Manufacturing of Composites
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Lecture – 17
Metal Matrix Composites

So, welcome back friends. So, today, we will move to a next set of composite which are called as metal matrix composites. So, till now what we saw was basic of composites properties of composites, then we went into different form of reinforcement which can be done on composites, then we took matrix as polymer and then in that we saw under thermo set; we saw some processes and then thermo plastic also we saw some processes.

Now from there, let us move to metal matrix composites. So, here as the word clearly says that we use metal as a matrix for reinforcing can we use the same processors; what we used for polymer composites or what are the bottlenecks when we use metal matrix as a metal as a matrix for composites. So, when I say metal; metal generally has very high temperature as compared to that of polymer composites. So, content wise; we will see introduction, then we will see metal matrix composites.

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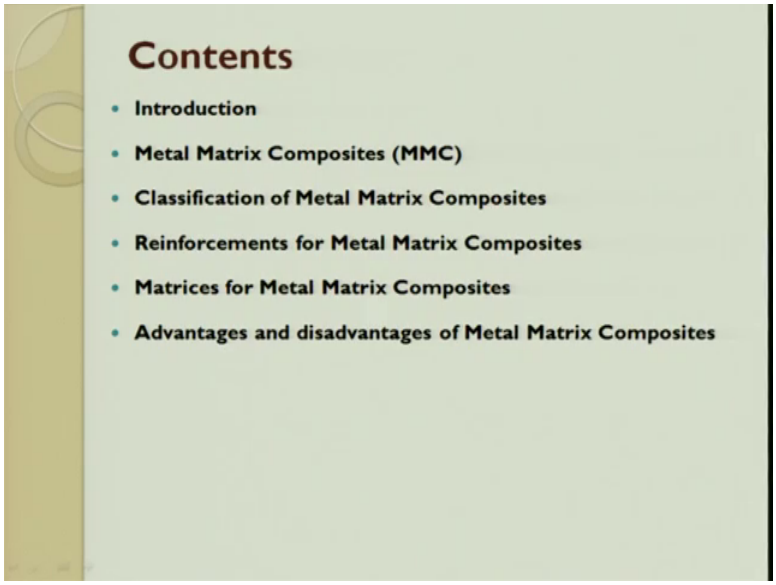

Then we will see classification and metal matrix composites, then reinforcement for metal matrix composites, then matrix for metal matrix composites then, advantages and disadvantages with some few applications.

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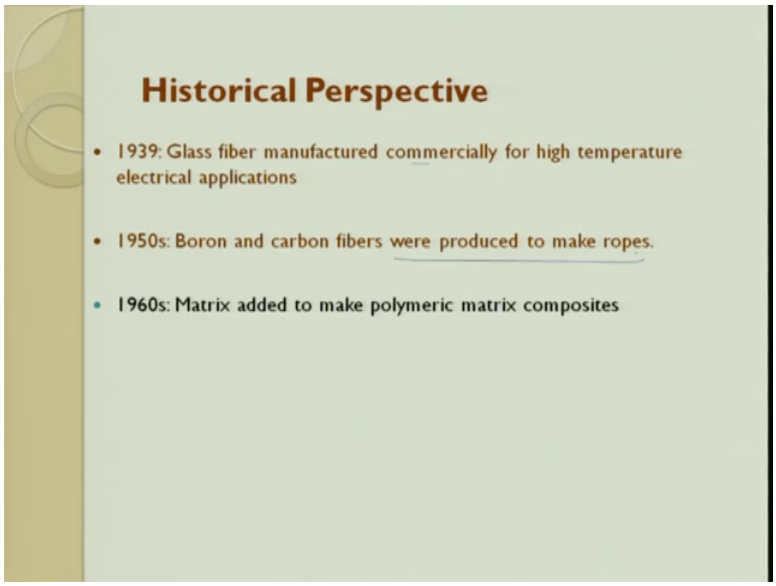

From the historical perspective, I am not going into in BC and come into AD; just coming in AD in 1939 glass; fiber manufacturing came into commercial application for high temperature electrical application it came then in 1950 boron and carbon fibers were produced for making ropes.

Then in 1960 matrix was added to make a polymeric matrix composites; 1970s the cold war force develop of metal matrix composites for military aircraft and missile guidance systems came into existence.

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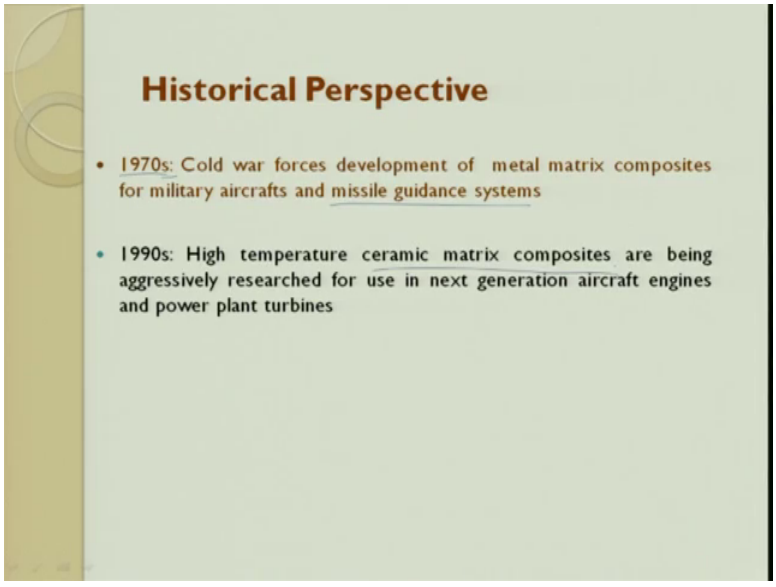

So, metal matrix composites somewhere in 1970s, it picked up and it started getting into action. In 1990s, high temperature ceramic matrix composites came and this started getting into the next generation of aircraft engines and power plant.

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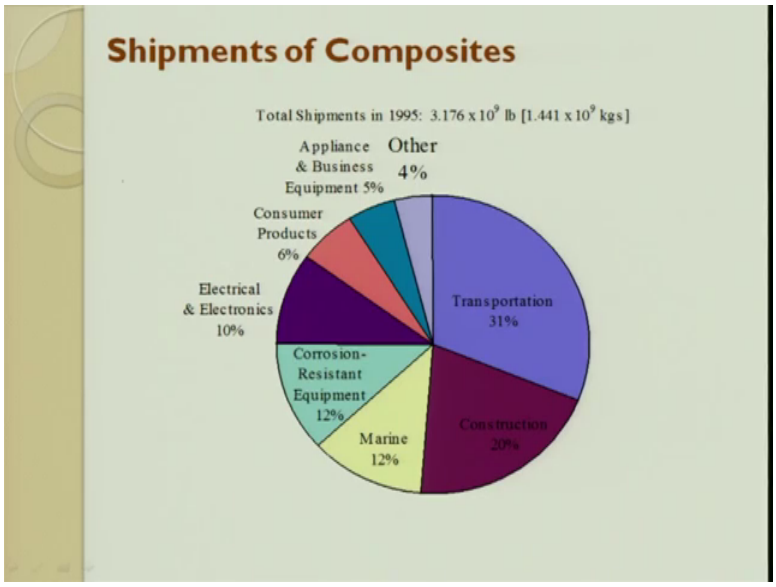

So, from 1970; started the metal matrix composites; so, if you see the total shipment of metal matrix composites. So, in transportation industry it was round about 31 percent. So, majority came from transportation industry, then came few in construction industry, then in marine then corrosion resistance equipment which came which was around about 12 percent and electrical and electronic are 10 percent, then we have other businesses which were close to 4 percent. So, the market for composites you can see in aircraft industry missile basically aerospace industry and marine industry; that means, the transportation industry pushed forward lot on these composites.

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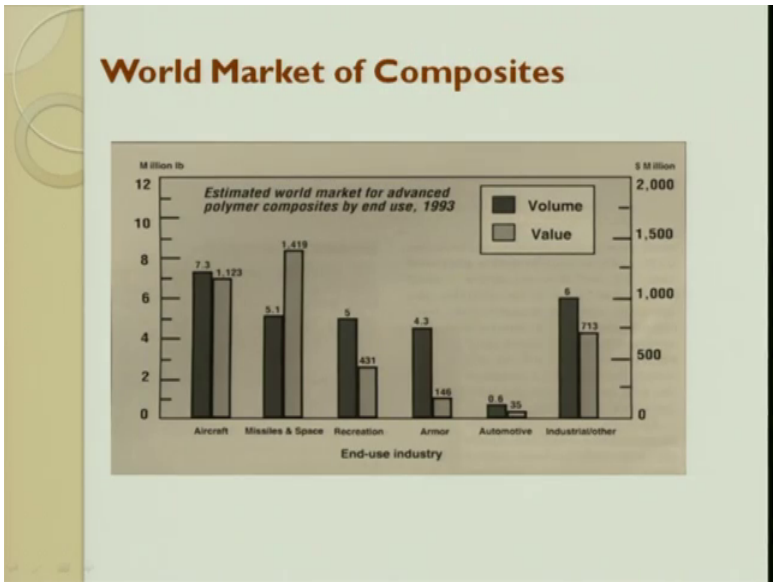

So, you can also see harmer martial which were made, automobile and industrial other industrial application were also made. So, this is figure which is 1993 which is little old.

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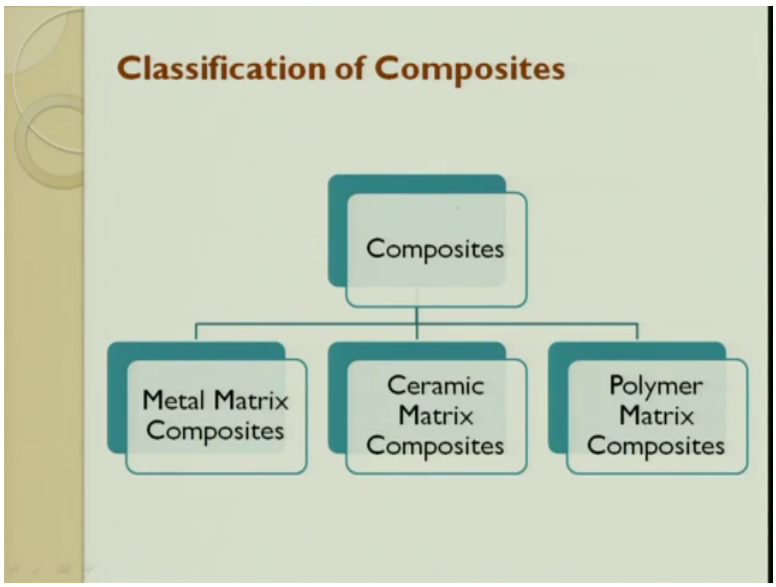

So, when we go a classification of composites, we are now focused into metal matrix composites.

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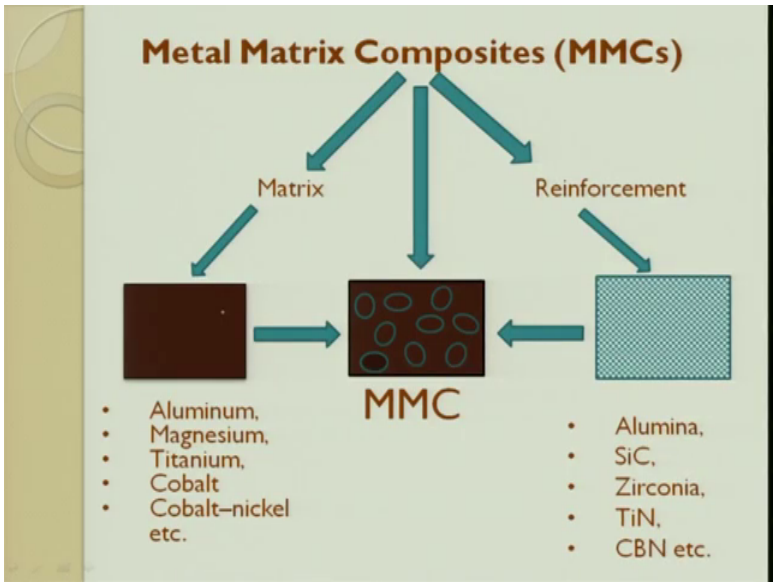

So, we know composites is made out of a matrix and then reinforcement; reinforcement can have several forms. So, when we do mix this matrix and the reinforcement we get something called as metal matrix composites. So, what are all the possible matrix we can have aluminum, we can have magnesium, we can have titanium, cobalt and cobalt nickel, etcetera depending upon your or requirement the matrix can be twit into some alloy. So, that you meet out your requirements; what are the reinforcing agent, it is alumina SiC, zirconia titanium, nitric titanium, carbonic cubic boron nitride.

So, movement I say alumina SiC you can; it is very clear that it is very difficult for it to make a long continues fiber out of it, once you do not make continues fiber then you cannot think of making a mats and other aspect. So, today there are technology where in which there are trying to make some aluminum mats, but generally this aluminas are not continuous. So, if it is not continuous then it has to be only particulate size.

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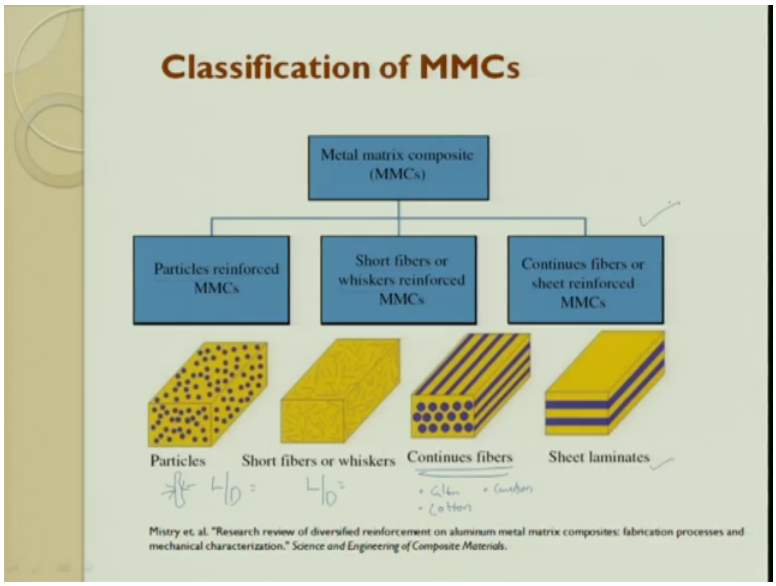

So, the metal matrix composite can be further classified into particles reinforced metal matrix composite; that means, to say you try to take very small particles with aspect ratio; that means, to say L by D ratio of 1, 2, 3, less than 5. So, here we try to take very small particles these small particle are disperse inside the matrix. So, this composite are called a particulate reinforce metal matrix composite.

The next form is short fibers short fibers are slightly higher aspect ratio that is a whisker can be used or a higher or short fiber can be use. So, here again the L by D ratio it changes. So, you will have short fibers, it can be made out of fiber can be made out of glass or it can be made out of any ceramic martials. So, it is dispersed inside a metal matrix. So, that you try to get composite the last one is going to be continues fiber or sheet reinforced metal matrix composite where in which a continues fiber a continues fiber of glass; glass fiber mat can be used or any other application any other small small people are today trying to even use cotton for cotton continues fiber mat or there trying to use carbon roving. So, as continues fiber.

So, there are laying it and then there are trying to get an output. So, you can also do sheet laminate where in which the metal in these 3 cases metal will be taken to liquid state and then brought to a brought to a solid state. So, here what we do is we start the solid sheet and then we keep the reinforcement with we sandwich it and then we process it to get a

composite. So, these 2 application continues fibers finds at high strength applications we always go for this continues fiber reinforcement.

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So, when we look in to metal matrix composite, metal matrix composite is a composite material with at least to constituent parts one being a metal necessary the other being material may be of an different metal or any other material such as ceramic or an organic compound the definition same is for composite. So, we have already seen reinforcements can be Alumina, Zirconia, SiC, TiN, tic, ticm, cubic boron nitride; all these things can be used. So, matrix can be aluminum steel magnesium titanium cobalt and cobalt nickel aluminum.

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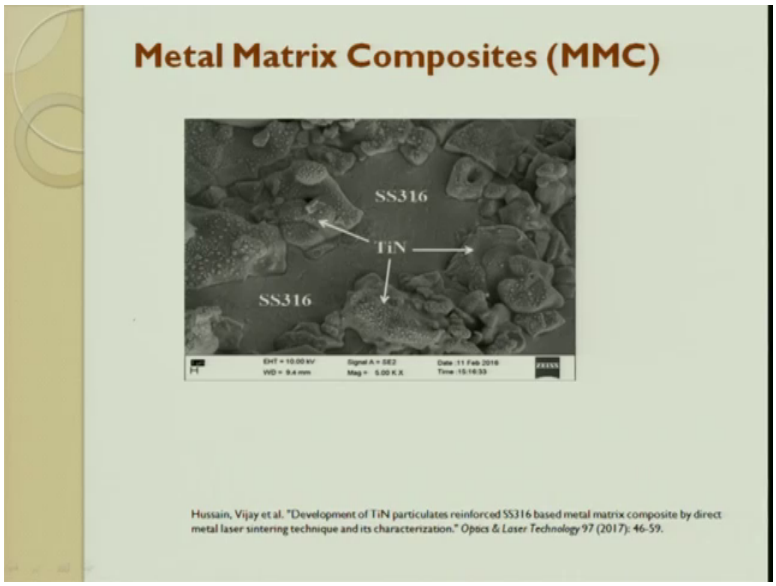

So, when you try to see microscopically, what happens when you try to mix it up with the metal? So, here if you see TiN is a ceramic particle; this ceramic particle sits inside a matrix tim these are tim particle this sits in a here it is the starriness steel.

So, here you see that this sits in a matrix and this is used for this is metal matrix composite and this is finding application for where assistance; that means, to say enhance tribology and strength properties.

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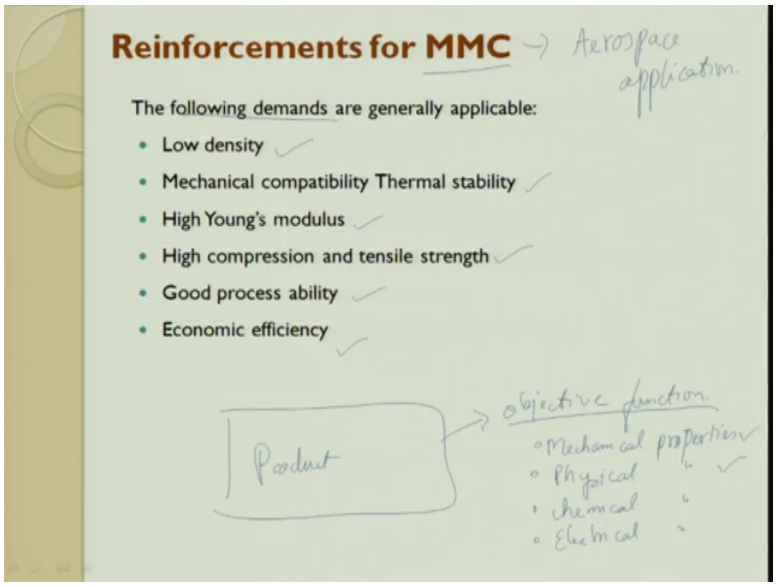

So, what are all the basic demand see when you make any product, when you make any product the first thing which comes to your mind is you have to fix up what is your objective function. So, the objective function is always in terms of composites or I would say it is mechanical properties are very important then it is also the physical properties, then you have the chemical properties then at last you have the electrical properties or electrical properties. In fact, gets into the physical properties itself. So, we are more focused towards physical and mechanical properties.

So, these are the demand for moving into metal matrix composite keep in your mind when we talk about always aerospace application. So, aerospace application it always demands for a light weight high strength application height stiffness application. So, it has low density and it has to have high young modules, the high compression and tensile strength good process ability, it has to be economical, it has to be mechanically compactable with the thermal stability basically when we try to move out a of polymer and get into metals, what we always look forward is straightly high temperatures applications.

So, in high temperature application at the higher temperature the material properties should not change. So, somehow you have to arrest the property expansion of contraction whatever it is. So, what we do is; we add one more phase into it and make sure that it stop that expansion and contraction. So, these are the properties which we always demand from the application point view it has to be low density, it has to be mechanically compactable with thermal stability; that means, to say high temperature applications, then high Young's modules high compression and tensile strength good process ability; that means, to say I should be able to produce the required product in a very economical way.

So, economical in terms of number of steps involve to reach the output, second thing is the machine the capital investment what is involved third thing is how reliable the processes to produce the output. You can have a processes which produces the output, but if the capital cost is very high then the processing becomes a challenge.

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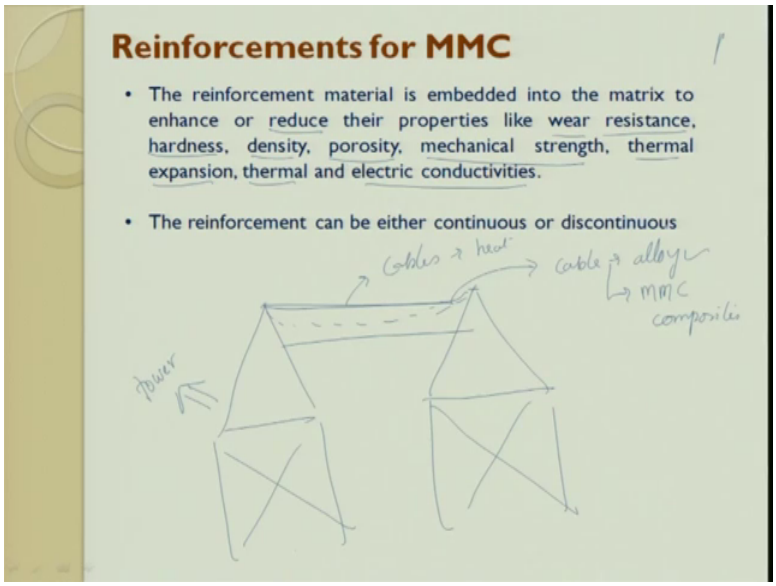

So, you will not have customer for it then finally, it is it should be economically efficient for applications. The reinforcement whatever is the material is embedded into the matrix to enhance or even reduce if you want reduce the properties like wear, resistance, hardness, density, porosity, mechanical strength, thermal expansion, contraction on electrical conductivity.

See just as a like example; we see all these towers which are there transmission towers which transmits power from one place to the other you see this transmission towers and these transmission tower are connected with cables or these cables take the power and it runs for several thousand kilometers to transmit power from the production to the customer. So, this cable tries to this cable is quite heavy and in order to avoid this cable sagging they always go for these towers and the towers basic function is only to hold the cable.

So, as and when you transmit for a longer distance the cable when your transmit it gets heated and it tries to sag. In order to avoid this sagging, what people do is we sag these towers and these towers are pretty expensive. So, what are people are done is they are now started changing this cable whatever was earlier made out of an alloy into a metal matrix composite. So, what is the advantage? It has now enhanced properties such that it does not sag very much. So, once it does not sag the number of towers goes down.

So, the initially investment cost of laying for electrification goes down significantly. So, this is another example where in which the cables are converted from alloys to metal matrix composite. So, it is basically made out of copper metal matrice composites. So, that is what we said electrical conductivity also. So, we try to enhance the thermal stability plus we also try to maintain the electrical conductivity.

So, here I repeat the resin reinforcement is added to reduce the wears or to enhance wear resistance property to enhance the hardness, to reduce the density, to reduce the porosity or if you want by adding this you can also enhance the porosity; why is porosity very important? For example, if you want to make think of an application where in which you wanted to observe some material to go further down, you have spilled water on top of a table, you have to remove the water what it is we put a poro structure which is sponge just on the top of the water compress it.

So, because of vacuum all the water which is there is sucked and then we try to squeeze it out. Same way you can also think of applications where in which your; want to remove the oxide layer from the top, you wanted to enhance some properties. So, this porosities can be used mechanical strength, thermal expansion and thermal and electrical conductivity also use. The reinforcement can be discontinuous can also be continues discontinuous gives me more freedom from the manufacturing point of view as compared to the term continuous.

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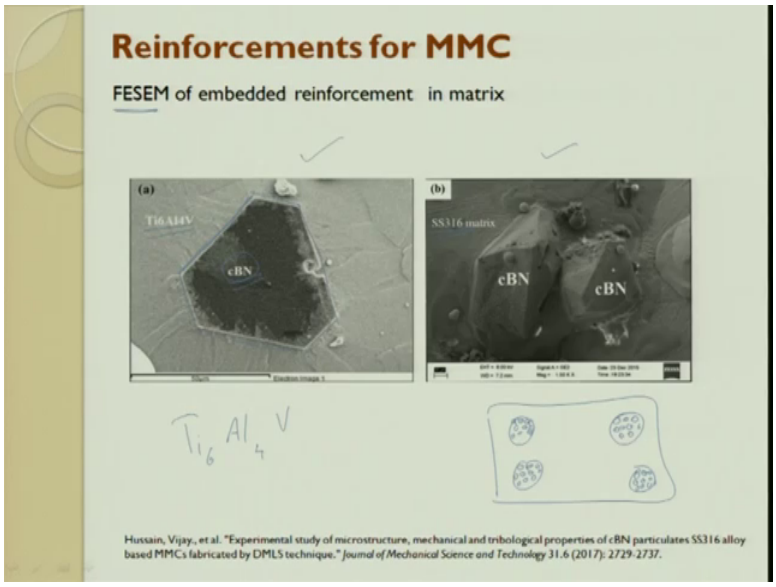

And if you see here FESEM; FESEM is nothing, but a scanning electron microscope; it is on the higher end. So, you can see at higher magnification where in which we used electron as a source to look at the micro structure. So, that they can understand whether the particle is exactly sitting with sitting or is there any miss match between the reinforcement on the basic metal. For example, here we take metal matrix of Ti6 Al4 V. So, this is the matrix which is the titanium alloy which is taken as a matrix and we add ceramic particle in to the metal matrix composite, the ceramic particle is nothing, but cubic boron nitric. So, maybe this can be use for enhancing the wear resistance. So, we have added this.

So, here if you see that exactly at the inter face if there is a poor inter face or a weak inter face then this ceramic particles will come out very easily. So, now, what people do is. So, people always try to see what is the wettability between the alloy and this ceramic particle if there is a proper inter face, then it is good for the from the mechanical point of view. So, in order to see this proper adherent proper inter face, we always go for scanning electron micro scope.

So, here it is field machine scanning the electron microscope images are done, to see the cubic boron nitrate getting embedded in Ti6 Al4 V alloy. So, here the other one is you can also see in a stainless steel matrix, you can see CBM sitting. So, here if you see the CBM are just projecting out and here the CBM are sitting perfectly inside. So, just by looking at are figures alone you can compare and say this looks to have a better inter face as compared to this and second thing you when you do this FESEM image you should also keep it in mind there should not be any agglomeration; agglomeration means sticking or adhering of the small particles together.

So, what happens is in if you take a transition of a metal matrix composite you can have few clusters where in which you can have particle sitting. So, these clusters what will happen is they will try to bring in non uniform properties as far as the metal matrixes concern. In order to avoid this your it is better to have a visual inspection by using a FESEM and trying to find out. So, basic thing is these particles which are disbursed inside the matrix should not have agglomeration. So, you should make sure that is the same here what we studied for polymer matrix composite, that is short fiber is another thing there should not be any agglomeration.

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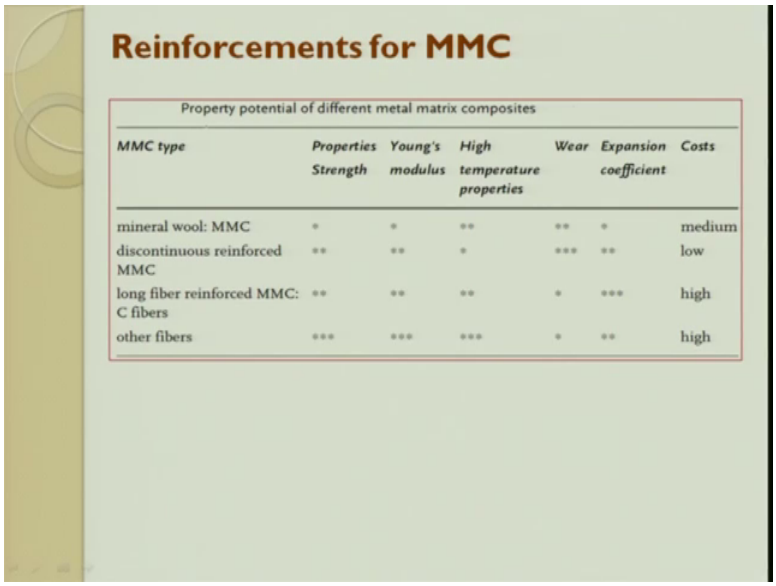

So, if you look at the different properties potential of different metal matrix composite. So, you have properties strength, Young's modules, higher temperature, wear resistance codification of expansion and cost. So, if you look at it, if you take a long fiber reinforcement metal matrix composite which is made out of carbon fiber, the properties are very good young modules is very good high temperature wear resistance is expansion is extremely good, but it is extremely costly.

So, these types of composite are use to for only aerospace application and not in automobile application.

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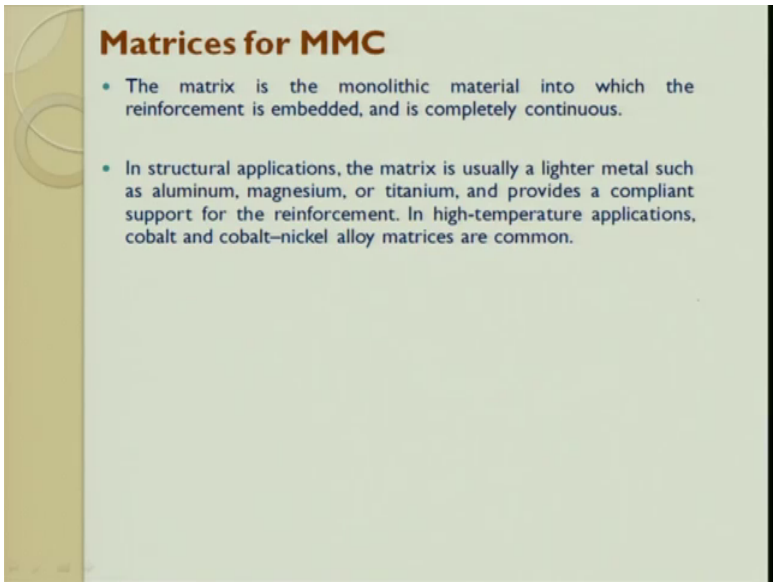

So, what is the property of this matrix? The matrix is the monolithic material it monolithic material in into which the reinforcement is embedded and it is completely continue; that means, to say it is getting dispersed that what we are trying to say in structural application the matrix which usually light metal such as aluminum magnesium and titanium structural application where there is load baring, where it takes load provides complain support for the reinforcement. In high temperature applications cobalt and cobalt nickel alloys are used very common.

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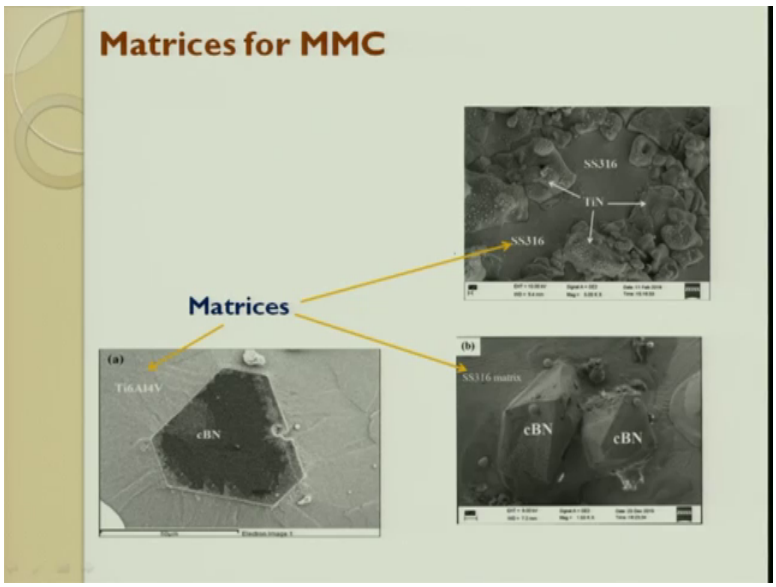

So, this we are already seen this is the matrix and this is the matrix and these are the reinforcement.

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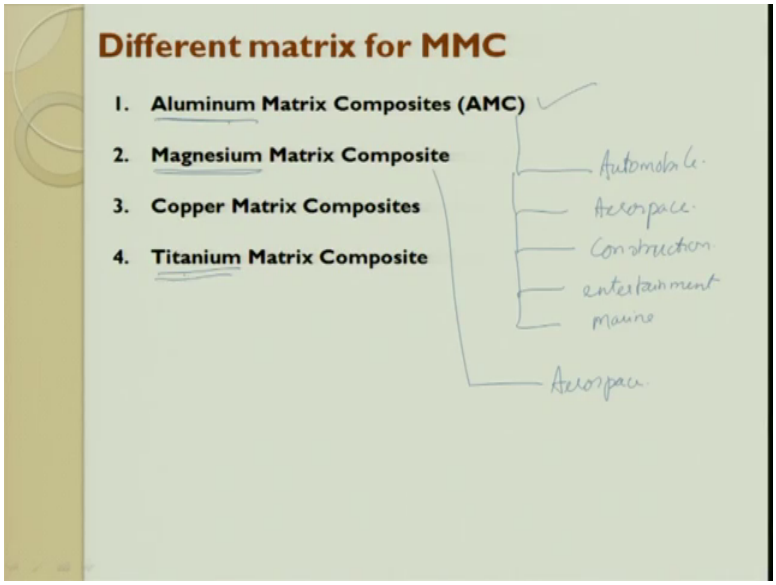

So, most commonly used metal matrix composite is aluminum metal metric composite, which finds lot of applications in automobile aerospace construction industry, it also finds in entertainment industry that means, say very low cost which is used for some applications. So, aluminum light weight.

So, it is used next is magnesium which is much lighter, but it also finds lot of application in aerospace, I have found missed one marine aerospace is one the copper we have seen in several applications like conductivity thermal; thermal conductivity electrical conductivity always go for copper metal matrix composite people today have using this for wear resistance; also for example, these switch breakers are now made out of copper; copper metal matrix composite that it can have rather than by metallic there are now going for copper metal matrix composite for enhanced life. So, then you have a also titanium which is again used for aerospace aluminum among these 3 fellows aluminum is the most economic fellow and the magnesium and titanium are slightly expensive and processing for magnesium and titanium are little tricky because tit we will see that as and when we go.

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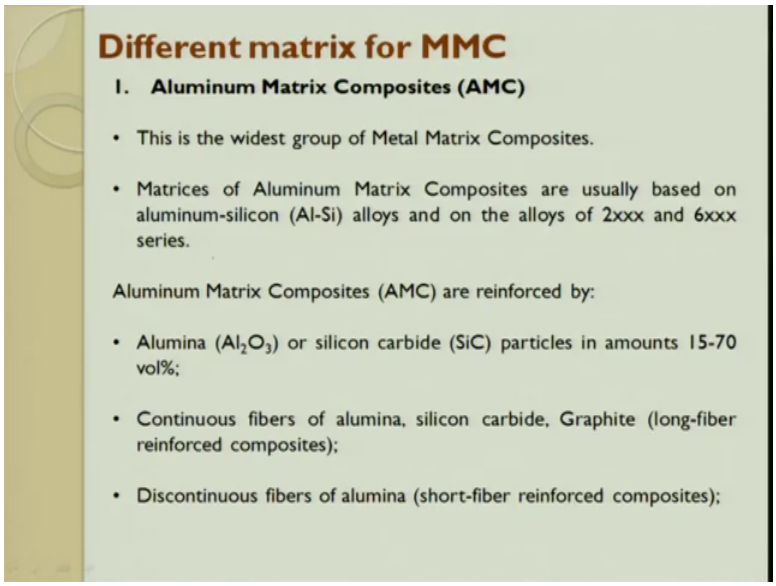

So, metal matrix composite which I said aluminum metal matrix composite which has wide applications. So, aluminum metal matrix composite are usually based on aluminum silicon alloys and on the alloy there are 2 x x and 6 there are several series. So, aluminum silicon on other alloy also you can have; so, every aluminum alloy is given a number. So, with this by looking at the number you can quickly go and find out composition. So, this is used as a metal matrix and then the reinforcements are generally learn done with alumina particle or sic particle.

So, this can go for a volume fraction when I say particle we should quickly, it should strike how much should be the content. So, the content you can talk in terms of weight percentage or in terms of volume percentage generally we talk in terms of volume percentage. So, volume to weight conversion is nothing, but multiplied by rho; rho is nothing, but mass wave volume. So, you play with that and you get what you want. So, aluminum and sic you can also have continuous fibers of alumina and sic grapheme long fibers and you can also have discontinuous fibers of alumina.

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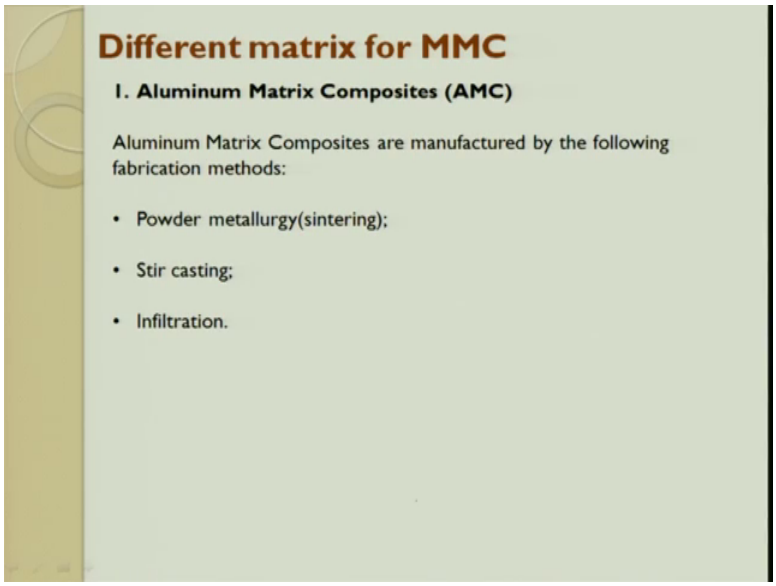

The metal matrix composite; that means, to say aluminum metal matrix composite are made by 3 processes. So, one is power metallurgy root which is sintering process we will see sintering process little later then we have stir casting and then we also have infiltration methods.

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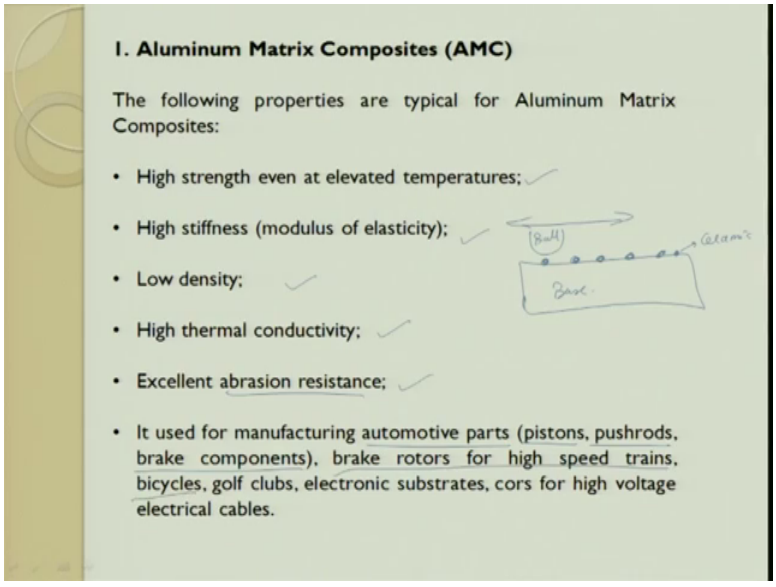

What are the properties; the properties are high strength at elevated temperatures high modulus low density high thermal conductivity excellent abrasion resistance see when you have metal matrix composite you and you have ceramic particle setting. So, these

are ceramic particles which are reinforced. So, what happens when you have any tribological application when there is a ball or a flat surface moving?

So, these fellows will try to prevent the contact between the sliding surface ball and the base material and then what happens when we tries to protect this fellow he always tries to reduce the wear. So, this is what is abrasion wear right. So, it is used for automotive parts like pistons pushrods break components then brake rotors for high speed trains bicycles today are made out of metal matrix composite today you have very like bicycles coming out first stage all this bicycles moved from steel frame to aluminum frame where the weight reduction was there from aluminum today they have gone to carbon; carbon composite which are much more lighter and all the parts which are made are made out of aluminum metal matrix composite. So, golf clubs and the electronic substrates, then cors of high voltage and electric cables are made out of it.

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When you got magnesium metal matrix composite are generally reinforced with sic particles. So, it as it is low density high stiffness high wear resistance, it has good strength at elevated temperatures it as also good creep assistance we already studied what is creep when we studied the mechanical properties I would request you to go back look in to the slides and get the information. So, it is used in racing cars automobile braking system aircrafts gearboxes transmission and compressors of a; and engines, then copper metal metric composite.

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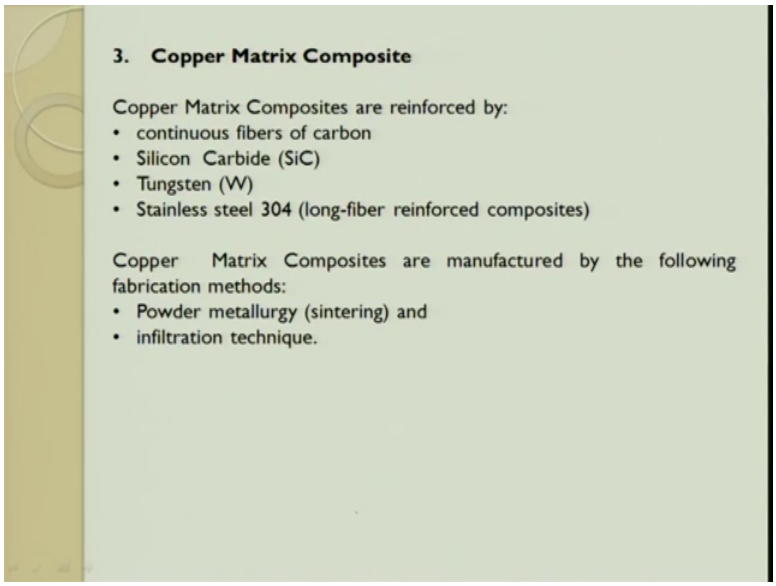

So, continuous fiber of carbon sic can be used tungsten can be used stainless steel it can be used. So, the process for making copper metal matrix composite is power metallurgy and infiltration same way when we talk about magnesium it is also the same. So, we have the same processes powder metallurgy stir casting and infiltration for magnesium also.

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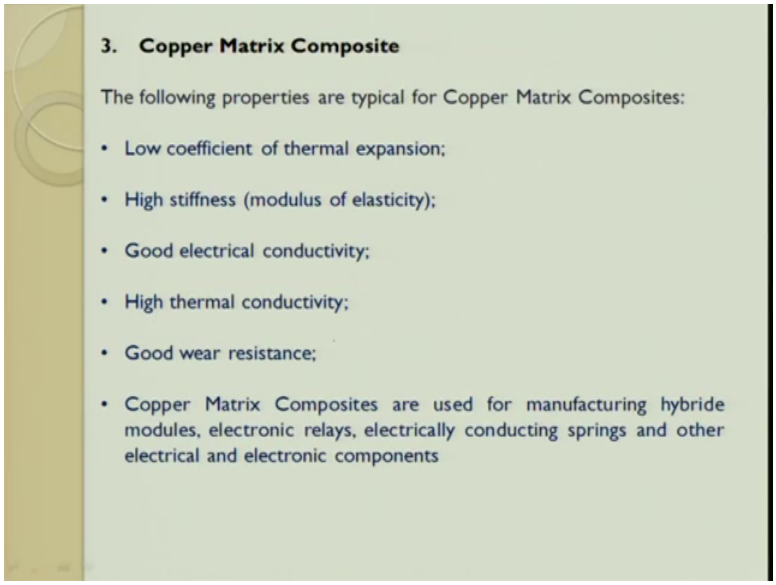

So, again the properties low coefficient of expansion then high stiffness good electrical conductivity high thermal conductivity good wear resistance, here we do not talk about density because copper density is high when you got titanium.

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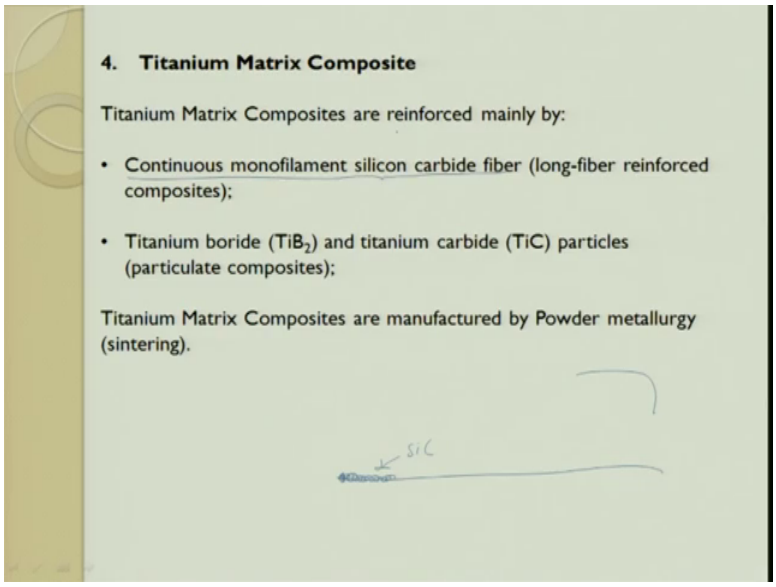

So, titanium metal matrix composite are continuous mono monofilament silicon carbide fiber. So, when you talk about silicon carbide fiber is basically you have metal fiber and on top of it they keep coating by CVD process the silicon carbide. So, what is the problem with this thing when you have a curve surface vendibility becomes a problem or the corner radiusing become a problem. So, when you talk about titanium boride TiB 2 and TiC; this are the some of the particles which can also be reinforced with titanium metal matrix composite predominantly what we uses power metrology root.

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So, here the strength comes stiffness creep assistance thermal stability were assistance is also there it and it also light weight.

So, here sixteen-16 jet landing here are made out of it, turbine engine components high temperature fan blade actuator pistons synchronization rings connecting links shafts this are made automotive engine component are made drive train parts and other general machine parts are made out of titanium metal matrix composite.

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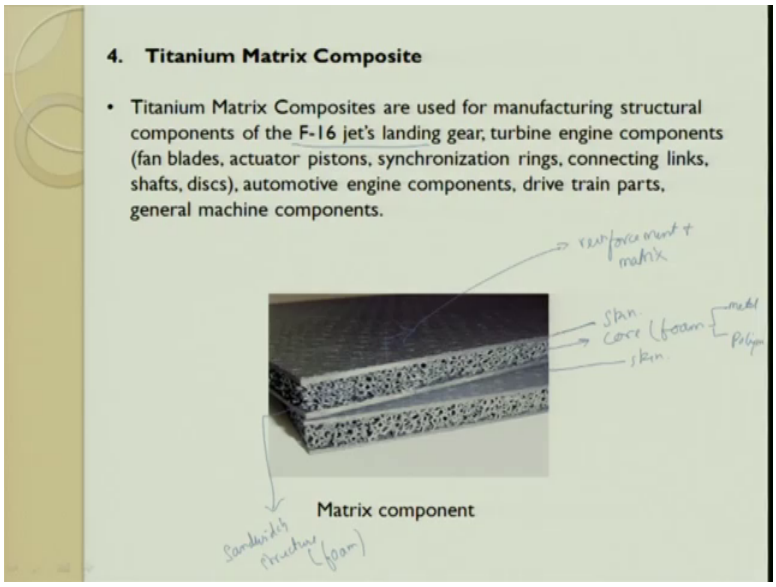

If you look at titanium metal matrix composite which are used in for structural application in f sixteen jet landing here the; so, you can see here this is sandwich structure sandwich structure which is foam a metal foam and then it as reinforcement on the top. So, reinforcement on the top and the bottom these are this are reinforcement and the reinforcement plus matrix is also there. So, it is skin the skin is there you have a core and then you have one more skin depending upon your requirements you can try to use it this core whatever I said this can be foam and this foam can be a 2 types it can be a metal foam or it can be polymer foam. So, here in this application there made out of metal foam. So, what are the applications?

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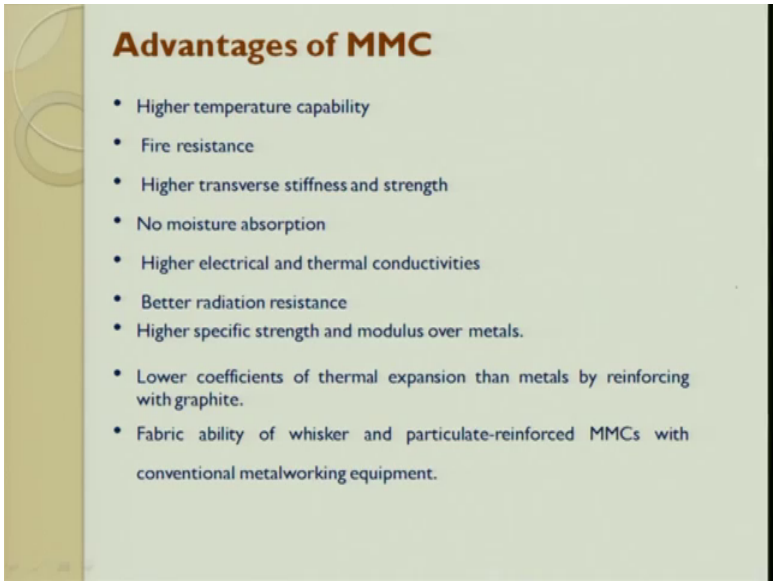

So, high temperature capability; fire resistance, high transfers, stiffness, strength is there; no moisture observation in polymers; you have a problem of this hygroscopicity, but here it is no moisture observation it is highly con conductive in terms of electrical and thermal better radiation assistance high strength and modulus we have low thermal coefficient of expansion and when you use this whisker and this thing with are use for conversion equipments can be used for fabricating this type of composite.

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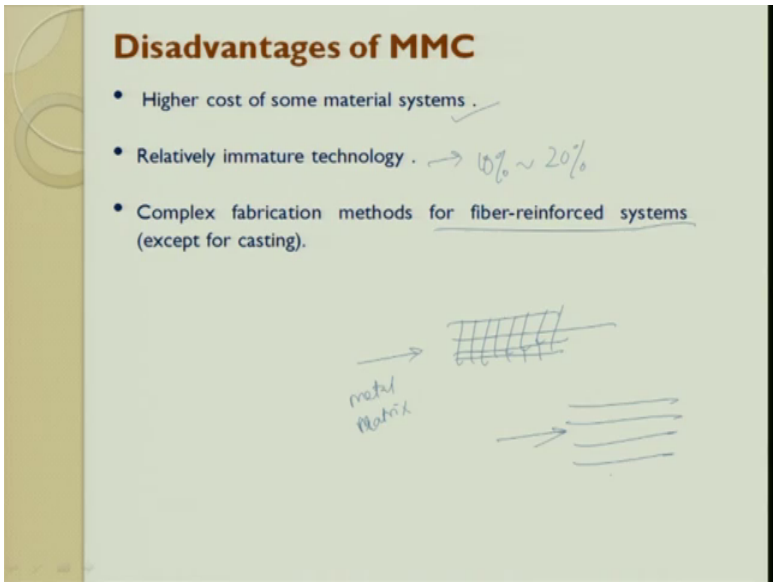

But the main disadvantage it is still it as not economically getting completed expect for the transportation industry where aluminum metal matrix composite is used. So, that is completing with aluminum alloys and people are changed a lot and keeping efficiency; energy efficiency titanium alloys are got into the aerospace industry, but still it is very expensive for a regular customer to use and relatively that technology is immature; that means, to say the consistency in the product output when you use for a large areas are even now a challenge; there are few company how have learn this skills and they (Refer Time: 29:46), but other they always try to made the rejection rate somewhere while making metal matrix composite changes from varies from 10 to 20 percent depending upon the size and shape and accuracy whatever it is the complex fiber fabrication method for fiber reinforcement is always a challenge.

So, if it is a particulate reinforcement it is very easy fiber is always a challenge. So, people still have lot of challenges with respect to fabrication using long fibers and using given viewed fiber mats for metal matrix composite today people are working on take glass fiber mat and then try to infuse metal matrix. So, only problem is this glass fibers are very light. So, if you want to make several layers laminates and then if you want to infuse these reinforcements displace from their existing potion and we are not able to controll flow the metal matrix in to the glass fiber.

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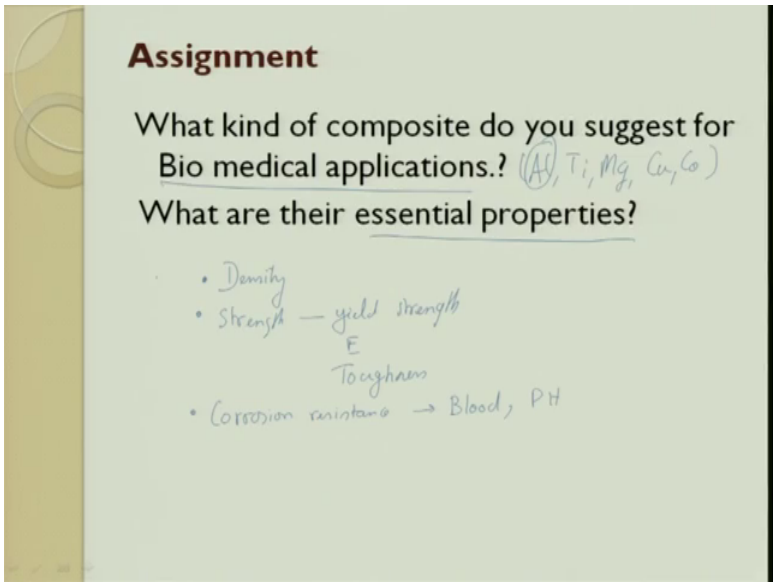

So, today, we end the lecture with a small assignment and again it if for your own self learning; what kind of composites do you suggest for bio medical application; whatever we have seen; what are we seen; we are seen aluminum titanium magnesium copper which one cobalt which one do you suggest and if you suggest any thing say for example, you suggest aluminum then suggest why did you choose this composite.

So, I repeat you are suppose to choose a composite for bio medical application. So, after making your choice please try to list down all your essential properties and justify your answer that this is the best as comparative. So, basically what are you supposed to do you are supposed to look into the when it gets into the body its density you do its strength when you talk about strength you look at yield strength you look at e you look at toughness then you look at corrosion resistance because in our body we have blood which has a PH.

So, you have to find out; what is a PH and which material is conducive for it and then choose the proper composite material. So, with this we come to an end of this lecture and this assignment is self learning for you please take it seriously do lot of search in internet you get lot of material from there you can try to choose it.

Thank you very much.