Processing of non metals

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Module - 7
Secondary Processing of Composite Materials
Lecture - 1
Drilling of Polymer Matrix Composites

Good morning to all of you with this become to the end of the course on Processing of Non-Metals. As today we are going start our last module that is secondary processing. In the very beginning during the first module, we have discuss that in this particular course we are going to cover the processing techniques for various types of non-metals which we have covered in the different modules. But secondary processing is imperative when we have to make or fabricate or process products out of non metals using primary processing techniques which we have already covered. We are able to generate various shapes of the non-metals. For example, we have seen how different products can be made out of polymers, how different types of products can be made out of ceramics.

But certainly when a very large structure has to be made. It cannot be made in a single shot. Therefore, we have to make use of the secondary operations, so that we are able to assemble the whole product or the whole structure together. Although, the big structure would be made in a large number of small, small, small, small parts, and these small small parts will be made by the techniques which we have already covered in the primary processing of various types of non-metals. But certainly in order to a facilitate, the assembly operations, we require the secondary operation. There are different types of secondary operations that are done on the various types of products that are made with metals and non metals and the operations are like machining. In machining, we can do drilling edge trimming or other forms of machining operations hole making operations and we also undergo or or we also undertake joining of the various members.

Joining can be adhesive joining, it can be a permanent joining, we can use nuts and bolts for fastening the joints. So, different types of all these operations fall under the secondary operations. In primary operations, we have all the techniques, we have already discussed which are use to generate the various shapes of different types of non metals. So, now, in this particular module that we are going to cover that is going to start today,

we will be having five lectures, in which we will be discussing the various types of secondary operations like on your screen. You can see the title of lecture number one in module number seven is drilling of polymer matrix composite. So, we will start with the challenge is that what are the challenges when we have to machine these advanced materials such as polymer matrix composites. We will try to address that how this challenges have been overcome by the research community world wide.

Then we will have a lecture on the joining aspects of the composite materials, in which we will see what are the different types of joints which have which can be used to make assemble, different types of components together. And then we will see that how under different types of loading these joints behave and also we will see various tools and techniques that are used for doing research in the field of secondary processing of composite materials.

Due to start with let us just revise what we have already covered for the listeners, or for the audience, who have not listened or who have not undertaken the lecture on polymers or the polymer matrix composite, because in the title today there are two important aspects. What are the two important aspects first one is the process and second is the material the process is drilling which is very common and every engineer knows about the drilling operation, and the second aspect is the polymer matrix composite. So, drilling is well-known to everybody, our focus now would be just to revise the basic concept of polymer matrix composite. So, that we are able to correlate the two things together that is the drilling and the polymer matrix composite that when we perform the drilling operation on a polymer composite, what type of problems take place, what type of problems arise and what are the remedies to overcome those problems.

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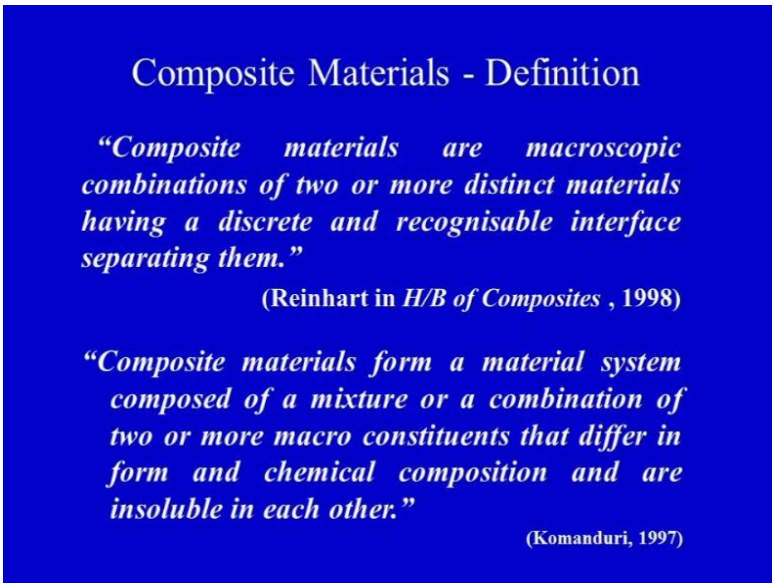

Now, what are composite materials? This definition already we have seen. The definition was covered in one of the important lectures on module five, in which we have seen the different types of composite materials. So, composite material as the definition goes composite materials are macroscopic combinations of two or more distinct materials, having a discrete and recognizable interface separating them. So, composite is basically made up of two macro constituents which are combined together and they are mechanically mixed. So, that they have a recognizable interface separating the matrix from the reinforcement. So, two constituents are called the matrix and the reinforcement. The reinforcement is the load-bearing member and matrix provides the bulk of the material and supports the reinforcements, and helps in the load transfer among the various reinforcement fibers or various reinforcing fiber.

So, basically in this definition it is very very clear that a composite material is made up of two macro constituents or two different constituents which are mixed together mechanically and there is a interface separating them. According to the second definition, we can see composite materials form a material system composed of a mixture or a combination of two or more macro constituents that differ in form and chemical composition and are insoluble in each other. So, these two macro constituents are insoluble in each other, they have a distinct interface separating them and one of the macro constituents is called a matrix, another constituent is called a reinforcement. So, we mix this two macro constituents together, what are the various mixing techniques or

we should say processing techniques for making a composite material have already been discussed in module five. And today again we will revise that what are the primary processing techniques for composite material, before shifting our attention towards the secondary processing of polymer matrix composites.

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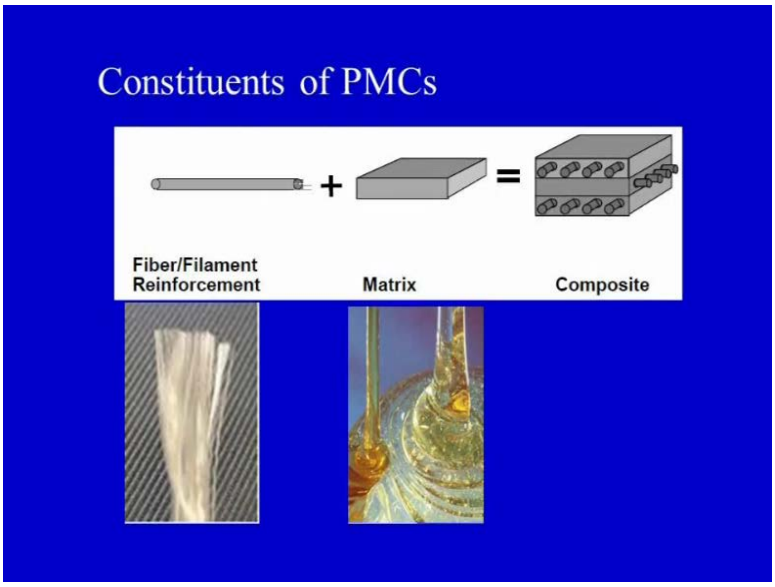

Now, this is a very simplistic diagram or very simple diagram which gives us an idea that how a composite material is made. Although, we have already studied all the processes I should not say all the but most of the processes which are used for the processing of polymer matrix composites in one of the previous modules. But again just to revise, we can see a composite material is made up of two constituents which have a fibers reinforcement and a bulk of a matrix. So, in case of polymer matrix composites, on your screen you see PMC's. So, PMC means polymer matrix composite. So, matrix in this case would be a polymer and the reinforcement in this case would be a fibres reinforcement different types of fibers can be used as the reinforcing materials for example, glass fibers carbon fibers or aramid fibers. So, we have the fibres reinforcement, it can be randomly or oriented shot fibers or it can be a long fibers unidirectional or oriented or we can a woven mat in which we a fiberes in both the directions x direction also and y direction also.

So, we have fibers, we have the matrix, and we combined the two things together and finally, we get a composite material. All these details have already been discussed in

module five. So, once we get a composite material, we get a adequate shape of a material using any of the process like pultrusion, filament, winding, resin, transfer molding or vacuum bag molding. Any process is used to give a shape to a composite material by combining the two macro constituents together mechanically that is the two macro constituents that is the fibres reinforcement which can be any type of a fiber and in any form and the matrix.

Matrix can also be a thermoset matrix or a thermoplastic matrix, and there are different types of thermosets and different types of thermoplastics. So, we have the polymer matrix and the reinforcing fibers and these blend it together with any of the primary processing techniques, and we get a composite material as you can see on your screen this is a finally, a composite material in which we have we can see the fibers (( )) out of the matrix material. So, this is the final composite which we have got now. Suppose this particular composite has to be used as the structural member in a very big structure this has to be assembled with the other structural members they may be composites or non-composites. So, when this particular product which we have made out of a fibrous reinforcement and a polymeric matrix this particular composite product or we can say a fiber reinforce plastic product or a polymer matrix composite product.

This particular product when it has to be assembled with any other product, which may be a composite product or may not be a composite can be a any metal or it can be wood or any other material. So, when these two structural members have to be combined together, we have to have certain secondary operations in terms of machining of holes or in terms of adhesive joining or in terms of mechanical fastening. So, we have to take undertake certain secondary operations in order to assemble a composite part to another composite part or to apart made up of any other material. So, this is the basic concept with which we have designed this module, in which we would be covering the machining aspects of the polymer composite. And we would be seeing the joining aspect in which we would focus on micro wave joining of polymer composite as well as we would focus on the adhesive and the mechanical joining of polymer composites.

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So, processing of composites, basically as we have seen in the previous slide we have to combine the two macro constituents together to get a final composite part. So, important issues that need to be considered while selecting any processing technique or any manufacturing process is the economic viability of the process and the quality of the product to be manufacture as well as we have to see the technical versatility of the process. If you remember in module five, we have seen so many different processes - open mold processes, closed mold processes, in others such as pultrusion and filament, winding and each process has got its technical versatility. Each type of process can be applied to produce or to process different shapes and sizes of the composite product.

So, whenever we have to choose a particular process, we have to focus on the economic violability, we have to focus on the quality of the product that it can produce and the technical versatility of the process. So, today in today's competitive business environment, the focus is on high quality cost effective manufacturing or in other terms we can say high quality cost effective processing.

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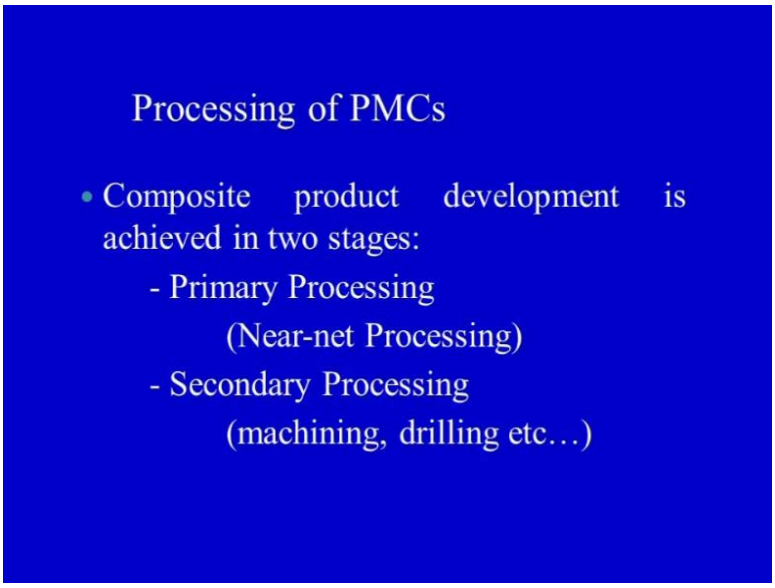

Now, this processing of polymer matrix composites. These are the previous slide we have seen, it is a very general slide in which we will seen that what should be the focus, we should be cost effective, we should focus on good quality and we should focus on technically versatile processes. So, processing for PMC is can broadly we categorized into two categories. As you can see on your screen, the composite product development is achieved in two stages that is primary processing and secondary processing. In primary processing, we are near net processing; and secondary processing, we go for machining drilling and joining. And there are other secondary processes such as sometimes we want to do some surface treatment of the final surface which has been made all these processes fall under the secondary processing.

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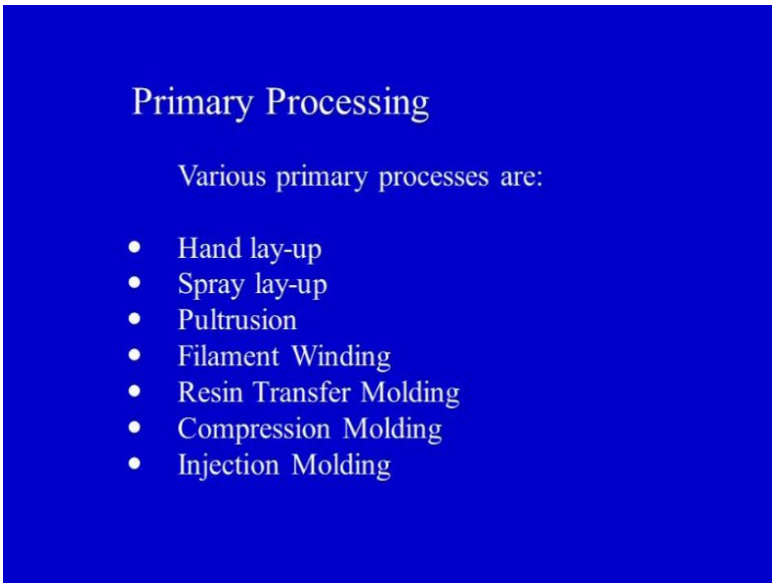

To whatever techniques we have seen in module five such as the hand layup process, spray layup process, resin transfer molding, vacuum bag molding, pultrusion, filament winding, compressing molding all these processes fall under the primary processing. Why we call them primary, because in these processes we generate a particular shape of the product. Now once this product is ready, this may be requiring certain secondary operations to facilitate the assembly of this particular part with other parts which I have already emphasized in the beginning of today's lecture.

So, secondary operations are required or secondary processing of the composite parts made by primary processing is required. In order to facilitate the assembly operations or in order to assemble these particular part with any other part of made up of any other material sometimes, we may required the secondary operation for the finishing and sometimes the secondary operation may even be required to improve the sales appeal of the product. So, secondary operations are necessary and the information and the knowledge about the various types of secondary operation for advanced material such as polymer composite is really really important.

So, today we will focus on what are the problems when we try to make a hole inside a composite material and specifically a polymer matrix composite material. So, various type of primary processing techniques which are able to generate the shape of the polymer matrix composite or the fiber reinforce plastic are now what are these processes

some of the processes are there. On your screen, you can see we can use a hand layup process, we can use a spray layup process, pultrusion, filament winding, resin transfer molding, compression molding, injection molding. So, at least there are six to seven processes on the screen, and most of them we have already discussed in module five which are which processes are able these processes are to generate a shape of a composite product by combining the fibrous reinforcement with the resin was matrix. So, we have the reinforcement in terms of fibers we have matrix and these processes are able to combined the fiber and the matrix in order to give us a composite product.

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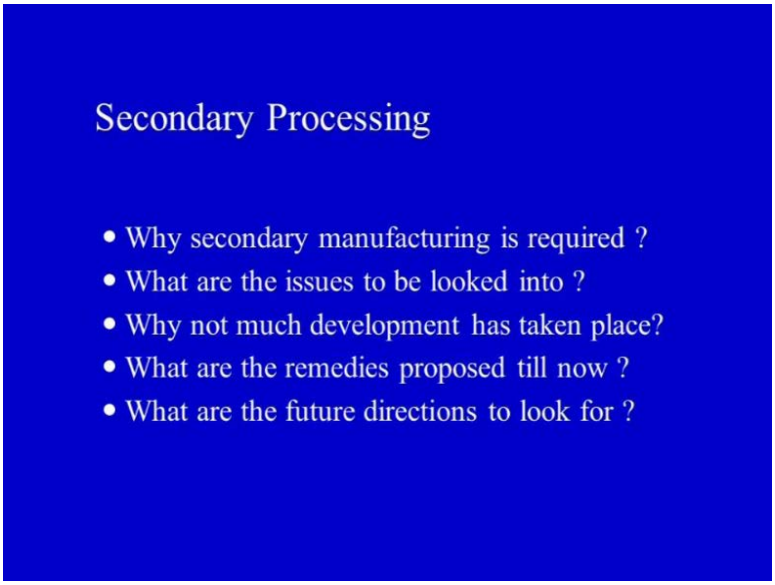

Now, secondary processing of that composite product is required to ascertain. So, many different objectives which I have been highlighting in the today's lecture. Now, secondary processing again coming on to the secondary the product we have already got using the primary processing techniques there are. So, many primary processing techniques I have listed only the most important once there are other important techniques which are there which are use to generate the shape of the composite product

But once the composite product has been made, why the secondary processing is required. On your screen, we give will have an idea why secondary manufacturing is required or secondary processing is required. What are the issues to be looked into like, what are the challenges, why not much development has taken place in the secondary processing of polymer composites or for that matter composite materials in general like

metal matrix composites or ceramic matrix composites or polymer matrix composite. What are the remedies proposed till now. Because there are few problems associated. So, we have to suggest certain remedies also to overcome these problems or what are the future directions to look for. So, we have to see that in which direction the research should go as one of our lectures. In this particular module seven would focus on the tools and techniques for doing research in the field of secondary processing of composite materials. So, these are some of the questions with which we further discuss the various issues and challenges related to the drilling of polymer matrix composites.

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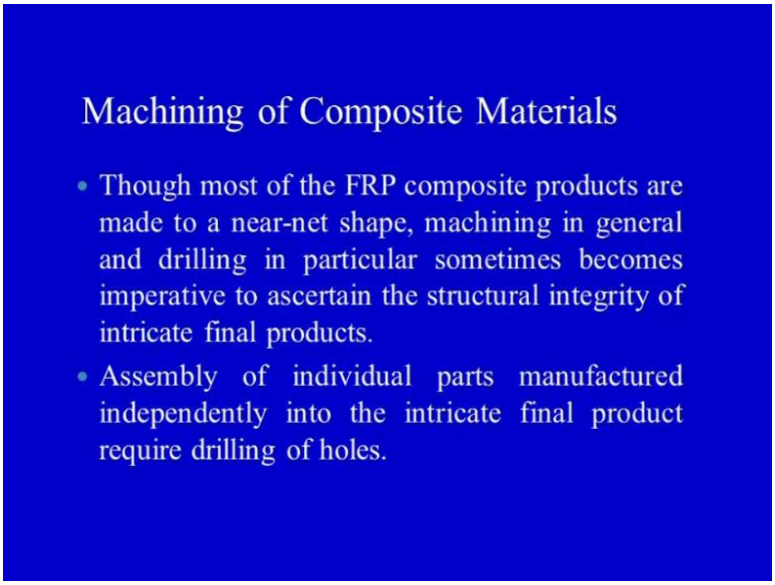

Now, machining of composite material, this is the summary of what I have been discussing today in today's lecture. You can just read the point though most of the FRP composite products are made to a near-net shape; near net shape means to the exact shape of the final product. So, most of the composite products are made to the near net shape. So, machining in general and drilling in particular, sometimes becomes imperative to ascertain the structural integrity of intricate composite products or intricate final products. So, again the point is very very clear to just explain this point, most of the composite products are made using the primary processing techniques such as listed in the previous slide that there are so many processes which are used to produce the near net composite products.

But once these products are ready, and then they have to be a send assembled with the other components, in those cases we require the machining operation. Why, because we will make a hole and then we can use nut and bolt assembly to fasten this particular product to the other product. So, assembly operations are facilitated, because of making of holes or machining of the coroners of the composite product. So, assembly of individual parts processed independently into the intricate final product require drilling of holes. So, again assembly of individual parts, which have been manufactured by any of the primary processing techniques independently. So, these parts have been made independently.

Suppose let us take an example, I have a big composite product, in which there are five different parts part number a, b, c, d and e. There is a big composite product, and it is made up of or it is assembly of five different parts a, b, c, d and e. A, b, c, d and e these are the parts and these can be processed by any of the primary processing techniques that we have already covered such as hand layup process, spray layup process, filament winding, pultrusion. So, these products five different parts can be made by all these processes, but when these five different parts have to be assembled together to make a single unit composite product, in those cases we require the assembly operations to take place. And this assembly requires the drilling of holes sometimes or sometimes the edge trimming, so that the one parts fits into the other part.

So although there are so many machining operations which can be done, but drilling is most widely practiced operation in polymer composites. So, again I am emphasizing the last point that why drilling is a required or why machining of composite products is required. Assembly of individual parts manufactured independently into a final product or a fine into a final complex product requires the drilling of holes. Now, it is easier said than done that we can make a hole easily into a composite product. If you remember in module one we have seen that non-metals have a property that they are soft, and when there soft people may have a notion that it is easier to machine them, but it is not the case. There are so many challenges associated with the composite materials. So, when we machine a composite material there are so many issues and challenges which have to be taken into account. Now one by one we will see these challenges that have to be taken into account, while we try to make a hole inside a composite material.

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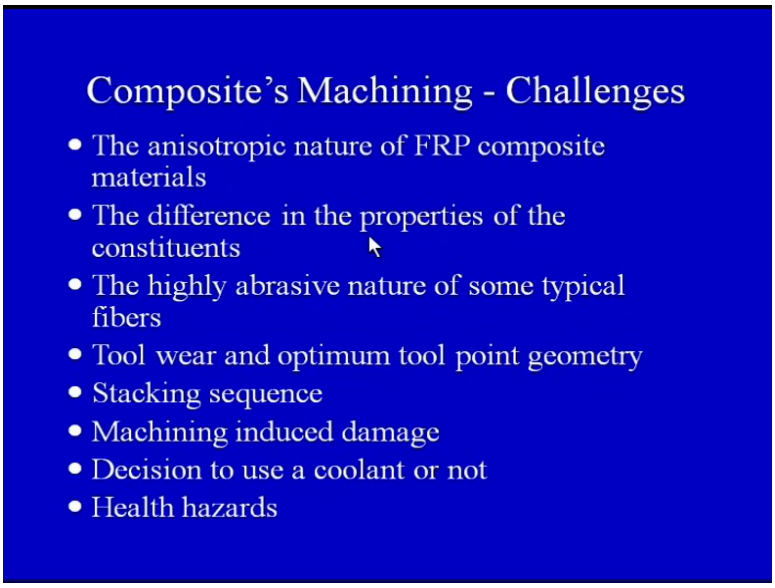

So, point number one on your screen, the anisotropic nature of the FRP composite materials. So, here we have two types of constituents going into a composite, FRP means fiber reinforced plastic; FRP - fiber reinforced plastic or fiber reinforced polymer. We have been using the term polymer matrix composite. So, we have a polymer matrix which has been reinforced with the fibers and we are calling it a fiber reinforced plastic. Anisotropic nature means that all the fibers suppose are oriented in one particular direction, we have a aliened fibers in a particular direction then the properties would be different in x, y and z direction. So, when the properties are different in x, y and z direction at different points in the bulk of the composite material, we have a anisotropic material in our hands. And when we have a anisotropic material and we are trying to machine it, this property of anisotropy may affect the machining behavior or the machining characteristics of the polymer matrix composites, because the properties of the material are different in x, y and z directions. So, anisotropy place a very important role in defending the machining behavior of polymer matrix composites.

Point number two: the difference in the properties of the constituents. So, we have seen what are the constituents, the constituents is a fibres reinforcement and a polymer matrix. So, we have a fiber and we have a polymer and if you remember we have seen the stress strain curve for the polymer that is the matrix and the fibres reinforcement and there is a distinction in the property similarly the other physical and chemical property is a also different for the fibres reinforcement and the resinous matrix. So, the matrix and

reinforcement they have different properties and they will render them self differently to the machining operation. So, the difference in the properties of the constituent also affect the machining behavior of the polymer composites. You can just imagine that we have a composite laminate in which we have the fibers, and we have the polymer matrix, when the drill is trying to remove the material, the drill will encounter at one movement of time the fiber and at immediately after another movement it would find the matrix. So, the property is a different, and therefore, we will get different responses when we are making a hole in a polymer composite. So, the important point is the difference in the properties of the constituents affect the machining behavior of the polymer composites.

The third point - highly abrasive nature of some typical fibers, because we have the fibrous reinforcement in the polymer matrix, these fibers sometimes some of the fibers sometimes are abrasive in nature, for example, the glass fibers. So that has to be taken into account while we are selecting that tool material which would be used for the machining operation. Because if the fibers are abrasive in nature, they will abrade the tool material, and the tool we are would be very high and the tools have to be replaced at intermittent intervals of time or regular intervals of time. So, that we do not want we want to have a longer tool life. Therefore the highly abrasive nature of the typical fibers may also be a challenge when we are trying to machine a composite material which has been reinforced with abrasive fibers.

As already emphasized, next point, tool wear and optimum tool point geometry. In today's lecture we will see different types of tool point geometries which are used for making holes inside the composite laminate. So, tool wear and optimal tool point geometry is another challenge. We have to select that which particular geometry should be use for making a hole inside a composite laminate or what particular single point tool geometry should be able to should be used in order to provide a good surface finish if you are trying to machine the composite material.

Then thus stacking sequence although we have not investigated or studied or we have not discussed the design aspects of the composite material, but stacking sequence is one of the important aspects, which means the how the layers are staged up in a laminate. So, if I have a laminate suppose of four layers, so all four layers can be made up of the same material, for example, the glass fiber and the epoxy matrix. But in certain cases, in order to have some specific design requirements or in order to design a composite material for

a specific application, we may have these layers of different materials also. Such as on your screen, you can see the word stacking sequence. We can have different layers of different materials which is called the stack, change in the stacking sequence. So, stacking sequence, we can a one layer of carbon fiber, another layer of glass fiber, again carbon, again glass or in between we can have sometimes metallic layers also. For example, aluminum plates or aluminum layers can be aluminum sheets can be put inside the lamination sequence, when we are making a laminate.

So, laminate may be made up of same material, all layers of same material and a laminate may be made up of all layers of different material. So, this is called the stacking sequence, and when the stacking sequence changes, the machining behavior will automatically change. Because if you have metallic sheets inside the laminate, the drill or the cutting tool will encounter the composite material as well as it will encounter at a certain depth the metallic material. And therefore, the whole machining characteristics would be affected and the whole machining behavior would be affected with the stacking sequence.

Next point on your screen is the machining induced damage, which is the most important aspect in case of drilling of polymer composites or machining of polymer composites. Why, because most of the holes that are made are rejected, because of the damage that takes place during the drilling of polymer composites. We will see what are the different types of damage forms that are noted while drilling composite materials, but machining induced damage is an area where people or researchers worldwide are putting efforts, so as to how to reduce the machining induced damage. There are various approaches which has been suggested which we would be covering in this particular module to reduce the drilling induced damage. So, our focus would be on finding out the remedies suggested for reducing the damage, when we try to make hole inside a composite material and more specifically a polymer matrix composite material.

Next point on your screen, the decision to use a coolant or not, we have to take a decision should we use a coolant or should we avoid the coolant. Coolant would also be containing certain chemicals and the polymeric matrix is also you can say a type of a chemical. So, at a elevated temperature when the drilling operation or the machining operation is going on slight increase in the temperature may be noted, and at that elevated temperature the matrix may have a affinity towards the chemical which we are

using for the cooling medium. So, we have to take a judicious decision and we have to decide that whether the matrix material will react with the coolant material or will not react. If it will not react then certainly we can use the coolant, and also when we are using the liquid or a water based coolant there is a tendency in the composite material to absorb the water and swell in size. So, all these points have to be taken into account.

The last point is the health hazards. Sometimes this chips that are generated during the machining operation or the drilling operation are never continuous in nature specifically in case of thermoset materials. So, when we do not get continuous chip, the material that is removed in the form of small small fibers, or you can say it is a powdery material, and the lot of dust is generated because of the machining operation. So, this dust should not be inhaled by the operators or the engineers while performing the machining operations because it can calls severe health hazards. So, the dust that is generated or the we can say powders that are generated because of the machining action are dangerous for the health. So, proper precaution should be taken to avoid inhale, in haling of all these types of dust or dirt generated because of the drilling or the machining action

So, on your screen you have seen that there are so many challenges that are there which engineer or scientist has to encounter when he is going to perform the secondary operation that is specifically machining or drilling in the polymer matrix composite. So, these are some of the challenges, but research and development has taken place and lot many facts have already been establish. So, there are certain facts which help us to perform a good quality and cost effective drilling in composite materials, and most commonly used composite that is the polymer matrix composite materials.

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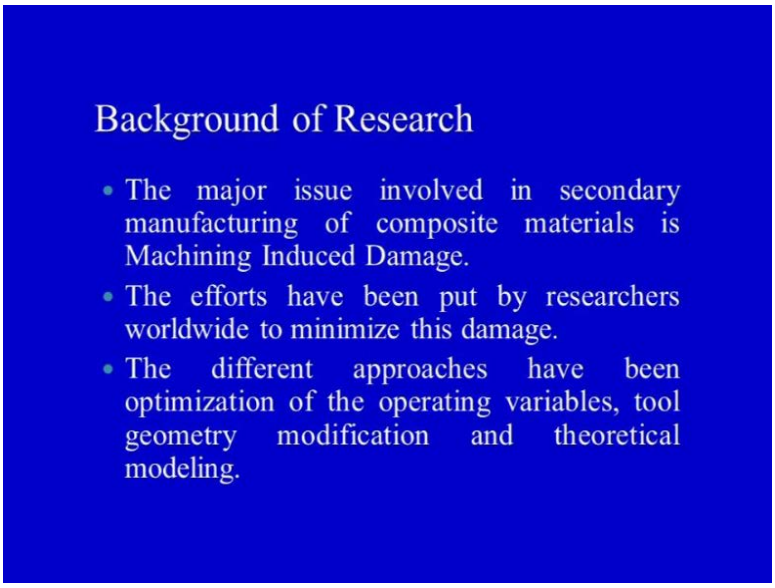

Now, what is the research that has taken place the major issue involved in the secondary manufacturing of composite materials is machining induced damage which I have already emphasized in the previous slide that one of the important or paramount important material or paramount an important objective is to minimize the machining induced damage. One of the paramount objective means one of the most important objective of the research community is that how to minimize the damage that takes place during drilling or machining of polymer composites. So, again I want emphasize you can read on your screen the major issue involved in secondary processing of composite materials is the machining induced damage and the objective of the researcher is to minimize this drilling induced damage the efforts have been put by researchers worldwide to minimize this damage

So, important point is the damage and the efforts have been put to minimize this damage. The different approaches have been used such as optimization of the operating variables when we are machining. There are few operating variables that are use or that are we can say important for the process, the process variables are for example, we want to make a hole, two important operating variables or process parameters are the cutting speed and the feed rate. So, researchers have tried to optimize that at what speed or at what cutting and at what feed rate we should use the tool. So that we are able to generate a good quality hole. So, optimization of the operating variables, because if we use the very cutting speed and a very high feed rate we may not get a good quality hole.

On the other hand, if we are using a very slow speed and a very low rate of feed, we may still not get a very good quality hole. So, optimization of the operating variable specifically in case of drilling operation, we have to find out that at what cutting speed and feed rate the hole should be made by the cutting tool. So, that we are able to get a good quality hole. Then what are the other things to be optimized, we have to optimize the tool geometry that which type of tools geometry should be use.

In today's lecture, we will see that what are the different types of tools geometry is which are use for making holes in the composite material and then we have to see we have to try to model the hole whole process. So, that we need not do experimentation for each and every class of the composite or the polymer composite. If you remember we have seen that polymer matrix composites is the very big family within this family, there are so many members we can have different types of fibers like the glass fibers within glass also there are different types of glass fibers which can be used.

Then we can have carbon fibers, we can have aramid fibers. So, there is a variety of fibers, which can be used as the reinforcement materials then we can have different types of matrix materials broad classification thermo sets and thermo plastics. In case of polymer matrix when we have a polymer matrix, we can have thermo set and thermo plastic within thermo set and thermo plastic we can have further different types of polymers which can be used. So, there is a wide variety of polymer matrix composites available, and suppose we establish the operating variables the cutting speed and feed rate with a single tool point geometry, because we have to optimize the tool geometry also. There are different types of tools that can be use. So, for one particular tool, if suppose we are able to find out that this particular tool at this much of cutting speed and this much of feed rate will make a acceptable quality hole in a polymer composite.

This particular result cannot be duplicated for the other class of composite material or the other class of polymer matrix composite. Why, because the thermoset matrix or thermo plastic matrix may be different or the type of polymer which has been used is different the fibrous reinforcement is different. The reinforcement may be continuous in the previous case, but now it has a discontinuous or randomly oriented reinforcement. So, for each and every talk class of composite material, we cannot go for experimentation and then finding out the operating variables. So, for that important aspect there is a important term on this particular screen that is the theoretical modeling. So, modeling of

the process can be done, the model which has been developed can be verified with the existing experiments and then we can try to use this model for the other materials and the other types of tools, so that we are done away with the experimentation. We are only now using the model which has been verified with the experiments earlier, and now we can predict the type of forces that can generate or the type of damage that can take place because of the model which has been generated. So, it will help us to reduce our experimental work and it will help us to reach to our objective of making a hole with minimum damage in the least possible time.

So, researchers worldwide have try to develop the theoretical models also which in a way try to minimize the works of the scientists and the engineers by providing a readymade tools which can help to predict the damage and the foresees which can be generated during the drilling of polymer matrix composite. So, the research work is going on towards minimization of the machining induced damage and some of the focus areas of research has been highlighted. Those are the optimization of the operating material operating variables tool geometry modifications and the optimization of the tool geometry and the theoretical modeling.

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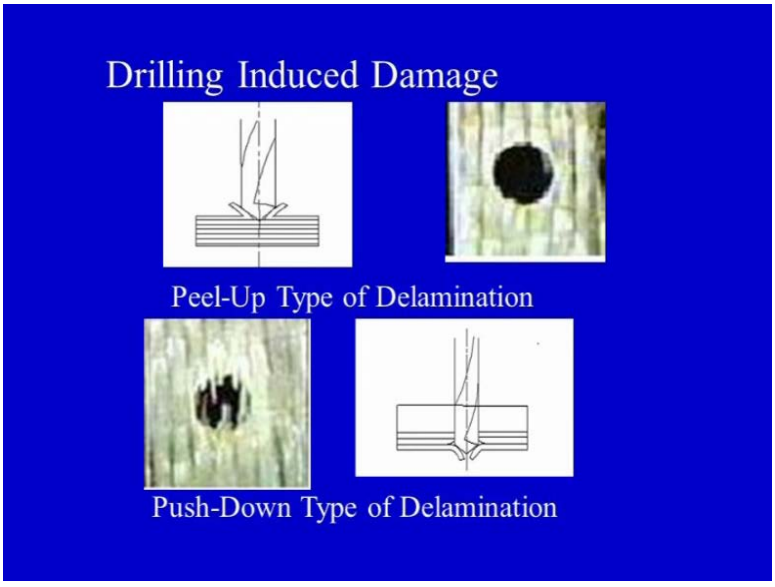

Now, this particular diagram on your screen shows the drilling induce damage. Now our focus is on the drilling operation in the polymer matrix composites. So, on your screen, you can see this is the damage that is called peel up type of delamination. This has this

terminology has been given by professor (( )), this peel up type of delamination in one of his papers. So, this peel up type of delamination basically means that the layers at the top of the laminate. Now this is a polymer matrix composite material in which we have different layers of glass fibers or carbon fibers or aramid fibers and which have been impregnated properly with the matrix material. The matrix can be epoxy or it can be any other type of polymeric matrix. So, we have a laminate of different layers or different lamina staged up in a definite stacking sequence to make a laminate we can have layers of all of same material. We can have layers of different materials, but when we have a laminate, we are trying to make hole inside the laminate in the beginning of the hole making operation some of the layers tries to get peeled up.

These are the layers top layers trying to get peeled up and this peeling up action would depend upon the operating variables and the geometry of the drill that we are going to use for making a hole inside the composite material. So, because this top layers try to peel up, this is called the peel up type of delamination. And on the other hand, as the drill exists from the bottom most lamina or the bottom most plies or the bottom most layers anything you can call the bottom most layers are shown here this laminate may be having suppose eight layers. So, the last two or three layers have the tendency to open up because of the constant feed rate and the thrust force being exerted during the drilling operation. So, these bottom most layers have the tendency to open up and when these layers open up they result in the push down type of delamination.

So, we can have peel up type of delamination we can have push down type of delamination and we can see that the peel up delamination is not that severe as compare to the push down type of delamination. So, another point that we can conclude from this slide is that the push type of delamination is much more severe and can cause extensive damage around the drilled hole in case of drilling of polymer matrix composites. Then we have the circularity defect sometimes we want with these all the horizontal lines represents the fibers.

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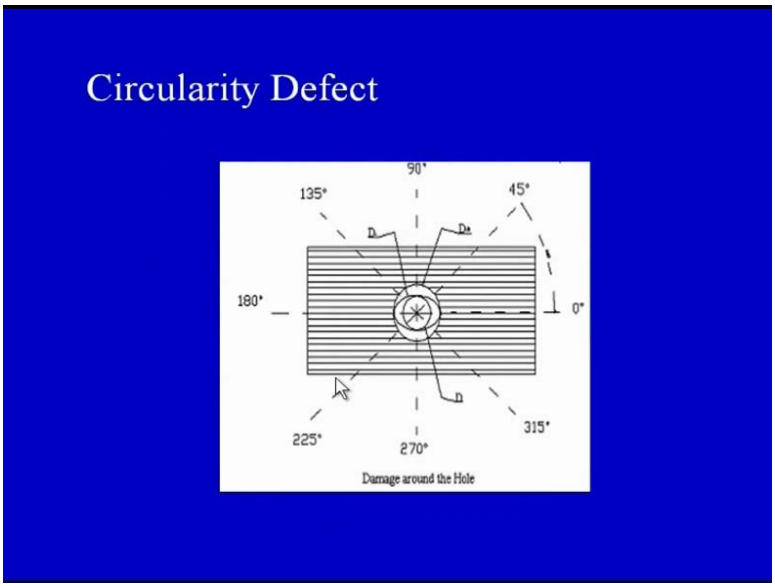

This is the top view of the hole. This is the top view of the hole, we want to make a circular hole, but sometimes we get a elliptical hole; why, because of the direction of the fibers. These all the fibers in one particular direction, all the fibers are in the direction of x axis and there are no fibers in the y axis. So, when we have all the fibers in the x direction, we are getting a hole which is not particularly circular and it is resulting in a hole which is elliptical in nature. So, we are not getting the exact hole that we want. So, that is called the circularity defect because of the anisotropic nature of the composite. And all the fibers being oriented in one particular direction, we are not getting a exactly circular hole we are getting a elliptical hole. So, this is called the circularity defect. So, three major types of defects we have seen peel up type of delamination at the entry point of the drill in to laminate push down type of delamination at the exit point of the drill from the laminate, and the circularity defect that is in plane defect all around the drilled hole.

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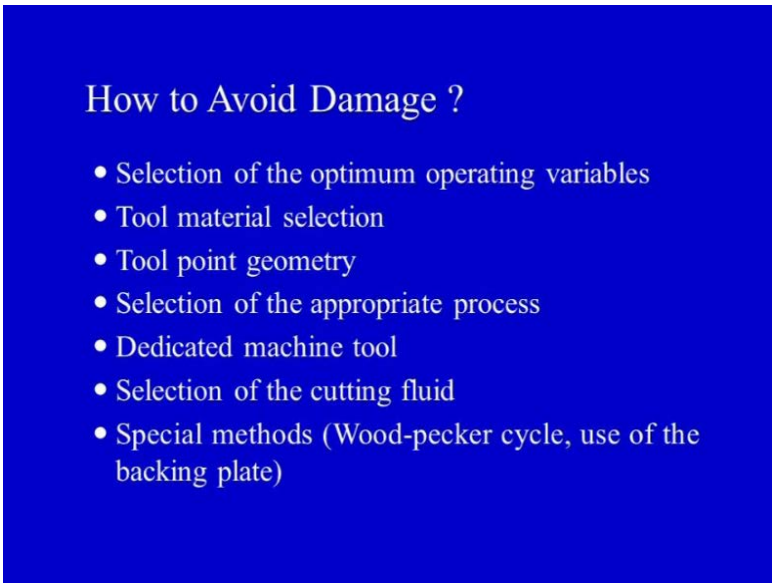

Now, how to avoid damage, now we have seen the damage certainly takes place when we are trying to make a hole inside of a composite laminate. How this damage can be avoided? So, this can be avoided by the selection of optimum operating variables as I have already highlighted what are the two most important operating variables in case of the drilling operation these are the cutting speed and the feed rate. So, we can optimize the cutting speed and the feed rate. So, that we are able to generate a good quality hole in the polymer matrix composite.

Second point tool material selection. So, we can have different tool materials for example, the high speed steel or the cemented carbide or even some time the diamond quoted tools are also use. So, when we have different types of tool materials we have to judiciously select that which tool material should be used because we have already see that some of the fibrous reinforcements are abrasive in nature. So, when we have abrasive reinforcement it will abrade the tool and tool we are would be substantial.

So, we have to somehow reduce the tool we are. So, the appropriate selection of the tool material should be done in order to make a damage free hole in a composite material. Next - tool point geometry, we will see some of the tool point geometries in the subsequent slide that what are the different types of tool point geometries which are used to in order to avoid the damage. Next point selection of the appropriate process, which we will see in one of the lecture that are the different types of modified processes.

Like one process is on a conventional drilling machine. We can mount the composite material fix the drill and then make a hole, but there are certain modifications suggested by the researchers worldwide that what what modifications can be done in the conventional drilling process, in order to make a hole which is better in quality as compare to traditionally or a conventionally drilled hole.

So, we have to select the appropriate process for making a damage free hole then we can think of dedicated machine tool, because that nature of drilling or the nature of machining of polymer composites is entirely different from the machining of metals. Therefore, the machines that are use for machining of metals should not be blindly use for machining of polymer composites. So, there is a need to understand the drilling or the machining characteristics of the polymer matrix composites and there is a need to design and develop dedicated machines for making holes or for machining of polymer matrix composite.

So, therefore, if we use the dedicated machine tool it has all the requirements which are there to be met for making a damage free hole we will be able to avoid the damage with the help of a dedicated machine tool selection of the cutting fluid that is another issue which we have seen. So, and in certain cases because of the drilling action or because of the machining action what happens matrix may burn because of high amount of heat generated in certain cases.

Although lot of heat is not generated in drilling of polymer composites, but in some case if the feed rates are very slow that drill in constant and engagement with the material for a long period of time certain in certain cases matrix burning may take place. So, matrix is the polymer. So, if the avoid that polymer burning we may sometime use a cutting fluid or a coolant to avoid over heating of the polymer and leading to the burning of the polymer. So, the selection of cutting fluid is also important to avoid the damage and last point special methods such as wood pecker cycle or use of the backing plate to avoid the damage are also exercised by the researchers worldwide. So, these are some of the common tools and techniques adopted worldwide to avoid the damage in case of polymer matrix composite materials.

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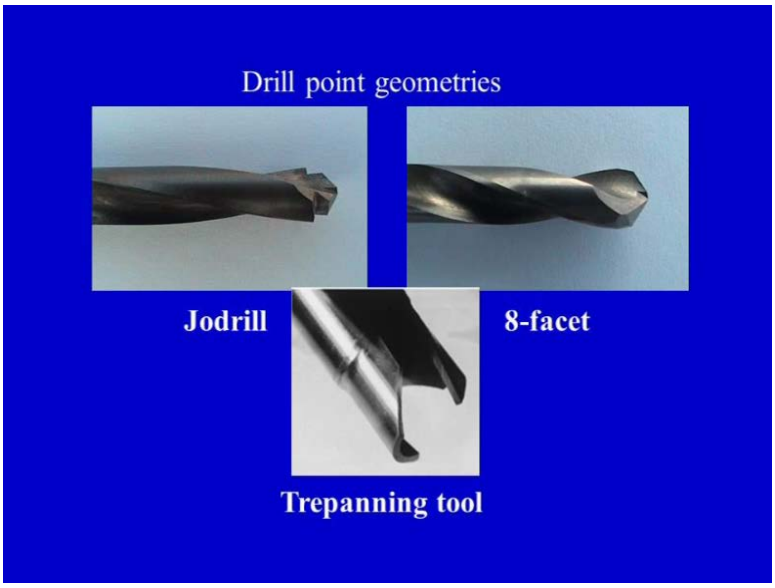

So, on your screen, you can see different types of drill point geometries which are use for making damage free holes in composite laminar. Although the research work is going on, people are trying worldwide to design and develop different types of drill point geometries which can be use for making holes in composite laminates. So, these are the three geometries which have been established to through avoid damage during drilling of polymer composite. So, one of the geometries is the jodrill, we can see the construction details of the jodrill. It is different from the conventional twist drill, and then we have eight facet drill in which we have four faces on one side and another four faces on the other side. And finally, we have a tree pruning tool which is a polo tool and which starts its cutting operation from the periphery of the hole.

So, these are some of the modified drill point geometries which are used for making, we can say or to avoid a damage during drilling of polymer composites. But generally as engineers, we are focused on using conventionally established tools for making holes. So, usually people used twist drill to make holes in composite laminate which is not we can say as feasible as useful as the modified drill point geometries which has already been establish in terms of the research studies or experimental investigations by most of the researchers worldwide.

So, with this we have come to one of the lectures of module number seven that is secondary processing of composite materials or secondary processing of polymer composite materials.

So, our focus in today's lecture was to understand the importance of the secondary processing and we have seen that if we try to make a hole in side a polymer matrix composite, what are the challenges, what are the important factors that have to considered in order to make a hole which has minimum damage or no damage. We have seen the challenges and we have seen how to avoid damage. So, whatever slides we have been shown, this is just a summary of the research findings which have been established worldwide. In our subsequent lectures, we would be focusing on the tools and techniques which have been used to facilitate the secondary operations in case of composite materials. We would be seeing the joining aspects of the composite materials as well with this we come to the end of lecture number one in module seven.

Thank you.