Processing of Polymers and Polymer Composites
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Lecture – 34
Drilling of Polymer Matrix Composites – I

[FL] friends, welcome to session 34 in our course on Processing of Polymers and Polymer Composites. Just to have a brief review of what we are covering we are currently in phase 3 of our course, in which we are focusing on the secondary processing of polymer matrix composites.

In secondary processing broadly we can classify the secondary processing into 2 major areas. The first is the joining techniques and the second one are the machining techniques. Sometimes we need to machine the composite materials in order to ascertain their assembly with the other parts or with the subsequent parts.

So, in joining process we have already covered at least very fundamental sorry issues related to 5 different processes. If you remember we have seen the effect of adhesive joining, we have seen mechanical fastening, we have seen microwave joining, we have seen induction welding, we have seen resistance welding. So, 5 different types of joining techniques we have already discussed. Although not in very depth or very detail, but we have definitely understood the working principle of these techniques or at least we know that these are the techniques that can be used for joining of the polymer matrix composite parts.

Now, if you remember we have seen that each one of this process has got certain limitations or the joining strategies have got certain limitations. Specifically in case of adhesive joining the joint area preparation or the surface preparation is a challenge. In case of mechanical fastening the damage of hole or the damage induced around the hole due to the drilling action or the hole making action is an issue. In micro wave joining the electrical and the magnetic properties of the material need to be compatible to the electromagnetic waves or to the microwave energy, there may be some materials which are completely not we can say susceptible to over microwaves and therefore, will not react to the exposure of the microwave radiation.

So, there are challenges there also similarly in case of induction welding we have seen that the process of heating is specifically dedicated towards the thermoplastic type of composite materials and thermoset type of composites cannot be joined using the induction heating effect.

Similarly, for resistance welding also there is a limitation that the material has to be thermoplastic or the matrix has to be thermoplastic in nature otherwise, it is difficult to join if the material is thermo setting in nature. So, each process that we have seen for joining of the composite part has got it is own limitations and most commonly used processes are the adhesive joining processes and the mechanical fastening techniques. So, adhesive joining we have already covered that there are challenges in adhesive joining, but in case of mechanical fastening I have addressed that that point of time also that making of holes in the composite materials is a very big challenge.

And slowly and slowly we are focusing towards the research area the latest trends in the joining, in the drilling, in the hole making of the composite products. So, all the processes that we have discussed till today for composite material just me let me revise for just maybe 1 or 2 minutes. We have seen hand layer process spray layup process compression molding, injection molding, resin transfer molding, filament winding, pultrusion, all these processes are well developed we can very easily go to the market or we can order them the machines which are used for used based on these particular processes, we can buy a pultrusion machine, we can by a filament winding machine, we can buy a spray layup set up, we can buy a vacuum bagging technique, we can buy pre pragging machine. So, different machines are available and all these machines are capable of producing the composite products.

But the large size composite products are intricate products required the joining and assembling operations and joining and assembling definitely require some additional processing that we usually classify as the secondary processing. And in secondary processing there is still lot of research work going on so whatever I have said whatever processes I have named by now are well developed and are used in industry, but whatever we are going to cover now onwards most of the thing is still people are doing research on that and this is going to act as catalyst for the learners, that if they want to go for higher studies. In this particular area they can just take this as a background and try to formulate a problem in which they can put research effort so this is just an introductory or maybe a very novel approach or very mini mini approach we can say just to introduce all of you to this topic: in which we are going to see that what are the challenges in the case of machining or specifically drilling of composite materials.

So, we will have maybe 2 or 3 sessions depending upon the content that we are able to cover, we will see that at least all of you have an idea that what is the latest trends in the context of making of holes in the composite products.

Today in the introductory part we will see what are the challenges, we will see what are the problem areas associated with making of holes in composite materials, in subsequent sessions we will try to see what are the strategies adopted, what are the remedies adopted by the researchers worldwide of the scientists, worldwide of the engineers, worldwide in order to address this problem of damage around the drilled hole or the poor quality of the drilled hole, that is generated because of the machining or the drilling action on the composite path or the product. And this sometimes becomes inevitable some of you may be suggesting that what is the need of making the hole in a composite material, we should make a hole during the molding stage only. So, that also is under investigation and under research, that what kind of damage or what kind of load bearing capacity do the composite part has if it has a pre molded hole inside.

So, that is also one of the research topics on which people are focusing their attention, but still today or till today people are making holes in the composite parts and lot of holes that are produced in the composites are rejected to the order maybe I can say with certainty that 50 percent of the holes that are made in composite materials do not pass the quality checks and are rejected because of the poor quality.

So, the rejection rate you can say is more you can see is more or less 50 percent which can easily be improved, we need to improve of on the acceptance rate we ideally we should be able to make all 100 percent holes specific to the quality criteria which has been laid out, but that is not possible because of the certain restrictions in terms of the process or the process mechanism. But still this 50 percent rejection or 50 percent acceptance is very very less in terms of percentage and we can adopt certain strategies to improve this rejection or to reduce the reaction rate and improve the acceptance rate.

So, we should make focus on making good quality low cost holes in the composite materials and that is one big challenge there are research articles being published today even today in this area of making holes in composite materials and this is a research topic, which many researchers all across the globe are doing their research and their reporting newer and newer techniques methods for making damage free holes in the composite materials.

So, we will also be focusing our attention on maybe 2 or 3 sessions on this particular topic only and try to understand that what is the problem? Why this problem? Is so rampant and so big in case of composite materials and what are the you we can say opportunities for all of us to maybe address and in order to solve this problem.

So, let us quickly today our focus would primarily be to understand that what is the problem actually. So, once we know that is the problem. So, many ideas can come to our mind that yes this is the problem we can solve it in this way or that way, so many ideas will come to our mind, but today it is just a food for thought that I am offering to all of you, that there are problems associated with making holes in the polymer matrix composites or the fiber reinforced plastics and these have to be overcome either today or tomorrow or maybe day after tomorrow. Maybe that this is a ongoing process and people across the globe are still in the stage of doing research in this area and trying to find out the method which will which can produce a damage free whole in a composite material.

Specifically in case of a fiber reinforced plastic or a polymer matrix composite material.

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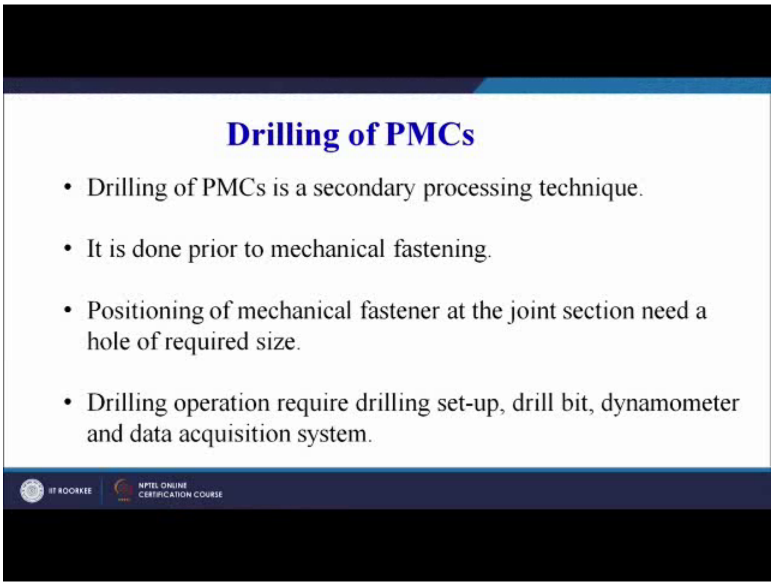

So, let us quickly see what the problem actually is PMCs as all of you know our polymer matrix composite. So, drilling of polymer matrix composites is a secondary processing technique. So, we have already shared this thing again I am emphasizing that currently our focus is on the secondary manufacturing or secondary processing of polymer matrix composites. It is done prior to mechanical fastening. So, we have seen 5 join methods in our previous sessions we have seen adhesive joining mechanical fastening, microwave joining, induction welding, resistance welding, there are other welding techniques also, but we have seen the 5 types of welding techniques that can be used for joining of polymer matrix composite.

So, here specifically in case of mechanical joining of polymer matrix composites we require holes and for making of holes it is a cumbersome or it is a difficult task why because of the discussion that we are going to develop today. So, making of holes in composite products is done prior to the mechanical fastening or it is a prerequisite for doing the mechanical fastening technique or for doing the mechanical fastening process.

Positioning of mechanical fastener at joint section need a hole of the required size, now why drilling of holes or making of holes in the polymer composites is a prerequisite to mechanical fasting because this hole has to act as a location where we are going to use our mechanical fastener.

Now, drilling operation requires a drilling setup we need to have a drilling machine, it requires a drilling tool or a drill bit it requires a dynamometer which is used for recording of the forces that are generated during the drilling action and it requires the data acquisition system, in order to plot the forces that how the forces are varying over the period of the drilling cycle or over the time.

So, very quickly we will see one typical setup that is used for drilling of holes.

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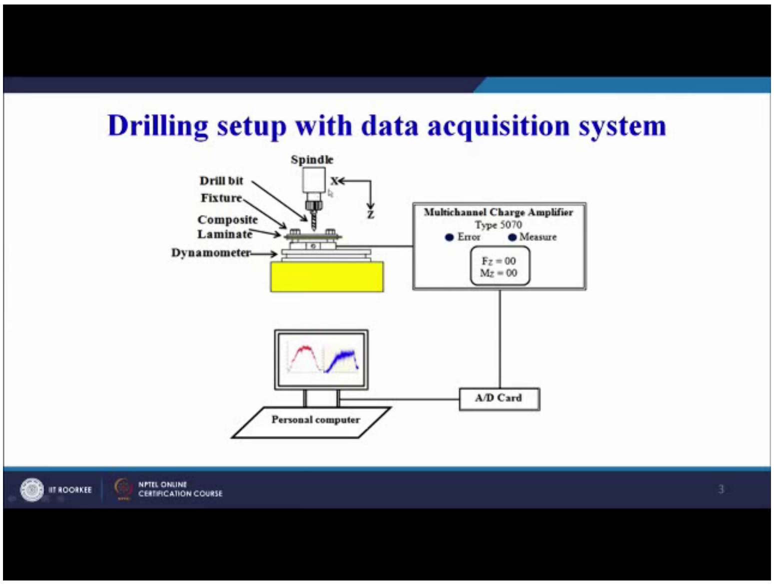

So, here we can see this is the spindle, this is the drill, most commonly twisted drill is used for metals, but we will see that twist drill may not be applicable specifically in case of composite materials or in case of polymer matrix composite materials. So, usually drill bit whenever the name of drill comes into the discussion most of the engineers I am also one among them only focus on the twist drill, but twist drill is not the most applicable or is not the most commonly used drill or drill point geometry for making of holes in the composite material that we are going to see in our subsequent slides.

Then we have a drilling machine or a dealing set up we have a spindle, we have a drill we have a fixture which is used to hold the composite, then there is a composite laminate, just below the fixture then there is a dynamometer which is used for measuring the forces, the dynamometer is connected to the multi channel charge amplifier here you see F z thrust force M z movement or the torque 0 0. Then there is A 2 D card which is these days integral with the charge amplifier and then we have a system or a computer system in which we can record the signals the red and the blue signals. So, here then can be thrust force another can be torque.

So, this type of setup is usually used to do research or to conduct experiments in context of the drilling of polymer composites. So, this is not the only setup which can be used for drilling of polymer composites, it can be use for drilling of metals also it can be use for drilling of, ceramics also it can be used for drilling of, polymers also it can be use for drilling of any material it is a general setup not dedicated only for composite materials, but this setup can be used for polymer matrix composite materials also. Just you can again look the various component you need to have a drilling machine, you need to a fixture for holding the composite material, you need to have a dynamometer to record the forces and then you can conduct your research even in case of machining of metals, you can do for machining of polymers as well as you can do for machining of polymer matrix composites.

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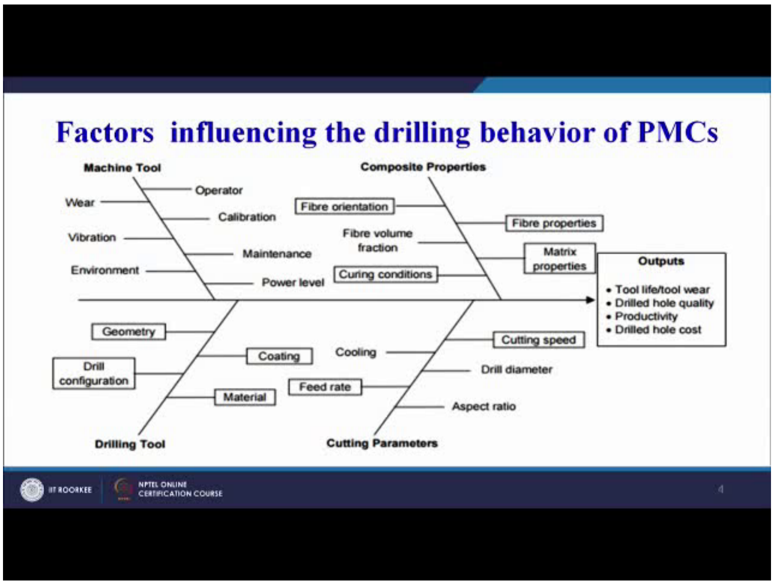

Very busy slide on your screen so this is a factors influencing the drilling behavior of polymer matrix composites and when such a busy slide we can have on the screen itself implies that drilling of polymer based composites is not a very easy process to control because of so many parameters.

So, you can see the outputs in case of drilling action on the polymer composites can be the tool life or the tool wear, I think it is can come second the first one should be drilled hole quality. The hole quality as I have already emphasized that we get after drilling action or after the hole making process is not of adequate quality very poor quality, we will see in the subsequent slide what type of damage takes place because of the hole making action in case of polymer matrix composite.

So, you can see hole quality is one output tool viewer is another output productivity as I have already told 50 percent of the holes are rejected because of the damage and then the cost is also a limiting parameter because of the high rate of rejection of the drilled holes.

So, these are the output parameters, but what we can control from the machine tool point of view wear and tear of the machine, operator skill, vibration in that machine tool, than the working environment. So, one thing is the machine before showing this diagram I have already shown the basic setup for doing the machining experiments and there you can see machine is one integral part of the setup or the machine tool.

Second is the composite material. Now all of you are experts all of you know much more in composite materials than me all of you know there in composite material there is a polymer, there is a fiber, then we combine them together and we make a composite material.

Now, the properties of the matrix or the polymer, properties of the reinforcement or the fiber they play a very important role. Fiber can be in the continuous form it can be in the short form, it can be in the woven, it can be in the mat form. So, the type and shape of the fiber also plays a important role, the polymer whether it is a thermosetting or thermoplastic that is also going to play it is own role . So, the fiber properties the orientation of the fiber we will try to see the or how the orientation will affect the machining behavior of the polymer based composites.

Similarly, the fiber volume fraction now fiber volume fraction is how much amount of fiber is present in the composite by volume. So, that is also suppose you are making a hole in a composite material which has only 10 percent fibers. The machining behavior or the machinability will be different; on the contrary you are making a hole in a composite material which has 60 percent fibers by volume. The machining behavior will be entirely different so the amount of fiber present in the composite material is also going to influence the machining behavior.

Similarly, the curing conditions of the composite material as we have seen when we cure the material, we can go for room temperature curing, we can go for accelerated curing; so the curing behavior of the curing cycle which we have used for curing our polymer composite is also going to affect our output.

So, we can see the fiber properties, the matrix properties, the curing conditions, the amount of fiber present the direction of the fiber present all these are the composite material related properties or composite material related characteristics that are going to affect the machining the behavior of the polymer matrix composite.

Similarly, now coming on to the drilling tool as I have already told you usually when we talk of the drilling tool only twisted drill comes to our mind, but the geometry of the tool can be different. It is not only the twist drill that is used for making a holes in composite materials there are number of other geometries which have been tried worldwide for making damage free holes in composite material and that some of those geometries we are going to see today in our session.

Similarly the drill configuration that is also very very important, coating, on the drill or the drill tool, material of the drill many times we use high speed steel, sometimes we use high hardness quoted it drill bits for making holes, sometimes you solid carbide drill bits for making holes. So, that drill tool material that drill geometry the coating on the drilling tool all these are going to influence the machinability behavior of the polymer based composite.

Finally the cutting parameters 2 important cutting parameters are the cutting speed and the feed rate. So, we can see it is already highlighted then the cooling the environment under which we are providing the machining machining operational we are conducting the machining operation, drill diameter it should have ideally come in the drilling tool, then the aspect ratio the depth or the depth for which we are doing the hole and the diameter of that drill. So, that is also the may be the ratio of that to may be called as aspect ratio that is also going to affect our quality of the hole that we are producing.

So, the cutting parameters the tool parameters, the material parameters, the machine tool parameters, all these parameters are going to influence the machining behavior or specifically the drilling behavior of the polymer matrix composites. And you can by now have understood or you can appreciate the complexity of the issue, we need to have a optimal combination of all these parameters all these characteristics in order to develop a good quality hole.

So, 4 important points are coming out from this slide. First one is the material in which we want to make the hole, second one is the machine that we are going to use for making the hole, third one is the tool that we are using for making the hole, and fourth one are the operating variables operating parameters that we need to control in order to make a good quality hole. So, these 4 things we need to judiciously select in order to make a good quality hole.

So, we will see from machine tool point of view the diagram that we have seen in the previous slide, it was a conventional drilling machine with spindle which is having a drill bit and that is used for making the hole, but researchers have tried different types of machines for making holes in composite material. Even different types of process mechanisms have been adopted in order to minimize the damage in the polymer based composite. So, we will try whatever time is available with us we will try to cover as much as possible related to this specific topic in context of the fiber reinforced plastics or the polymer matrix composites, now taking these 4 points further the material, the machine tool, the cutting tool, and the operating variables.

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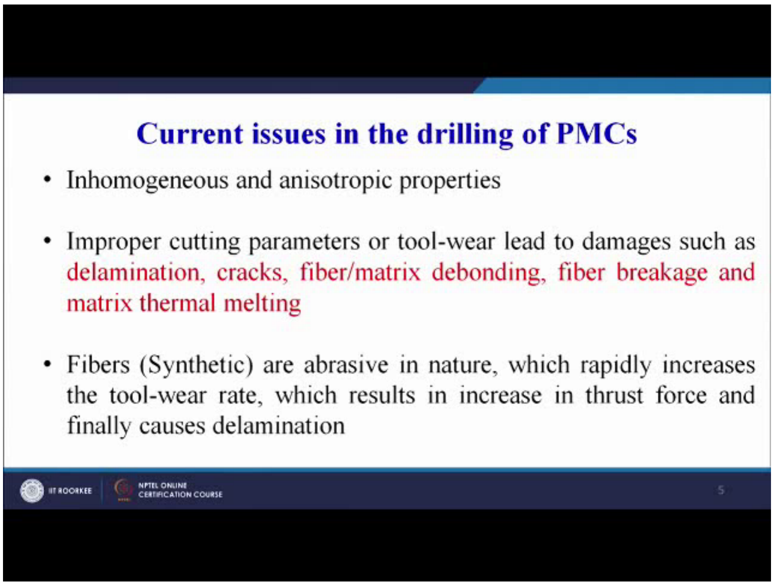

Let us see that what are the challenges now; what are the current issues in the drilling of PMCs the first issue is inhomogeneous and the unisotropic property. So, we have seen first is material. So, from material point of view we are inhomogeneous it is not a homogeneous material why because we have 2 phases we have a fiber and we have a matrix. So, the properties are different in different directions also therefore, they are anisotropic if we check the properties at location x y z and then we check the properties that x 1 y 1 z 1 in the bulk of the composite material there are bound to be changes in the properties why therefore, the materials are Unisotropic.

So, they are inhomogeneous their Unisotropic. So, the material has got it is own challenge, how to cut this material which has 2 phases it has a fiber it has a matrix, fiber as different properties, polymer has different properties. So, how to develop a strategy to cut this material so from material point of view first challenge.

Second challenge is improper cutting parameters or tool we are leading to damages such as delamination cracks fiber matrix d bonding fiber breakage and matrix thermal melting challenges. Again from the material point of view from the processing parameters point of view from the tool material point of view so tool we are leading to damage and that is also related to the 4 important things that we have already discussed.

Now, fiber specifically synthetic fibers like glass fiber, carbon fiber, aramid fiber, are abrasive in nature most abrasive is the glass fiber, the other 2 are not that abrasive. So, the glass fiber is very very abrasive in nature. So, the fiber that abrasive in nature so once the fibers are abrasive, you can yourself imagine this is a composite plate maybe it has let as assume it has 4 layers of glass fibers and we have use the polymer and we have use the hand layer process for making this 4 layer glass fiber epoxy laminate; 4 layered means 4 layers of glass fiber epoxy means the polymer that is the matrix is the epoxy and then it is a laminate because there are 4 layers of glass fiber. So, this is made by hand layer process.

Now, this laminate suppose we are going to make a hole. So, when we are going to make a hole the drill will come in contact with the abrasive glass fibers and the glass fibers will abrade the drill and it will lead to lot of tool wear, and then the drill is worn out the forces will increase and when the forces will increase the delamination will happen at the exit of the drill from the laminate.

So, synthetic fibers are abrasive in nature which rapidly decreases the tool wear rate that subsequently leads to the increase in the thrust force and the increased thrust force or the high thrust force will cause delamination at the exit of the drill point.

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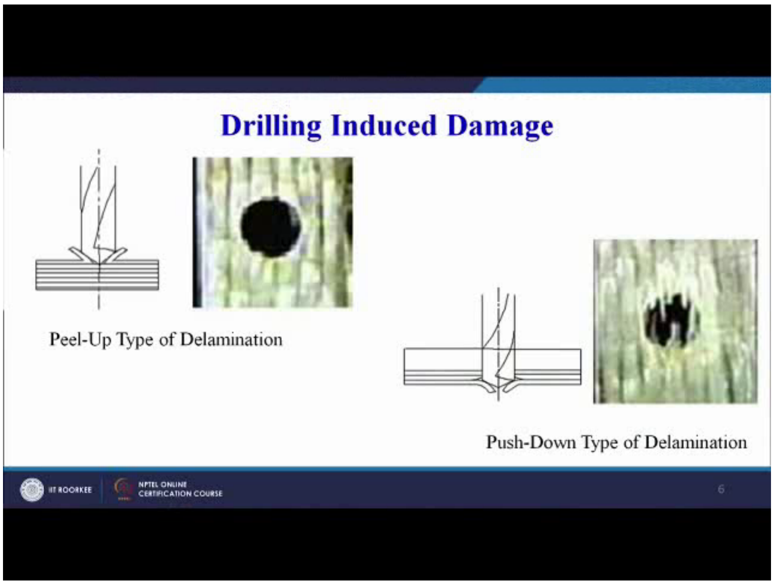

This there you can see the Drilling Induced Damage. So, Delamination basically you can see there is a peel up type of delamination when the drill just starts to enter the laminate. So, this is the laminate when the drill starts to enter the laminate the top layers try to peel up or the drill subjects these flies or the top layers or the top laminate, to the peeling effect at the layers debond from their bottom layers and peel up along with the drill and this is called the peeling up type of delamination.

So, all of you know lamination usually we get our certificates laminated. So, that is the most common analogy that I can suggest. So, when you laminate something you are 2 or 3 or 4 or 5 layers together and you call it lamination. D means opposite of lamination. So, the layer will try to delaminate me they will try to debond from one another. So, when the drill tends to enter the laminate the top layers try to debond from the bottom layers or the base layer and that is called the pilling up of the peeling up type of delamination or peeling up of the top layers of the laminate or the composite laminate.

Similarly, when the drill tends to exit the laminate the drill tends to exit the laminate the bottom layer tends to open up and that debond from their (Refer Time: 27:53) layers or the debond from their top layers. So, the bottom layers stand to open up because of the higher thrust force being generated because of the drilling action. So, that is called the push down type of delamination, that drill tends to go out from the composite laminate and it forms damage in the form of push down type of delamination.

So, you can see that there is a peel up type of delamination there is a push down type of delamination, then this type of delamination is not at all acceptable and may lead to the rejection of the drilled hole. And the actual holes also you can see this is push down type of delamination all around the hole and here you can see it is more severe this is this is the peel up type sorry oh peel up type of delamination at the entry of the hole and this is a push down type of delamination, which is much more severe the push down type of delamination is much more severe as compared to the peel up type of delamination which is absorbed at the entry and push down type of delamination is observed at the exit of the hole.

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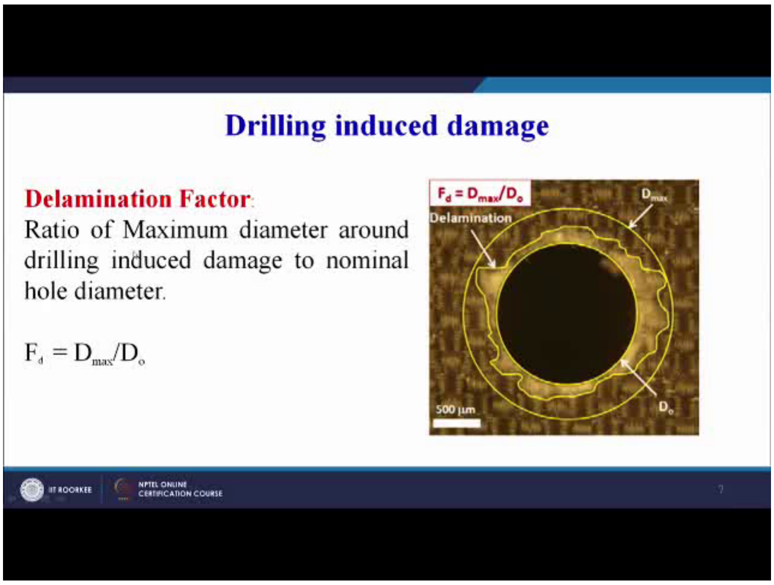

Then there is drilling induced damage all around the hole this we call a we can we can quantify this with the help of a delamination factor. So, FD we can see D max. So, D max is the maximum area or the diameter of the maximum area around the hole that has been damaged and D O is the original diameter that we planned to make or the original diameter of the hole that was our objective.

So, delamination factor usually is defined as the maximum maximum diameter around the hole which has been damaged D O is the objective or the original diameter that we planned to make or whatever was the diameter of the hole that was planned. So, the ratio of the maximum diameter around the drilling induced damage to the nominal hole diameter nominal hole diameter is our target diameter.

So, we usually quantify the damage around the drilled hole by the delamination factor which is very simple FD is equal to D max by D O, here you can see in the diagram this is the damage the light color portion is the damage and this damage you can see the maximum diameter of this damage area D max is in the numerator and the our original diameter of the hole that we wanted is the in the denominator. So, this is d max by D O which gives us the delamination factor.

So, with this we come to the end of today's session I have already highlighted that for joining of composite materials we need to do number of secondary operations and for joining most important processes are adhesive joining and mechanical fastening in mechanical fastening hole making is an un unavoidable drilling operation or unavoidable machining operation, while we need to locate our fasteners in order to form the joint and hole making is a challenging task specifically in case of composite materials, fiber reinforced plastics or polymer matrix composites.

Today we have tried to see that why most of the holes that are made in the composite materials are rejected. So, we will carry forward our discussion our session in the next lecture where we will see, that what are the other forms of damage and then we will try to see that what are the remedies in our subsequent sections or subsequent sessions.

Thank you.