Smart Materials and Intelligent System Design
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Lecture – 06
Introduction to composites

Good morning and welcome to the course on Smart Materials and Intelligent System Design. Now, in the last module we have talked about smart materials.

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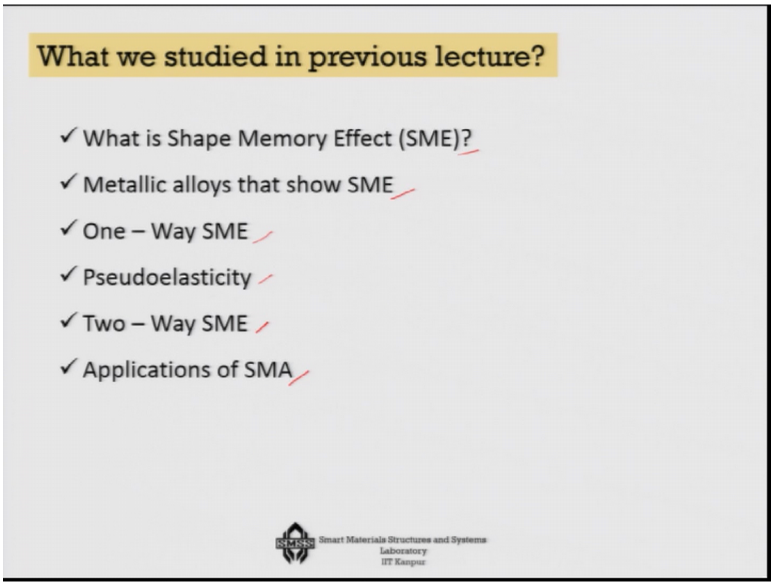

So, we have talked about in the very last lecture about the shape memory effect, metallic alloys that show shape memory effect, one-way SME, Pseudoelasticity two-way SME and applications of shape memory alloy.

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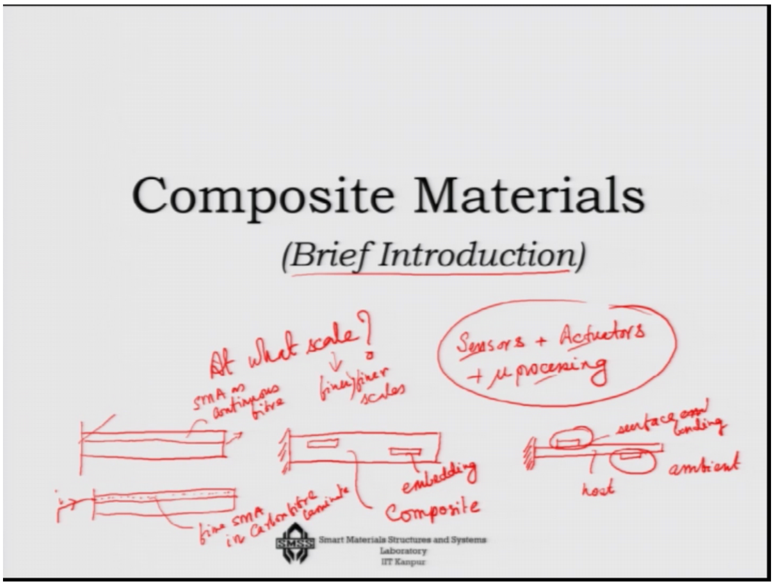

So, after the review of all the smart materials, now we will talk about composite materials, we will give you a brief introduction about the composite materials.

So, what is the requirement of coming back to composite materials? Some of you might have actually gone through this in my course on nature and properties of materials. Now smart materials and composite materials, these two are integrated with each other; and that has happened not just today, but something like last 30 years, this is the effort that is continuously happening in this domain. Now why is these two concepts are so close to each other? Well if you remember that in the very definition of smart materials I told you that it consists of three things. It has sensors, it has actuators, and it has some micro processing capability. So, a best example of any smart material we will have all these three things.

Now, you remember that you know if you take any system say suppose if you want to develop a structure which has these capabilities, then where will you put such sensors actuators or micro processing? You will put it on the structure. So, the moment suppose I have taking a cantilever beam, which can be representative of so many things staring from the helicopter wing, aircraft wing, so many things. Now if I put a sensor here on the top or an actuator here on the top, then until and unless it is not totally integrated into the host structure this is the host structure, it will not work functionally well. Because you know all these parts will be actually subjected to the ambient conditions and you remember that (Refer Time: 02:50) think of it that suppose this particular system is working at a high altitude or at high temperature etcetera, then this sensors and actuators will be inoperative because you have a cooly point limitations.

So, the best strategy towards designing any intelligent system is that, suppose if you have such sensors and actuators, and you want to integrate it. Now I am just you know magnifying the whole thing we embed this things inside the system. So, this is embeddings. So, this is surface bonding which is not very functional surface bonding, and this is embedding. Now the moment we embed the sensors and actuators, what happens these becomes composite structure.

Because it would start to contain many of these you know different types of materials inside it. And not only that the question is once you make such composite the you know what scale at what scale you are making this composite at what scale? Well one of the directions that we take is that we reduce the scale to as low as possible so that we can increase the degree of integrity of all these sensors actuators microprocessors with the structure itself. Take for example, the case of shape memory alloy which you have just studied.

So, I have suppose the same beam whose shape I want to control and instead of putting the wires outside you know like surface bonded, suppose I am keeping this wires inside. Now this is one way of actually accommodating SMA in terms of a just like a continuous fiber, the way we do it in terms of composite materials.

But in order to you know activate such SMA continuous fiber SMA as continuous fiber, you need to have power supply. Now the moment you give this power supply from outside the integrity of the system is lost. Instead of that suppose if you have a composite and in that you have a layer and that layer is made of carbon fibers and some chopped sms. So, you have verifying you know even you can go up to so, find SMA in carbon fiber reinforced composite.

What will be the advantage? The advantage will be that the carbon fibers will increase its conductivity, and hinds you know you can directly actually apply the current on the carbon fiber from some source, and the moment you apply the power on the carbon fiber it is getting heated up. And that heat is transmitted to the that it is transmitted to this a shape memory alloy based chopped wires or even find nano fibers of shape memory alloy wire and it will activate the whole system.

So, as we are going to finer and finer scales finer and finer scales. So, what happens is that, we are going to get actually composite systems all along. So, that is what you know brings us to the realm of composites because you need to have some of ideas of this composites in terms of modeling such systems.

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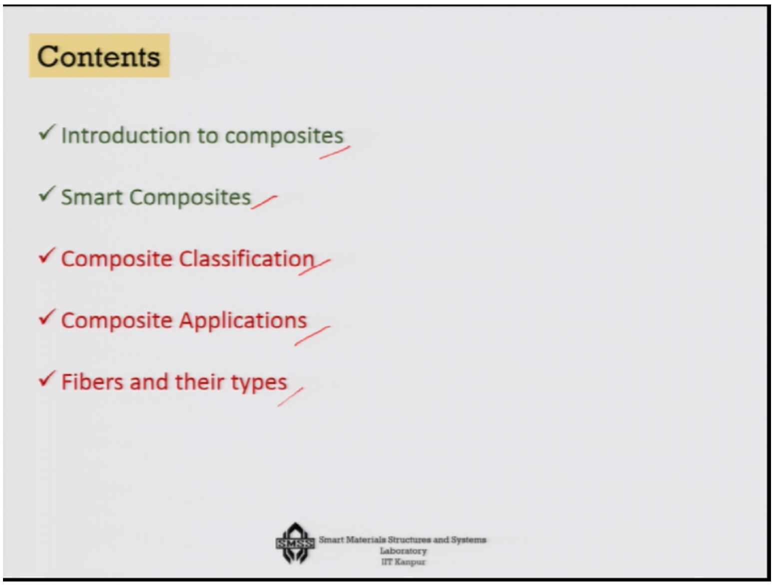

So, today I will first give you a brief introduction to composites and smart composites. We will then talk about some classifications of composite, composite applications and some fibers and their types. In subsequent lectures I will talk about the mechanics of such composite materials.

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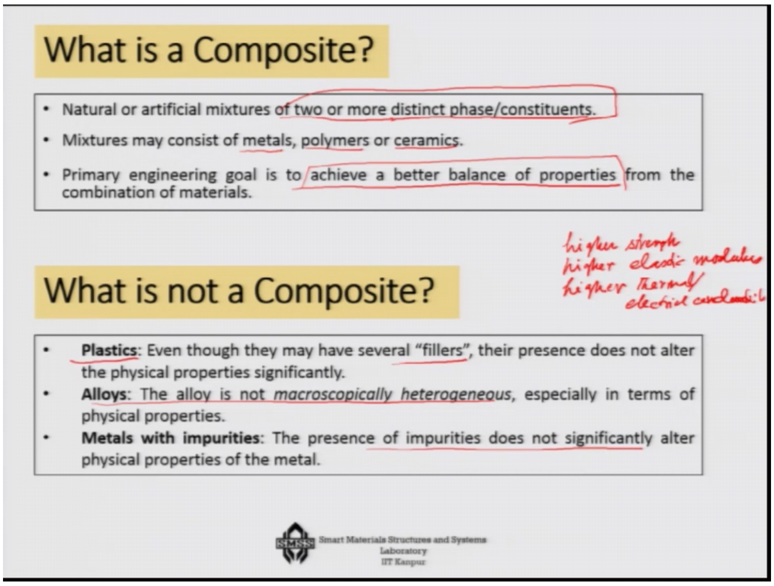

So, what is a composite? We all know that you know in order to make a composite you need two or three materials to be mixed at a micro to macro scale depending on you know what type you want developing. But, you must ensure that in this mixture there will be distinct phase or constituents. And this mixture then may consist of all our known classifications of materials like metals polymers like ceramics all of them you can mix and match depending on whatever is your requirement.

Now, when we are mixing this we have a primary engineering goal in mind that, you want to achieve a better balance of properties from the combination of materials. So, this definition also we will alert was that what we cannot considered to be a composite. Like if you use some fillers it is indeed used in plastics like plasticizes etcetera, then it would become composite.

You need to have distinct mixture of some significant ratio in order to have composites. If you develop some alloys you know which is macroscopically it is not heterogeneous. That means, it has some kind of microscopic bonding etcetera then we cannot consider to be a composite. So, from that shape memory alloy itself is not a composite you put the, but if you put the shape memory alloys inside polymeric system or any other system, then it will become a composite. Metals with impurities same reason you cannot really consider they to be composites.

So, that that is what you know alerts us about, that what we can consider as a composite where you are having two or more distinct phase or constituents and those which are not actually chemically bonded, but macroscopically from the physically there is a interaction that is there between the phases. So, that you can achieve a better balance of properties, you can achieve say for example, higher strength one of the objective always invariably, you can achieve say for example, higher elastic modulus. You can achieve just now I have given you the example of shape memory composite, you can achieve higher conductivity, thermal conductivity or electrical conductivity so, this kind of objectives posses us to make a composite system.

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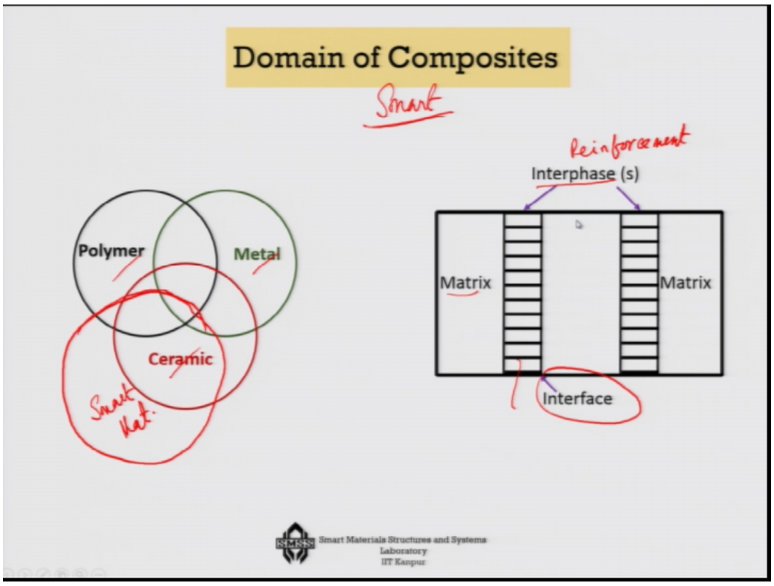

So, it is just the reputation of what I told you that in the domain of composites we have polymers, we have metals, we have ceramics ok; and if we consider smart composite, then we have one more here which will be interacting with each one of them little less in terms of the metals so and more in terms of polymers and ceramics. So, I am keeping small overlap with the metals of course, SMA is are there, but this can be smart materials. So, then our domain will be complete in terms of smart composites if we want to think of it.

. So, and another point is that you know in any such composites there will be matrix and there will be fibers, and you see there are distinct interface between these fiber and the matrix. So, this is reinforce metal interface; interfaces are actually reinforcements very popularly we call it and there is a distinct interface between the two.

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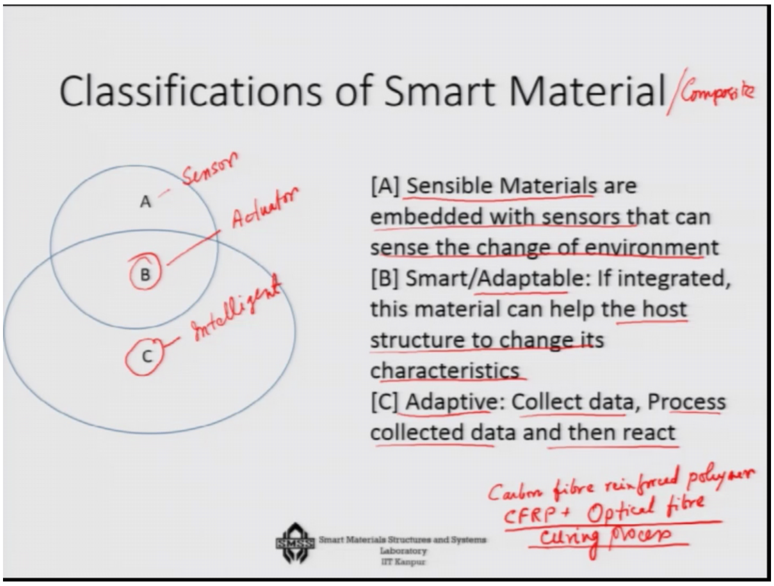

There are some classifications of smart material in terms of I would say smart composite material, what are this classifications? There are basically three groups group A is called sensible materials, which are just embedded with sensors that can sense the change of environment ok. Let us say I have a composite and I have added some optical fibers in it one of the example right.

Say this carbon fiber reinforced plastic, we will talk about it later on, but this name is very important to reinforced plastic or polymer CFRP and that if I add with that some optical fiber as is intuition of a smart material. What it can do? It can actually sense that the curing process how the carbon fiber is how the polymer in which the carbon fiber is kept how it is getting hard end. So, it will give you this process it can also talk about a give us information about the evolution of fractures etcetera inside the system. So, these kind of smart composites are called sensible you know smart material based composite.

One degree further is actually adaptable. In this if these are integrated they can actually help the host structure to change its characteristics. Let us say they can help the whole structure to get you know to change its modulus of elasticity or to change it is you know geometric shape or to change its stiffness or to change the viscosity in some cases. So, all this things are actually in the category B that is adaptive.

So, you can more or less think in this manner that A is related to sensor and B is related to actuator, group B is related to actuator and finally, group C. Group C are the adaptive ones which can not only sense or not only actuate, but it actually after collecting the data process the collected data and then react. So, that is the maximum degree of smartness that you can achieve and this is you know intelligent system. So, that is the kind of classification that we are talking about and you can see in each one of these cases as I have discussed with you earlier, you have to develop a composite in order to you know give these kind of features to the system.

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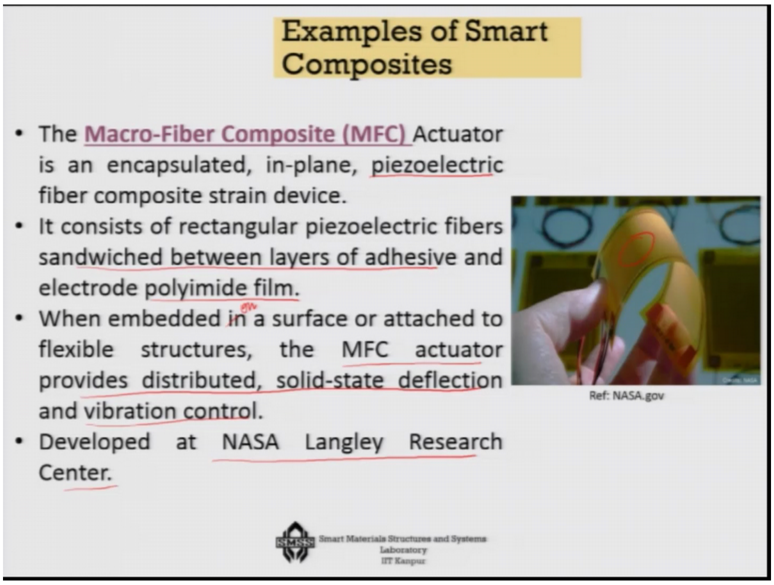

There are couple of examples I want to give you in this respect. The one that that first comes to my mind is the macro fiber composite, as you know I have brought a sample for you from laboratory.

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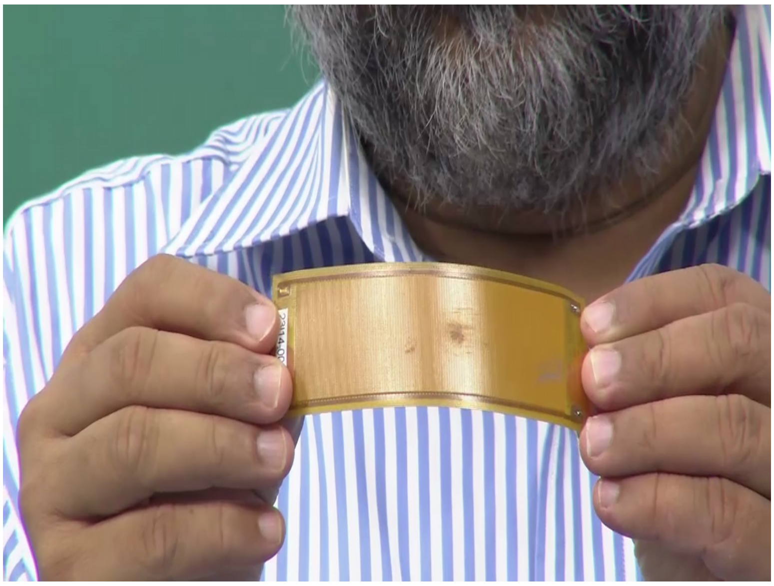

You can see this macro fiber composite here and you may be able to see very thin lines inside and also in the two sides you can see that the electrodes are there. And this thin lines that if you are able to see is this are actually the reinforcing active fibers that is there in a macro fiber composite in this whole system. And you can see how flexible this whole system is. So, that is something that you cannot achieve with the piezoceramic materials if be.

So, by applying voltage, we will show you that this will you know start to actually vibrate you know like this and that will impose vibration on a composite system. So, that is something that you can see in this particular small video from the laboratory where you can see that how this macro fiber composite you can see how it is surface bonded.

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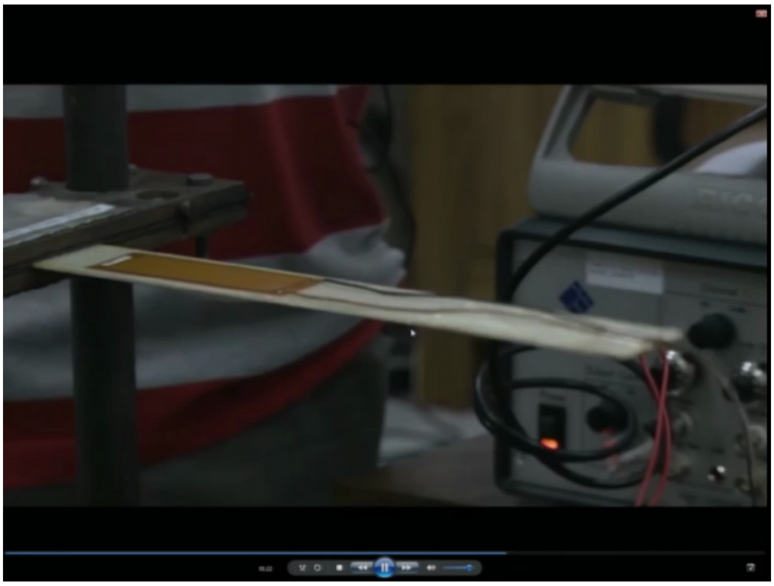

In this case you can also embedded it is expensive. So, I have just simply surface bonded it. So, that we can use it for many different purposes and you can see that this is a composite beam made of glass, fiber reinforced plastic and we have two power lines from here and what we are doing? We are going to apply an alternating voltage in the system, as I am applying the alternating voltage in the system. And as I will be gradually you know increasing the amplitude of the voltage, you should be able to see that the vibration will be coming out on you can see that already. As I am increasing the voltage the amplitude of vibration is gradually increasing on this composite beam.

So, by further increasing the voltage you can increase it to a even more vigorous level that talks about the power of this simple system; so nicely integrable to a system ok. So, this gives you some idea about the power of the composite material. So, this is macro fiber composite and let us look into some of its properties, that what it essentially consist of is piezoelectric you know fibers, and you use it both as sensor as well as an actuator. So, these piezoelectric fibers of sandwich between layers of adhesive and electrode polyimide film; so this yellow color that you have see is because of the polyimide film.

And when you embedded on a surface embedded it in a inside or you know bond on a surface so to say or attached to the flexible structures, this MFC actuator will provide you distributed you know deflection and vibration control. These basically developed at NASA Langley Research Centre. The key technology here is to actually get this active fibers that is there inside, then actually we can also make such a system, but to do it is a micro scale is something for which you need a high precision laboratory.

So, this is one of the example of a smart composite.

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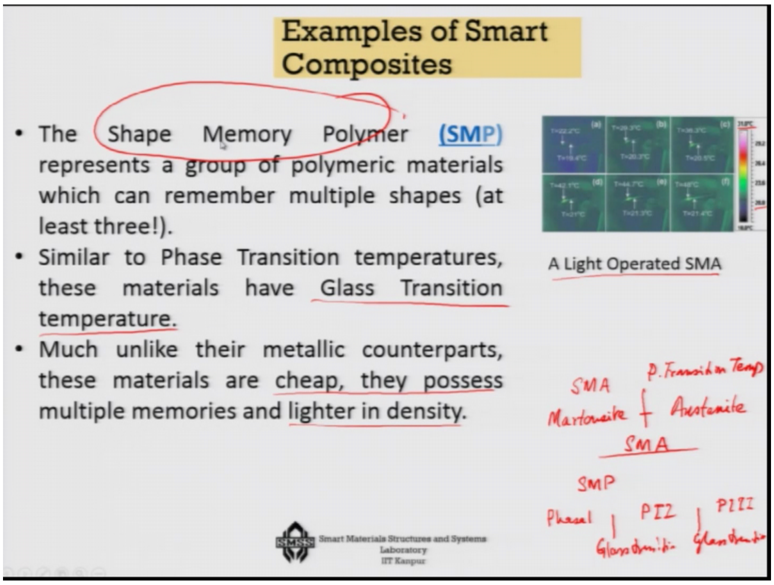

The other example I was talking about shape memory alloy, what I have not told you is that Shape Memory Polymers SMPV call it they are also very interesting group of materials, which can actually they are naturally composite you can say. And that can remember not only just one phase change that is if you know that for SMA it is between martensite and to austenite right high temperature base.

But in the SMP there are this is; what is our phase transition temperature right phase transition temperature. But for the SMPs this is SMA for the SMPs what you are going to see is that there are many such phases let us call them as phase 1 2 phase 3 etcetera and each one of them has a typical you know temperature we call it as glass transition temperature. In which the polymer chains it is basically form in terms of you know the motion of the polymeric chains or the arrangement of the polymeric chains. This is you know is by the glass transition temperature it defines.

So, the advantage is that, instead of getting one or two you can actually generate many shapes in these materials. And much unlike their metallic counterparts this materials are cheap they possess multiple memories and lighter in density. One example I have given you which is coming a very nicely is a light operated SMA. So, this is a light operated SMA system and you can see that in this system you have actually optical fibers inside. And this, optical fibers carry the light that actually increases the temperature and because of that slight increase of temperature from 28.8 to 30 degree centigrade, you can see that the shape memory polymer starts to work.

So, these are fantastic examples of such things.

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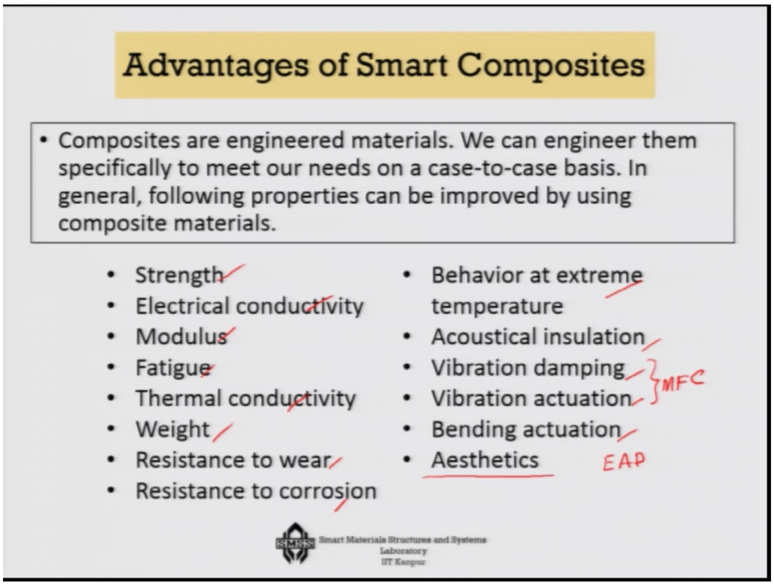

What are the advantages of these systems? Already I told you, but let us put these points in our mind, the strength is one of the advantage electrical conductivity, modulus, fatigue, thermal conductivity, weight resistance to wear resistant to corrosion. These are some of the things which particularly comes from passive materials as reinforcements that you put. Behavior at extreme temperature, acoustical insulation, vibration damping or vibration actuation I have shown you using MFC how you are doing, a bending actuation same and sometimes the aesthetics also particularly the electro active polymers EAPs, they are these days used for many such aesthetics applications.

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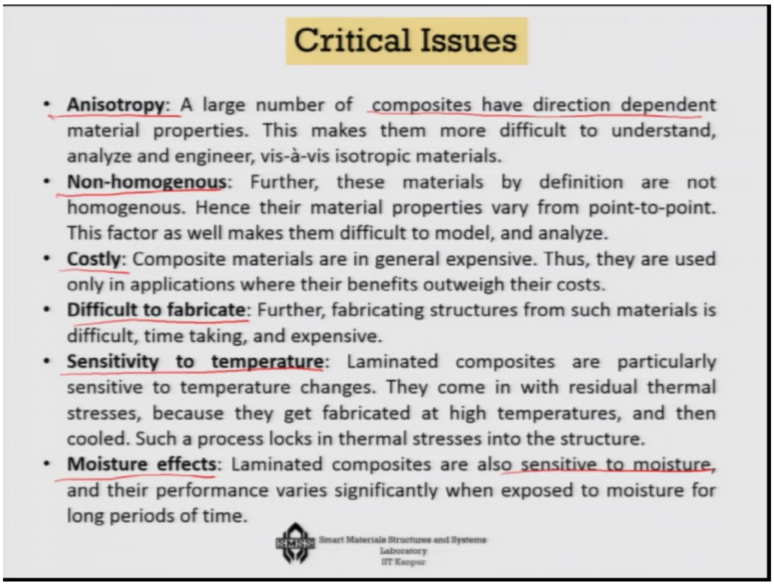

What are the critical issues here ok? We have to you know cross some of this hurdles. So, when you will be actually modeling this system. The first and foremost important issue is the anisotropy because a large number of composites have direction dependant material properties. Say for example: in this particular case with this particular composite system, we have shown the fibers. So, fibers this is the fiber direction along this direction it has a different property and along this direction the transfers direction it has a different property. So, the anisotropy is a very important as this is the most important one.

Secondly sometimes we cannot really control the process like if you think of chocked SMA fibers or any such chocked fibers. Then you cannot control how it is distributed. So, it will become non homogeneous so that is a second critical issue. While cost of course, in some cases will be really important particularly when we are developing systems, which will be for mass use.

Then there are difficult is to fabricate I told you that some of them at a very small scale it is very difficult to fabricate, they have sensitivity to temperature very much. The usual polymers itself degrades, because there are polymers there. So, the composite polymeric composite itself degrade for that if we have smart materials, some of this smart materials we will suffer from the cooly temperature. So, you know you it has the sensitivity and then of course, the moisture effect, because laminated composites are in general sensitive. So, that we will you know you have to consider while modeling such systems.

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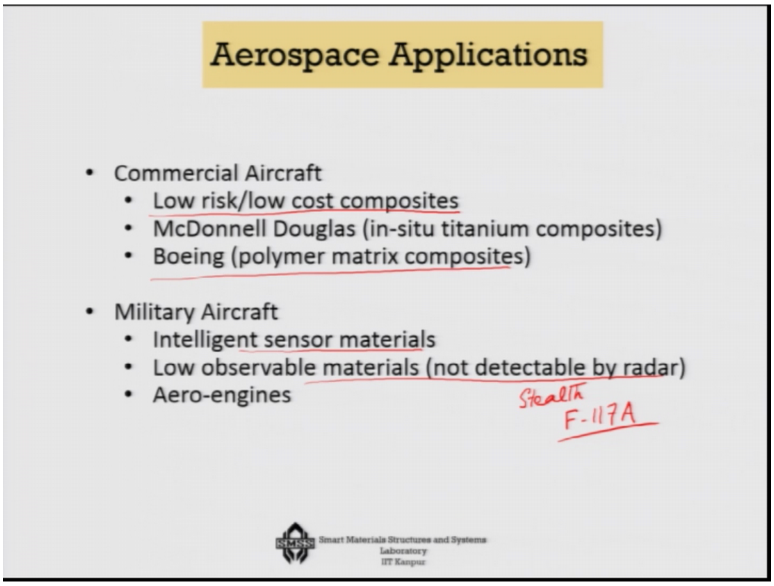

Now, there are various applications of it for example, the commercial aircraft, where you have low risk low cost composites in the wings like McDonnell Douglas or Boeing you know they heavily used these composite. Military aircraft use it for that sensible you know sensible system that I told you earlier, with intelligent sensor materials stealth materials for example. And then low observable these are the stealth materials this is also known as stealth technology, this is used in F 117 A if I recall say stealth bomber, then aero engines and all these you know actually are some of the applications in aero space.

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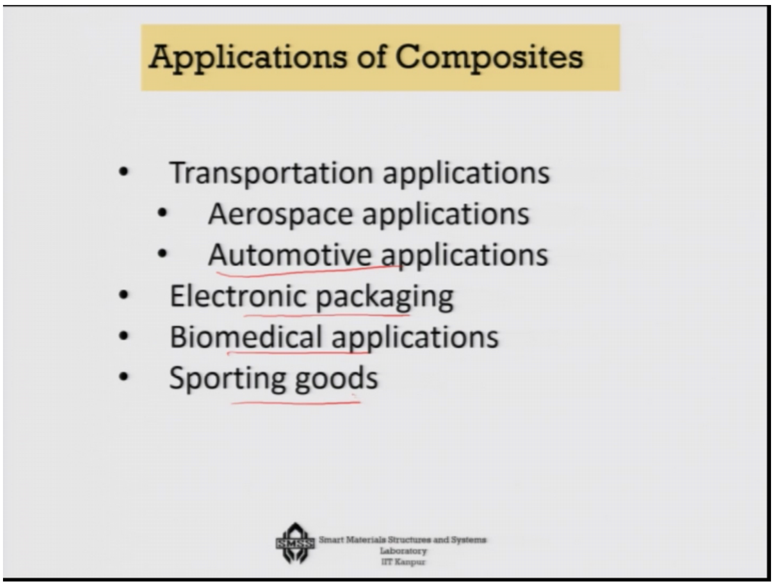

There are other transport applications also other than aero space for example, automotive applications, then there is applications in electronic packaging biomedical, and sporting goods. So, the lots of applications are coming up.

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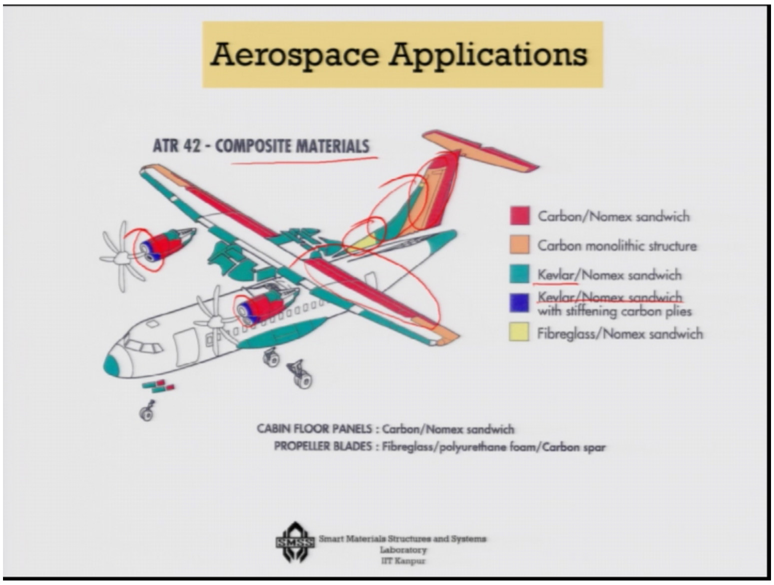

See aero space applications if you look at this ART 42, which has the composite materials and you can see that this are the areas where you have the composite materials right like the carbon, based system here and here also you have a carbon based system, the green parts are more prone to impacts etcetera. So, you have Kevlar this system there. So, you have and also some of these areas where you have Kevlar based systems.

And then some parts which are not that actually critical you have you know fiber glass based system there. You can see that even a simple aircraft like ATR 42 has so many composites in it.

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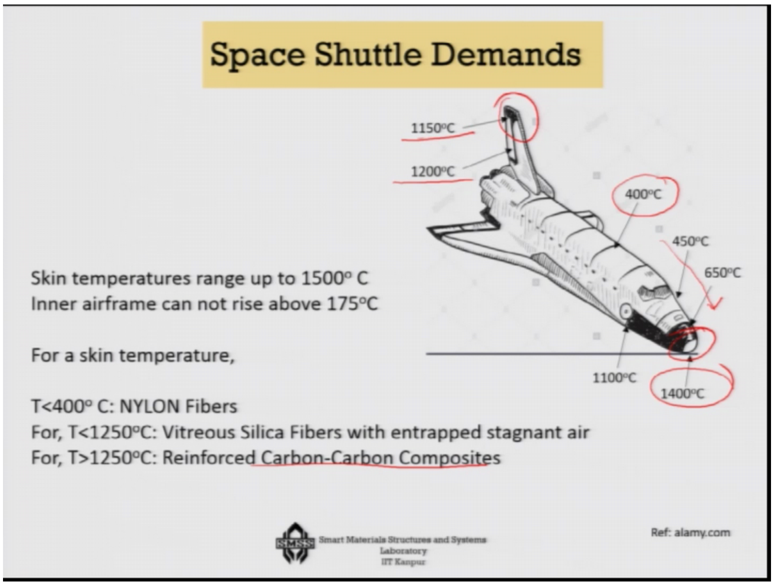

If you think of space shuttle even more because without composite you cannot sustain. So, you can see the temperatures that it faces huge temperatures like this part lowest 400 degree. As you are going towards the tip it is increasing it goes up to 1400 degree centigrade here and at the back also these are the areas which is also expose; so 100 1000 150 or about 1200 degree centigrade. So, at such high temperature you must have composites, which are like carbon composites and you also need to have sensors you know embedded inside it.

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Look at automotive applications, some of them like the GM cards it has the CFTP hoods in it valve cover is composites, the lift gate is composite these bodies. For example, brake calipers, steel reinforce tyres it is full of various types of composites that is there in the automotive applications.

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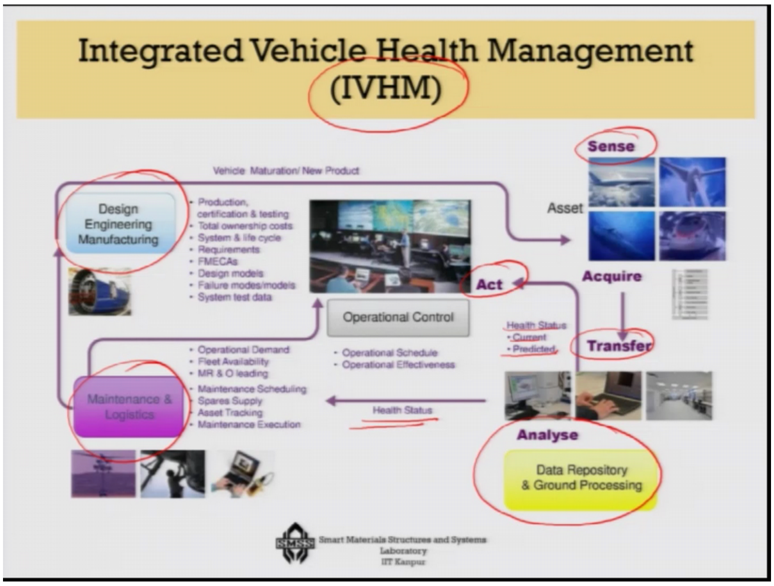

Now one interesting thing that is coming up is called integrated vehicle health management or IVHM is a fantastic example where sensors actuators processors everything is getting integrated in the vehicle.

So, what it can do is that it can sense the change in temperature etcetera, it can acquire data transfer the data and then it can act accordingly. And when it is acting on the situations, there are lots of things that it can do in terms of change of shape, in terms of change of operational conditions. And it also does the back of the you know system processing the moment it starts to sense.

Say for example, it goes to the design engineering and manufacturing how the products is doing? It goes to the maintenance group what is the condition of the system? So, these all gives us the health status of the system and also when you are taking action, then you are also you know analyzing the results of these actions. And the health status current and the predicted one what is going to happen in future. So, all these things together you know when it comes in a composite system, it is as IVHM Integrated Vehicle Health Management.

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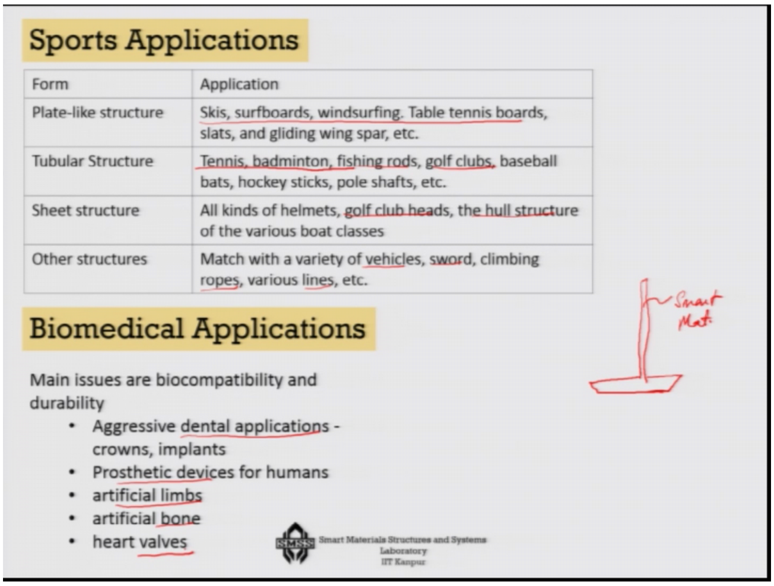

Talking about sports applications, there are applications of 18 plate like structures like for surfings, table tennis boards. One of the most important application of smart with allow the very fast one actually came in sports structures that is in terms of the masks actually, electronic masks in the boats that is used for a various types of competitions of navigations etcetera. So, this parts was passed made of smart material; that was one of the fast actually example of the smart material in sports structures.

Then of course, there is a this tubular structures like badminton, tennis, fishing rods, golf clubs, baseball bats etcetera. There is the shit structures which is used in golf club heads in the hull structure. And there are other structures also like variety of vehicles sword, climbing ropes, lines etcetera where this sports applications composites are used and also smart materials today. In biomedical applications once again in dental applications and prosthetic devices artificial limbs artificial bones and heart valves all full of smart materials.

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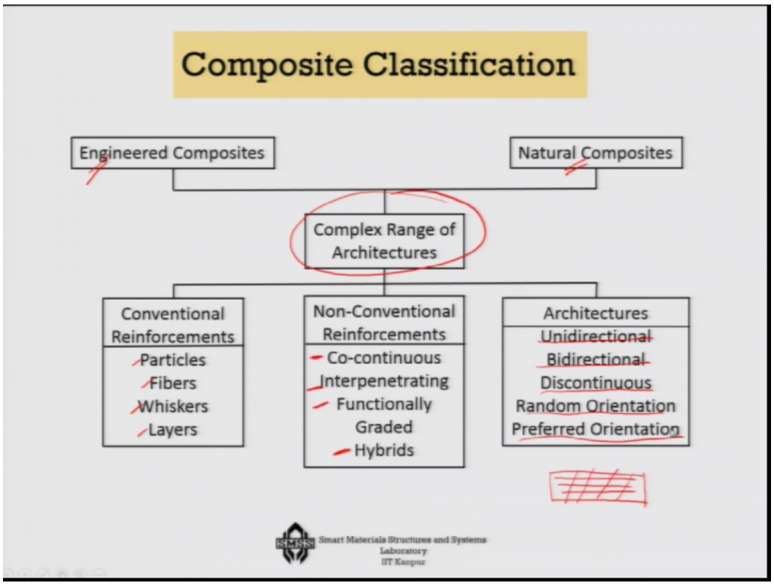

Now, when you talk about composite classification, we will actually talk about two groups basically engineered composite and natural composite. And these things can be arranged in complex range of architectures of course, natural composite itself comes is a complex architecture, but engineered composites are artificially designed with complex architectures in order to derive special type of activities from them.

Now in the form of reinforcements you can have conventional reinforcement like particles, fibers, whiskers or layers or you can have non-conventional architectures like co continuous system, where the fiber and the matrix develops together; interpenetrating networks is happens in polymers functionally graded materials, I talked about it earlier and the hybrids where more than one reinforcements are present in the system.

And in terms of architectures, if it is just that you have the reinforcements suppose this is what is my beam and you have reinforcements only in one direction, you have it as unidirectional. If you have reinforcements in another direction it will be bidirectional. If it is you know divided into small parts, then it will become discontinuous, and it can have random orientation or a preferred orientation in the system.

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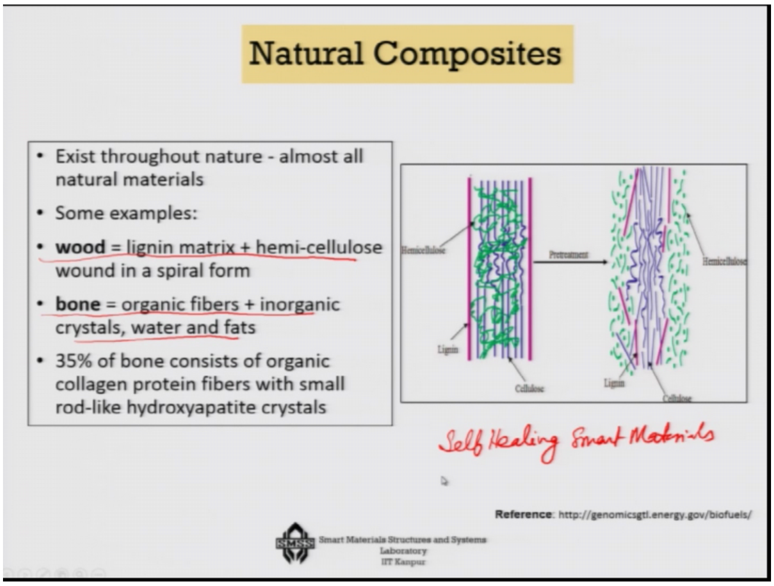

Natural composites you would be knowing that you know two of the most important structural systems are actually having natural composites. One is wood and which has lignin matrix plus hemi cellulose and another is bone which has organic fibers plus inorganic crystals you know with it. Both of them are good examples of natural composites which is worth of emulating. We will also see that we take inspiration from both of them in smart materials in terms of developing composites which can heal itself, self healing materials. We will talk about it towards the end of our course self healing smart materials so, that is about the natural composites.

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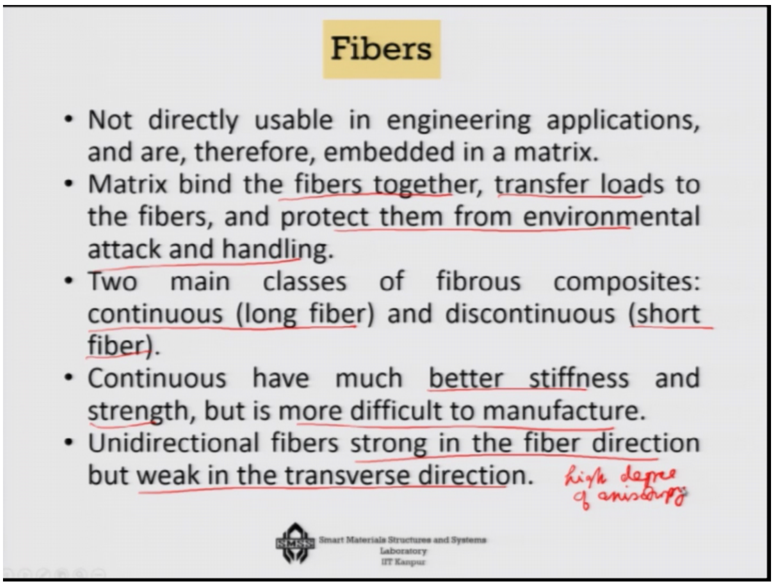

Now when we talk about the engineering composites, then we will actually talk about you know fibers and matrix they are separate from each other, we form them. And the role of the fiber as I told you is to improve the properties of the matrix. So, matrix on the other hand bind the fibers together, it transfer loads to the fibers and protect them from environmental attack and handling.

Now, there are two main classes of fibrous composites one is architecturally long fiber and small short fibers. So, if I go for long fibers I get better stiffness strength, but it is more difficult to manufacture. And unidirectional fibers are actually strong in the fiber direction, but it will be weak in the transverse direction. So, it will have high degree of an isotropy.

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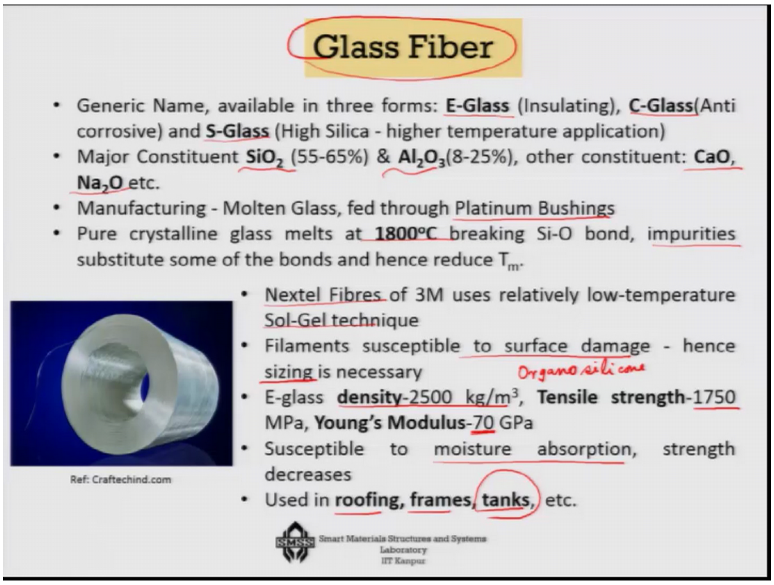

We are talking about different types of fibers. So, let us try to you know go through the fibers; the most popular one is the glass fiber which is quite economic and so very lavishly you can use it. At the same time you will get all the advantages of the smart fibers if you actually use the glass fiber. Now glass fibers actually consists of three different types of glass fibers; E glass fiber which is basically in electrical insulating in nature, but thermally conductive, then C glass fiber and S glass fiber. So, S is for strength, C is for corrosion and E is for electrical applications.

Now major constituent in this glass fibers are actually silica and alumina, also there is a bit of calcium oxide and sodium oxide. They you know we generally make it from the molten glass and we feed it to the platinum bushings. So, usually this you know all ceramic fibers are made in the same manner and these is at a quite a high temperature 1800 degrees centigrade, and because you need to break the bonds and then you need to take the impurities out and then you need to get it out in the form of fibers.

Some of the examples are Nextel fibers, which they use actually sol gel technique and this is at a little low temperature, then filaments which susceptible to surface damage that is there that is the problem of the glass fibers. So, you need to apply something which is called sizing. Sizing is like a chemical that we apply sometimes think like organo silicon organo silicon. So, this kind of a silicone oil which we give so that the fibers will not actually rub with each other or we will not get in touch with the external you know stress concentration so that it will not get broken easily.

And the density you can see is very low 2500 kg per meter cube, tensile strength is good we will not see it is very high, but it is quite good and Young's modulus is also quite good almost same as the aluminum. However, it is susceptible to moisture absorption and the strength decreases as a result of it so, one has to take care of it that is why sometimes if the glass fibers you know optical fibers are also included so, that you can check; what is the moisture absorption in the fibers.

This is used in roofing frames, tanks, there are high volume containers today, which they are actually making using the glass fiber based system and health monitoring of such a system is absolutely essential. Because, otherwise if such containers collapse you know that will create catastrophes in terms of storage. So, that is what is our glass fiber.

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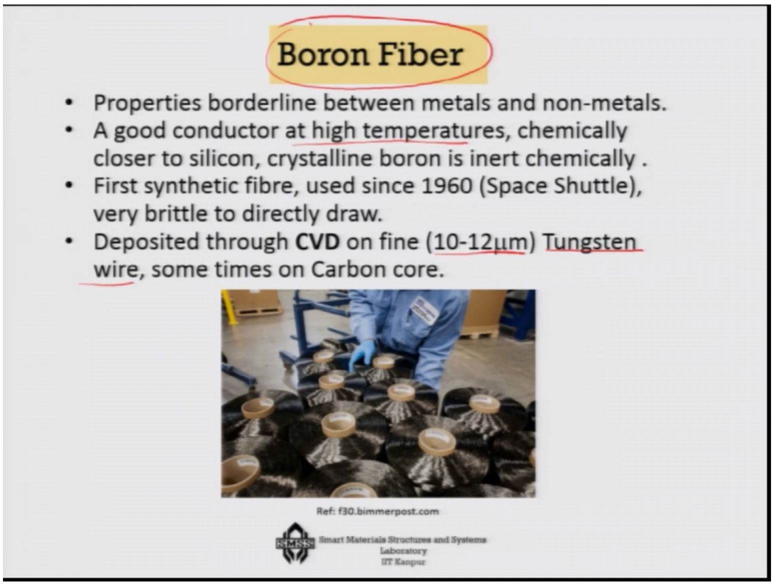

The second one is not very popular because it is very expensive to make that is what is boron fiber. It was generally used in space shuttle type of applications and what one has to do is that, one has to actually vaporize this boron and then deposited on tungsten wire. That is why finally, the fiber is not very thin, it is something like 75 80 microns because it contains inside 10 to 12 micron of tungsten wire. So however, naturally tungsten and boron together it gives a very good property in terms of high temperature. So, you can use such composites in high temperature, naturally this is used in space shuttles one of the first space shuttles are made of the boron fibers.

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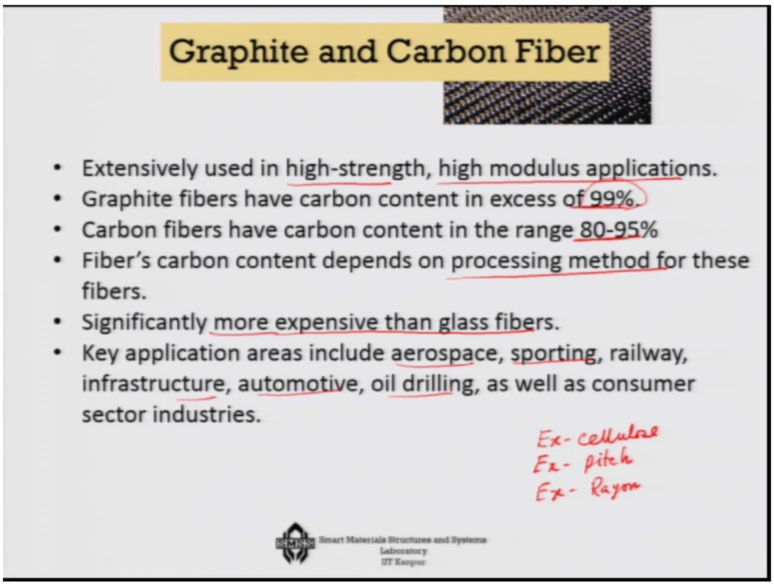

Then wherever you need a good strength and high temperature, you also have graphite and carbon fibers extensively used in high strength, high modulus applications. Graphite fibers contain carbon in excess of 99 percent whereas, carbon fibers is about 80 to 95 percent. The more the carbon fiber the better it is in terms of say thermal conductivity, in terms of strength, in terms of high temperature resistivitys etcetera.

You know how you will increase this carbon content that will depend on the processing method, there are various processing methods I would not discuss it here, I have discussed it in natural properties of materials, just tell that there are methods like x cellulose there are methods like x pitch and there are methods like x Rayons. So, based on what type of material you are a using to begin with, and then you know different processes are utilized in order to gain a good amount of carbonization of the system.

So, the key applications are that well of course, one point you have to keep in my, this is more expensive, than the glass materials glass fibers. And as the key applications will include aerospace applications definitely some sports applications, and to some extent railways automotive only for sports, cars, oil drilling this type of things the application is becoming very heavy.

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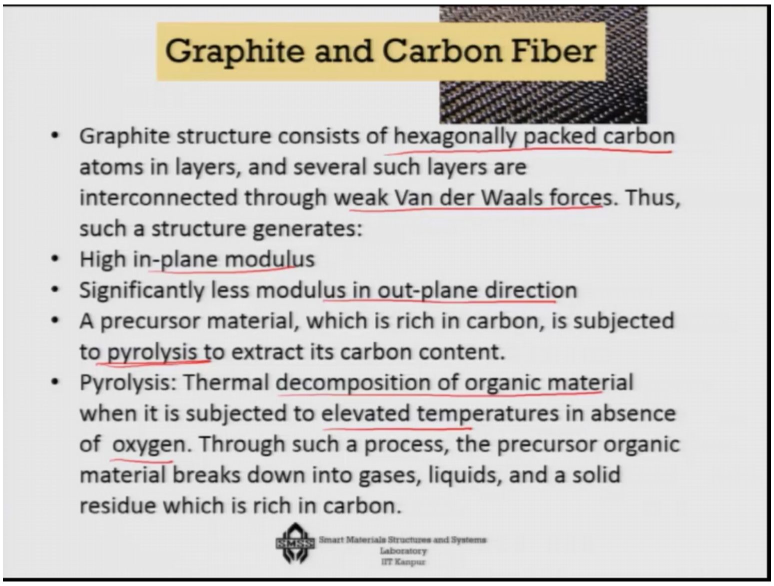

Source of the strength particularly in graphite structure that consists of the hexagonally packed carbon atoms in layers. So, that layered plate like structure that in plane it has tremendous strength, but it is interconnected through weak Van Der Waals forces such structure will give you high in plane modulus and less modulus in out of plane direction.

And a precursor material which is rich in carbon, that is subjected to a high temperature which is called pyrolysis. Which is a thermal decomposition of organic material when it is subjected to elevated temperature in absence of oxygen, that is what is the pyrolysis process. So, using the pyrolysis process what actually carryout this kind of graphitization of a system.

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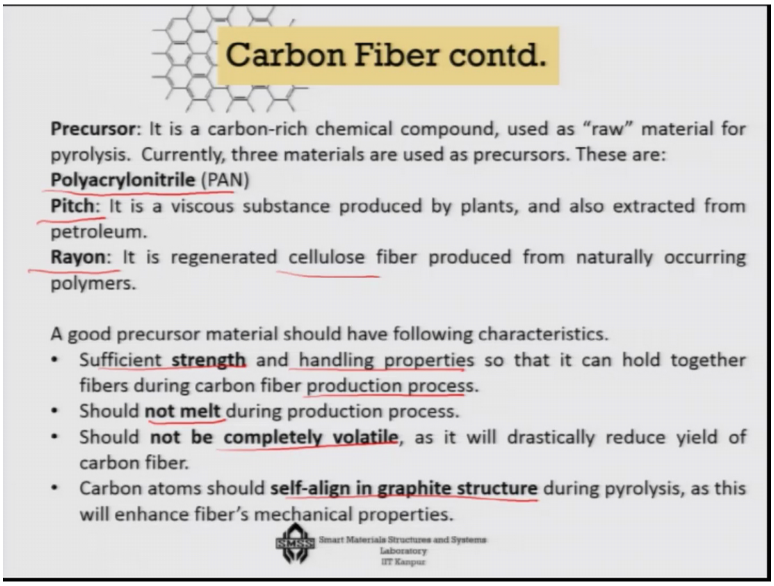

Now, in terms of carbon fibers I told you that there is a precursor that is needed and very often we take actually polyacrylonitrile as precursor fiber, the precursor is the point of the initial material from which you are actually developing the final material the final fiber. So, the p pan is one of the common one, other than that that pitch is one that is the x pitch process I told you, then rayon is another which is from cellulose type of fibers. So, there are different types of sources from which you can make such carbon fiber.

When you choose the precursor material, we check that it first have sufficient strength and handling properties. So, that you know it can hold together the fibers during the production process, it should not melt during the production process, only thing is that all the volatile should go out and you get a fine you know high carbon content structure and it should not be completely volatile, then you will not get that structure and it should self align in graphite structure during pyrolysis.

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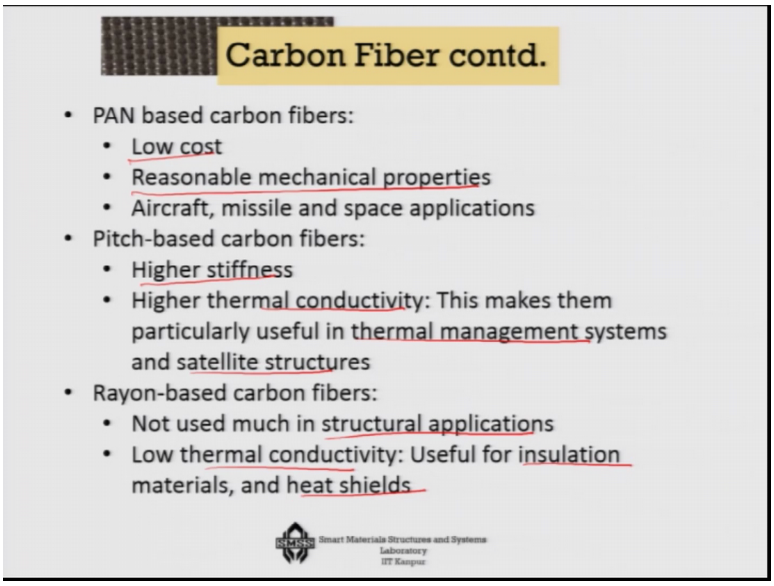

So, based on that typically such kinds of materials are chosen by few, I told you about the pan based carbon fibers, which is the cheapest of them low cost. It has reasonable mechanical properties and that is mostly used in aircraft missile and space applications. For pitch based carbon fibers it has highest stiffness, higher thermal conductivity where is cheaper also, but it is mostly used in thermal management systems and some satellite structures. The rayon based carbon fibers they are not much used in structural applications, which has low thermal conductivity and generally useful for insulations and heat shields.

So, depending on what source you are choosing for making a carbon fiber, you are landing up with different types of at least three different types of variants of the carbon fiber.

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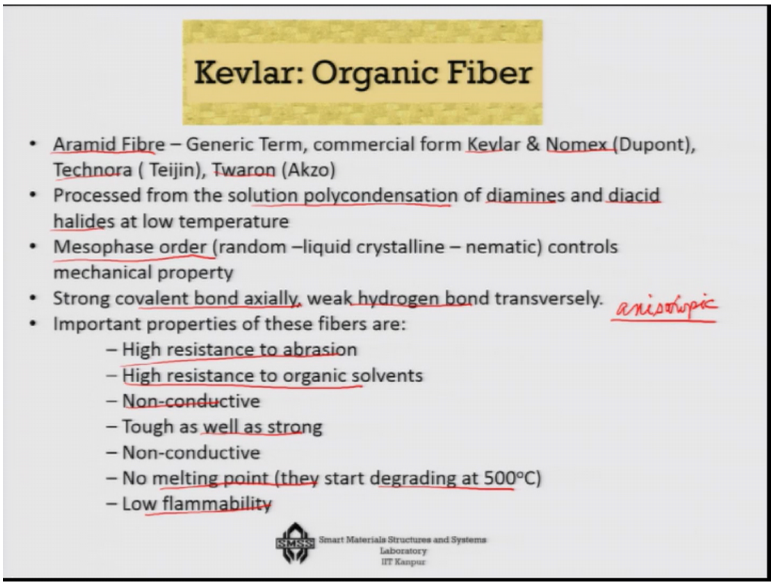

There is another interesting fiber which is used to make composites that is called Kevlar. And Kevlar is the though the commercial name the actual technical name is called Aramid fiber. And this is a generic term and the commercial names are Kevlar and Nomex from Dupont Technora from Teijin and Twaron from Akzo. So, these are developed mucher like the pyrolysis process in carbon fiber development here it is develop through solution polycondensation of certain materials like diamines and diacid diacid halides at low temperature. So, temperature is low. So, that way it is easier or less expensive to fabricate.

And they have a Mesophase order at low temperature and which is something like a liquid crystalline form and that we you know is used for in terms of alignment of the system in a fibrous. Form this kind of polyamides they have a high covalent bond axially, but transfers to their weeks. So, they are actually anisotropic. So, to begin with itself some fibers are anisotropic. So, in the composite when you put them, the composite would definitely become an isotropic in nature.

But they have high resistance to abrasion, high resistance to organic solvent they are non conductive tough as well as strong and no melting point actually it degrades directly, that is why it does not have a melting point. From the solid state it directly degrades gets volatile and it has a low flammability. So, it will not burn very easily these are some of the good points of Kevlar.

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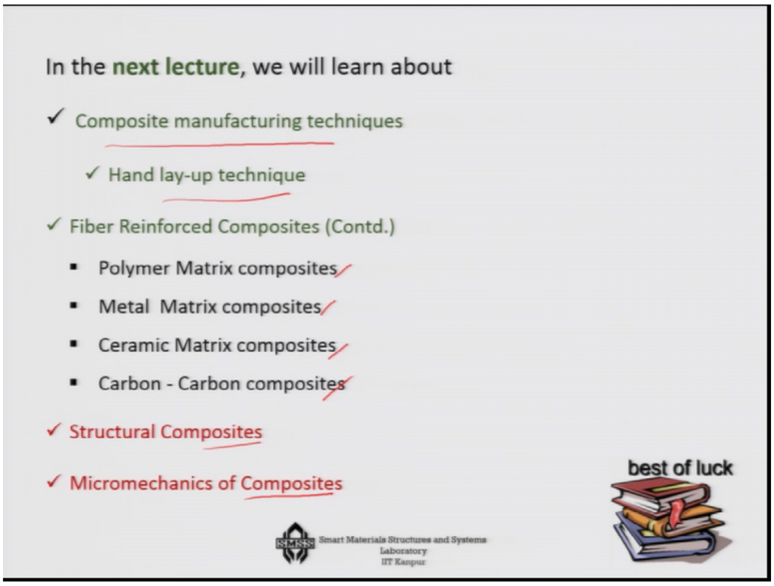

This is where you now we have given you an overview of such composite materials. In the next lecture we will also talk about how do you manufacture such materials some of the techniques. And we will talk about polymer matrix, composite, metal matrix, composites ceramic matrix composite and carbon-carbon composites. Also we will discuss about some structural composites and the micromechanics of the composites in the coming lectures.

Thank you very much.