Nature and Properties of Materials
Professor Bishak Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology Kanpur
Lecture 21
Composite Materials 2

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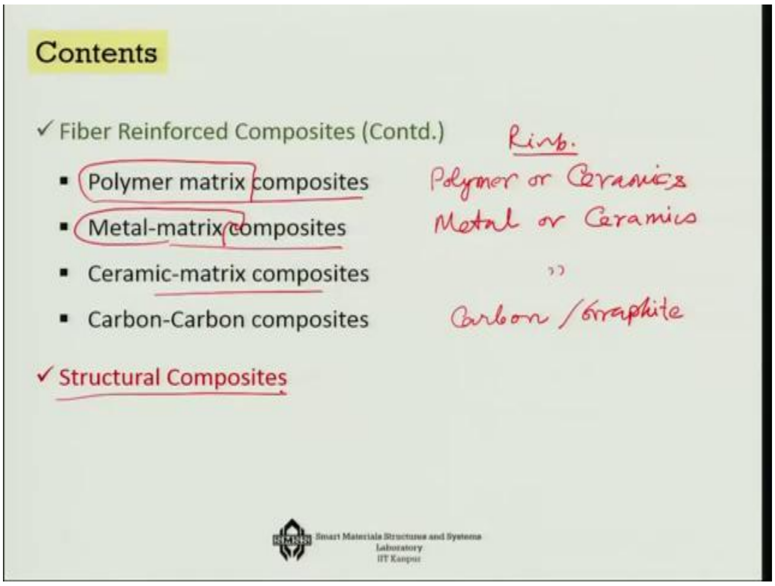

Today, we are going to talk about some of the composite materials with a special focus on the fibres of some of these composite materials. So we are going to talk about fibre reinforced composites and mostly polymer matrix composite that is the 1st very important thing. Then also we will talk about little bit on metal matrix and ceramic matrix composites. Now, when I am talking about polymer matrix composite, what we are telling is that the matrix has to be polymer okay.

But what about the reinforcement, we are remaining silent about it, but the reinforcement for polymer matrix composites are generally either polymer or ceramic. When we are talking about metal matrix composites, then so these are the reinforcements, then it will be either metal itself as a metallic fibre or ceramics. The reason why polymer and ceramics for polymer matrix composites are chosen because of matching of coefficient of thermal expansion plays an important role.

And secondly, the strength and I mean exactly the interlocking that takes place between the fibre and the matrix that plays an important role, so also in the fabrication process plays an important role. So this is metal matrix and for ceramic matrix composites it is the same thing, metal or ceramics. For carbon-carbon composites, carbon itself is the matrix and carbon itself is the reinforcement okay.

Mostly the carbon or graphite form, so this is what we are going to have an overview on the whole thing and then finally we are going to talk about structural composites that means how do you make a composite layer by layer. Now let us 1st of about fibre reinforcement composites.

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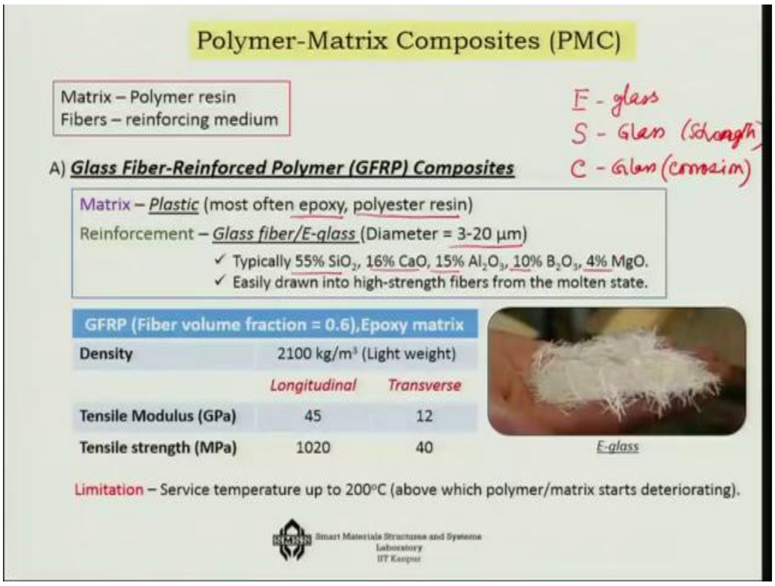

So the 1st example of such composite is GFRP that is Glass Fibre Reinforced Polymer composites. And that name itself is telling us that reinforcement is Glass fibre and when we talk about glass fibre, there are various types of glass fibres they are in fact, like E-glass fibre that is for electrical purposes, insulation that was 1st discovered, so it is important.

And there are now couple of very specific glass fibres like S-glass fibre which is good for a strength point of view, so this is available today as a special type and also C glass fiber, so this is against corrosion, from the corrosion point of view. So however, the most common one is E-glass fibre and the most common matrix is actually epoxy, polyester resin. The diameter of this fibre is between 3 to 20 micrometer.

And typically each one of this fibre if you look at the composition, you will see about 55% of silica, so silica has the major composition, then 16% calcium oxide, 15% Alumina, 10% boron oxide and 4% magnesium oxide, so all these things together actually makes the glass fibre. In fact, you can see the glass fibre here you can see it here that the 1st one and the 2nd one, these are the 2 where the fibres are actually whitish, transparent translucent in nature.

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These are the glass fibres, this is the symbol fibre and this is the fibre when it is having some cross S in it to keep it into collusion, so these are the 2 glass fibre examples. So these are the glass fibres and then if I actually apply the epoxy resin, then it becomes a composite and this composite will look something like this.

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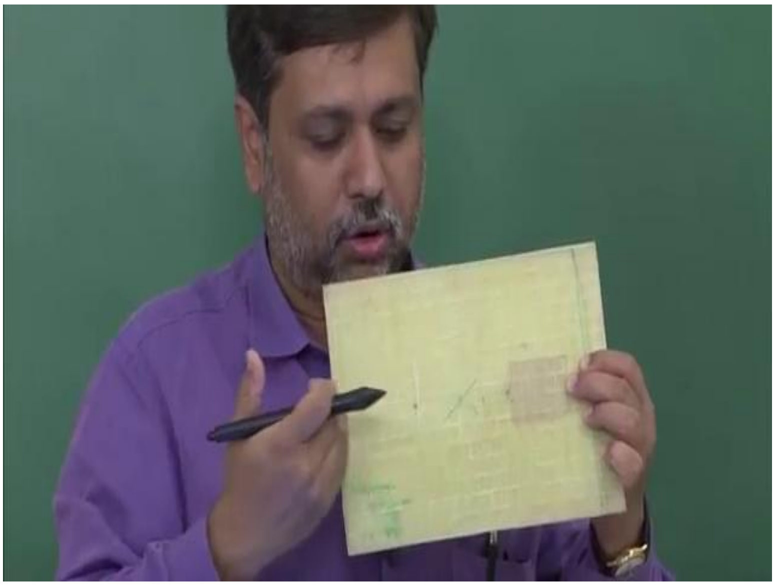

So you can see that the fibres are there inside and then there are layers of this epoxy resins, the polymorphic resins that are applied and finally you will get a strong structural composite out of the whole system.

Of course there is also an embedded damage in it, rectangular damage; I will talk about such a thing at a later stage, but this an example of a glass fibre reinforced composite. So what is the kind of weightage possible? By weightage what do you mean, what is the maximum fibre volume fraction possible that is generally 0.6 that means 60% volume will be fibre maximum.

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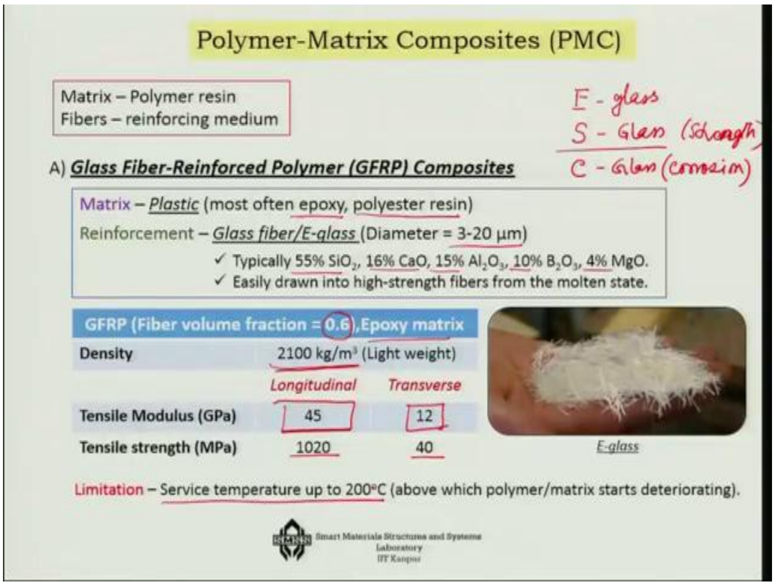

You try to always increase the amount of fibre in order to improve the strength and modulus of elasticity, etc. So 60% is generally the maximum possible and 40% then is the Epoxy matrix, with that composition the density will come about 2100 kg per meter cube. Just compare that will be density of steel and that is about 7400kg per meter cube, so you can see that how light this system is.

The tensile modulus is about 45 gigapascal, just compare this with something very close will be maybe Aluminium which is close to 70 gigapascal and this is however anisotropic, this is the longitudinal modulus and the transverse modulus is much lower that is 12. If you remember the spring analogy that I have shown you in the last class that explains this.

Then the tensile strength is about 1020MPa for the longitudinal direction and about 40MPa in the transverse direction. The only limitation, so structurally it is quite good in fact, whenever steel with moderately lower rate element is needed or Aluminium, you can very safely use the glass fibre reinforced plastic. If you need slightly more strength, you can go for S classes, etcetera. But the limitation is that the service temperature is up to 200 degree centigrade, which should not go beyond that. If it goes, then the flow will start or the degradation of the matrix will start, so hence this is the limitation temperature wise.

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There are many applications of it like you can see automotive and marine bodies, many of the sports yard for example are actually made of glass fibre reinforced plastic because that way you can make it very like and then die plastic pipes, storage containers, industrial floorings. We can see that this is a typical bar ribbed bar, which is made of actually GFRP; GFRP rebars which is used for making the pedestrian bridges.

So there are varied applications and GFRP is coming up to be one of the most I would say widely used composite because of these advantages. The next composite which has very-very high-performance applications are actually Carbon Fibre Reinforced Polymer composites.

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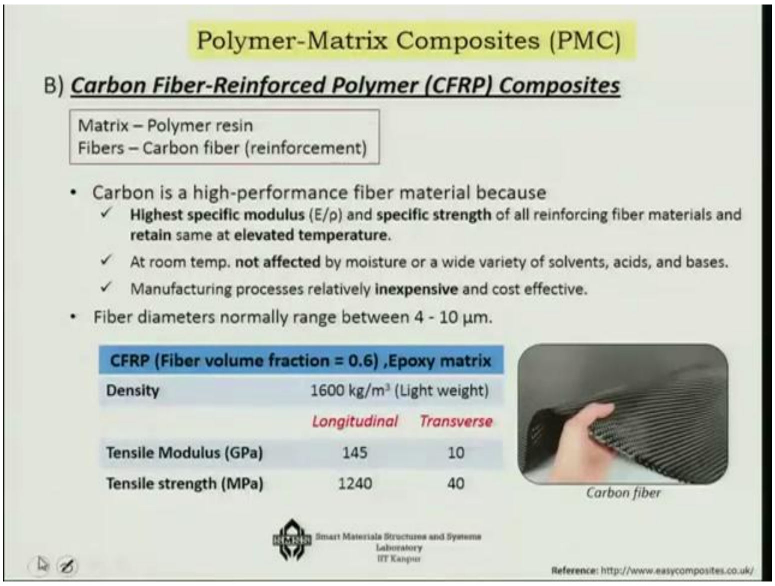

So carbon fibre if you look at it, once again I will show you how it looks like. These are blackish things, these are the carbon fibres and in various forms you can have. This is unidirectional fibre and then you can have such carbon fibres which are oval form for example okay.

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Or in cross plies or prep rake forms okay, random orientation, etcetera, you can have the carbon fibres in various forms. So these 3, 1 2 3 these are examples carbon fibres. So you can just like GFRP, you can actually make Carbon Fibre Reinforced Composite. Now carbon is a very high-performance fibre in comparison to glass fibre. It has very high specific modulus E by Rho ratio that is modulus of elasticity to density ratio.

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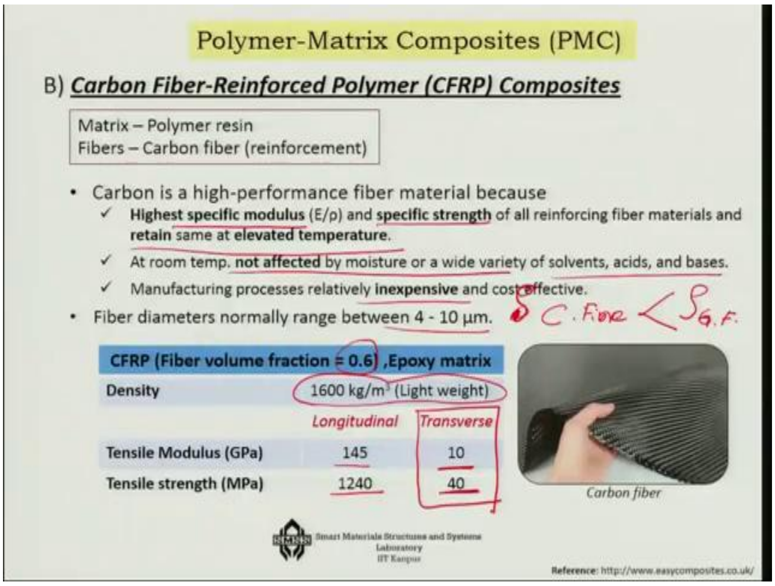

And also it has a very high specific strength, so high specific modulus and high specific strength. Not only that, it can retain the same at any rated temperature. GFRP by 200 degree centigrade it is of no use, whereas CFRP can be used to a much higher degree of temperature. And at room temperature it is not affected by moisture and a wide variety of solvents, acids and bases, but the manufacturing process is relatively inexpensive and cost-effective, still it is expensive particularly carbon fibres are expensive.

So with the same 0.6 kind of a volume fraction and a fibre diameter about 4 to 10 micrometer, you will achieve here a density of 1600 that means C carbon fibre is actually lighter in terms of density the Rho the density of the carbon fibre okay that is lighter than the density of the glass fibre, so that is something that is very important.

On the other hand, if you look at the tensile modulus you get something like 145 which is very close to steel, double the Aluminium, transverse highly anisotropic, transverse is only 10GPa and tensile strength is 1240MPa, transverse strength is about 40MPa, so that is anisotropy is something that one has to keep in mind while making a structural composite out of this system.

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These are various applications of carbon fibre composites as you can see that this is a BMW carbon fibre wheel okay, this is the steering of carbon fibre okay and then there is the special seat, etcetera, so there are many applications of carbon fibre you will see. Why for example, mountain bike frames you will see, 787 Dream liner has nearly 50% frame made of CFRP.

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And the other interesting application is in terms of the racing cars like Lamborghini Aventador, you will see that CFRP is used in its wheels, in its frames and in the seats itself CFRP is used. CFRP is also getting a lot of use in the sports goods for example, the rackets. So by making it light but strong, you can actually save lot of muscular energy and hence you can improve the performance in the game, thus CFRP is very well popular in such sports applications as well.

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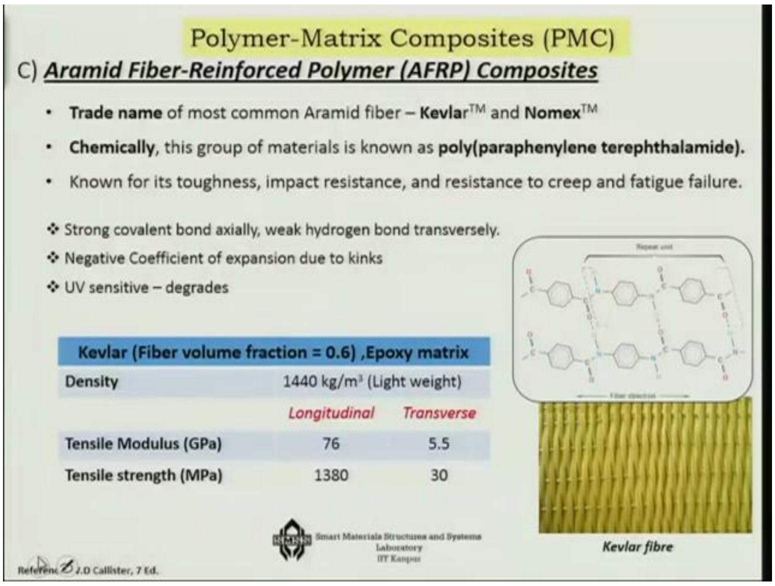

The 3rd one in the 1 matrix composite that is equally important in terms of application is actually Aramid Fibre Reinforced Polymer AFRP. So here the fibre is like glass work, the glass fibre and carbon fibre that in this case the fibre is actually Poly Aramid fibre, once again I will show you how it would look like, so this one is yellowish one, these are the Poly aramid fibres.

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You can get it in various forms as simple fibres as well as woven fibres so woven cross, bidirectional, so these are actually Kevlar or Nomex that is the name of such a system. So this actually is very much known for its toughness, impact resistance, resistance to creep and fatigue failure. And the reason of its high strength is because of the axial covalent bonds and however, it is very anisotropic, it has weak hydrogen bond in the transverse direction.

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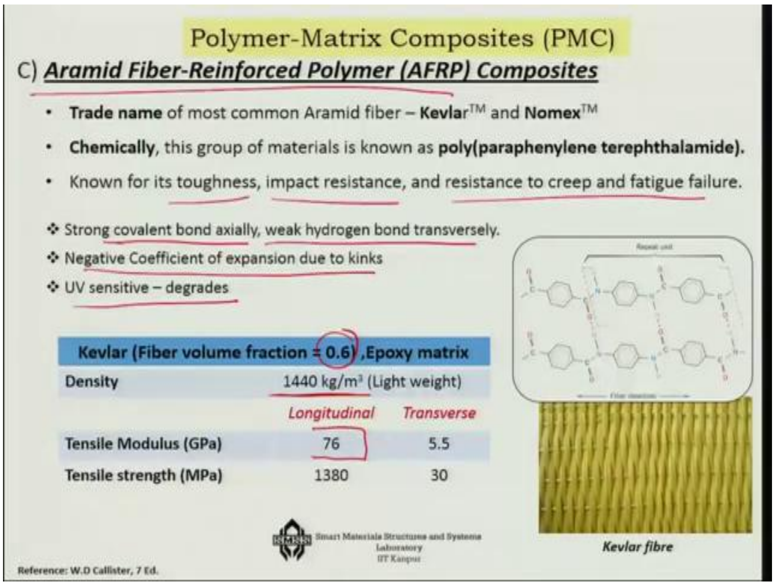

And it has negative coefficient of expansion due to kinks, so that is also another interesting point you have to keep in mind while designing and it is really sensitive within little bit of a negative sign of it that it degrades with the UV exposure. Now Kevlar with a 0.6 volume fraction, you can see that the density is 1440, so it is even lighter than CFRP in some of the cases and definitely it is lighter than GFRP.

And if you look at the tensile modulus, it is close to aluminium 76GPa in the longitudinal, transverse it is pretty weak only 5.5. And this is tensile modulus; tensile strength is 1380MPa in the longitudinal direction and 30MPa in the transverse direction. One important thing we have to keep in our mind that in terms of fibres, glass fibre is inorganic in nature, carbon fibre you may call carbon inorganic or organic.

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But definitely this one the Aramid fibre this has the organic fibre that organic fibre is actually this Poly paraphenylene terephthalamide or similar such fibre, so that is about the Kevlar fibre. Typical applications, one of the most important applications today is for the BPJs or in other words bullet-proof jackets or vests. So it is because of its light weight, but I shock absorption capability, it is used in ballistic products.

Also it is used in sports goods, ropes for the climbers and missile cases and many cases it is working nicely as a replacement of asbestos in automotive brake and clutch lining. See, asbestos is a good fibre, but the problem of asbestos is that it is injurious to the health, so in such cases this particular fibre is actually working very well as a replacement. Now if we compare between the 3 types of composites with the same volume fraction 0.6 and the same matrix epoxy matrix otherwise, it will not be a fair comparison.

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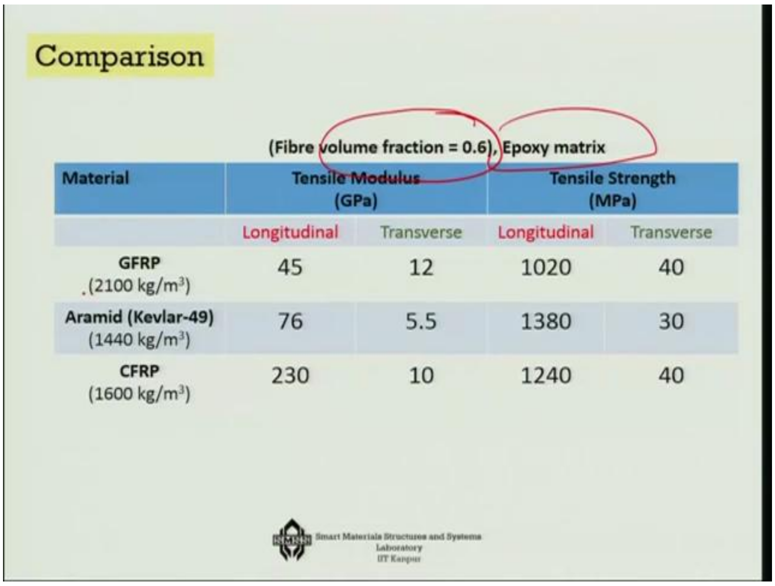

GFRP density is the highest 2100, Poly aramids they are in the middle 1440 in fact, they are the lightest and CFRP 1600, so you can call Poly aramid to be the lightest and GFRP to be the heaviest among them. And if you look at it from the stiffness point of view, then CFRP is very stiff, so this is very high stiffness, so very high stiffness.

In fact, close to steel somewhat more than steel in the longitudinal direction, in the transverse it is only 10 and the tensile strength wise it is close to steel that is 1240MPa whereas, transverse it is about 40, so in many senses other than the density CFRP is better because it has higher modulus of elasticity and higher strength in comparison to the other 2 materials which are mostly used. Now I will talk about some Metal Matrix Composites.

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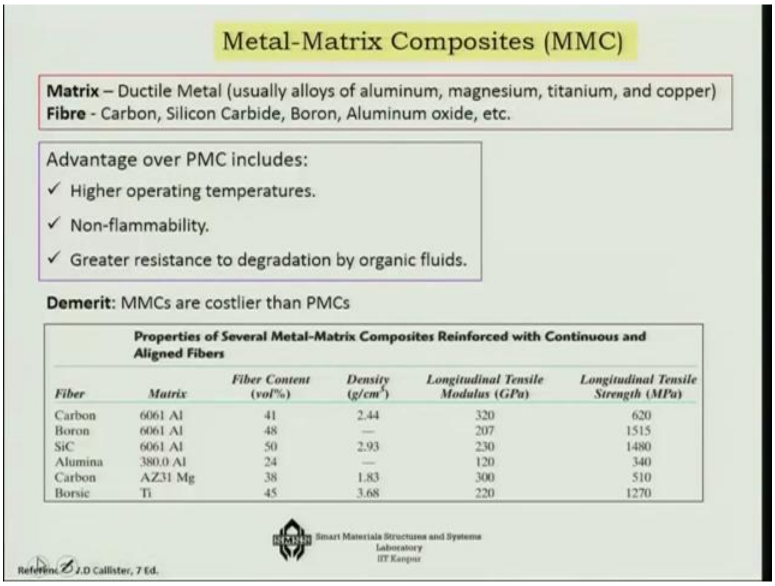

So in the Metal matrix composites, the fibre can be either metal or ceramic, where polymers typically we do not keep because they can sustain a high temperature and also there are this mismatch of coefficient of thermal expansion and also the conductivities etcetera. So matrix wise here it is ductile metal usually it is alloys of aluminium, magnesium, titanium and copper.

And fibre while it can be carbon fibre, silicon carbide, so these are inorganic fibres, then boron fibre and aluminium oxide that is the ceramic fibre, anyhow these fibres can be used in metal matrix composite. Advantage over PMC is definitely high operating temperature and definitely non-flammability and greater resistance to degradation by organic fluids. In many chemical plants there is this organic fluid, which can contaminate the pipelines, so this MMC is much better in all such cases including a good operating temperature.

So in fact, some of the MMCs if you look at it like carbon and aluminium as matrix, you can see you can get a very high tensile modulus something like 320 and the strength is something like 620, so it is very high considering the density only 2.44. Similarly, if you look at all of them you will get a kind of an idea that where exactly we are in terms of the metal matrix composites and in almost all the cases it is much better than the single metal-based system.

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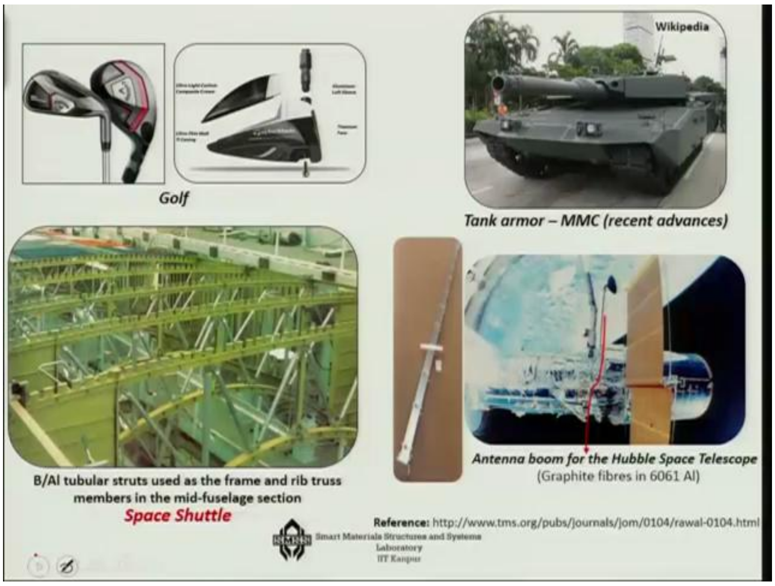

For places where you can use it like Golf definitely and then tubular struts which is used as the frame and rib truss members in the fuselage section that is in terms of aircraft applications, then the antenna boom for Hubble space telescope for space application, the tank armor MMC, though there are many such varied applications of metal matrix composites. Now we will talk about the ceramic matrix composites.

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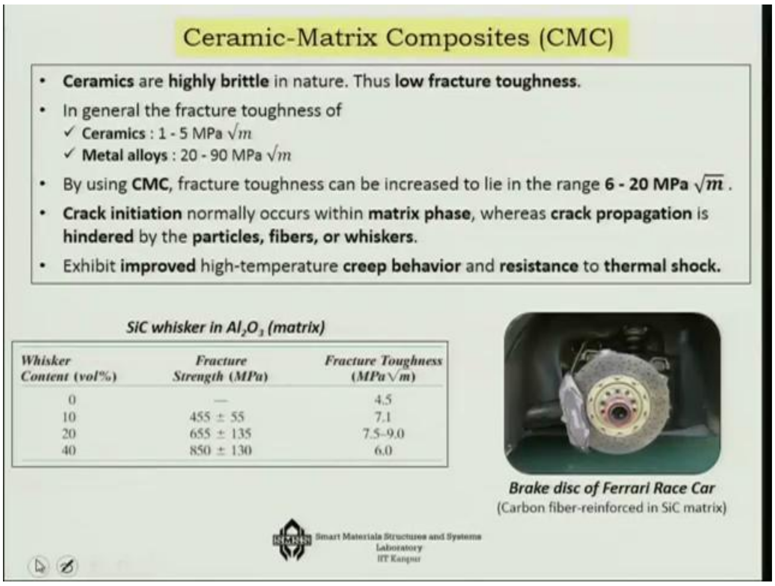

Now ceramics are highly bitter in nature that, right. And it has low fracture toughness, so you have to handle them very carefully that is the 1st important thing. In fact, to handle these ceramic fibres we do something which is known as actually Sizing. Sizing means you take a ceramic fibre and then you apply an oil coating over it okay and what coating you are giving that is trade secret because that enhances the life of the fibres and that increases the fracture toughness.

Now, in general the fracture toughness of ceramics is only about 1 to 5MPa square root meter and for metal it is only about 20 to 90MPa square root meter. So when we will be using CMC, then your target will be to lie as far as the fracture toughness concerned in any of 6 to 20MPa root meter. Now the crack initiation normally occurs here within the matrix phase, where as crack propagation is generally hindered by the particles, fibres or whiskers whatever you have inside in the matrix that will actually sort of stop the growth of the crack.

And it exhibits improved high temperature creep behavior and resistance to thermal shock, so these are some of the very good characteristics of ceramic matrix composites.

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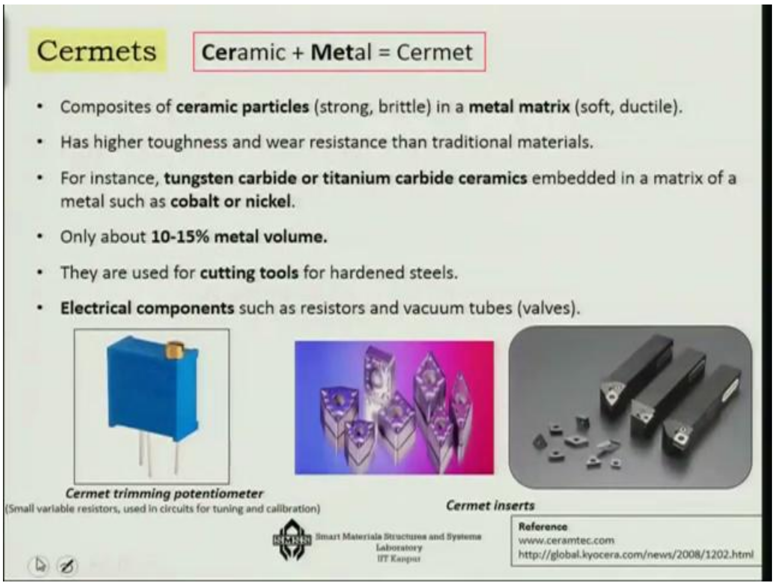

There is a one interesting ceramic matrix, I do not know whether he will call it composites or not but Cermets. So Cermet is actually is a composite of ceramic particles, which are very strong and brittle and that is kept in a metal matrix like soft and ductile metal matrix. It has higher toughness and wears resistance than the traditional materials. For instance, tungsten carbide or titanium carbide ceramics embedded in a matrix of metals such as cobalt or nickel that is one of the examples.

And it is only about 10 to 15% of the metal volume and it is used for cutting tools because you get a very good hardness out of it okay. Electrical component also it has used such as in resistors or vacuum tubes, etcetera. So here are some examples as you can see of Cermet, Cermet in potentiometer, Cermet inserts, etcetera. So that is about ceramic + metal together what do you see something called Cermet.

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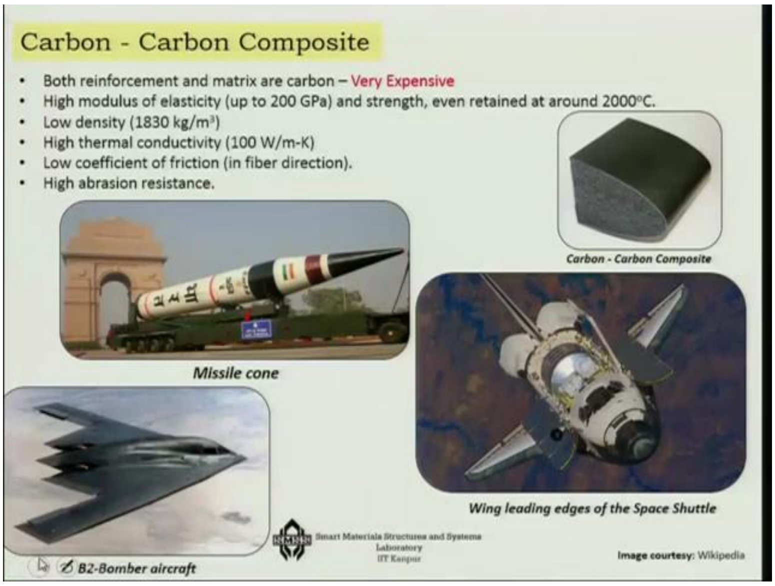

Next is a carbon-carbon composite, where the carbon is the fibre and carbon is the matrix. So here it is very expensive because the procedure by which we do it is also very expensive. It has high modulus of elasticity up to 200GPa and strength and it can retain its property even up to 2000 degree centigrade, which is a very high temperature. Also it has a low density, high thermal conductivity, it has a low coefficient of friction and it has a high abrasion resistance.

That is why, it is widely used in missile cones, in B2 bombers, in wing leading edges of the space shuttle so wherever there is a very challenging environment we actually apply this carbon-carbon composite. Now finally I will talk about the structural composite, which means how you make them layer by layer.

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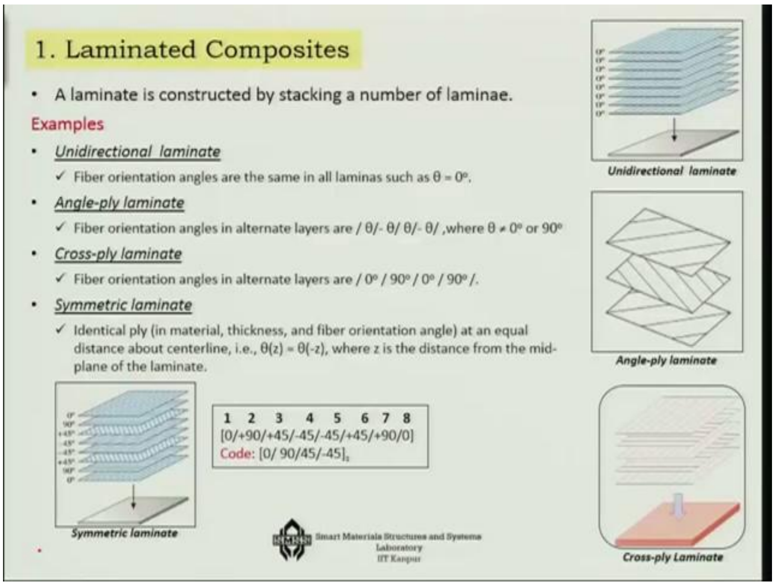

Yesterday in the last class itself I have explained you that a laminate is constructed by number of laminae, examples are unidirectional laminate for example, for the fibre orientation angles is the same in all lamina search as 0 degree or the cross ply laminate where it is like 0 90 0 90. If you want to put any other arbitrary angle of the fibre, then we will call it angle ply laminate, which is like theta, - theta, theta, - theta, etcetera.

And more importantly we can stack them in such a way that with respect to the meet frame they can be either symmetric or they can be asymmetric, so there are many variations that you can develop and each has its own characteristics.

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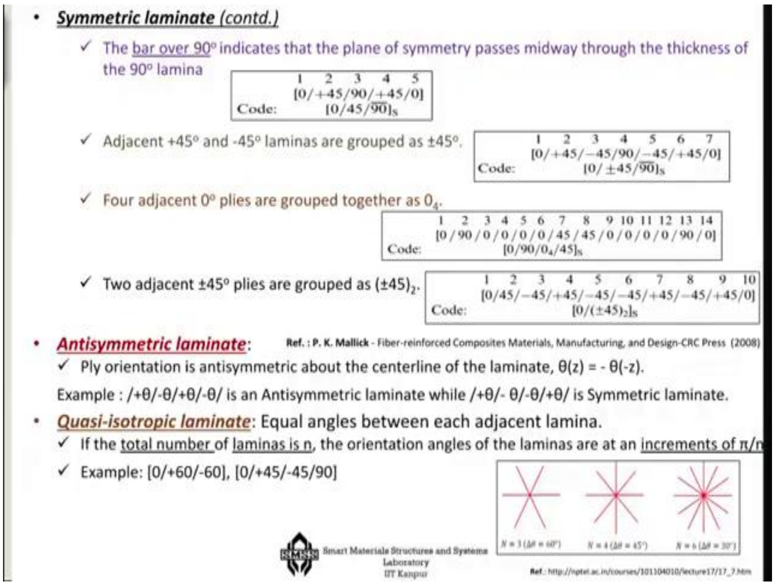

Now if you consider a symmetric laminate, so if there is a bar over such a sequence like 0, 45, and 90 bar, then that will mean that that is the plane of symmetry passes the midway through the thickness of this particular lamina. And the adjacent if you have + 45, - 45 you can also put it as + - 45. Four adjacent 0 degree plies if you get, whatever numbers are adjacent, you can put them as 0 4.

And two adjacent + - 45 are grouped; you can put them as + - 45 too, so that you can actually use these code names in order to make a symmetric laminate. Similarly, antisymmetric also, suppose there are 4 players can put it in this manner okay or antisymmetric another is + theta, - theta, + theta, - theta that means for every + theta the next layer is actually - theta.

There is another one which is known as Quasi isotropic laminate, quasi means it is only isotropic under certain special cases for example, if you consider that a composite which has ply angles only at the ratio of pie over N suppose if it is 3 layers, then it is 60 degree ratios 0, + 60, - 60. Similarly with 4 N as 4 it is 4 layer ratios, so this is known as Quasi isotropic.

For reasons that if the Matrix is found out for such material, then the intense stiffness does not vary with the direction, so that is a (())(25:55) sign isotropic situation where the properties do not vary with the direction. In this case it happens that only for the influent properties that is why it is called Quasi isotropic not fully isotropic.

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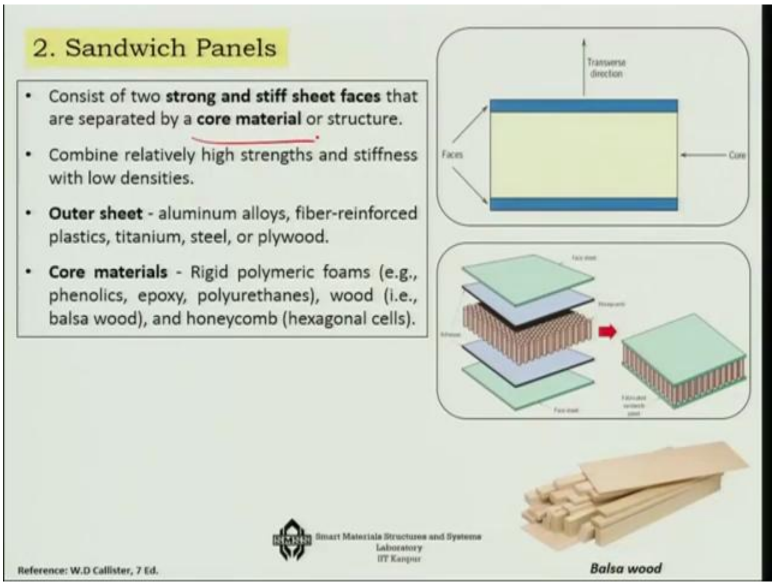

The other structural variation is known as sandwich panels, which consists of 2 strong and stiff sheet faces that are separated by a core material or structure. Usually the core material is a honeycomb structure, they try to reduce the way this way and it has a outer sheet which has aluminium alloys, fibre reinforced plastics, titanium, steel or plywood.

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And the core material is actually rigid polymer reforms example, phenolics, epoxy, polyurethane and then wood and honeycomb, so it is one of the lightest material and technology in terms of the composite material. Sandwich panels are used in various applications like low water absorption, good anti-corrosion activities, good thermal insulated capacity, so it is it is very popular in terms of its use.

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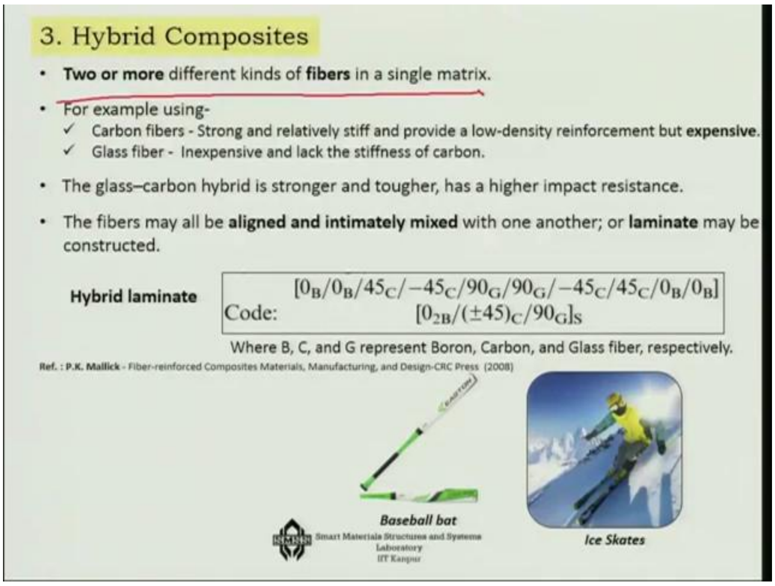

Finally there is this Hybrid composite where it is very rare, it is mostly in the lab scale, but generally for a very demanding thing you may have to design it. Two or more different kinds of fibres will appear in a single matrix. For example, using carbon fibres there is a strong and relatively stiff and it provides low-density reinforcement, but it is expensive.

Now suppose I add glass fibre which is inexpensive but lack the stiffness of carbon, then the two together will possibly make the stiffness to be little better and the cost will be little better, so that is how it can solve some of the contradictions. The glass carbon hybrid is stronger and tougher and it has a higher impact resistance. Now the fibres may be aligned or intimately mixed with one another or laminate can be constructed.

So it can be something like as you can see that 3 layers are already given or the 6 layers will be also given so that you can prepare various types of such composites, so this is where we will close and in the next lecture we will learn about manufacturing and processing of composites, thank you.