous. Here you can also have porosity in ceramics. It has very high density, it has very low density.

So, now, with this you can try to identify very clearly what is the difference between metals and ceramics, when to go for metal matrix, when to go for ceramic matrix, where ever you have very high temperature application, we always prefer to have ceramics. Where ever you would like to have very light, and where there is not much of impact load, we always go for ceramic matrix composite, ceramic matrix and ceramic matrix composites are made, if you look at ceramics.

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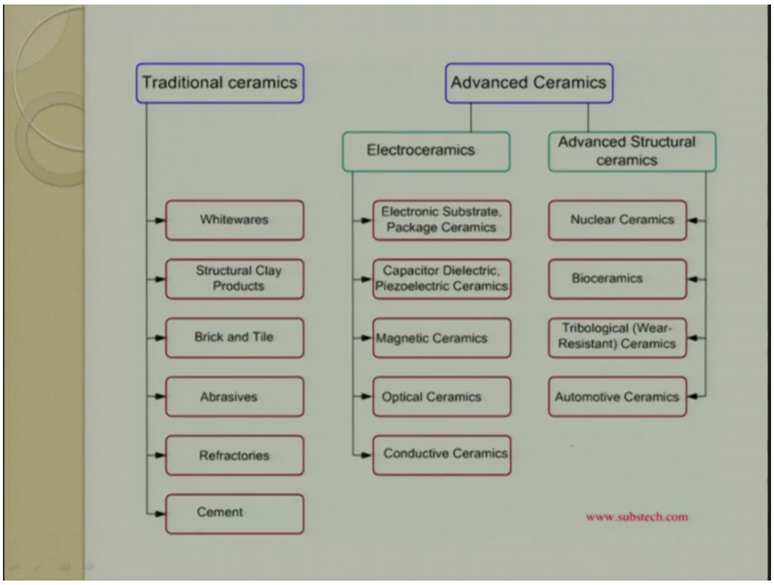

Ceramics are divided into two; one is called as traditional ceramics, the other one is called as advanced ceramics. So, traditional ceramics you have white wares, and then you have structural clay products, bricks and tiles abrasives, which is used in grinding, which is used in water jet cutting, which is used for lapping, polishing, all those things you have refractories and you have cement. These are the traditional ceramic materials, which we know and lot of products have been used, and when you go for advanced ceramics you have electronic ceramic, and you have advanced structural ceramic. Predominantly our focus will be on structural ceramics. So, in structural ceramics you have nuclear ceramics, bio ceramic, tribological ceramics and automotive ceramics.

So, bio ceramics, which is used as bio implants into the body, when you look at electro ceramics, we will have electronic substrate for package ceramics; we will have capacitor dielectric of piezo electric ceramic, magnetic ceramics, optical ceramics and conductive ceramics. So, all these things are electro ceramics. This is a new area, which is there from the last 50 60 years and today we are finding lot of applications in this areas. For example, magnetic ceramics which is not thought of, is now there, and we also have capacitor dielectric ceramics, which is for very small applications. We also have Piezo crystal ceramics, where and with very small displacement are to be measured, are to be given. We go for piezo crystal ceramics. So, when you talk about matrices.

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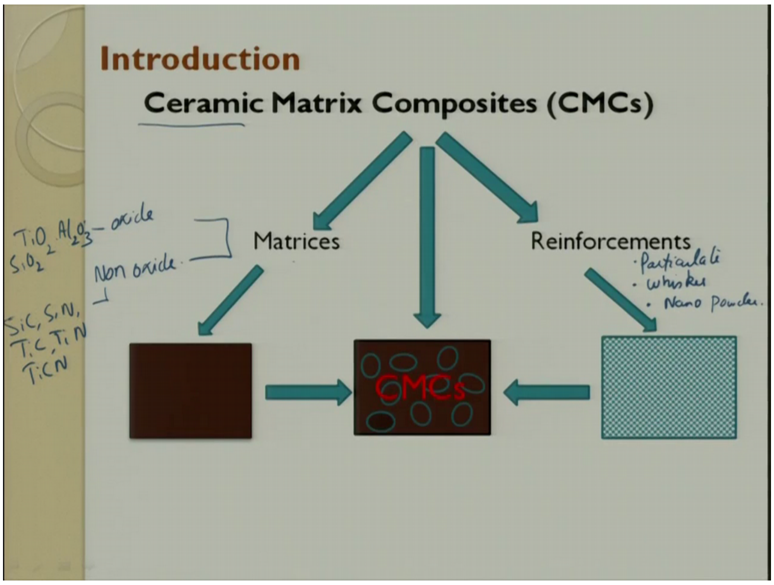

So, since ceramic is, the form of existence of ceramic, is always in powder form. So, the reinforcement whatever we mix, has to also be somewhere close to powder form. So, we always used particulate. So, we always use particulate whisker, we use nano, nano powder or nano whatever. So, these are the three reinforcement, which are predominantly used. The form can be particulate, where in which we talk about aspect ratio, then whisker then you can also have nano.

So, these are some of the reinforcements which are added to the matrix ceramics, to get a ceramic matrix composite. So, matrix can be of two types; it can be oxide and it can be non oxide. When I talk about oxide, it is TiO 2 Al 2 O 3 SiO 2. All these things can be there. When I talk about non oxides it can be SiC SiN TiC TiN TiCN, these are some of the non oxide ceramics which are there. So, you can choose, depending upon your requirements, choose any one of these ceramics as a matrix.

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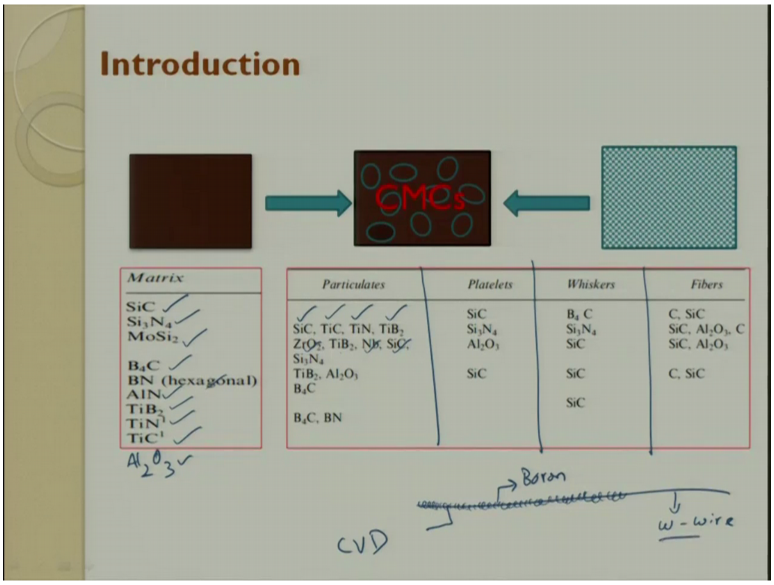

And then this matrix is blended or mixed with this reinforcement, and finally, you get the output ceramic matrix composite. So, we can see that. So, these are the matrices you have SiC Si 3 N 4 silicon nitride molybdenum silicid boron carbide boron nitride aluminium nitride TiB 2 TiN TiCN and alumina, which is very commonly used. So, if you see the particulates we can see, TiC can be there, SiC can be there, T i N can be there, TiB 2 can be there, you can have zirconium oxide, you can have niobium and you can have silicon nitride B 4 C we have seen. So, I can be in platelet form it can be in whisker form, and today we have also started using fiber form. So, fiber is, you will have fiber which is made out of metal, and this metal will be coated with ceramic material. So, this a coating which is done on top of ceramic. So, now, the fiber is called as ceramic fiber.

So, predominantly this is done by CVD process. This is done by, see chemical vapor deposition process, what we give; say for example, you can have a tungsten wire, and then which is coated with boron. You can have a carbon fiber also. So, you can also have alumina fiber, where in which it is coated, ductile wire, tungsten or something which is coated, because tungsten is very high temperature. So, when alumina is coated, it can withstand very high temperature applications.

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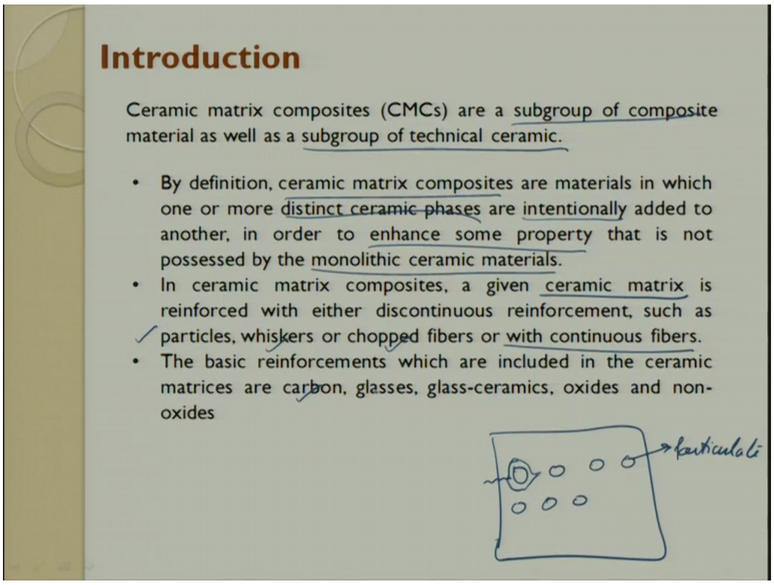

So, ceramics are sub group of composites, as well as sub group of technical ceramics. By definition ceramic matrix composites are materials, in which one or more district ceramic phase are intentionally added in order to enhance some properties; that is not possessed in the monolithic ceramic. So, the biggest thing what we are looking forward is, we would like to enhance the toughness property.

So, the toughness property can be enhanced by adding particulates. What happened when you have particulate? When you have a ceramics, and when you add particulates in it, and when a crack grows, the crack is getting diverted or distributed, or the crack energy is reduced, and it goes around the ceramics and then it goes. When it goes around the ceramics, the energy is dissipated and, because of this dissipation the crack does not go further. So, the toughness property increase. So, this is the particulate or particle whatever it is.

So, what I have done. I have intentionally added this, particulates; such that I can enhance the toughness property; that is what we are talking here. In ceramic matrix composite, a given ceramic matrix is reinforced either with discontinuous reinforcement, or it can be with a continuous reinforcement. Predominantly what we look forward is, discontinues. So, it can be in particulate form, whisker form, or it can be chopped fiber, the continuous fiber is also possible. So, the basic reinforcement which are included in a ceramic matrix are; carbon, glass, glass ceramics, oxide and non oxide ceramics are added to the basic ceramic matrix.

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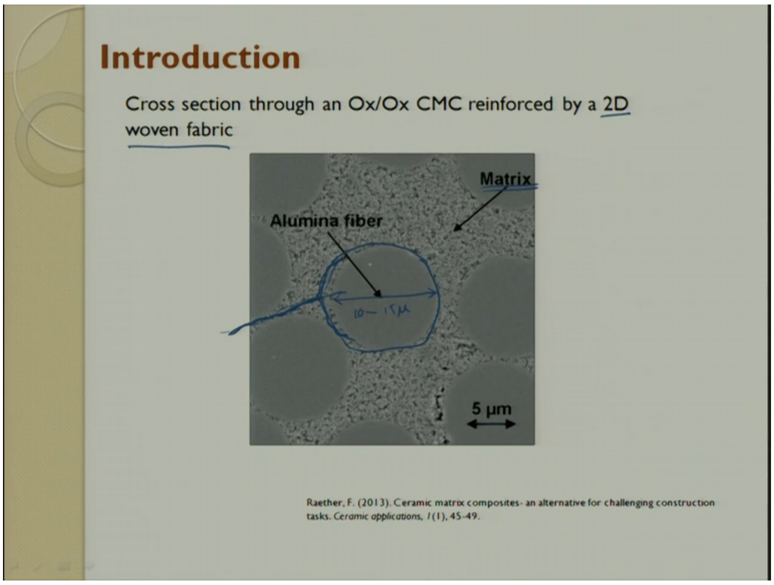

So, if you look at the A CM figure of a ceramic matrix composite, you can very well see, this is a matrix, and you can see this is the alumina fiber which is reinforced, and this is what I was trying to say, if at all there is a crack here. This crack grow goes around and the energy is dissipated. So, you can see this is 5 microns. So, this reinforcement, maybe somewhere around about 10 to 15 microns. This is an alumina fiber, this is one cross section. So, you can see how it is done. So, reinforced by 2 D woven fabric, they have done it with using it 2 D woven fabric.

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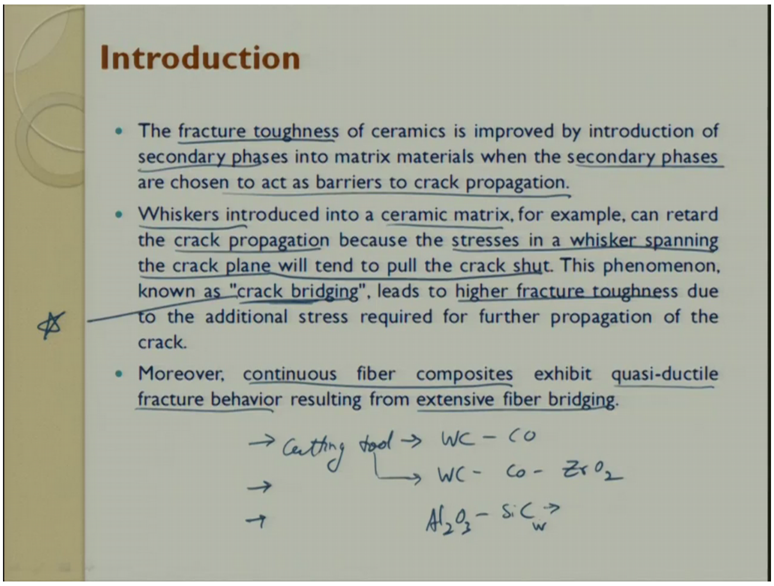

So, the fracture toughness of the ceramic is improved, by introducing a secondary phase which we were discussing. So, I was saying that the secondary phase are chosen, to act as a barrier for crack propagation. So, is it clear whatever we have seen here in the previous CM, we have just put it inwards predominately in ceramic matrix composite, we would try to enhance the toughness property; that is one property, but if you want to make it conducting ceramics. So, we try to add ingredients; such that it makes the ceramic conducting.

So, there we choose conducting particulates to be added, and then people are started using it today people have started using CMT in a big way, so that they would like get advantages over the toughness property. The whisker, whisker and particulate the different is aspect ratio, is introduce into the ceramic matrix for retard the crack propagation, because the stresses in the whisker, spanning the crack plane, will tend to pull the crack shut.

This phenomena called as crack bridging, crack bridging is one very important phenomena, very important phenomena. What is this phenomena. Here the crack propagation can. So, what happens whisker, when it is introduced into the ceramic matrix, it can retard the ceramic propagation, because the stresses in the whiskers spanning, the crack plane will tend to pull the crack shut, and this is called as crack bridging, which leads to very high fracture toughness. When we are using continuous fiber composite, it exhibits quasi ductile fracture behavior, which resulting in extensive fiber bridging, but please understand, using or reinforcing a ceramic fiber into the matrix, is really a challenge while manufacturing.

It is very easy to manufacture particulate type or whisker type ceramic matrix composite. Simple example is your cutting tool, where in which use tungsten carbide and cobalt. Then you can try to say, you can try to say add tungsten carbide, today we had cobalt and we also call add zirconium oxide. This is also a cutting tool which people have started using right, and then you can also use alumina, which is reinforced with S i C, which is in the whisker form. All these things are done only to enhance the fracture toughness behavior.

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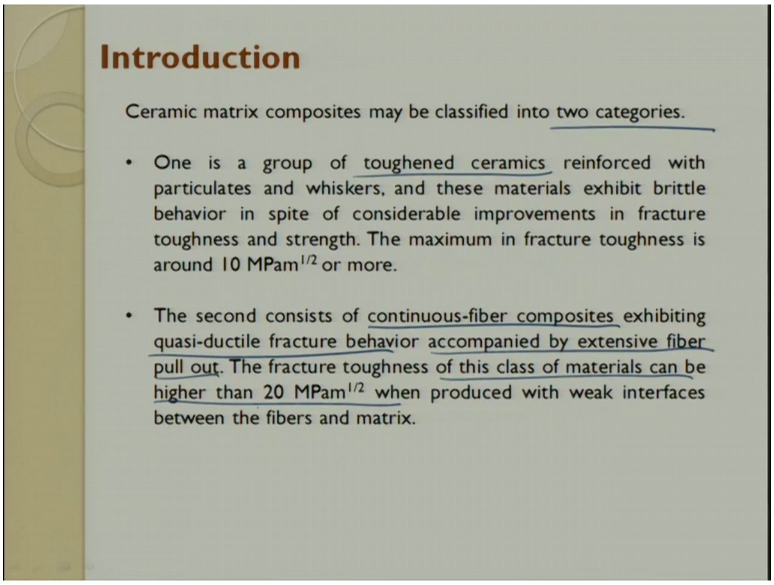

So, there are two categories of ceramic matrix composite; one is a group of toughened ceramic reinforced with the particulate. The second one is a continuous fiber composite which exhibits quasi ductile fracture behavior, accompanied by a expensive fiber pull out. So, basically what happens is, when the crack tries to grow, around the particulate either this particulate tries to distribute and do something, or the fiber or the particulate pulls out of the existing location. So, that all the energy gets dissipated in pulling it out. So, that crack does not go further.

So, the fracture toughness of this class of material, can be higher than 20 mega Pascal route meter, when produced with a weaken interface between the fiber and the matrix. For example, what are we trying say, let us go back to the cm which we are discussing. So, one way we are doing it to the crack which is growing here, one way is you distribute the crack energy. The other way is the crack is growing, you try to pull this particulate out or you try to pull this fiber out, when you try to pull the fiber out, the energy gets into pulling it out, because you have a very weak interface, weak interface means, it quickly goes around and tries to remove the particle very easily, and the energy is dissipated in to the fiber, in that location where we pull out has happened.

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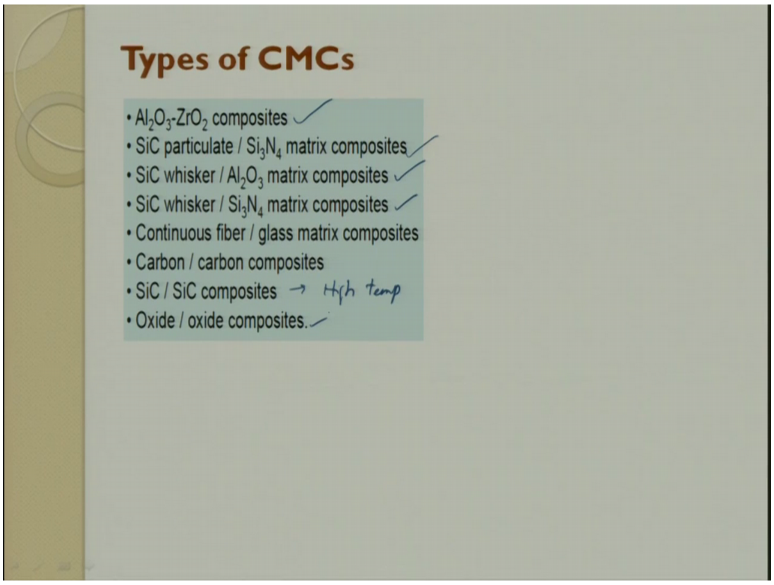

So, different types of ceramics alumina, zirconium oxide ceramics are there, SiC particulate reinforced in s silicon nitride. Again cutting usage, then alumina and SiC then we have a, this is whisker, first one was particulate, this was whisker, then you have continuous fiber, then carbon carbon composite is there SiC SiC. These are all very high temperature application high temperature, which is used in missile rocket all those things, oxide oxide composites are also there available. So, for example, alumina reinforced with an alumina particulate, or alumina reinforced with zirconium oxide. So, alumina reinforced to SiO 2.

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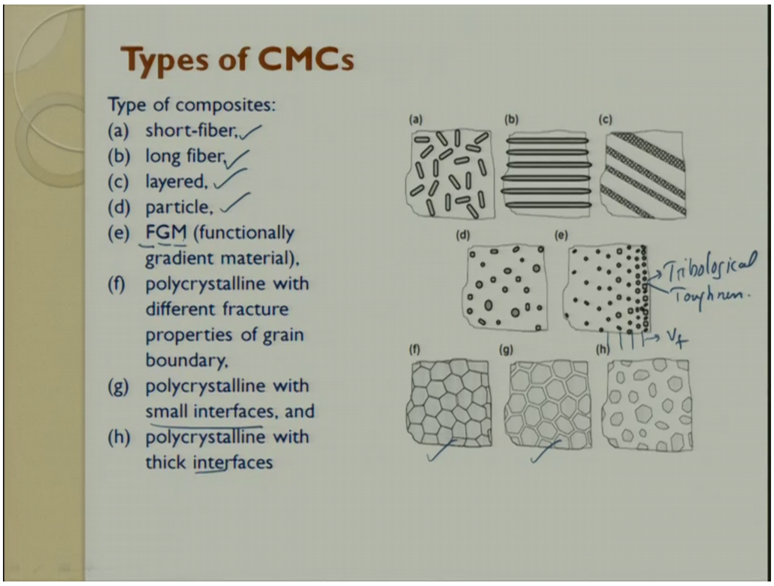

So, this are some of the examples. So, what are the different types of composites, ceramics matrix composite. It can be short fiber, it can be long fiber, it can be layer, it can be particulate, it can be functionally graded ceramics. Look at the functionally graded ceramics, the reinforcement if you see layer by layer by layer, there is the volume fraction keeps changing layer by layer by layer. So, what happened, on the periphery you have a large amount of particulates, as and when it goes down you it is less what, because of this, what happens the tribological properties and fracture toughness property enhances. This is functionally graded material today; there is a huge demand for functionally graded materials.

Then you can have polycrystalline with different fracture properties of grain boundaries you can have. Then particulate with small interface you, these are interface and then particulate with very thick interface. So, these are the different types of classification of ceramic matrix composite. I repeat it and can be shot fiber or if you want you can go one step ahead ok.

Shot fiber, then you can have long fiber, then you can have layer. Layered are basically at something like a tip type, you try to cut it down, or you try to make a preform or something like that, so you get that. Today you get, you have ceramic steps which are available. So, you put those steps as and when you want to reinforce, then you have particulates right. The difference between this and this is aspect ratio.

So, here particulates can be whiskers it can be particulates. The distribution of particulates between layer to layer to layer there is a variation, which leads to functionally graded materials. So, functionally graded materials, if you see, the function you try to reinforce the function, grades along the material. So, if you see after you remove the first three layers then the tribological property will be less, then you have a polycrystalline with a different fracture properties of grain boundaries, these are grain boundaries.

Then you will have with weak interface with strong interface. So; that means, to say this interface the crack can grow break it will yield out and then you get the required output. So, what are the properties of a ceramic matrix composite? Generally when you make a product, first thing what you have to look you have to right down the objectives, or you have write down on the specification, what is the specification this product has to execute when put on service condition.

So; that means, to say we will always tried the list down all the properties, what you want from this material, plus you will also try to put a quantifying value for each of the specification whatever you say. So, with this what did you get, you get the properties moment you have these properties then you start working on which matrix to choose, which interface to choose, what is a processing route and how do I meet out to the requirements. So, if you want to make a ceramic matrix composite. So, first thing is, you have to understand what are the properties of ceramic matrix composite.

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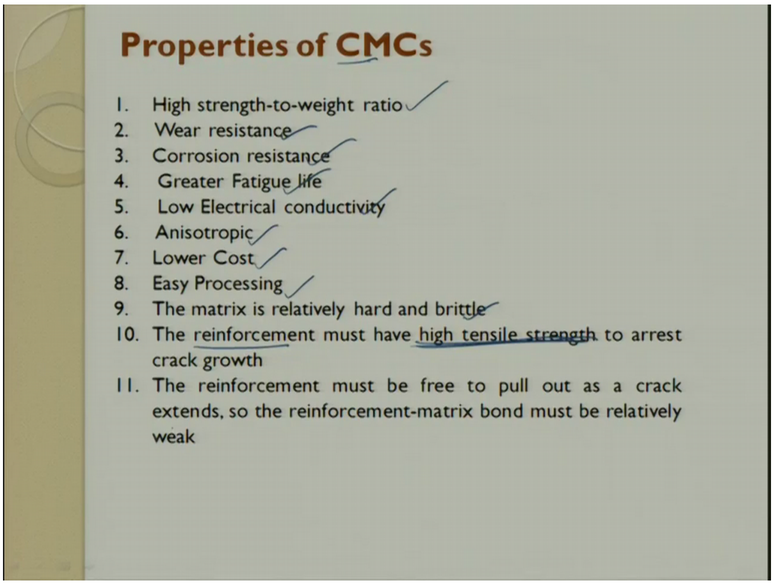

So, ceramic matrix composite the property which is common for all, composites is, it has very high strength to weight ratio. Ceramics of its own has very good wear resistance. So, ceramic matrix composite matrix will have wear resistance properties, ceramic matrix will have corrosion resistance.

Now, since it is ceramic matrix composite, it fatigue strength is enhanced. Suppose for ceramics you want to enhance the fatigue strength. So, then basically what we do is, we convert it into ceramic composites. Then we have low electrical conductivity, you can add particulates to change this property, it has an anisotropic property, it is low cost, it is easy for processing, the matrix is harder and brittle. The reinforcement must have high tensile strength to arrest the crack growth. This is very important. The reinforcement must have high tensile strength, then the reinforcement must be free to pull out as the track extends. So, basically what you doing energy which is getting dissipated into the product. So, the energy when it propagates, it should spend enough of energy.

So, that it pulls out the fiber, or it pulls out the particulates. So, once its pull out the energy it dissipated that point crack does not grow; the material retains for a longer time. So, the fatigue life enhances the toughness value goes high. This is a typically, I have just put different ceramic matrix composite, and I have put the ceramic matrix.

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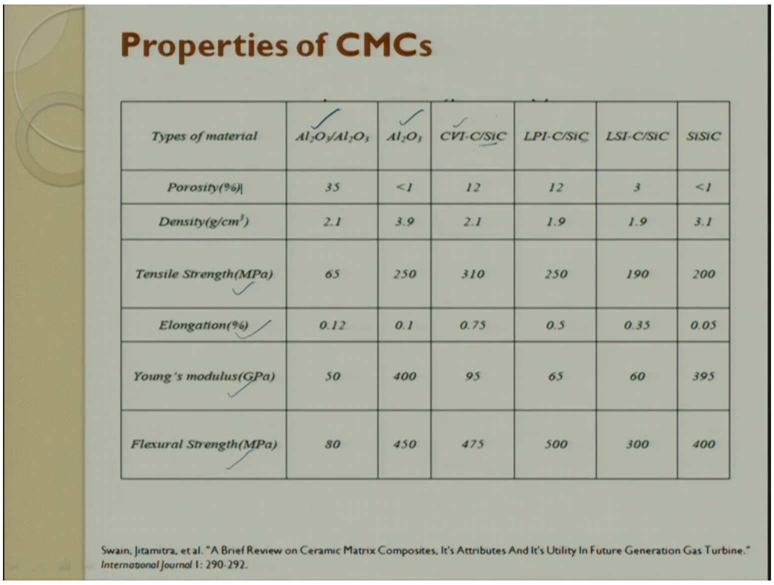
Properties of CMCs

Types of material	Al_2O_3/Al_2O_3	Al_2O_3	CVI-C/SiC	LPI-C/SiC	LSI-C/SiC	SiSiC
Porosity(%)	35	<1	12	12	3	<1
Density(g/cm^3)	2.1	3.9	2.1	1.9	1.9	3.1
Tensile Strength(MPa)	65	250	310	250	190	200
Elongation(%)	0.12	0.1	0.75	0.5	0.35	0.05
Young's modulus(GPa)	50	400	95	65	60	395
Flexural Strength(MPa)	80	450	475	500	300	400

Swain, Jitamitra, et al. "A Brief Review on Ceramic Matrix Composites, It's Attributes And It's Utility In Future Generation Gas Turbine." International Journal 1: 290-292.

What is there properties, when you talk about porosity density, you see alumina 3.8, when you make alumina alumina, it goes to 2.1, you have tensile properties, you have elongation, you have young's modulus, and then you have flexural strength. Young's modulus means, higher young's modulus means it is becoming harder it is brittle; like there is no, there is no elongation at all. So, you can do with carbon reinforced with SiC then C with SiC, these are different process which we will see later.

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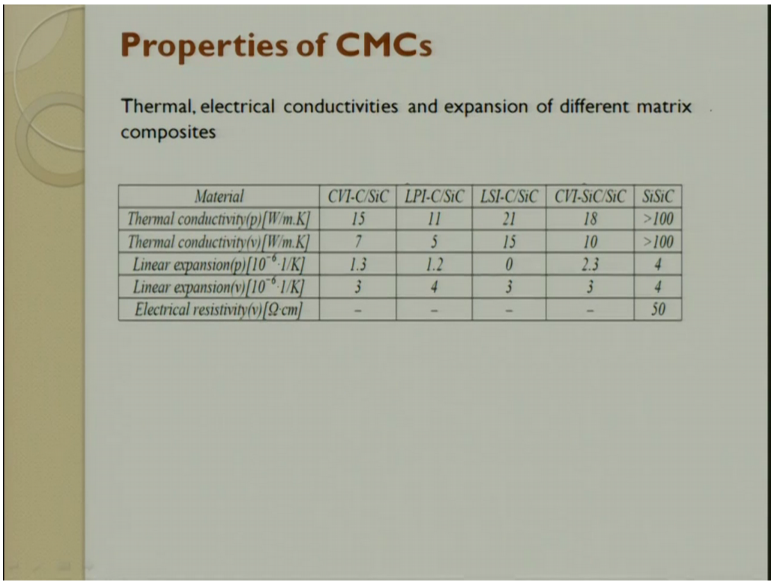

Material	CVI-C/SiC	LPI-C/SiC	LSI-C/SiC	CVI-SiC/SiC	SiSiC
Thermal conductivity(p)[W/m.K]	15	11	21	18	>100
Thermal conductivity(v)[W/m.K]	7	5	15	10	>100
Linear expansion(p)[10^{-6} 1/K]	1.3	1.2	0	2.3	4
Linear expansion(v)[10^{-6} 1/K]	3	4	3	3	4
Electrical resistivity(v)[Ω cm]	–	–	–	–	50

So, the other properties which people are now trying to enhance on a ceramics matrix is, they wanted to enhance the thermal conductivity, they want to enhance the linear expansion and the electrical resistance. So, these are the values by of different processes.

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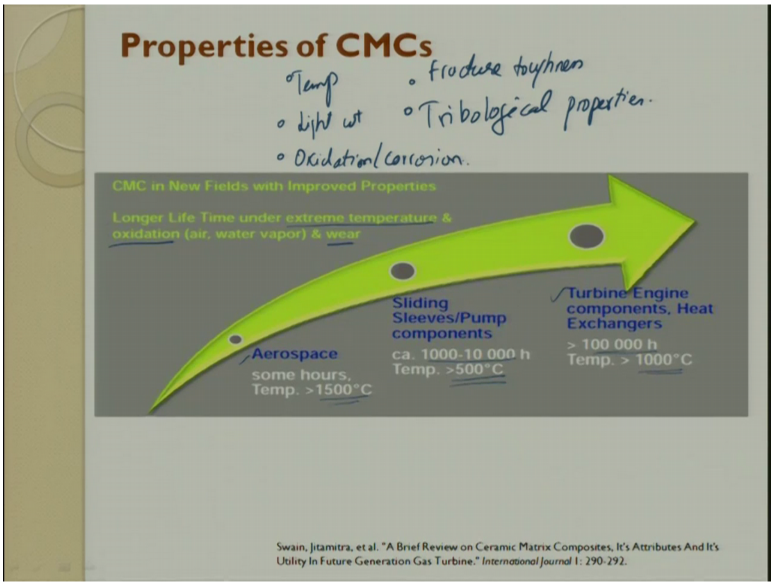

So, the property of ceramic matrix composite, if you see in the, it is exhaustively used in aerospace industry, and turbine engine. If you in aerospace engineer, the temperature what we talked about is about 1500 degree Celsius. Here it is about 1000 degree Celsius, and in turbo engine components are heat exchanges, it is expected to work for 10000 hours, and when you have a sliding and sleeve or in a pump components, it is expected the temperature will up to 500 degree Celsius. The temperatures are the working hours is going to be from 1000 to 10000 hours. So, here what we are looking at it, we are looking at properties which can enhance the temperature, which can be withstand for a longer temperature, which is light in weight. The fracture toughness is high, and the tribological properties, tribological ok.

So, long life time under extreme temperatures; that is oxidation and wear, we also a taking about oxidation resistance, and corrosion, oxidation and corrosion resistance are some of the properties, which we always expect from ceramic matrix composites.

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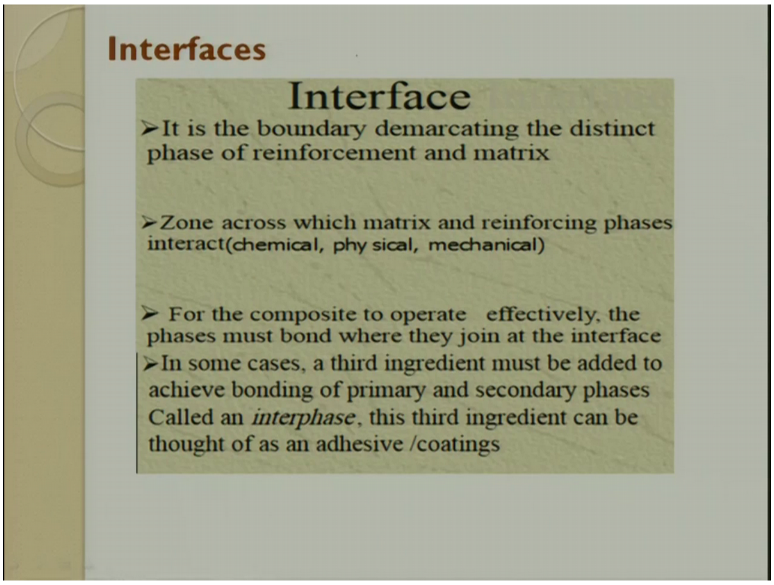

I already discuss this interface interphase, I will re, I tread the same thing, interface is very important, because if you want to enhance the crack propagation. So, basically what you have to do is, you have to enhance the interface property. So, it is the boundary demarketing, the distinct phase of the reinforcement and the matrix. This is a zone across which the matrix and the reinforcement phase interact. The interaction can be chemical, it can be physical, it can be through mechanical. Mechanical means, it can be through locking, mechanical locking right. For the composite to operate effectively, the phase must bond, where they join at the interface. In some cases the third ingredient must be added to achieve bonding of primary and secondary phase called an interphase. Is it clear? This third ingredient can be through an additive or a coating.

So, basically it is same reaction happens between these two, between the matrix and the ceramic, which is reinforced. So, now, what happens is, there is a reaction happening and it can format interphase. So, this interphase is between matrix and the ceramic, and this interface is between these two, we try to functional.

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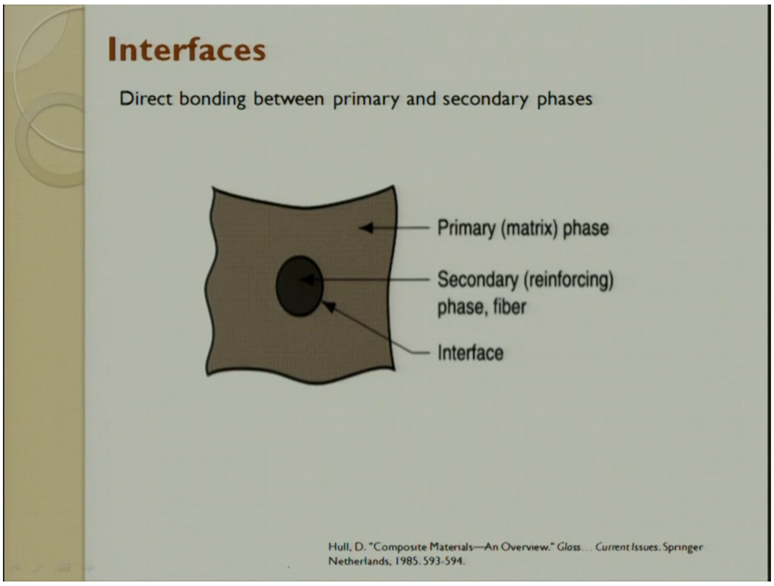

So, that you get a proper this thing. So, this we have already discussed I just wanted to put it for the reiteration. So, interface, what is interface. Right. Is it clear now?

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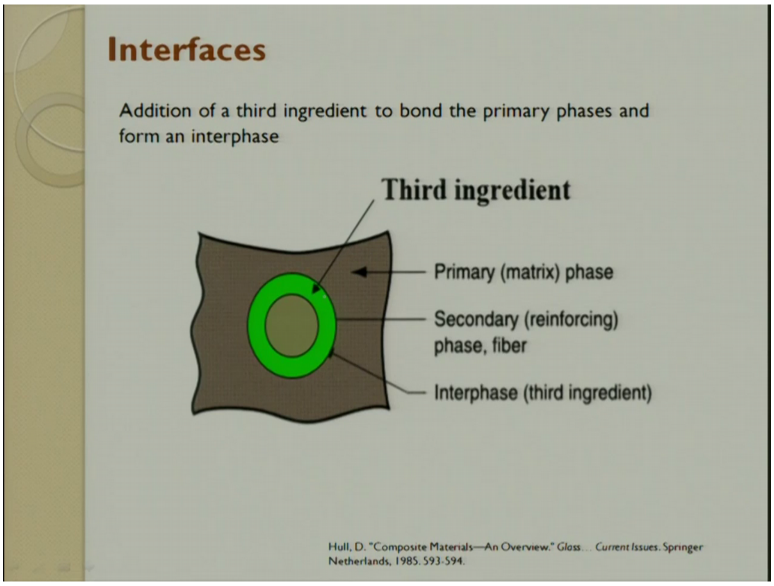

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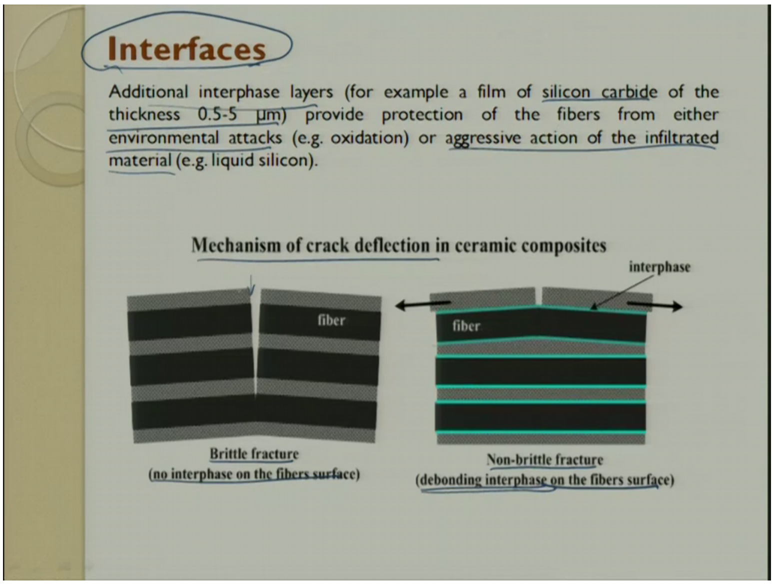

We studied in metal matrix composite also. I have just wanted to reiterate the same thing. So, interfaces, little bit when you look mechanical strength and other things. So, here we see a brittle fracture, here we see a non-brittle fracture. So, these are the mechanism of the crack deflection, which happens in a ceramic matrix composite. You can see here, if it is a brittle fracture. So, the crack just keeps propagating in this direction, fiber break this. These are the fiber, these are ceramic it breaks. So, no interface of the fiber, on the fiber surfaces are there. So, it is just breaks like this right. The next one is, if it is a non brittle fracture, there is debonding at the interphase of the fiber and surface.

So, what happens is crack gets distributed. So, this interphase tries to distribute the crack. So, it is going to withstand higher amount of toughness. So, here additional interphase layer for example, a film of sic of thickness 0.5 to 5 micron provides protection of the fiber, from either the environmental attack, or the aggrieve action of the of the infiltrator material. So, this is very important. So, this happens, this is the importance of interphase between a fiber and the ceramic matrix. The mechanism of failure can be brittle, or it can be non-brittle. So, the debonding at the interface happened here, it just crack propagates and then it breaks all the fiber and do, because it has no interface.

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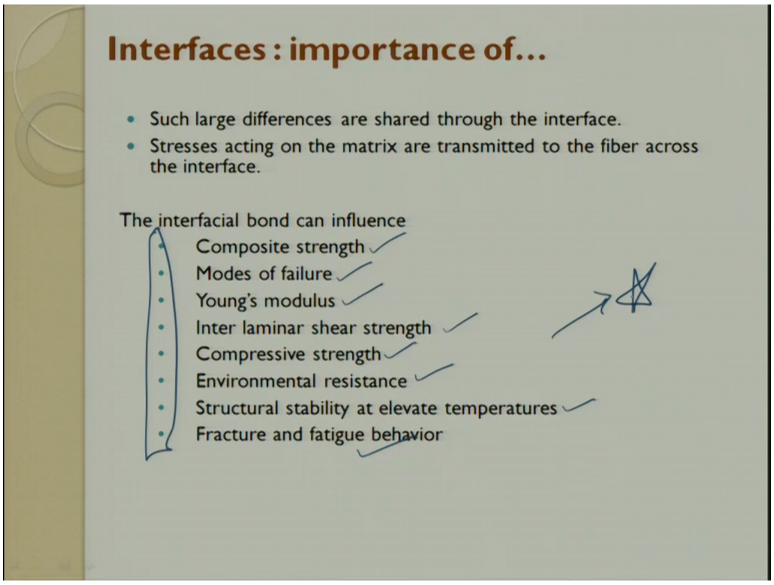

So, the interface can in influencing the composite strength, modes of failure, young's modulus, inter laminar shear stress, compressive strength, environmental resistance, sustainable at higher temperature, and fracture and fatigue behavior. These are all important properties for interface, very important, important for interface in ceramic matrix composites.

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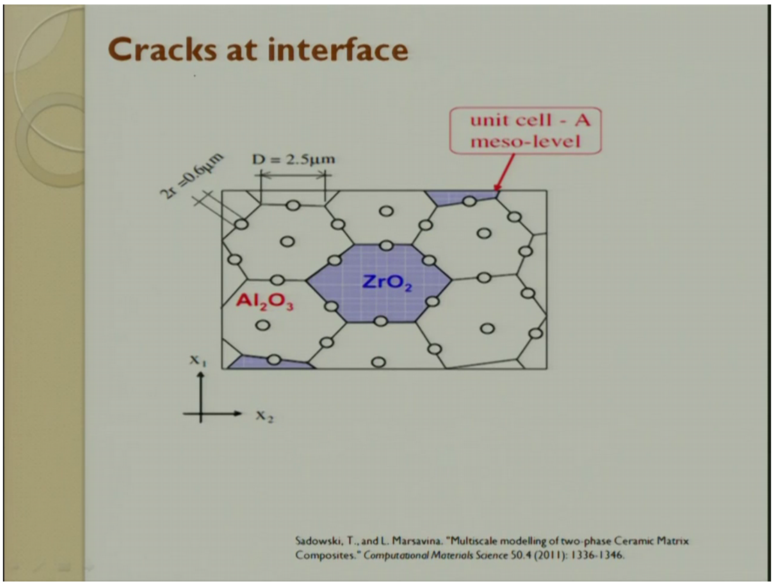

So, the cracks at interface, you can see here. This is alumina, this zirconium oxide. So, this is the diameter of the, there are saying 2.5 microns, and this is the small reinforcement which is there.

So, we can have, these are at the interface, this are the crack, and then you can see, a unit cell a with a meso cell level you have and we can make this. So, you look at it.

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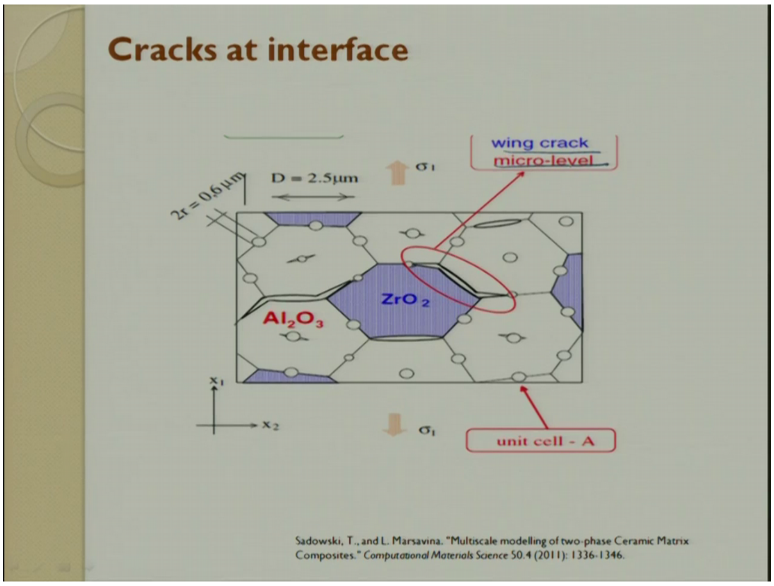

So, these are nothing, but wing cracks at micron level between the interface.

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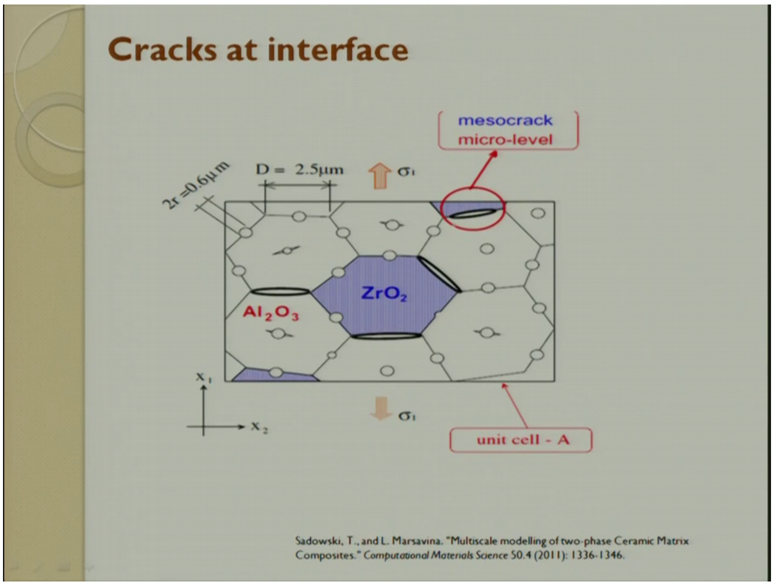

So, these are mesocrack, these are wing crack, micro level crack which happens and the crack keeps growing. So, you see beautifully that crack keeps going from here to the next crack. And the other thing is the micro level crack, between the grains it can have, and the last one is the second king initiative of the wink crack.

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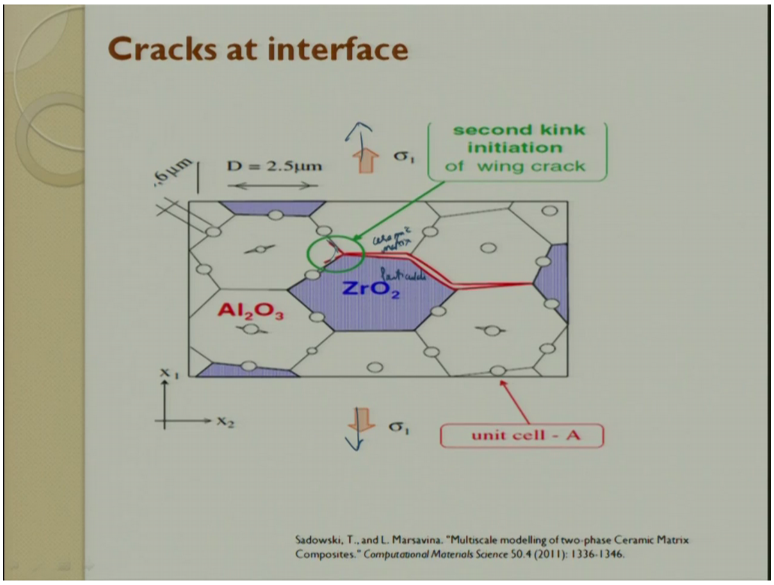

So, you can see here. So, here it again it bifurcates, and it starts growing, and this, this are the loads when they are applied, tensile load which is applied. So, you can see what happens to the crack and how does it grow. So, in all the three cases you see the important thing is, tensile is loaded, it is loaded tensile, and because of that the crack keeps growing. So, this is wing level, micro level crack, this is mesocrack, then this is secondary kink initiative for wing cracks.

So, the most important property between the ceramic, which is used as a particulate, and the ceramic which is used as a matrix, between these two fellows, to have a very good attachment or something, we need to look at their wettability property.

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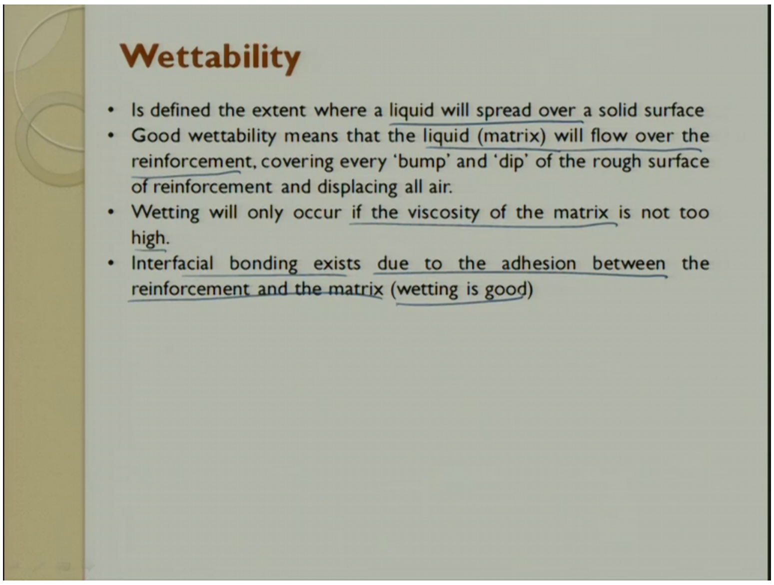

Wettability property becomes very important. So, wettability property, the liquid which spreads over the solid is wettability, good wettability means, that liquid matrix will flow over the reinforcement. Here it is already ceramic, so you cannot take it to the liquid face. So, you have to say how do you make this wettability property very good. The wetting will also occur, if the viscosity of the matrix is too high, the interfacial bound exits due to adhesion between the reinforcement at the matrix, which means to say, the wetting is good between the reinforcement and the ceramic matrix.

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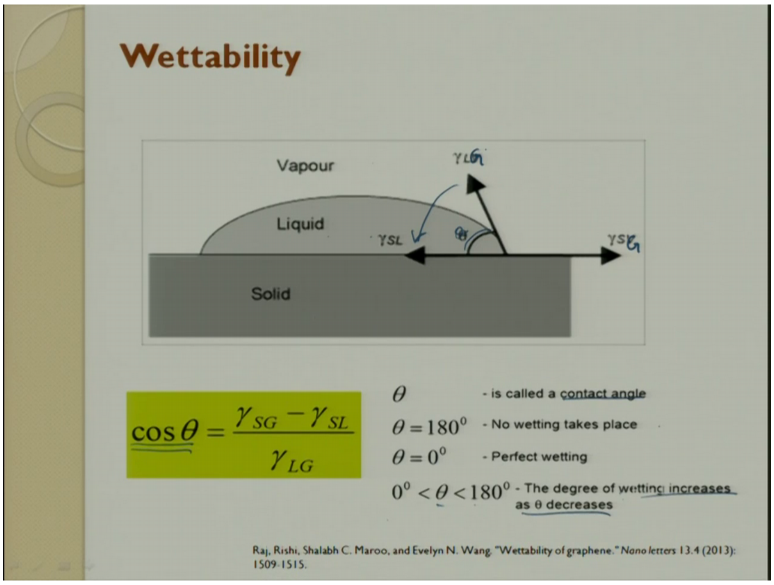

So, we have already seen it in the metal matrix. So, the same figure we have repeating here for ceramic matrix also. You have a vapour state, you have a liquid state, you have a solid state. This is a line which talks about the interface between the solid liquid, between an interface which talks about liquid vapour, and this is an angle which is made.

So, and this angle is called as the contact angle. We are more interested to find out the contact angle, and here I have forgotten to say this is a interface between the vapour phase and the solid face. So, if there if this theta is 180 degrees, then it as no wetting angle if it is 0, it is perfect wetting angle, so this goes 0. So, it goes down, it is perfectly wetting and if it is anything between 0 and 180, 0 and 180. The wetting, the degree of the wetting angle increases or as theta decreases.

So, when you go lower and lower and lower, wetting is good. When you go higher and higher and higher, it is not good, or it is it is having a poor wettability property. So, this can be found out by the formula cost theta equal to gamma SG minus gamma SL by gamma LG. So, SG is solid and the gas, solid and liquid, liquid and gas. So, if you want to look at it, solid and liquid. So, this is solid and gas, solid and vapour and. So, we can make it as G, and this we can make it as, this we are making it as SL, this is (Refer Time:32:40) and this is SG, vapor is SG right.

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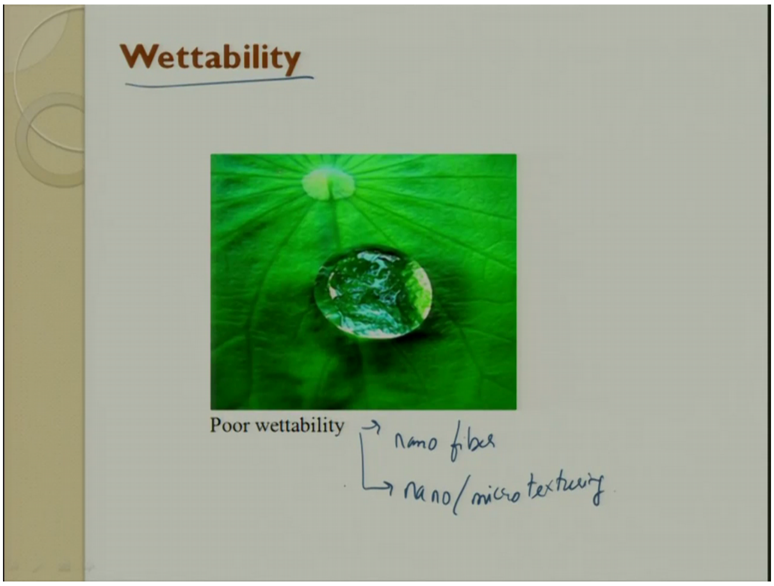

So, this is what is the formula, we try to find out the cos theta. This is wetting and the poor wettability lotus leaf effect. So, majority we have the insects, insects leaf and all, they have a nano fiber; nano fiber, or they call it as nano texturing, nano slash micro texture. On the surface of the leaf we have this nano or micro textures. So, this makes it have poor wettability property.

So, that the water droplet rolls out of the thing, of the leaf and falls down. The same is with respective of lot of animals on their skin. For example, sharp which is always in water never as a skin disease, why, because of the micro nano texting. So, here it is all more focus towards wettability.

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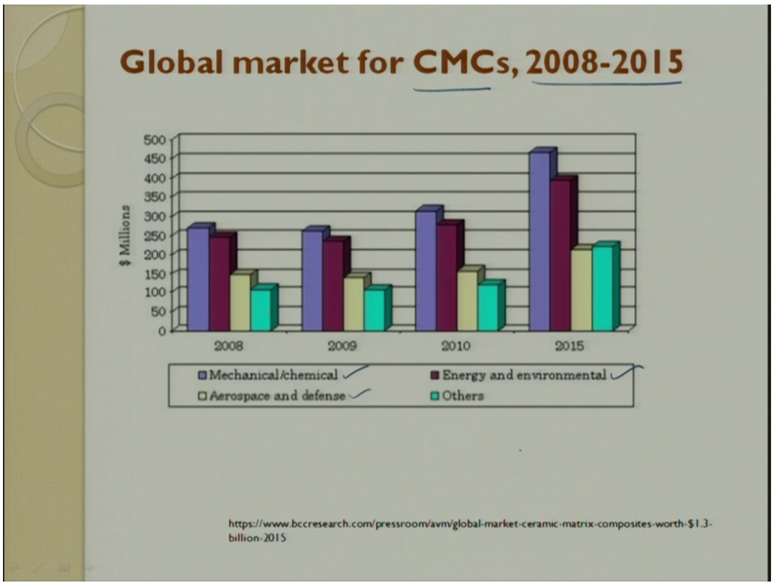

Globally, ceramic matrix composite in the last couple of years. What is happened is, slowly it has been started getting increased in different areas, where mechanical and chemical applications. So, it is there, it is used for example, it is used in heat exchangers, it is used in extraction unit, oil refineries. Now when they are looking forward for chemical aerospace and defense, if they wanted to make it lightweight material, they are looking for energy and environment, they are also looking for ceramic matrix composite and others are there, you can see slowly the manifold from 2005 to from 250 million dollars, it has gone too far, close to 450 million dollars.

So, this from 100 million dollars, it has gone down to 220 million dollar. So, the other industries are also there is lot amount of the usage of ceramic matrix composites.

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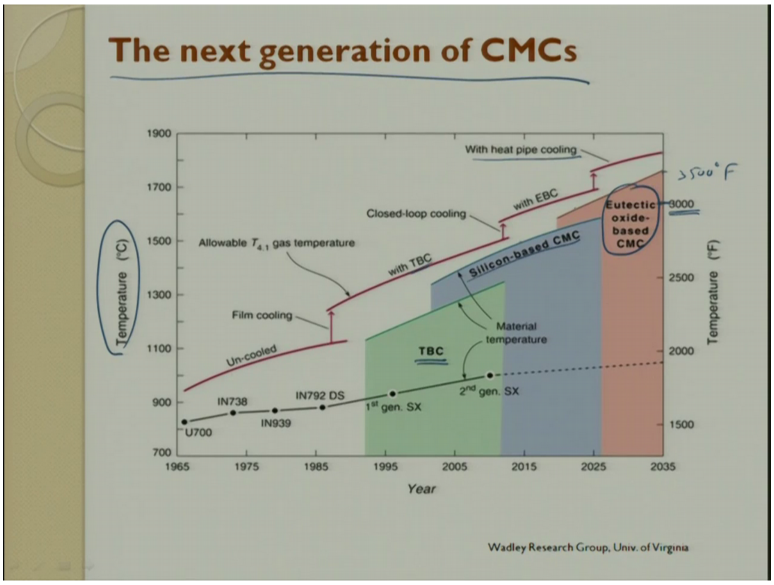

So, what is the next generation of ceramic matrix composite? So, the next generation of ceramic matrix composite are going to be. So, these are TBC, this is thermal barrier coating. Thermal barrier coating can be used for aerospace cutting tool, so many applications. First it was uncooled, now it is film cooled, then with thermal barrier coating, then with EBG. We are also now getting materials which are silicon based, ceramic matrix composites are there. We are, then this will go into eutectic oxide based ceramic matrix composite, with heat pipe cooling we will try to make. So, you can see these are the ceramic materials which can go up to 3000 to 3500 degrees. It can go up to 3500 degrees Fahrenheit.

So, this is what we are looking at it. We are looking at high temperatures, and very high temperature we are looking at. And now we are also looking at very good mechanical properties such that it can be used for that. So, this is electronic barrier coating, thermal barrier coating. So, electronic barrier coating silicon based. So, here we are looking at, these are the first generation, these are the second generation, and now it goes. We will move towards the application of ceramic matrix composite. It is today exhaustively used in automobile brake learning, what happens.

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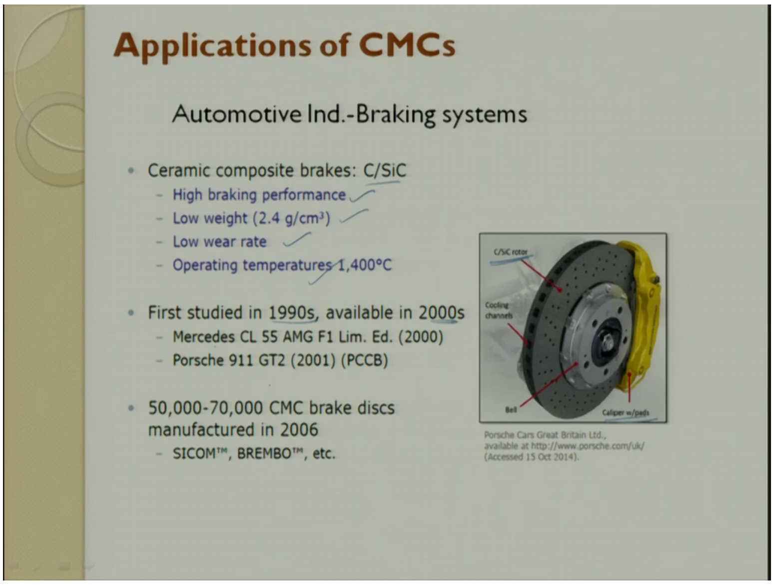

Now, a days we talk about very high speed. So, the very high speeds, if you apply brake, there will be lot of heat which is getting generated. So, there will thermal expansion, and softening of the material which we do not want to happen. So, we are nowadays going for C SIC rotors, and we also have cooling channel. These are the bells which are used, and these are tungsten pads which are used. So, when these to come in contact, we will try to get very high temperatures, and there will be very high frictions; that is reduced when we start using ceramic matrix composites.

So, carbon with SIC. So, high braking performance, the weight goes down, the wear resistance goes down, the temperature of which it is operating goes very high up to 1400 degree Celsius, and nothing happens. The first study has started in 1990, and it is available from 2000, it has been introduced in Mercedes and Porsche cars it has been introduced. There are 50000 to 70000 ceramic matrix composite brake disc, which are manufactured in 2006 by these two companies.

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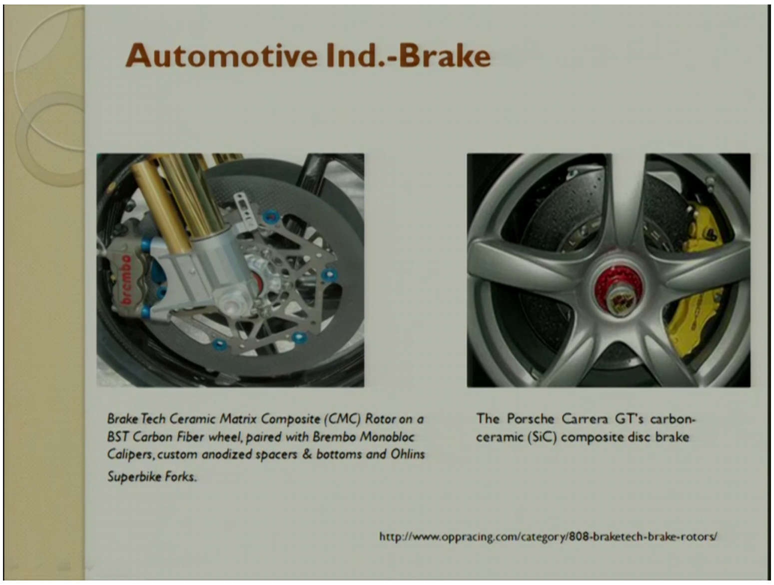

So, if you look at it, these are ceramic matrix composite rotor on a BST carbon fiber wheels. So, carbon fiber wheel is very light weight. So, paired with Brembo Monobloc Capillary, custom anodized spacer and bottom of this superhike bike forks, you can see this. So, these are the forks, and these, and this is completely now made of ceramic matrix composite. This is what the monobloc caliper, which is monobloc caliper which is used. So, this is best for are breaking. This is the carbon ceramic composite disc brakes which are used. So, this are the disc brakes, which are used in automobile today.

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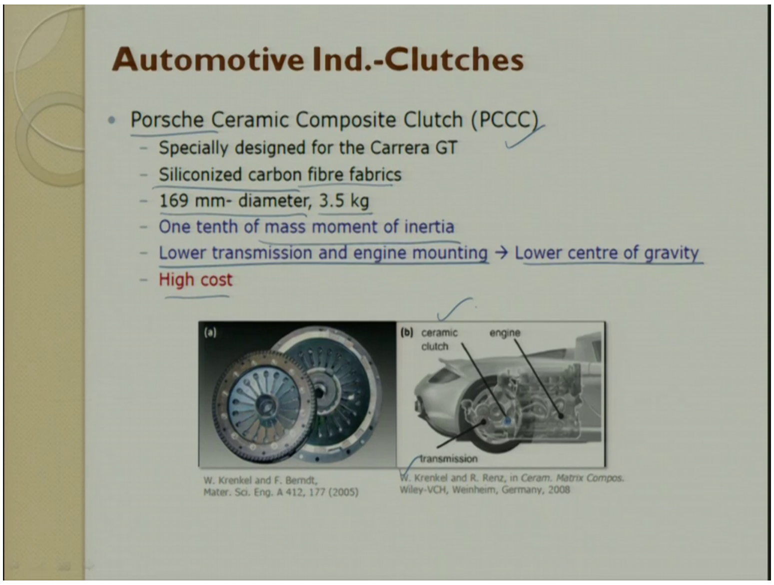

So, the Porsche ceramic composite clutches are made out of it, which is called as PCCC Porsche ceramic composite clutches, designed, designed and these siliconized carbon fiber is used here. The diameter is a round about 170 millimeter, weight is round about 3.5 kgs already it is made out of cast iron, which was like 7 10 kgs, now it has come to 3.5 one tenth of the mass moment of inertia comes, because of this ceramic matrix composite, which is a huge reduction in energy consumption and all those things, lower transmission and engine mounting, lower center gravity, and it is very high since the technology is not become popular, and intellectual property technology. So, still it is expensive. So, you can see that, in transmission systems also, the ceramic clutches, here are ceramic clutches which are there, and this as engine, and you have transmission. So, now, in transmission and in ceramic clutches, there are using ceramic matrix composites.

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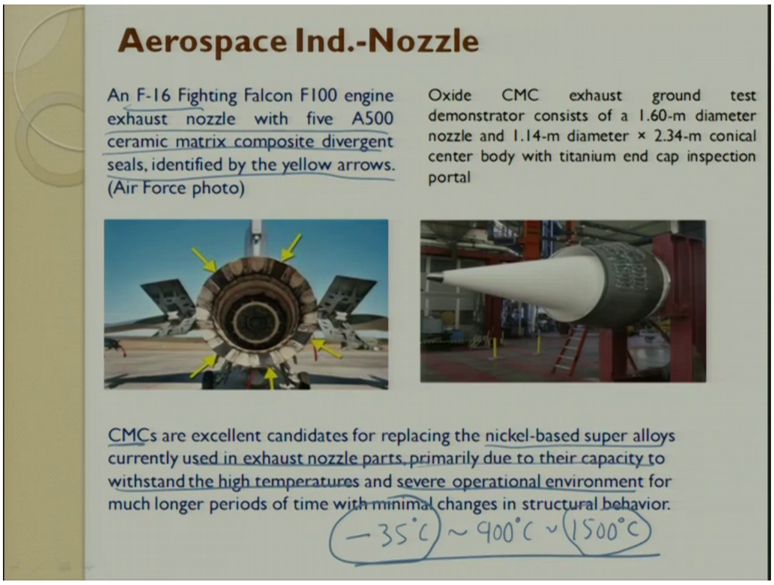

So, in the nozzle; the aerospace nozzles, which we use F 16 fighter planes right. So, the engine exhaust nozzles with five A 500 ceramic matrix composites divergent seals, which are. These are the divergent seals which are, you made out of ceramic matrix composites.

So, they are, and ceramic matrix composite are an excellent replacement for nickel based super alloys. Already these nickel base super alloys are very light in weight, fab manufacturing is big challenge of this, but where a ceramic matrix composite, the manufacturing to large extent is, as compare to this, it is very easy. So, currently used as exhaust nozzle parts and primarily due to the high capacity of withstanding very high temperature, and severe environmental conditions; very high temperature, severe it can be tribological it can be low and high temperature. So, for example, all these fighter plane go at minus 35 degree c. It can go up to, maybe somewhere and about 900 degrees c, or it can be also up to 1500 degree c. So, this is the ambient temperature, when it goes at very high altitude, this is the working temperature, when it is burning. So, that has to be minimum structural changes, there as to be minimum distortion which is happening, and it has to retain its shape. So, an oxide ceramic matrix composite exhaust ground demonstrates which is round about 1.6 meter diameter nozzles. This is 1.6 meter diameter nozzles, and it is one, which is also a, which is the conical shape. Fabrication is the big challenge. Now it is made out of ceramic matrix composite, with a titanium cap on top of it.

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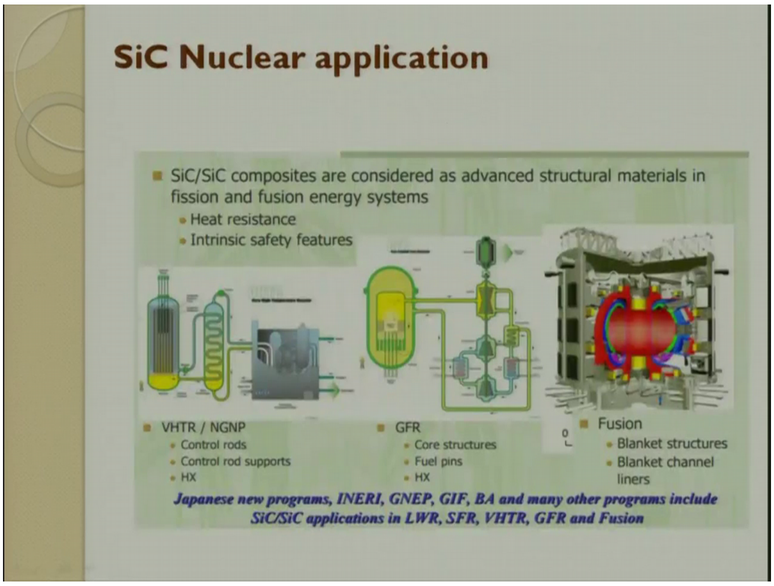

So, a complete turbine is made out of ceramic matrix composite, or the parts, which are, there are made out of ceramic matrix composite. So, invasion. So, what they are trying to do is, first there are trying to attack at lower pressure compressor side, then there are looking at higher point pressure composite side. So, here they would make ceramic matrix composite, either as insert or as a whole body, whole part body right. So, do not think completely the turbine would be made.

So, the either it they can make small inserts. For example, they can make a small insert here of very high temperature withstanding, and then they can also make the whole body is, what I am trying to say is a small portion where and which it gets attached to a another big portion of the entire system. So, combustor is there. So, here you will have high pressure turbine, and you will have a low pressure turbine. So, high pressure, here it is a compressor. So, high pressure compressor and high pressure turbine low pressure turbine. Today they are made of ceramic matrix composite material, because they have this CMC has toughness very high, and making small inserts is very easy as compared to make a complete body.

So, there is lot of aero engine which is made out of composite. Now CMC is getting (Refer Rime: 42:32) in all these things. So, that it can be made lighter and lighter. So, SIC nuclear application is other thing. Today we talk about SiC SiC silicon carbide silicon carbide reinforced composites, which are used for advanced structural materials in fusion and fission energy systems, where in which the heat resistance and integrated safety is also there. So, this is now thought of SIC in nuclear application is the next place where ceramic matrix composites are talk top in a very big way. So, when you talk about fusion the temperatures are very high. So, the blanket structure, the blanket channels liners are made out of ceramic matrix composites.

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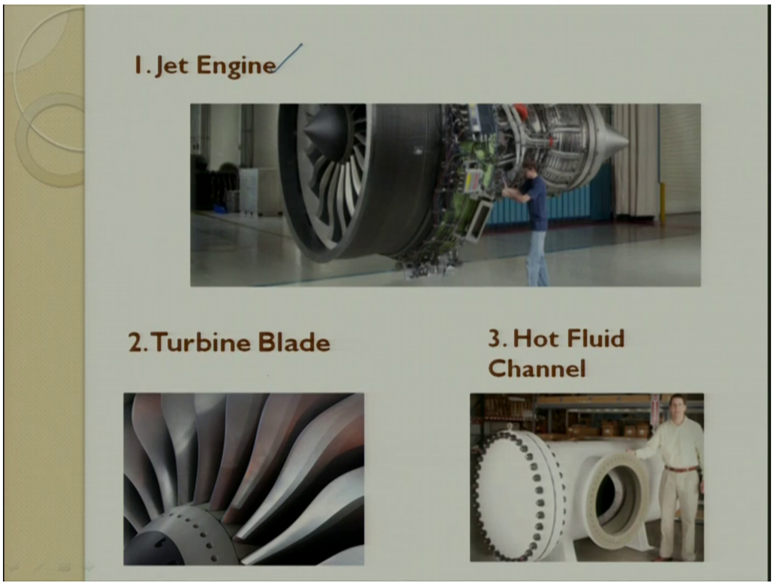

So, jet engines, turbine blade which we are already discussed. See if you look at it these are some inserts, this is a path, here is a joining adaptor and this is a slot. So, they are now made out of ceramics then you can also see hot fluid channels are there. So, these are all made out of ceramics or this all. So, that it can withstand very high temperature and corrosion resistance.

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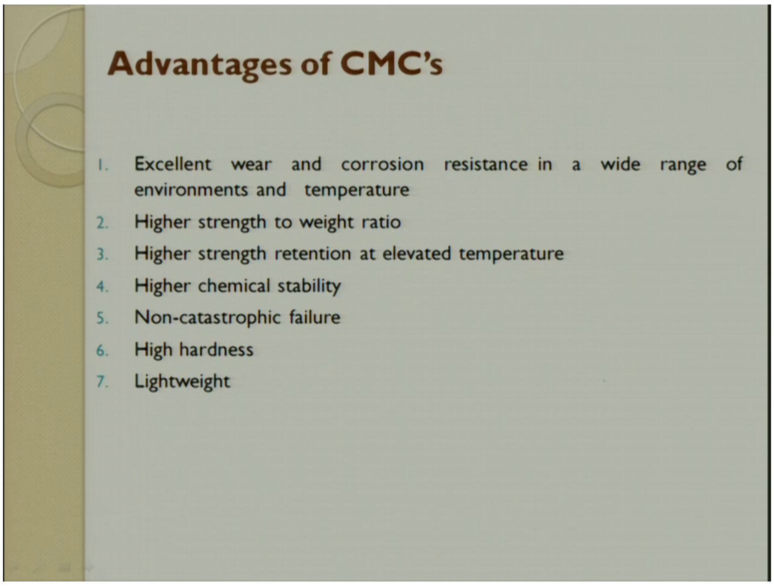

What are the advantage of ceramic matrix composite excellent where, excellent corrosion resistance strengths to weight ratio, elevated temperature retraining the structural properties, chemically stable, catastrophic failures, because of the reinforcement the cracks can go high hardness and light in weight, are some of the major advantages of ceramic matrix composites.

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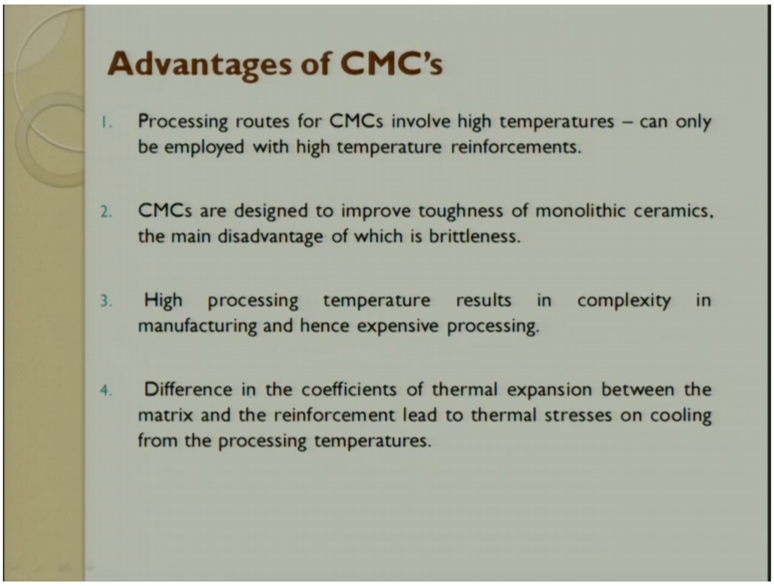

So, the advantage, the processing route of ceramic matrix composite involves very high temperature, and can be deployed only with high temperature reinforcements. So, whenever you need a very high temperature application, there we will use this. The ceramic matrix composites improved toughness. The high processing of temperature results in the complexity and manufacturing, in manufacturing and hence the process becomes costly. Then the difference and coefficient of thermal expansion between the matrix and reinforcement of thermal stresses on cooling for the processing temperature is very high.

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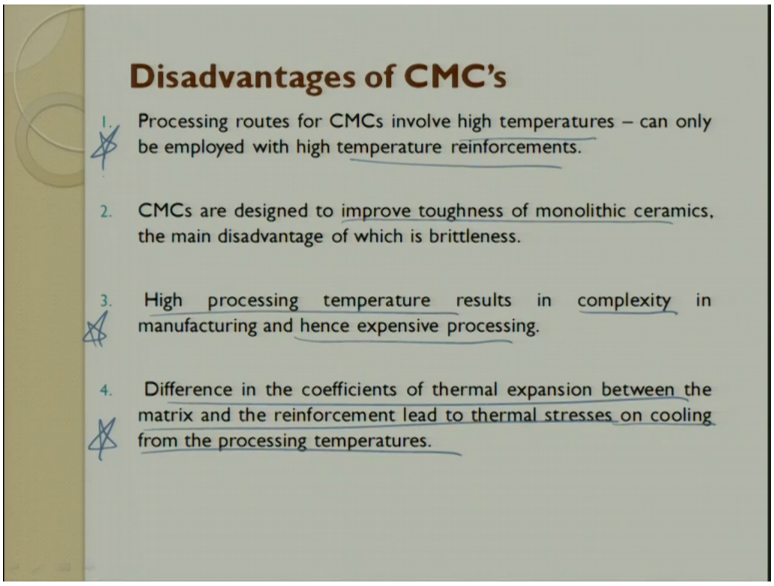

So, the disadvantages of what is processing difficulty and other things, the biggest disadvantages, it since it is, it has to be process at very high temperature. We have to have furnaces which can withstand very high temperature, and the reinforcement also should be of very high temperature withstanding. So, that is one of the disadvantages of ceramic matrix composite to it is used to enhance the toughness property.

So, because of the toughness property, you also have to see the match in the grain size, the match in their properties between these two. So, the next things is, since it is higher processing temperatures are there, all these, there are lot of complexity and the process is pretty expensive. The difference in the coefficient of thermal expansion between the matrix and reinforcement leads to thermal stress on cooling, while the processes made. This has to be taken care, while choosing the ceramic and the reinforcement for making ceramic matrix composite. So, this is expensive, this is challenging, and this is also. These three properties are very. These three are the biggest disadvantages of ceramic matrix composite.

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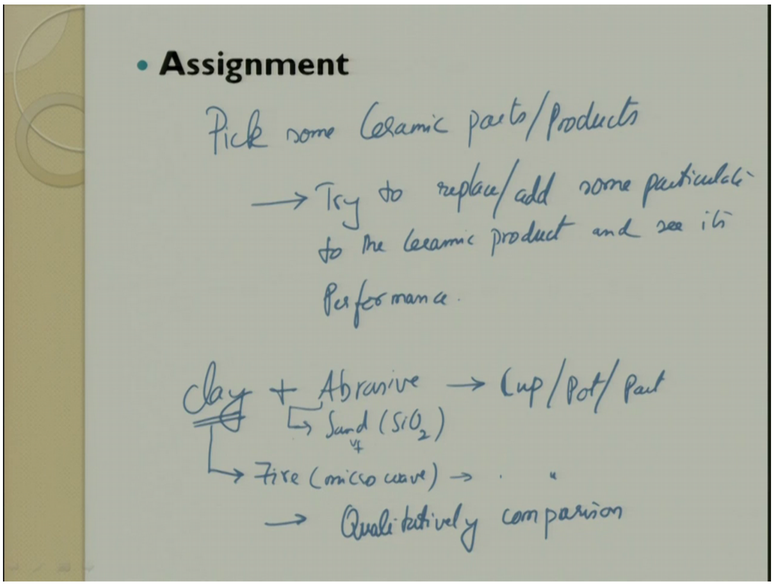

For this lecture assignment what I would request you is, I would request you to pick some ceramics, ceramic parts or products right, and try to replace or add some particulate to the ceramic product, and see its performance. For example, take clay, clay is a ceramic material, ordinary clay try to add abrasive to it. Try to add abrasive, abrasive means sand ordinary sand, which is nothing, but SIO two try to add to it.

Now, you try to try to make a something like a cup, cup or pot or a part whatever you want, a very simple trivial part. So, what you do is, first take clay, and then what you do is you try to fire the clay. The firing of the clay can be done on a microwave oven, or if you have, if you have a furnace you can put it in a furnace, maintain at slightly higher temperature.

So, around about 800, we are not looking for a very sound quality, but just for your understanding and experimentation sake. So, 800 degree Celsius, if you have a furnace you can put, or you can just put it in a microwave oven, and keep it for some time, maybe 2 minutes or 3 minutes, and see before it forms any cracks, you have to pull it out of the microwave. So, you can put in a microwave, and then try to make one again. So, cup slash pot slash part whatever it is. Next you take clay, mix with some volume fraction of SIO two, and then first see what happens in the formability while making a shape what happens, and then when you try to put it inside microwave what happens. Just qualitatively make a comparison and then just for your (refer time: 48:38) study comparison, comparison and study for yourself. So, you will make up a clay.

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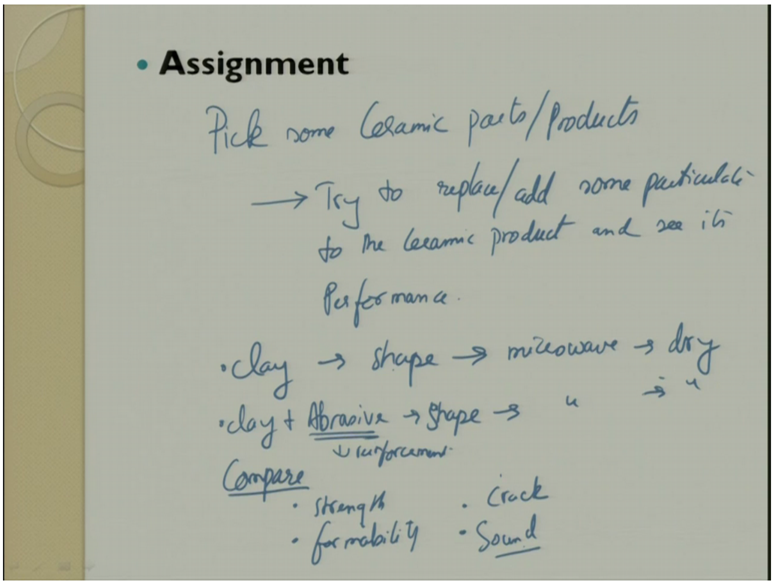

So, the steps involved if you want, I can. You take clay give a shape to it, and then put it inside microwave oven, and make sure it does not crack, and allow it to dry. The next thing is, a clay mixed with abrasive. Again you will try to shape, put in microwave and then allow it to dry right, and then you will try to compare.

So, here sic is a reinforcement agent. Compare what, compare strength, compare formability, compare the crack if it is growing, and finally, you can also compare it with respect to sound. So, just heat it with another surface, and then try to note down the sound, how shrieking it is coming and other things. So, this is an assignment which will try to give you an understanding of ceramic matrix, and ceramic matrix reinforced ceramics. So, that you compare the processing difficulty and the other properties with respect to these two.

Thank you.