Processing of Non-Metals

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Module - 5
Polymer Matrix Composites: Processing
Lecture - 3
Processing of Polymer Matrix Composites

A very warm welcome to all of you in this lecture on processing of polymer matrix composites. As you are well aware that we are discussing a series of lectures on processing of non-metals. In this series, we are now focusing on module number five, which is based on polymer matrix composites and the processing techniques and methods for polymer matrix composites. In this module, we have already taken two lectures; in lecture one, we have seen the challenge for selection of materials and the importance of composite materials in today's world. We have seen that how new materials are required in today's scenario. If you remember, we have seen that there are design modifications, as well as there are in-service requirements, which leads to the end requirements of new and new materials which can satisfy these design requirements as well as the in-service requirements.

We have also seen that why the new materials are needed and how the new materials are developed. We have seen that internal modifications or internal changes in the structure of the material and the external changes in the form of reinforcements added to the materials lead to the development of new material. As new and new materials are getting developed, we need to develop cost effective, high quality manufacturing techniques or processing techniques for these materials. In the first lecture, we have seen that when there are variety of materials available with us, we need to select the most or the most optimal material for that particular application for which we are thinking to design.

In lecture number two, we have seen the classification of composite materials. We have seen that how the composite materials can be classified, what are the various application area of different types of composite materials. If you remember, we have finished the lecture with three important classes of composite materials - that is the polymer matrix composites, the ceramic matrix composites and the metal matrix composites. I have highlighted that in these series of lectures on processing of non-metals, our focus would

primarily be on ceramic matrix composites and the polymer matrix composites. And this particular module is dictated or dedicated towards polymer matrix composites, and their processing techniques. So, today we will discuss the challenges and the issues as well as the basic constituents that go into the manufacturing or processing of polymer matrix composites.

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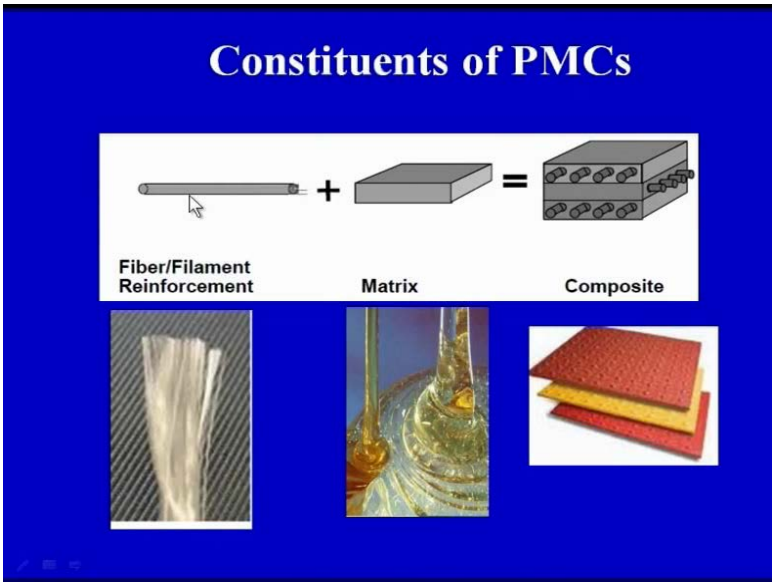

Now, what are the constituents of the polymer matrix composites. With PMC, as we have already seen in the previous lectures, PMCs means polymer matrix composites. So, the matrix is a polymer and the reinforcements is in the form of fibers. You can see, on your screen, very clearly it is mentioned that there is a fibrous reinforcement, fiber filament reinforcement and the matrix is in the form of a polymer. This is one representation of a polymer, and you have a fibrous reinforcement and when both of these constituents combine together, they lead to a composite. This is a composite, there are different layer; this is layer one of the composite, this is layer number two of the composite. If you remember in the previous class also, we have seen that how a composite looks like again I would like to revise that how a composite laminate would look like.

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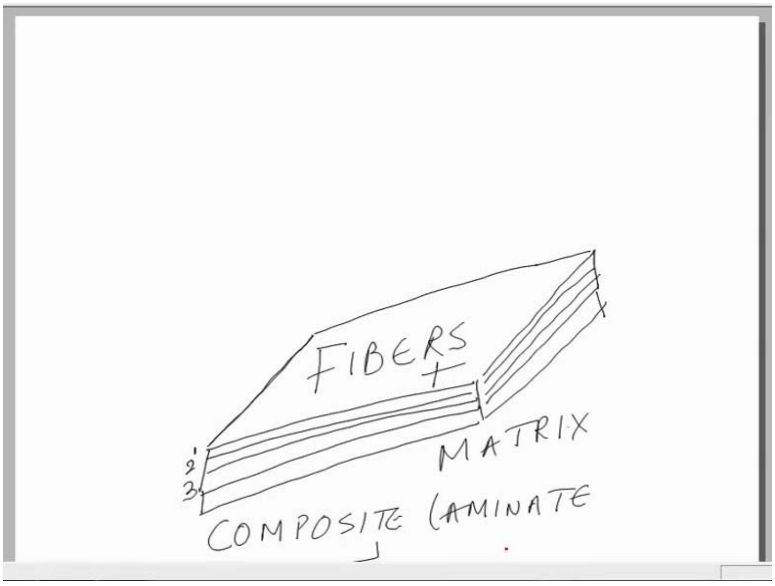

You can see on your screen, how a composite laminate would look like. Here you can see, this is a composite laminate, suppose now these lines represent the different layers. So, how many layers are there? Layer number one, two and three, so there are three layers. So, usually we make symmetric laminates, we will have four layers; in this direction also, there will be four layers. So, this is we can say is a composite laminate. Now in this composite laminate, there are two ingredients that is there can be fibers and there can be reinforcement. So, we can have fibers and there would be matrix plus matrix. So, we have fibers plus matrix which will add up into a composite material. So, on your screen in the slide, you can see that there are fibers as well as there is a matrix.

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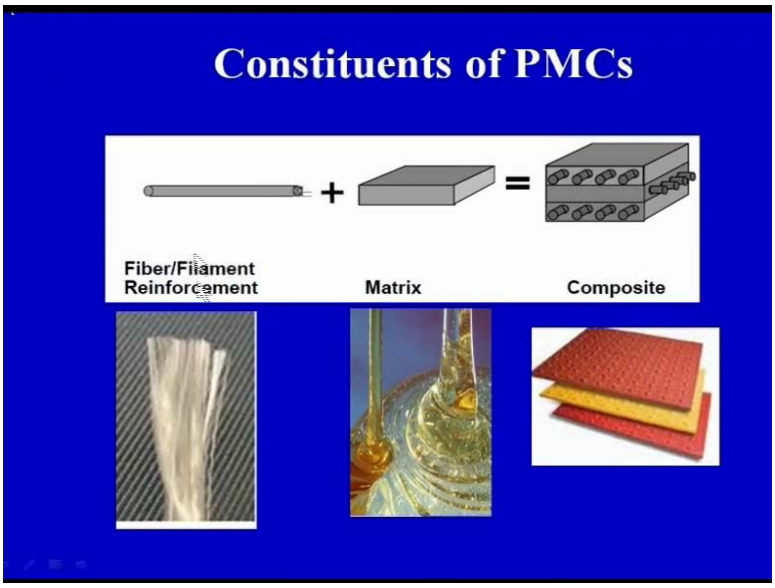

As you can see on your screen, you have the fibers and the matrix. So, fibers and the matrix, they add up to make this particular composite which we have just I have drawn one diagram of a composite laminate. In that laminate, there are fibers in this particular form and there is a matrix in you can say semi liquid form, in a semi solid form. And when these two things are combined together we get a composite plate. So, here you can see different types of coloured composite plates.

So, basically the constituents that go into the fabrication or processing of a polymer matrix composites are two major constituents; the two major constituents are the fibrous reinforcement and the polymer matrix. The matrix would always be in the form of polymer; polymer can be of different types; may be, it can be thermo plastic, it can be thermoset. The fibrous reinforcement that also be a different type see in the subsequent slides that what type of fibrous reinforcement will go into making a polymer matrix composite. So, there is a diagram which explains on the basis of reinforcement, how the composites are named, it is a very big family of polymer matrix composites.

So, depending upon the type of reinforcement that we are putting in or the shape of the reinforcement, there would be different types of polymer matrix composites. But one thing for all of you to remember is that when we are talking of a polymer matrix composite, there are two things that should be always kept in mind that the matrix would always be a polymer, and the reinforcement would always be in the term of a fibrous

material. Now a fibrous material can be continuous or discontinuous, it can be aligned in one particular direction or it can be randomly oriented. So, all these things we are going to see in today's lecture.

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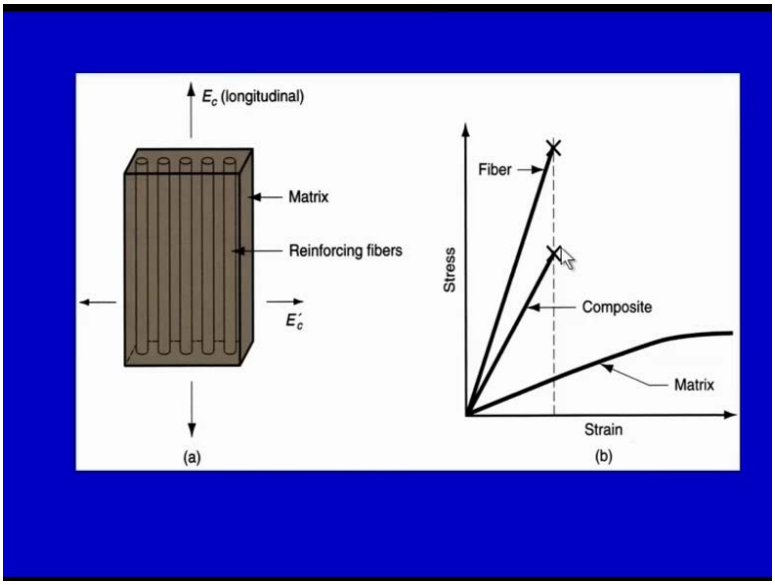

Now, here again on your screen, you can see, there is a very simple diagram in which we can see these round circular cylinders are fibers in this particular direction and these are again they have been classified as reinforcing fibers. So, these long cylinder inside this particular cubiod are reinforcing fibers and the rest materials is filled with the matrix. So, we have fibers in this particular direction only and we have matrix which is encapsulating these fibers. So, we have this modulus of elasticity in longitudinal direction and in the transverse direction also. So, we can see there are reinforcing fibers and there is a matrix. So, this is you can say one simple representation of a polymer matrix composites in which we are reinforcing fibers and bulk of the matrix. So, the matrix is in the form of a polymer which has been reinforced with the fibers now this fibers can be of different materials that we will see in the subsequent slides.

So, here on the stress strain plot you can see the stress strain behavior of a matrix and this is the stress strain behavior of a fiber. So, the stress strain behavior of a composite is lying in between the stress strain curve for the matrix and the fiber. So, this clearly outline one of the important aspects that we have already seen in the previous slides or in the previous lectures that the properties of the composites should be a combination of the

properties of the matrix and the reinforcement. So, here we can see the stress strain behavior of a composite is made up by the stress strain behavior of the matrix and the stress strain behavior of the fiber.

So, it can be very easily understood that when we are combining two different macro constituents together to make a composite material, the properties of the composite would be dictated by the properties of the two macro constituents. And sometimes it is also possible to attain those properties which are not possible with the individual constituents alone. So, this particular diagram shows represents physically how the reinforcing fibers are used to reinforce the polymer matrix, and then we have properties which are different in x, y and z direction. And here with the stress strain curve, we can very easily see that the composite represents the both the macro constituents, the constituents are the fiber and the matrix.

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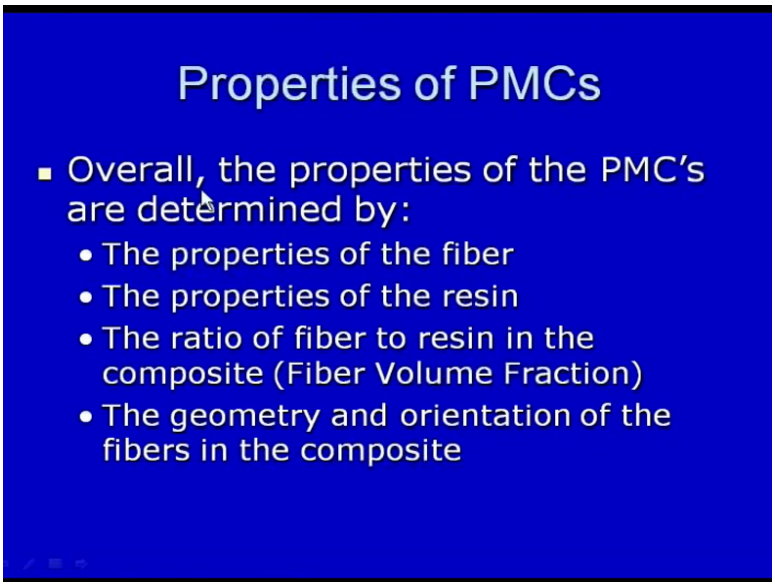

Now what are the properties of the PMCs. As we have seen in the previous slide, the properties are dependent on the properties of the fiber and the property of the matrix. So, here you can see on your screen, overall the properties of the polymer matrix composites are determined by the properties of the fiber, the properties of the resin, the ratio of fiber to resin in the composite which is called as the fiber volume fraction, the geometry and the orientation of the fibers in the composite. So, on this screen, it is just a continuation of what we have discussed on the previous slide. As we have seen the properties stress

strain behavior of the composite is dependant on the stress strain behavior of the matrix and stress strain behavior of the fiber. Or in other language we can see it is governed by the stress strain behavior of the matrix and the fiber and it lies in between the behavior in between the two characteristic curves. So, the same thing has been put in towards in this particular slide where we can see that the properties of polymer matrix composites are dependant upon the properties of the fiber, the properties of the resin, and the ratio of the fiber to the resin.

So, when we are combining the two micro constituents, the decision is in our hands, we have to take a decision how much fiber we have to add and how much matrix we have to add. Sometimes the fiber volume fraction may be 20 percent and the bulk of the material that is matrix can be 80 percent. On the other hand, we can have fibers up to 50 percent and the resin or matrix can also be 50 percent that is fibers 50 percent polymer 50 percent combined together to make a composite, so the decision lies with us. And the properties of the polymer matrix composites are dependant upon the amount of fibrous reinforcement, we have put into the polymer matrix.

The last point the geometry and the orientation of the fibers in the composite. So, if all the fibers are aligned in one particular direction, the properties would be different. If the fibers are randomly oriented, they are distributed randomly in the bulk that is distributed randomly in the polymer matrix, the properties would be different. Now depending upon the requirement we will see whether we want to use a randomly oriented composite or we want to use a aligned fibrous reinforcement in the composite, whether we need to have a continuous reinforcement or we can have a discontinuous, but aligned reinforcement. So, the reinforcement can be added in the polymer matrix in a number of ways. So that we will see in the subsequent slide with the help of a diagram that how the different types of composites are made with the help of different types of reinforcements being put into the polymer matrix.

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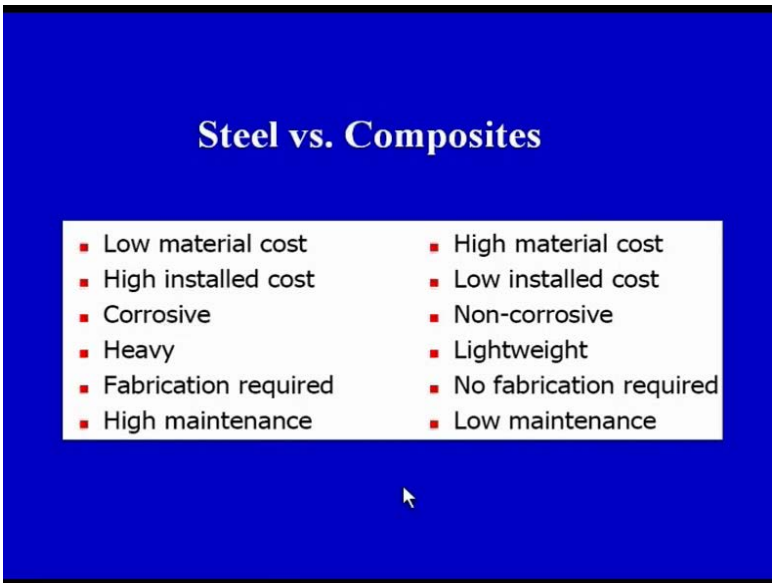

Now, this gives just a very I should say simplistic view of the comparison between the steel and the composites. On your left hand side, you can see, we have steel and the composites. Now steel we can say it has low material cost, I will just read out the some of the characteristics of steel. It has low material cost high installed cost, it can be corrosive, it is heavy, fabrication is required, if we want to make a steel structure different types of fabrication are required, sometimes welding may be required to join the two steel members together, and the maintenance cost are hugely high for steel. So, these are some of the important points in context of steel.

Coming on to the composites, I will just read out for you. Composites in the very beginning have high material cost, they have low installed cost, they are non-corrosive in nature, light in weight, no fabrication is required and low maintenance cost. So, we can see for any structural member, if we are comparing the two materials out of which we can choose our material. Composites usually give us a better alternative compared to steel, but yes in some specific instances, some specific requirements steel may even be better than the composites. For example, composites have a huge disadvantages in terms where the temperatures are very very high. Because the polymer may be able to sustain a temperature at a particular level; whereas, steel can sustain a very very high temperature. So, there are few areas where steel has got a lot advantage over composites, but these points have been highlighted where composites have an edge over the steel. A here in

this particular case lets take the last particular point is high maintenance in case of steel and low maintenance in case of composites.

So, suppose we have a underwater application, and we have used a a steel structure under water, so always there is a corrosive environment under water. So, steel may require frequent painting in order to or frequent coating on surface in order to avoid that corrosive environment. Whereas, if we are using a composite structure under water, as it is non-corrosive, it can be made non-corrosive as we have already seen in the previous lectures on this particular module that we can add some pigments or we can add additives in the polymer composites to make them non-corrosive. So, if we have made a composite which is non corrosive we have tailored the properties of composites in order to make it non-corrosive then this particular composite can challenge even steel in underwater application.

So, each and every point which has been mentioned as a comparative point between a steel and a composite, it can be explained with help of examples. For example, we can take point number four - that is steel is heavy, and the composites are lightweight. As we have seen in the previous lecture composites have a very good mechanical property of strength to weight ratio, so composites are light in weight. If we have aerospace applications, in aerospace application the first and foremost criteria is light weight. So, the composites have an edge over steel in aerospace application. So, because they may provide the same strength, but at a relatively lower weight. So, each and every point can be explained with help of examples. So, in these particular comparison, we can just have an idea that composites have got some specific applications in engineering structures. So, wherever steel is being used, it can be in certain circumstances be changed by the composite materials or the composite materials can be used for replacing conventional materials like steel and other structural materials.

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Now, what are the challenges in context of materials. So, we have seen one comparison which is a very very simple comparison between steel and a composite material. Now we are going to see that what are the challenges among different materials, our focus would be just to highlight the use of composite materials in certain engineering applications. So, we would be focusing on the applications and the specific properties of composites and how they have been challenged by the conventional materials. So, on your screen, you can see the very first point. Challenge from the technical innovation in metals. If we purpose the use of a composite materiel, there is a some innovation in the field of metals also; suppose we say that composites are most suitable or most suited for the low weight applications. There may be some innovations in metals, which are light in weight or there may be development of some alloys, which are light in weight. So, there is a competition between the composites and the metals industry. So for light weight applications also we have composites, but we have some alloys and metals also which can challenge the applicability of polymer composites in light weight application.

Coming on to point number two, on your screen, you can see misconception about the durability of plastic products. Sometimes we feel it is in our mindset that if it is a metal then it is going to be very strong, tough, hard; this is a Lehman's terminology for any metal. If you say how would you compare a metal and a plastic, the person would always give thumbs up approach for the metals. Why, because there is a general conception that metals are strong they are tough, and the durability of plastic products is always

questionable. So, there has to be a justification that yes plastics are equally or even more durable than the metals.

The third point combustion and smoke liberation characteristics, whenever we will purpose the use of a polymer matrix composite one of the doubts in the use or in the users mind would be the combustion and the smoke liberation characteristics that it can catch fire that is it can be inflammable in nature. So, combustion and the smoke liberation characteristics is another challenge which has to be addressed when we are talking of using of composites in everyday applications.

Fourth point long term durability and fatigue characteristics. Long term durability means the metals have been in use for a very long period of time, we can see metallic structures all around us, and the durability characteristics are already established for metals. Suppose I take a particular alloy and I want to design a structure with that particular alloy, I have the historical data available with me that this particular alloy under these particular operating conditions and in service conditions should be able to sustain this much period of life or this much period of reliable life. Or we can set the life of a particular structure, if we know the long term durability data for that particular material which is going to make that structure. But in case of composites which are materials which are not having life more than four decades; mostly this composites, this polymer metal composites have been developed in nineteen seventies, specifically for aerospace applications. So, the long term durability for composite materials is not yet available. So, when it is not available, there is always a doubt among the designers that how these materials are going to behave for a longer period of time, but yes these days there are accelerate testing mechanisms to find out that how the material will behave under certain set of conditions. So, long term durability and fatigue characteristics are also important when we are proposing the use of a composite material for a particular application.

Failure mechanisms of laminates and composite structural systems, so failure mechanism of laminates means that for a metal everybody knows, anybody who has studied engineering that if a load is acting on a material, how and the material is a metal how it is going to fail. Whereas in case of composites, it is not clearly understood because composites have un isotropic the properties are different in x, y and z. So, when you are loading the material in one particular direction, what is going to happen in the other directions that is not well understood, yes, the work is progressive in that particular

direction, but still the actual failure mechanism has to be established for composite materials then approved industry design codes and common repair system.

Till now, the composites are being developed. So, the standards have to be developed for the designs as well as for the fabrication of composite materials. So, that standardization process is still going on and because the family is too wide different types of fibers can be used to reinforce different types, matrices different types of polymers, so the standards that have been set for one particular family has to be adjusted for other particular family. So, this particular slide highlights on the challenges that the composites face from its counterparts or from the conventional materials. So, if I just read the slides this particular points on this particular slide from the metals perspective, we can see I have just read the slide from the perspective of composite material that what are the issues and challenges in context of composite materials.

If I see what are the advantages in terms of the metals in this particular slide, we can see first challenge from the technical innovation in metal. In metals industry, the focus is on developing low weight metals or lightweight metals. Misconception about the durability of plastic products, the durability of metal products is already well established; combustion and smoke liberation characteristics is not an issue with the metals, long term durability and fatigue characteristics data for metals is already available, when it is exposed to different loading and operating environment.

Failure mechanisms for metals are easily understood and well established and properly recorded in the design data books, and there are approved standard design codes for metals and there are proper repair systems for the metals. So, for metals industry, which is in lie in particular use for such a long time for metals lot many things have been established. Whereas in case of composite materials many things are in the process of establishment and few things have already been established. So, there are few challenges for composites from the metals industry, but there are new and new applications for polymer matrix composites that we are seeing in our everyday life. So, this particular slide and previous slide gives a comparison between the metal and a polymer composite and it highlights that what are the challenges for the polymer composite in context of the things, or the characteristics or the properties which have been already established for metals.

For metals we have a full design data books; for composites the process is going on, and it is not too far that when we will be having a complete design guidelines, a complete fabrication guidelines, a complete data book for composites also. In which which can be used for different types of fibers, different types of matrices, different types of additives and different types of processing procedure. So, the process is on and it is not too far away time when we will be able to see that the things which we are seeing established in terms of metals would also be established in terms of polymer composites.

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Then there are few challenges in general nature, those were the technical challenges which are there. Now there are few challenges, which are general in nature, for example, the cost justification. Processing methods developed for aerospace industry cost justification. Let me just highlight the cost justification. If you remember a slide on the comparison between steel and a composite, steel was the initial cost was low or the cost for steel is lower as compared to the cost of the composite material. So, whenever we are proposing the use of composite material, we have to emphasize that how we are going to justify the escalation in the cost or we are going to justify the high cost of the composite material in comparison to the lower cost of the conventional materials such as steel.

So, there are two important points which can be highlighted to justify the cost. First important point is the processing methods, which are used for fabricating or processing the composite materials were developed for aerospace industry. As I have already

highlighted in today's lecture that the composite material specifically the polymer matrix composite materials were developed for aerospace industry in the 1970's. So, when these were developed for aerospace industry, the processing techniques or methods that were used were also developed for the quality constraints or the quality requirements of the aerospace industry.

These particular days in today's scenario the composites are finding application in household items also, in automotive industry also, in marine industry also and the processing techniques that were developed are still the same or nearly the same which are developed for the aerospace industry. So, the quality constraints are quite stringent in aerospace industry, but they are quite relaxed in household application. So, when we are making a component for household application, we can use a different processing technique which is not so quality conscious. We can slightly compromise with the quality when the product has to be used in any simplistic household application. So, the processing technique which were developed for aerospace application have to be modified, so that they are able they become cost effective and they may be able to produce a particular product for household application at a lower overall cost. So, the need of the hour is to develop certain processing techniques which are not very costly.

The second important cost justification is the lowest cost bit accepted and no importance is given to the life cycle cost. So, as we are going to procure a particular material, we would be just looking at the lowest cost, we would not be taking the life cycle cost into picture usually this is the trend. So, when the composites have high initial cost, people are not going to accept the composite in place of any conventional material. But if we see the life cycle cost if you remember the slide on the comparison between the steel and the composite material, one of the points was maintenance. In case of steel, suppose I have given the example of underwater application frequent maintenance is required; whereas, in composite materials the maintenance requirements are less which leads to a lower life cycle cost of a composite material as compared to a high life cycle cost of a any conventional material. So, if we only focus on the lowest bit, we would never be able to propose the use of a composite material. So, these two points if taken into account, the two points being the processing technique should be reinvented to suit the needs and requirements of low end applications, and the lowest lifecycle cost material should be chosen.

And only at the first instance the lowest cost or the lowest cost bit should not be taken into account the life cycle costing should always be used as a criteria to select a particular material for a particular application. So, cost justification is another issue that should be in go in favor of the composite material, then the standardization issues standards not followed specifically in Indian scenario. So, there are may be this scenario may be some ten years back, but today there are lot of standards which have been developed and the composite industry has seen lot many changes over the last five to ten years. But at the very beginning there were few issues and challenges in context of the standardization, but today I can very empathetically put this point that lot of standards have been developed and all the standards are in place. But still there is inhibition there are few issues which are related to waste disposal there are fewer issues related to recycling, and finally, the resistance to change.

Again to emphasize these challenges of general nature, cost justification yes it can be done; standardization issues they are already been settled, there are already industry standard codes which are now in practice. Waste disposal, recycling and resistance to change are three issues which still require approval from the composites fraternity or from the engineering fraternity at large. Composites fraternity or composites people would always propose the use of the composite material; whereas, there are few challenges in terms of resistance to change. Always when a new thing, a new particular material or new processing technique or a new method of doing a job would be proposed there would always be a resistance to change. So, if we propose the use of a composite material for a particular application, always there would be resistance to change because that particular application is in place for so many years when the conventional materials have been used to make that product.

Now if I say, I will tell the industry to change from conventional material to advanced material like a composite, they may have that resistance to change. Although when we propose, we have all the standards in place, will all those standards will go and we propose the use of composite, but still there is a resistance to change. So, a change management is required and there is a complete branch of management which is change management which can be used or the principles of that particular tech or that particular method can be used to change the mindset of the people. So, there are challenges for polymer matrix composites. So, just to summarize there are few technical challenges,

there are few challenges which are general in nature. In the previous slide we have seen the challenges in context of material which are technical in nature. In the second slide, we have seen the challenges which are general in nature. So, in general nature cost justification can be done, standardize issues have been settled, yes the work is going on in waste disposal recycling and resistance to change.

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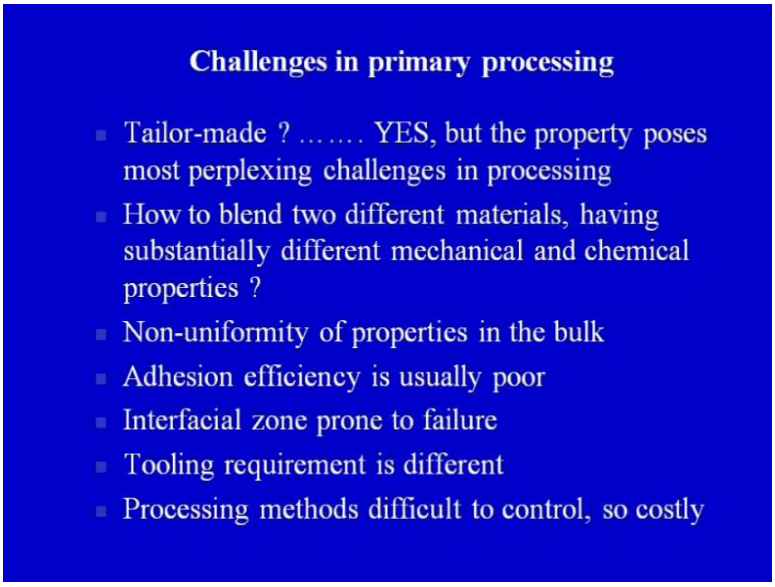

Now, coming on to the challenges in the primary processing, so when we are talking of a particular module, we are seeing in this particular module, we have to cover the processing of polymer matrix composites. So, there are two important things the polymer matrix composites and the processing. We have till now seen the materials aspect of polymer matrix composite; what are these materials, what are the macro constituents, what are the specific advantages, what are the specific challenges these materials have in context of or in comparison to metals. Now we will see when we have to process them then what are the challenges. Now we know what is a polymer matrix composite, what are the ingredients going into the polymer matrix composite that we have already understood that. There is a fibrous reinforcement, there is a polymeric matrix, we have to combine these two things together to make a composite material. When the composite is made, how it can challenge the conventional materials or what are the advantages limitations or the important properties of the conventional materials, what are the you can say application areas, properties of polymer matrix composites. In which particular areas, the polymer matrix composites can challenge the conventional materials and what

are the limitations of polymer matrix composites as one example I have given as the high temperature application, which is one of the important limitations of polymer matrix composites.

So, from the materials aspect, I think we have developed adequate knowledge which is required to go now towards the processing of these materials. Now what are the challenges of processing the polymer matrix composites, we would focus on these points. Let us see the point number one Tailor made, which we have already seen that depending upon the requirement. We can chose which type of fiber whether it would be a continuous or a discontinuous fiber, whether it would be aligned or it would be randomly oriented, we can take some decision in terms of fiber. We can take some decision in terms of polymer matrix, it can be thermoset, it can be thermo plastic what types of additives are required to be added.

So, we can design our material, we can make a polymer matrix composite depending upon the requirement or the design requirement or the in service requirement. But the major challenge is that how to blend these two parts together or two macro constituents together or the two constituents together in order to design and develop a composite material. See yes these materials have the properties of tailor ability, we can we can design our materials, but the property poses most perplexing challenges in processing. So, there are few challenges in the processing that are there because so many types of materials available, there are so many types of matrices available and when we have to combine them together, one particular process cannot be used. So Tailor ability of the polymer matrix composite, till now we understand it is a advantage, but how to incorporate this tailor ability into processing that is one of the biggest challenge.

Second point how to blend two different materials having substantially different mechanical and chemical properties. Now fibrous reinforcement has got its own mechanical and physical and chemical properties. The matrix has got its own mechanical physical and chemical properties. Now there are two materials or two constituents which have different properties and we have to blend them together in order to make a new material which we are calling as a composite material. So, this is another challenge because the properties are different, the techniques have to have that generability nature that they are able to blend these things together. If we suppose we are going to heat and blend the two things together, the melting point of fiber would be different, the melting

point of matrix would be different. So, the we have to take into account that which process can be used to blend this two things together. So, the first challenge is tailor ability; the second challenge is the difference in the properties of the macro constituents or the constituents of the polymer.

The third point is the non-uniformity of the properties in the bulk; in the bulk form, the properties are different, so that is another challenge. Fourth adhesion efficiency is usually poor. Now adhesion efficiency means that these are two important parts that go into the making of composite, there are two important constituent that go into the making a composite material. So, adhesion means how these will adhere to one another. So, adhesion efficiency means the bonding or in the loose terms we can say it is the bonding efficiency that how the fiber will bond with the matrix. If it bonds well, the resultant composite can take lot of load; if it does not bond well, the load taken by the composite would be comparatively less. So, we can say that adhesion efficiency is another issue we have to see that how the fibers should be used. Whether the fibers should be given treatment when they are being put into the matrix, so that the bonding between the fiber and the matrix is good the adhesion efficiency between the fiber and the matrix are extremely high. So, the adhesion efficiency usually sometimes is poor, therefore, the resultant composite is not able to take a lot of load. It is not able to bear the type of load that the composite has been designed for.

The interfacial zone is prone to failure sometimes. Now there is a matrix, there is fiber; suppose this is fiber, this is a matrix and they have been combined together. The interface is the line, the line between the fiber and the matrix. So, this particular interface sometimes may fail on loading. So, this is the interfacial zone which is prone to failure. If you remember in the previous lecture on this particular module, we have seen that there is a matrix, there is a fiber and there is a thin line separating the fiber and the matrix, which is called the interface. So, adhesion efficiency is poor, interfacial zone is prone to failure.

The tooling requirements are entirely different because some of the fibers like the glass fiber are abrasive in nature, and when they are flowing in the tool or when they are put in the tool, they are going to abrade the tool material. So, the tool I mean to say the mould which we are going to make the composite material. So, we will see what is a mould in the subsequent lecture. So till today, we can just take it as a we can just call it as a mould

tool. So, there is a mould tool in which we are putting our constituents that is the fiber and the matrix. So, fibers being abrasive in nature may abrade the tool or the tool material, therefore that is another issue which has to be taken into account when we are thinking of designing a process to fabricate the or to process the polymer matrix composites.

Then the next requirement is the processing methods are difficult to control, and therefore, they are costly. So, processing method there are number of processing method how they are classified that we are going to see, but there are few challenges in the control of these processing methods. Because if you see in today's lecture, the very first slide we have seen there is fibrous reinforcement and there is a polymer. So, polymer has got some viscosity, so it will flow. So, when the polymer will flow, we have to convert the polymer into a solid product. So, we will see in the subsequent slide that how the polymer which has got some viscosity is getting converted into a solid product that we are going to see with the help of some processes, but we have to control the flow of the polymer, and we have to incorporate the fibers in that flowing polymer. So, how to control this complete process is also a very big challenge.

So, in order to summarize this slide, there are challenges in primary processing. Yes tailor ability it is advantage in context of polymer matrix composite, but it is a big challenge when it comes to the processing of the polymer matrix composite. In terms of materials aspect, tailor ability is advantage in terms of processing aspects tailor ability is a challenge. The two components the fiber and the matrix or the fiber and the polymer have different properties, how to blend these two things together to be a composite material that is a challenge. Non-uniformity in the properties of the bulk is another challenge; adhesion efficiency between the fiber and the matrix can be poor, so that is another challenge. How to improve adhesion efficiency interfacial zone between fiber and the matrix is prone to failure, most of the failures may take place at the interfacial zone that is another challenge. Then the tooling requirements are different, the tooling requirements are not the same as that for metals; for composites we different type of the tooling requirements. And finally, the processing methods are difficult to control. So, the summary says that yes there are few challenges in context of the processing of the polymer matrix composites, and which we have to address when we are discussing the various types of various methods of processing the polymer matrix composites.

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Now processing of composites, important issues to be considered while selecting any manufacturing process. So, when we are selecting any manufacturing process, because for composites for polymer matrix composites, we will have a series of processes or we will have a different types of processes which can be used to blend the two constituents together. Now what are the two constituents, the two constituents are the fiber and the matrix. So, there are different processes which are used. So, how we are going to select or what are the criteria or what is the criteria we should be kept in mind when we are thinking of studying a particular process.

First is the economic viability of the process; second is the quality of the product to be manufactured, and third is the technical versatility of the process. How versatile is the process, what are the different types of products it can process, what are the different types of volumes it can process, the technical versatility - quality of the product to be manufactured, and economic viability of the process. Although the process is generating product of very high quality, but on the other hand it is very costly, so that does not give the economical product economical viability of the process has to be good quality of the product that is produced should be adequate or good. And the technical versatility of the product has to be considered when we are thinking of proposing certain methods for processing of polymer matrix composites.

Last point, give the summary. The need of the hour today when the of polymer matrix composites are being used worldwide in different applications. The applications spectrum has increased over the period of years. The need of the hour is high quality. So, the quality of the product which we are making out of a polymer matrix composite should be good. The product should have a good quality and it should be cost effective manufacturing. The product cost should not be very high owing to the manufacturing. So, we have to think of manufacturing method we have to study and understand the manufacturing method, we should generate or we should produce the composite products which are low in cost. So, the need of the hour just to summarize in single line is the high quality, cost effective manufacturing or high quality cost effective processing of a polymer matrix composites.

So, till now we have seen the materials aspect of polymer matrix composites and the slight you can say introduction towards the processing aspects. We have seen what are the challenges in the processing of composite materials, and we have seen what are the focus areas when we start our discussion on the processing of composites that is the economic viability of the process, technical versatility of the process, and the quality of the product produced.

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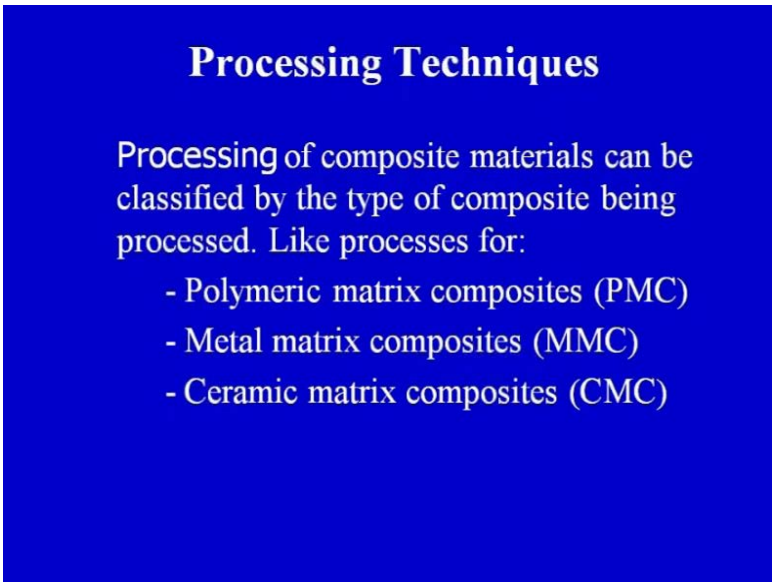

Now, processing techniques are different for different types of composites. Although the main important focus is same or the important focus is on high quality cost effectiveness

and technical versatility, but the processes which are used for the processing the composites on the basis on the matrix material. If you see in this particular slide, we are only focusing on the matrix the classification on the basis of the matrix material. The first one - the polymer matrix composite, the second one - metal matrix composite, third one - the ceramic matrix composites, so the polymer matrix composite, ceramic matrix, metal matrix, the matrix is the catch word. On the basis of the matrix, we have three different types of composites, and from the processing point of view the processing terms, the processing requirements, the processing needs are different from are different from all these three types of composites. So, our focus primarily would be on the polymer matrix composites in this particular module.

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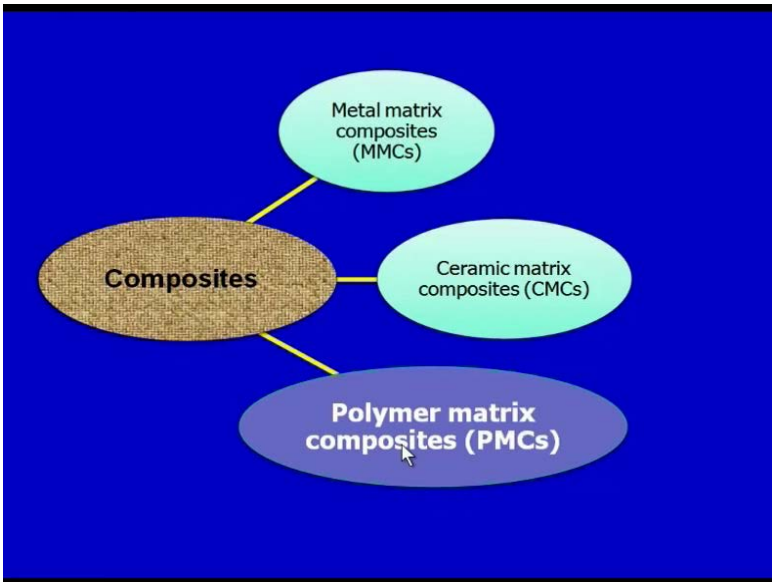

So, here you can see the composites can be processed, we can have metal matrix composite, we can have ceramic matrix composites, but in this particular case or in this particular module, our focus is on the polymer matrix composite. So, we would see different methods to process the polymer matrix composites. So, in the next lecture our focus would be on certain techniques which would be used for processing the polymer matrix composites. More importantly we would focus on one of the simplest and most economical method of making the polymer matrix composite that is the hand lay up technique.

So, just to summarize what we have covered in this particular lecture, we have covered the basic aspect of polymer matrix composite, what are the constituents that go into the polymer matrix composite, how the polymer matrix composites compare with the conventional materials, what are the challenges for the polymer matrix composites. When they are purposed as the alternative material to the conventional material such as steel, we have seen what are the challenges in the processing of the polymer matrix composites, and finally, we have seen that the processes are different for metal matrix composites, ceramic matrix composites and polymer matrix composites. So, this particular module is focusing on the processing of polymer matrix composites; and in the subsequent lectures, we would be focusing our attention on the various techniques which are used for processing of polymer matrix composites.

Thank you.