Manufacturing of Composites
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Lecture - 01
Introduction to Manufacturing of Composites

Good morning everybody, welcome to the course on Introduction to Manufacturing of Composites. Thank you very much for choosing for this course, we have a huge registration for this course. So, I hope, I will keep up your tempo till the end of this course. And as I told earlier this course will have lecture series as well as assignments in between. And we will also have quizzes in between to be held and you have to upload the answers for it. We have a T A with me Dr. Amandeep Singh; he will be helping me in carrying out all the corrections.

So, getting into the topic, Introduction to Manufacturing of Composites; during my introductory slide I used a word called as bio inspired material or bio inspired composite; what is that. Today, what mankind have found out is the best materials are going to be are nothing but the natural materials which are available. So, people are trying to understand more and more about the natural materials which are available; how it is getting evolved and how we can fabricate it such that we can make very intelligent products to meet customer demands.

That is why, today, you see many products which are in the market; talk about smart phones, intelligent phones, smart material, intelligent material so many new things come. All these things are getting inspired from nature. So, composites, is manmade and now we are moving towards bio-mimicking composites. We were try to see some of the bio-mimicking composites in the last phase of this course.

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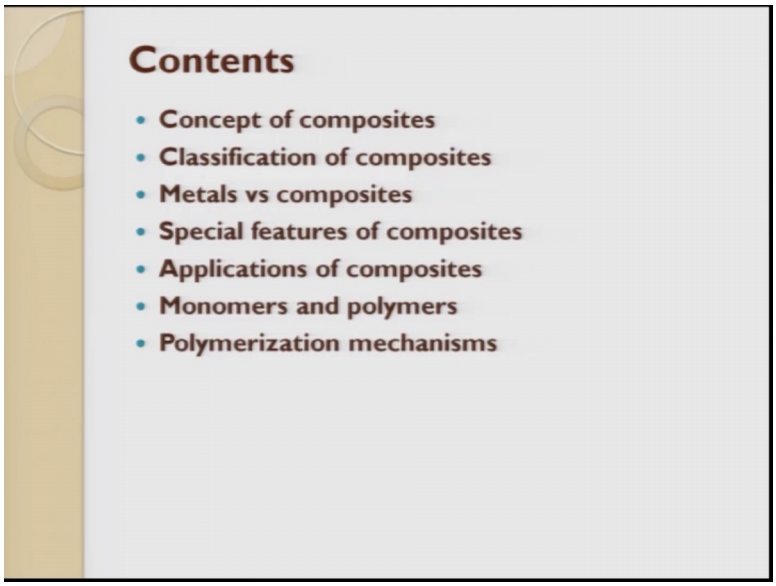

So, in today's lecture what we are trying to cover is, we will try to cover the content of composites, then we will talk about classification of composites then, What is the advantage of composites as compared to that of metals, then special features of composites, applications of composites, then we check exclusively polymer matrix composite and we will talk about, what is monomer, what is polymer, what are the different mechanism, wherein which this polymerization can happen.

So, what is composite; though composite is a term which is used almost for a century still a clear definition has not been evolved. Based on my understanding and with their literature available I have just put a very broad sense of definition of composite.

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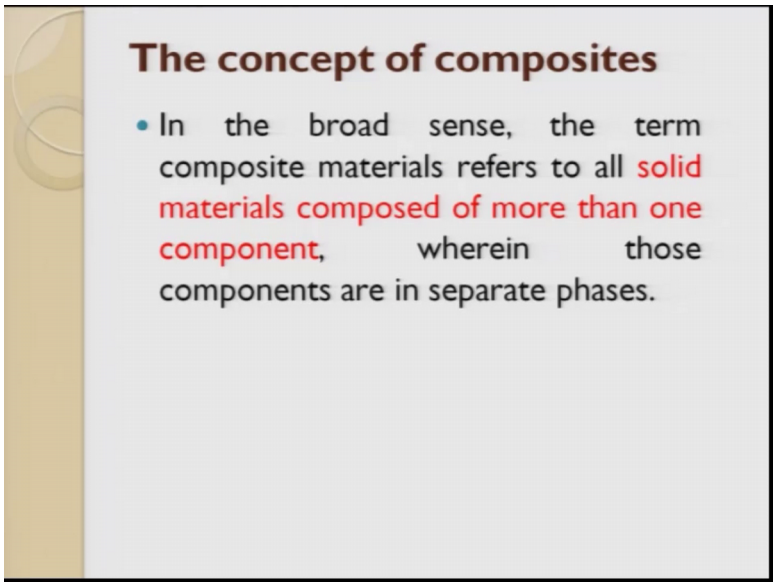

In a broad sense, the term composite materials refers to a solid matter composed of more than one component, wherein those components are in separate phases. For example, I take material A, I take material B, when I mix this 2 or when I do a process; that means, to say I apply pressure, temperature with respect to time, then, I get a product out. This product will always be a synergy, that means to say, it will try to take the advantages of A, advantages of B and try to give a new product, wherein which that has a required material property and when I try to take the cross section of the composite material I can still distinguish, what is the component A added, what is component B added. So, this is a definition for composites.

So, the component A is called the matrix and component B is called the reinforcement. There is a difference between composite and alloy. In an alloy, when I try to mix material A plus material B and it forms a product C. The product C which is formed will have a better property as per the customers requirement, but when I try to take a cross section, I will not be individually able to detect the presence of material A and B. So, this is what is a difference between composite and an alloy.

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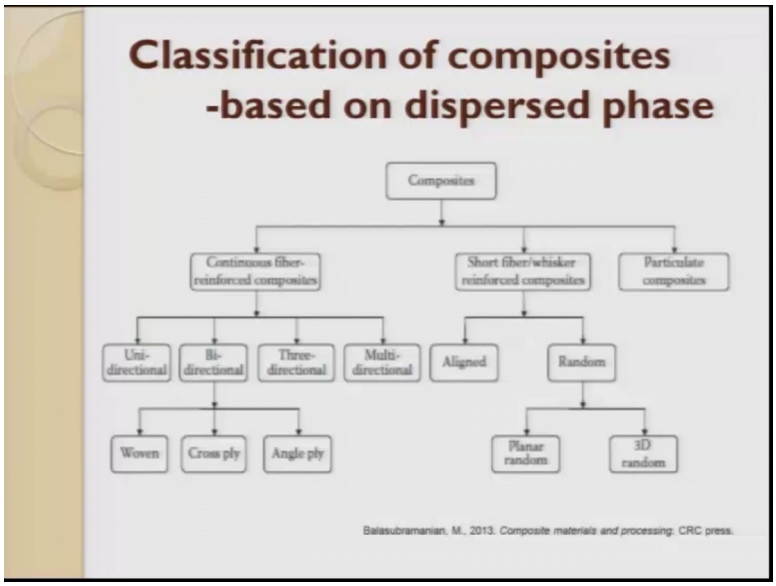

Now, let us see the classifications of composite based on the dispersed phase. Here, the dispersed phase means the reinforcement getting dispersed in a matrix. Now, it is very clear; you will have 2 products which I said material A, material B; 2 materials: material A and material B. So, material A is called as the matrix, wherein which, we try to reinforce the matrix by material B.

The first classification which is shown here is based on the dispersion of phase, phase's reinforcement. Here, if you see composites can be classified into 3 types; one is called as continuous fiber reinforced composite, short fiber reinforced composite and particulate type reinforced composites. Long fiber means its length, when we talk about aspect ratio, it is length by diameter, we have a long length divided by the diameter of few tens of microns. So, these are called as long fibers. It is very similar to that of a thread which is used for stitching, the shape and the length.

The next one is short fibers, I cut this long fiber into very short fibers and then I try to make something like a mat. So, here the aspect ratio is very small; that means, to say length is small, diameter will be the same. So, these are called as short fibers. If the diameter goes very small and if the length is still maintained or slightly less, the aspect ratio is maintained, those reinforcement are called as whisker. The difference between short fiber and a whisker is, in whisker the defect densities are very low.

The third classification here is particulate composites. In particulate composites, the reinforcement, whatever we use, will be the length to diameter ratio will be approximately equal to 1, slightly higher than 1, less than 5 something like that. It is something like a sand size. Those are reinforcing materials; those things are called as particulate composites. So, particulate composites are predominantly used in ceramic matrix composite and metal matrix composite.

When we go ahead with the continuous fiber reinforced composite, again you have uni--directional, bi-directional; uni-directional means, all the fibers running in one direction length, bi-direction means, it is woven like your cloth, shirt, what we wear. So, you have fibers running in both directions. You can also have fibers running in the third direction. These composites are now getting into market and it has very high strength and these composites are called as 3D composites.

So, the fibers runs in all 3 directions, so that, you get x y and zero, thickness also. Then you can also have multi directional. When you talk about short fibers, it can be aligned in one direction or it can be random in nature. When you go to bi-direction, we call it as woven and then we also call it as, there is a classification called as cross fiber. You can also have angle fibers; angle fibers are these textiles like material arc cut in different directions and they are laid.

We will see more in detail, when we go talk about composite, laminate, laminae and other places. We will see more details and as far as random is concerned, it can be planar random or it can be 3D random.

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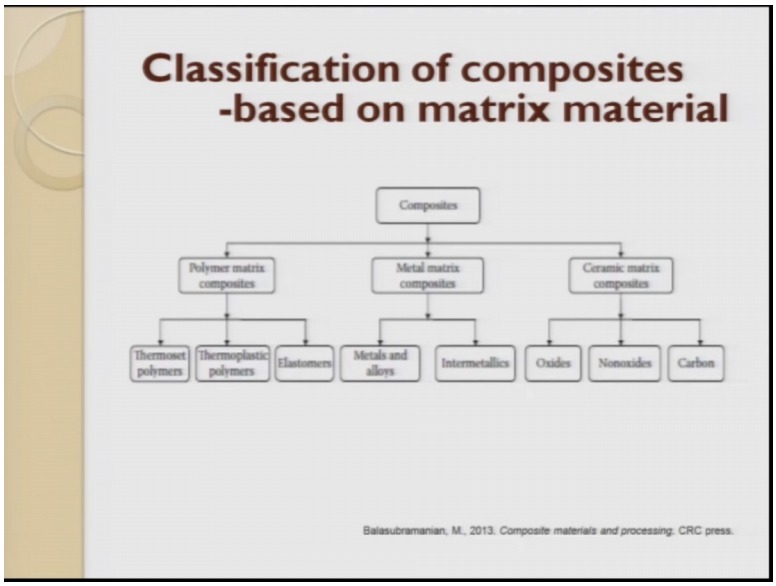

When I talk about composites, based on matrix classification, there are 3 types of matrix classification; one is called as polymer matrix composite where this matrix composite is very predominantly used in mankind today. The next one, is metal matrix composite; metal matrix composite are used wherein which, there are high strength and you need more high strength materials and more other properties like stiffness and corrosion resistance, all these things we are now trying to add metal matrix composites there. You also have ceramic matrix composite. Ceramics are very poor in toughness, so now we add reinforcing agent to enhance their toughness property, same way with metals we add reinforcement, so that, we enhance their strength property.

When you talk about polymer matrix composite, they are further classified into 3. Generally there are 3 types or 3 kinds in polymer; one is called as thermoset polymer and another one is called as thermoplastic polymer and the third one is called as elastomers. Thermoset polymers are polymers wherein which, it was very high strength and stiffness, but as far as ductility is concerned, is very poor and on top of it these composites are not recyclable. Today, there is a major challenge which is thrown in front of us, is how do we process the thermosetting polymers, which has been installed in service condition in the last few decades.

Thermoplastic polymers, these polymers are recyclable, they have strength, they have also ductility. The major advantage of thermoplastic is, recyclable. Today, there is a new

offshoot of thermoplastic polymer which is coming, which is called as biodegradable polymer. They are slowly gaining importance; however, they have not gone into the application of strength, stiffness requirements.

The last one is elastomer. Elastomer is also part of polymer. The only difference between thermoplastic and elastomer are; elastomer has ductility from 100 percent it can go up to even 2000 percent, the elongation can happen. Simple example is your rubber band. The elastomers, you can see a wide spectrum of a application, right from a rubber band to a cycle tyre, to a plane tyre, all these things are elastomers based composite materials. In the tyre, we always try to reinforce with steel and carbon fibers to get the required properties.

When you go for metals, we take 2 kinds. In them, one is called as metals; you can take pure metals, try to mix it or you can take an alloy and try to mix it. Predominantly, whenever we talk about strength, we always talk about metal alloys getting mixed with the reinforcing to match out the requirements. So, here again strength verses weight ratio is taken and here they are found to be major advantage. 1 good example today, what is happening is the huge electrical transmission towers are made out of metal matrix composite today. The copper wire, the cable, which carries very high current are now made out of metal matrix composite. Because of this coming of metal matrix composite wires, the sagging happens slow, the number of towers for reinforcement has also reduced. This has given the transmission industries a huge boon.

Next is, intermetallics. Intermetallics are an offshoot of metal matrix. Here, the alloys occupy a fixed stoichiometry ratio and these intermetallic composites are used for high temperature applications.

When you talk about ceramics there are 3 classifications; one is oxides ceramics, another one is non oxides ceramics and the third one is carbon. When we talk about oxides alumina SiO_2 are some of the examples. Here this ceramics are bonded together and sintered along with the reinforcement to get a toughness property. So, oxides; non oxides example is SiC, CBN, WC, tungsten carbide, these are some of the examples. And the last one is the carbon which is used in the matrix for matrix in which, there is a reinforcement happening. A very good example for carbon composite is used in radomes, which is in the front nose cone of a plane, wherein which, there is a huge amount of

temperature and pressure and friction when it tries to come down from very high altitudes to the ground level. So, this is classification of composite based on matrix. First, I was talking to an about dispersion phase, now I talked about matrix phase.

Now, let us see some of the properties of the composite, when I compare it with that of metal. I take only 2 metals, because these 2 are commonly used; one is steel, the other is alumina. If you see weight wise, steel has a very high density followed by it is aluminum.

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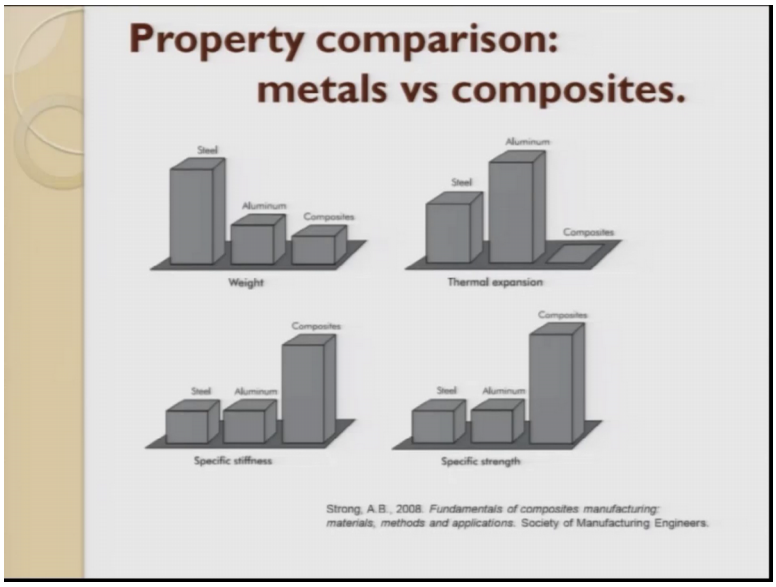

This aluminum is nowadays getting replaced wherever steel was used and second, aluminum has an advantage of corrosion resistance. Aluminum is now playing a major role. Now, when we move towards composites, it is much lighter than even aluminum. So, if you have a moving body and if you want to have a better efficiency of mileage, then we replace that aluminum also by composite materials.

So, next one is thermal expansion; you see thermal expansion of steel is much better than that of aluminum, but when I try to make a composite, it is almost close to negligible. When I talk about stiffness, it is also steamed that, steel and alumina are very close by composites have a very high specific stiffness. Then, with specific strength the composites excel out.

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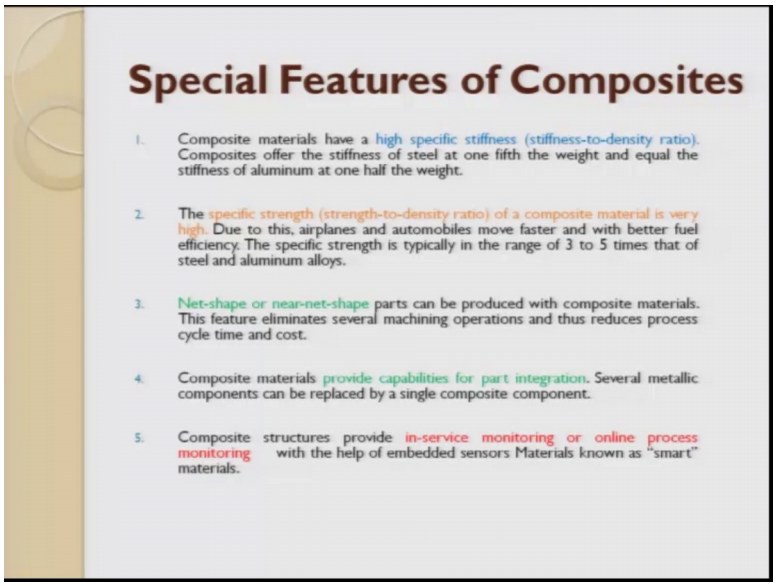

With this, let us see, move further and see; what are all the special features of composites. So, the composite materials are materials, which have high specific stiffness; what is high specific stiffness: stiffness to density ratio. Stiffness divided by density, this will try to give an advantage and see; what is the weight I have to add, to get a required stiffness.

The next one is with respect to strength: stiffness and strength are 2 different properties. Please make a note: people interchange unknowingly. Stiffness is different, strength is different. Stiffness is taken in the elastic zone and strength we always take in the ultimate strength and we talk about that.

Next one, composites are those materials, which can be made up to near-net-shape. Today, in manufacturing, the entire manufacturing domain or regime is moving towards near-net-shape machining or near-net-shape part making. So, one example is rapid manufacturing or rapid prototyping, wherein which, the prototype or the product is made exactly to the near-net and we do final secondary operation, either giving a painting or giving a finishing operations, such that, we can directly take it to the market. So, near-net-shape is one of the biggest advantages of composites and on top of it composites gives a wonderful property of getting integrated along with other parts.

The capability of part integration is very easy and good with composite materials. And latest advancement which have happened in composite structures are, in-service

monitoring; for example, I make a composite, I make a composite bridge, I embed few sensors. These sensors will try to tell me what is a load going on the bridge, plus it would also try to tell me; what is the health of the composite, which is put there. So, today smart materials are embedded into the composite materials and we try to use it for inline service monitoring.

So, now let us see some of the examples, application industries where composites are exhaustively used.

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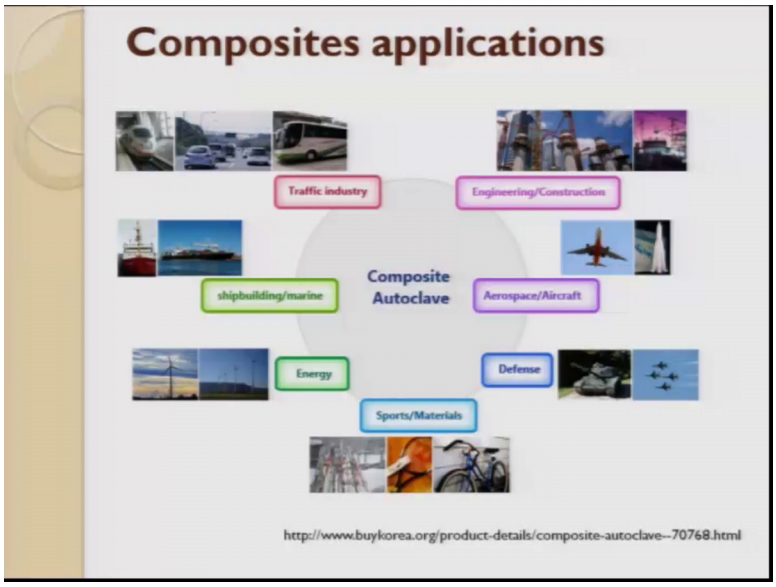

It is used in transportation; for example: it is used in train, car, as well as buses, wherein which, in all these the performance gets enhanced. The biggest advantage is energy efficiency. Today, world is talking about carbon footprint and pollution, composites are coming up in their way to help them in reducing the pollution. The next one is engineering construction; I have given you example of towers and then in process industries, in transmission industries.

Next, in aerospace industries, you can see, it is the commercial flights are becoming lighter and lighter. The biggest advantage is, they do not have to stop over at different countries to have a refueling. They start from one destination and they go to the other destination or almost half of the globe without any stoppage, because of the composite material getting added there.

In space shuttles, yes, very high temperature, very high strength, there a composite, ceramics matrix composites are coming up in a big way. Defense applications; today, people are talking about bullet proof jackets, bulletproof helmets. Earlier, the weight which was talked about was 15 kilos, 21 kilos, today they are talking about none about 3 kilos and 5 kilos which gives a soldier a big boon to wear it and use it during the operations. Sports: the cycles have become very light. The cycle today, are made out of carbon fiber composites, which they claim to be around about 3 kilos, the entire cycle can be can be collapsed and it can be taken to places. People are also looking at sports material, people are talking about T-shirts wherein which, it is coated with nano materials and it is performing very well, it does not give you odor. So, there are and shoes are made out of composite materials, which are predominantly elastomer composites, polymer matrix composites.

The next one is energy, wherein which the windmill the blades are made out of polymer matrix composites. The biggest advantage is the shape of the blades today, can change, it can stretch by few centimeters or few millimeter, the diameter can change, the surface can change, depending upon the wind. The shipping industry is also one industry where there is a lot of change which has happened from steel to polymer matrix composites.

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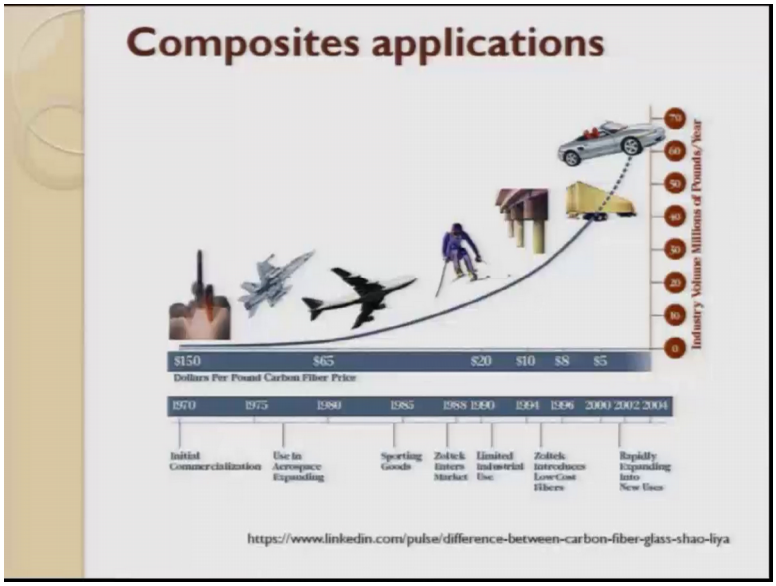

So, this graph, tells you the bottoms tells you about the year in from 1970 to 2004. You can see the usage of composite materials in various industries have enhanced and also

the amount of money which is getting invested in millions of pounds per year is shown in this graph. This is a old graph 2004 and the graph keeps exponential increasing even today for various applications.

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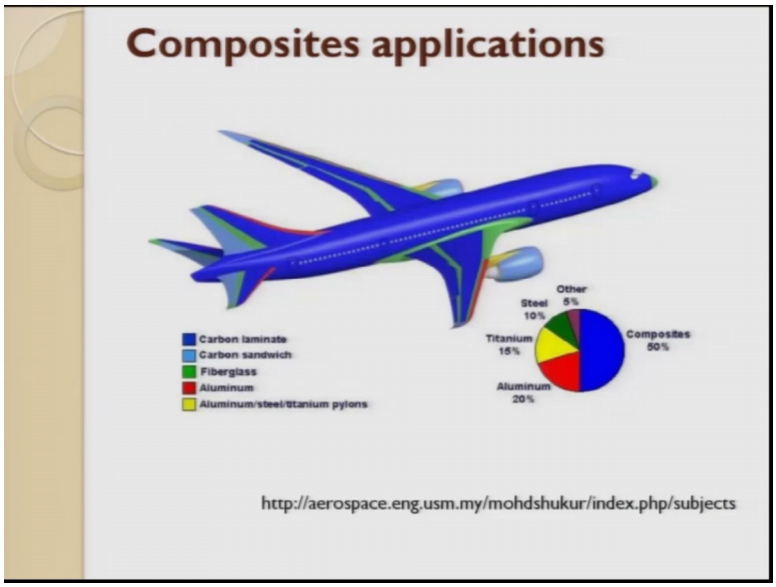

So, when we take commercial aero plane, there are about 50 percent of the material is made out of composites I will repeat, it has very high strength to density, stiffness to density, it is made up to near-net-shape. I can give aerodynamic profile very easily; I can integrate with other parts very easily. When I want to do part integration, composite comes up in a very big way. Today, from 50 percent of the composites, people are now stretching themselves to go up to 75 percent made out of composites.

So here, in which I have different color codes, I am sure it is visible for you. We have, people have started using carbon composite. People have started using carbon sandwich composite, we will see what a sandwich later, fiberglass and they have also started using aluminum metal matrix composites.

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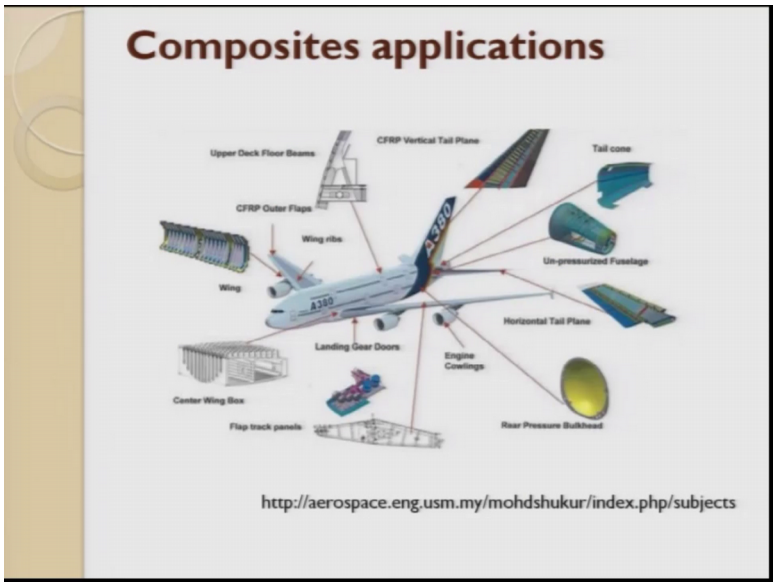

These are some of the parts which are used, which are made out of composites. For example, CFRP vertical tail planes are there, tails cones made out of it, rear pressure bulkhead is made out of composites, engine cowlings is made out of composites, wings are made out of composites and center wing box is made out of composites.

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Today, houses are made out of composite materials and these houses are first it came into existence for disaster management, but today, what has happened is rapid construction are required in the third world countries. So, here, the complete roof and the side panels

are made out of polymer matrix composite, which has acoustic proof plus it also has part integration with steel fasteners, so you can quickly go assemble it at the required site and it gives a big boon for the construction industries.

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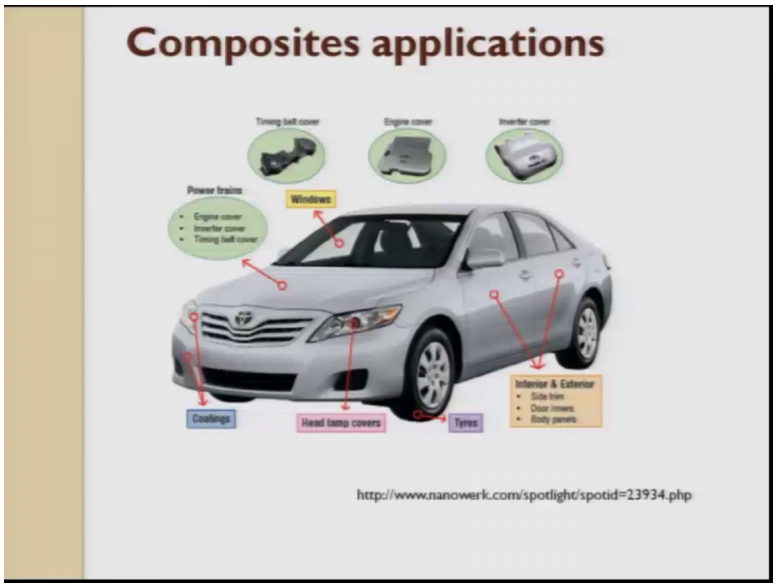

Cars, as I told earlier, today, in cars also there are lot of parts which was earlier made out of alloys are getting replaced by metal matrix composite materials, for making the car lighter stiffer and perform much higher.

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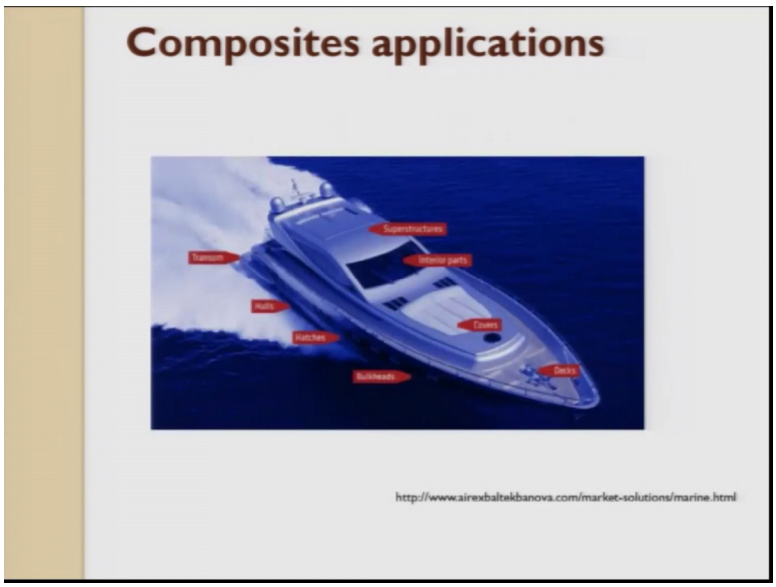

Marine industry, where corrosion is a big problem; so here, the superstructure, interior parts, cover, the deck, bulkhead, hatches, hull and transforms all are made out of polymer matrix composite. So, again here, when you make composites you have to look at 2 things; one is called as primary structure and other one is called as secondary structure. In primary structures are structures wherein which predominantly it takes load. Secondary structures are used for filling, for giving other secondary properties, which are required for the product.

So, when you take a marine application of composite there are lot of primary structures made out of polymer matrix composite as well as secondary structures made out of polymer matrix composites. Simple example for secondary structure is deck, wherein which, it is only as spacer wherein which, it is used for the movement of human being around.

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As I was talking to you about defense; helmets have become much lighter. Bullet proof jackets have become much lighter, but lighter and high performance. So, inside a bullet jacket now ceramic tiles are used. These ceramic tiles are again a composite material which has very high toughness and very light in weight, which helps the soldier without getting fatigue when he is an operation he can perform efficiently.

The helicopters are made of the carbon fiber reinforced composites; the blades of a quad copter or a helicopter are made out of lightweight material, so that, it gives stiffness as well as weight is less.

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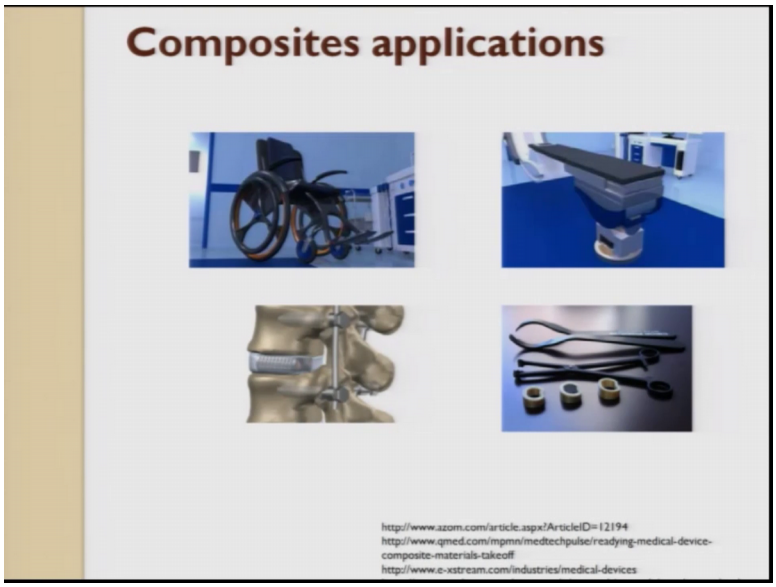

In biomedical applications, there are lot of products which are coming out, which is made out of composites, wheelchairs is one and then you see lot of appliance which are or the fixed lot of fixtures and apparatus are made out of composite metal matrix composite material, so that, they perform high or they perform good.

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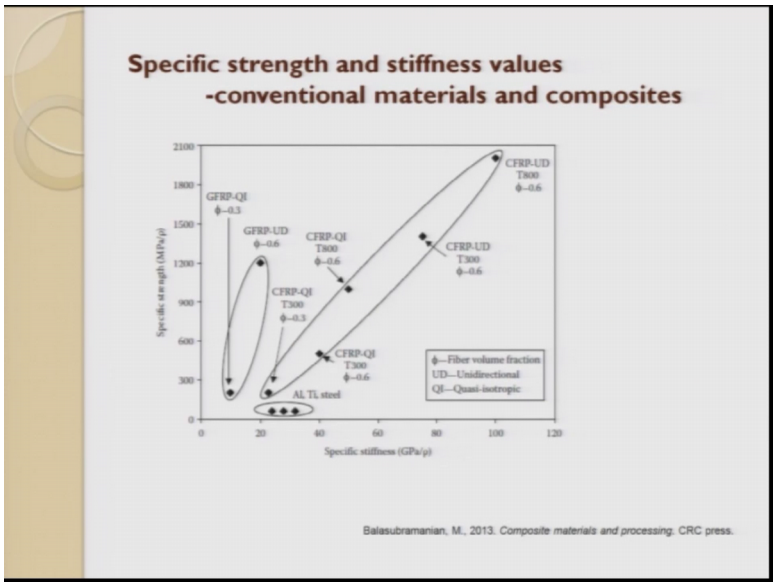

In a nutshell, if I want to put a plot between specific strength to specific stiffness, as I told earlier, these 2 properties are different. Stiffness versus strength, if I draw a plot, you can see in this plot I have accommodated glass fiber reinforced composites, carbon fiber reinforced composite, so you can choose which one to pick, you can choose and pick what is required depending upon your application. So, you look at conventional materials, aluminum, titanium, steel; look at their specific strength to stiffness ratio and look at carbon fiber reinforced plastics unidirectional, the strength verses stiffness value.

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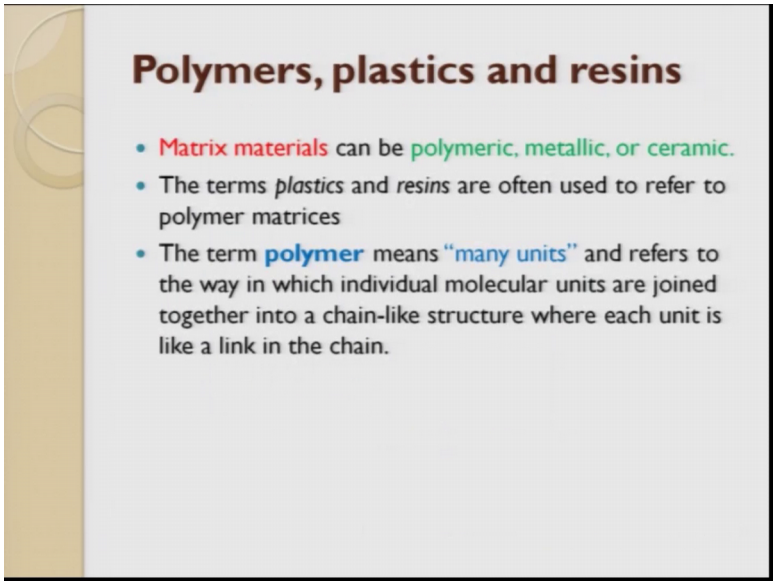

Now, let us get into polymer. Polymer is otherwise called as plastics and when it is used for fabrication it is called as resin. The name polymer clearly tells that there are a lot of monomers join together to form a polymer. The matrix material can be polymer, metal or ceramics, but, from now on for the next few lectures we will focus only on polymer matrix composite.

The term plastics and reinforcement are often used to refer polymer matrix composite. The term polymer means many units are joined together and form a chain and this chain like structure is called as polymer and inside this polymer we try to add reinforcement and make a composite material.

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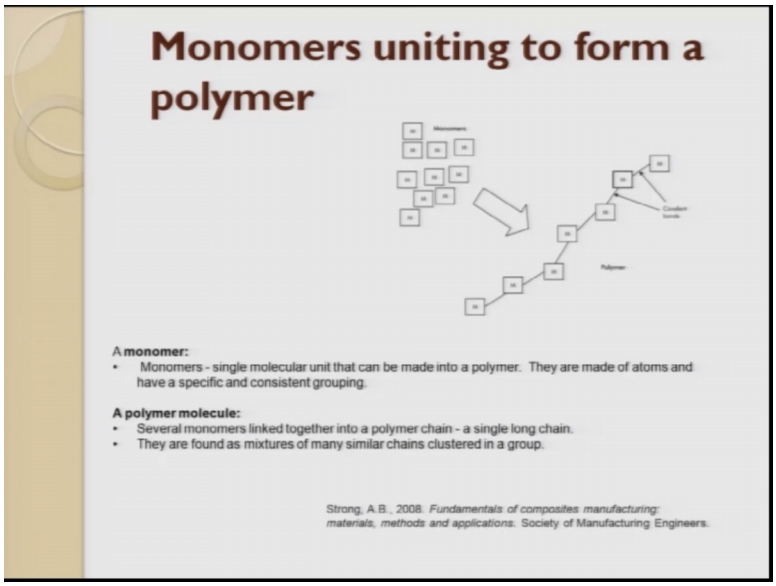

So, these are schematic diagram, you see lot of mers which are dispersed and these mers joined together like a chain. The mer is nothing but a bead in a chain. All these beads which are nothing but monomers are joined together to form a wonderful chain and this formation is called as polymer.

A monomer is a single molecular unit that can be made into a polymer. So, a monomer is made out of atoms and have a specific and consistent grouping. What is a polymer; a polymer molecules are nothing but several monomers linked together to form a polymer chain. It is a single long chain. The single long chain alone cannot be used for applications. There will be several chains attached together and there will be forming clusters and this clustering of monomers into a chain fashion is called a polymer.

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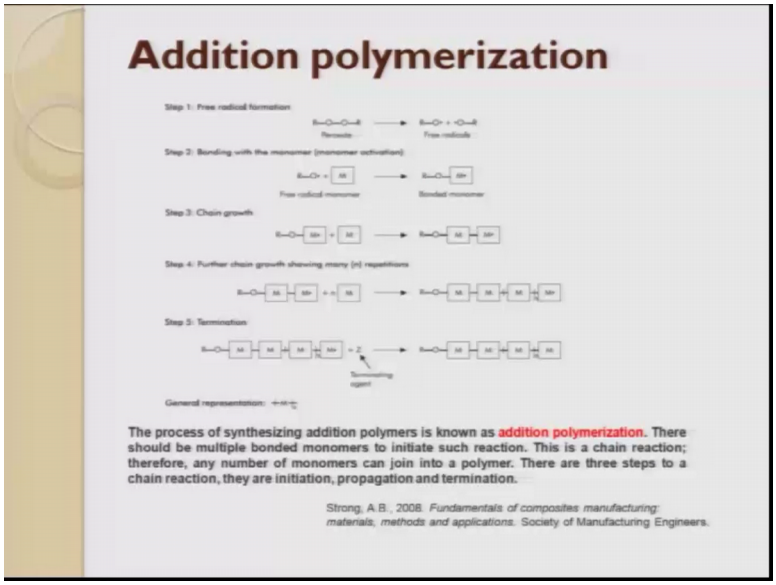

So, there are 2 basic mechanisms which are involved for this polymerization process; one is called as additional polymerization, another one is called as condensation polymerization. In additional polymerization there are 5 steps involved. The 5 steps are: first, the free radicals are formed, then bonding this, the formed free radicals try to bond with the monomer and then this monomer tries to join with each other, they form a chain and this chain keeps on further multiplying and growing and this cannot keep growing for infinity period.

There will be something called as termination step, so that, it terminates the polymer. If you want, it is a simple analogy is, I have a set of beads, all these beads are there in a box. These beads have to be linked to each other, how do we link with; one we apply adhesion and stick all the beads, the other way around is we use a twine, which can pass through all the beads and form a chain.

It is almost the same thing. The radical is, which is a peroxide, which forms free radicals. These radicals get attached to the monomer and monomer gets attached to monomer, monomers get attached and then finally, they get terminated. This mechanism is called addition polymerization.

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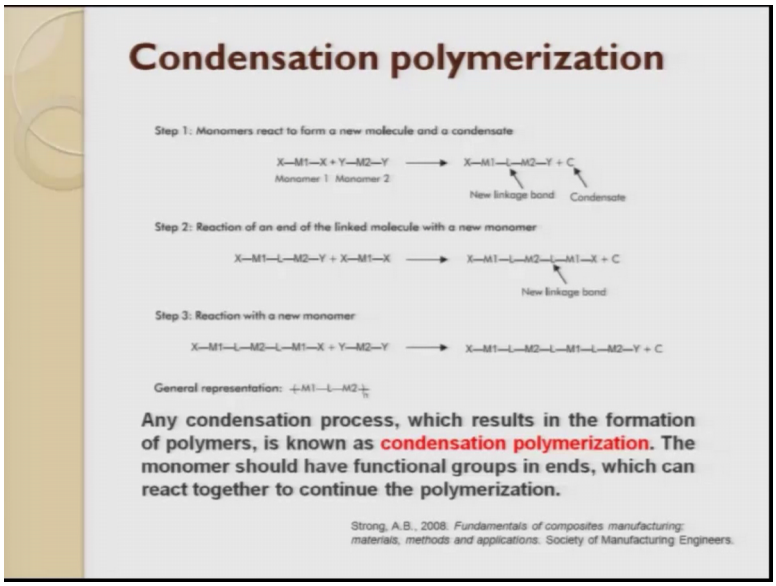

The next mechanism is condensation polymerization. In condensation polymerization what happens; the monomer reacts to form a new molecule and a condensate, the condensate is predominantly nothing but water, so it is, you have this monomer joining with another monomer when these monomers join together form a link they also form a condensate.

So, the reaction of an end of the link molecules, with the new monomer happens and this reaction with the new monomer keeps continuing and finally, it forms a chain. Any condensation process which results in the formation of a polymer is called as condensation polymer. The monomer should have functional groups in the ends, which can react together to continue for polymerization. These are the 2 predominant mechanism of polymerization happening, such that, a mer is converted into polymer. Now, the polymer is ready, we will try to add reinforcement to make it into composite.

I would like to conclude today's lecture. In today's lecture what we saw was; we saw what is a composite, what are the applications of composite, what are the properties of composites and we saw different polymerization mechanism, such that, how a mer is converted into a polymer. We saw only the major mechanisms.

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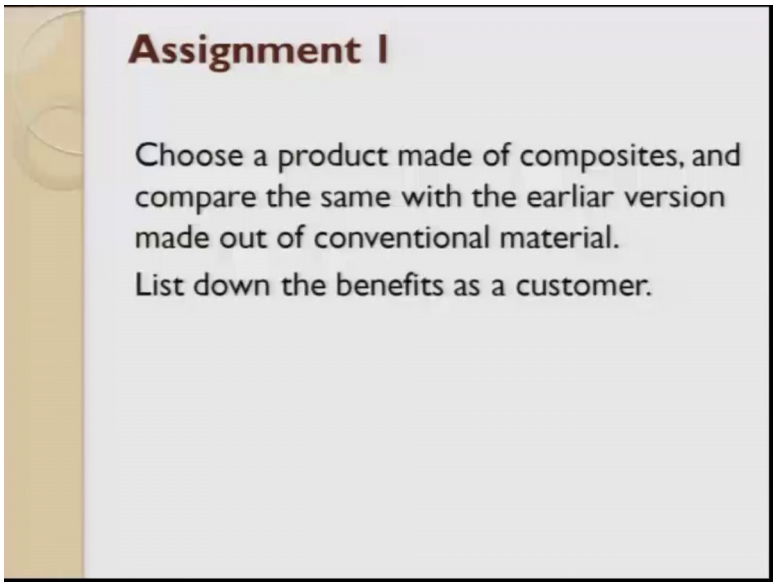

As an assignment, today, we will have first assignment based on this lecture. So, what I would request you is, you use internet as your source, search for you product which is now made of composite, in the past which was made out of metal.

So, just take that part if you have it physically, it is excellent, if you do not have it physically, at least by looking at it you have a feel and please list down all the advantages of the products today, since it has made of made out of composite materials. You please list it down and then you will try to see the advantage, what composites have given over conventional material in that product. You do not have to submit this assignment and this is an assignment for your self-learning only.

Thank you very much. We will start the second lecture with, what are all the ingredients of composite and how do you fabricate a composite, with some more on property analysis.

Thank you very much.