Processing of Polymers and Polymer Composites

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Lecture – 35
Drilling of Polymer Matrix Composites – II

[FL] friends. So, a warm welcome to all of you in session 35, in our course on Processing of Polymers and Polymer Matrix Composites. As we are discussing the secondary processing of polymer matrix composites, I think the operations that are done towards the last stage of the product development cycle; that is we conceptualize a product, we design a product. We have already done a MOOCS course; under product design and development, in which we have seen what are the various stages of product design and development.

Secondary manufacturing that we are discussing currently comes towards the end of the product development cycle. Similarly, we are also discussing this topic towards the end of our course. So, our course now is towards the fag end; we are at session number 35 and we have to discuss; maybe the complete aspects of polymer, specifically processing of polymers and polymer based composites in 40; half an hour sessions; this is a 20 hour course.

And since we are towards the end of our course, we are also towards the end of the technology which is used during the last stages of the product development cycle. So, once we have conceptualize the product, we have done the functional analysis of the product, we have done the prototyping of the product, we start manufacturing the product on a full scale. And during the manufacturing of the product, we use various processes; we use primary manufacturing processes, we use secondary manufacturing process.

Similarly, you can say we can draw the analogy between the processing of or manufacturing of our fabrication of metallic components also. In metals what do we do usually? Primary forming processes are maybe casting is one example, now in casting we produce a cast and later on what do we do in order to improve the surface finish? We do the machining operation; sometimes to improve the properties in the bulk, we do the heat treatment processes.

So, these machining processes, heat treatment processes; sometimes we weld the cast parts together if the geometry of the product is very very complicated. So, joining using the welding operation; sometimes we join two metallic part using nut and bolts. So mechanical fastening. So, all these processes; so, the primary forming in terms of casting is primary and welding, joining, mechanical fastening, machining heat treatment; all these processes will majorly fall under or in secondary manufacturing basket.

So, in primary manufacturing also we have number of processes and in secondary manufacturing also we have a number of processes. Currently, our focus is on secondary manufacturing processes for polymer matrix composites. So, we know what are the primary manufacturing processes, again and again I am repeating the same things. Because these sessions will be standalone sessions; standalone means that somebody may directly go to session number 35; once they are in the public domain. So, once it is in the public domain; somebody is attending only session 35, must get an idea that where do the drilling of polymer composites fit in, in the overall product development cycle?

So, we can develop different parts of composites using different processes like; hand layup, spray layup, filament widening, pultrusion. But for assembly we require secondary manufacturing and for secondary manufacturing, we can either join the parts using adhesive joining, we can do mechanical fastening using fasteners or we can do microwave joining, we can do induction welding, we can do resistance welding but depending upon the situation, circumstances, the application areas; we will select a particular joining methods.

Suppose, we select mechanical fastening; in mechanical fastening, we will definitely require holes through which we can screw or we can have our mechanical fasteners on to the assembly. So, the drilling or hole making becomes an inevitable machining operation, and if you remember in the last session our topic was drilling of polymer matrix composites 1.

So, we have seen what is the importance of drilling; specially in context of polymer matrix composites. And today again we are continuing our discussion on the same topic and if you remember in the previous session; we have seen that is session number 34; we have seen that there are challenges in hole making; hole making it is easier said than done, there are lot of problem areas; some of them we have tried to see in the last

session. And one of the major problem areas was; the damage that happens or that occurs around the hole; when you do any hole making operation in polymer matrix composite. So, that damage we have to somehow control and there are different strategies adopted by researcher, scientist, engineers worldwide in order to avoid this drilling induced damage or the damage that happens due to the hole making operations.

So, today again we will start our discussion with the damage that happens around the; or that occurs around the hole and we will try to see that what are the strategies adopted worldwide for minimizing this damage or completely eliminating this damage? So, let us start our discussion with this background; just to have a brief overview of what we have already discussed.

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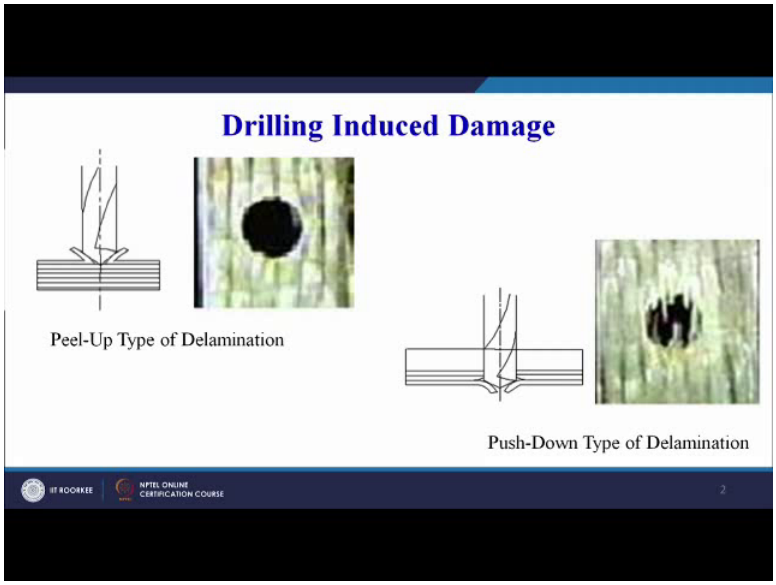

We have seen the different types of damage forms may happen or may be seen or may be observed or maybe recorded or may be quantified in case of drilling of polymer matrix composites.

Most prominent among them is the peel up type of delamination and the push down type of delamination. There can be damage in forms of fiber pull out, it can be matrix burning, it can be chipping, it can be spalling. So, there are different types of damage forms that may happen during the drilling operation or that may occur during the drilling operation.

But these two damage forms that you see on your screen; that is peel up type of delamination and the push down type of delamination are more severe. Because the debonding of the layers take place, specifically if you are composite it is a laminated composites which has 4 to 6 to 8 layers of woven mat or may be used to reinforce the polymeric matrix. So the damage may happen during the entry of the drill; as well as when the drill exist the hole.

So, we can have the peeling up of the layers at the top of the laminate, during the start of the drilling operation or we may have the debonding or delamination of the lowermost layer or the bottom layers of the laminate, when the drill exits the laminate. So, both are disadvantages; both are limiting factors, both are the limiting criteria, but if you look at the two and if you compare the two types of delamination; it has been reported worldwide that the push down type of limit delamination is much more severe as compared to the peel up type of delamination.

So, this is just one background that this is one form of damage that takes place during drilling of the laminated composite materials; specifically polymer matrix composite materials. Then there are other forms of damage that is reported; in the last session also we have seen, there is a damage called circularity defect in which we do not get exact circular hole that is our target or our objective.

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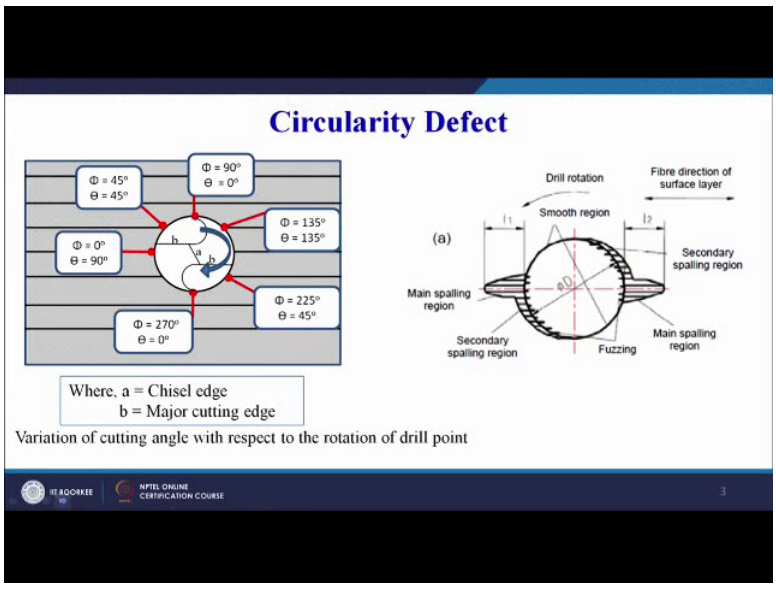

So on your screen you can see; the exact circular hole was our target, but we are not getting the exact circular hole; we are getting a damaged hole. So, we see that there is a damage all around the hole; this is the drill rotation, the drill is rotating in this direction and these a fiber direction is shown here, this is the direction of the fiber.

So, we see that spalling is one of damage that is reported, fuzzing is another form the surface is not smooth; it is a fuzzy surface. So, that there are different forms; the matrix burning is another form, chipping is another form, fiber pull out is another form. So, you have different types of damage that takes place during the drilling operation and we have to avoid this type of damage.

Now, this is just showing the rotation of the drill; this is the rotation of the drill from my direction it is clockwise. So, clockwise rotation of the drill; when the drill rotates the cutting edges encounter the fibers at different angles; so, angles are shown here 0, 90, 135 degree, 45 to 225 degree. So, when the drill rotates it encounters the fibers at different angles and when has been reported, it has been observed, it has been experimentally validated that the direction of the fibers also play significant role in influencing the damage that what happens due to the machining action.

One simple example that comes to my mind is that; a carpenter when he or she plays the wood first of all the carpenter will observe the wood very very carefully. He will see that what is the direction of the fibers in the wood? And accordingly he will choose his direction of plaining; why? Because the angle at which the fibers are there; will definitely influence the surface finish, that we can be achieved on the wood.

Similarly in case of synthetic composites like glass fiber reinforced epoxy or carbon fiber reinforced polyester composites. So, you have polyester and epoxy as the matrix and glass and carbon or graphite as the reinforcing agents. So, in these type of composite materials, the direction of fiber will play a important role. And similarly during the drilling action also, the drill will encounter fibers at different angles and that will also influence the surface finish around the hole, it will also influence the surface roughness of the hole wall and that needs to be controlled.

It is not in our control to or you change the fiber orientation; because it is decided during the design stage of the component. Because that has the influence on the load bearing as well as the strength values of the developed composites. So, the composite has been

developed taking into account the fiber orientation required, the number of layers required; all that is pre decided.

At the processing stage, we can just tweak our machining operation a bit or drilling operation a bit so that we can minimize the effect of this fiber orientation. Especially in case of woven type of fibers; this type of effect is not much observed because you have fibers running in both the directions and the drill will encounter fibers at almost all angles from 0 to 360x degree.

And therefore, in woven case this effect of fiber orientation is minimized, but if all fibers are in one direction only and there are no fibers across in the transfers direction; there the effect of fiber orientation becomes much more severe. And must be taken into account when we are drilling a hole in a composite laminate; which has all the fibers running in one direction only, but in woven mat form the effect is little bit less. So, this is also one area; concern area which has to be taken into account when we are planning a hole making strategy in case of polymer matrix composites.

Now, we have till now tried understand that drilling of polymer composites is not an easy task; it is a difficult task and it requires lot of research and development. But this is not, we can see the beginning of research in this area. The composites were developed maybe 50 years back and people have put lot of efforts to find out the ways in which the damage can be minimized. So, based on my experience; based on the research articles that have already been published, we have tried to summarize the methods that have been adopted by the Researchers, Scientists, Engineer’s worldwide to minimize this damage.

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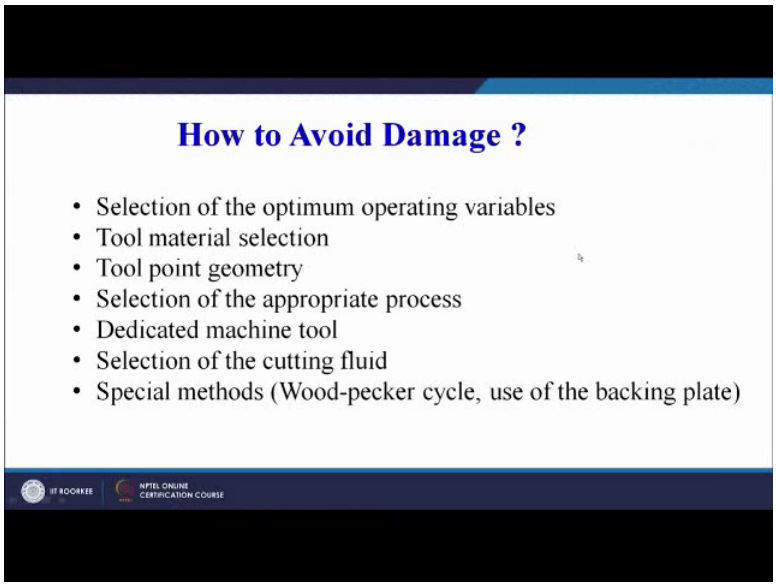

Now, how it can be minimized? You can have on your screen, the methods that have been used or I should say the techniques or the tools that have been adopted by the researchers in order to avoid the damage.

Let us have a quick overview of the strategies, tools, techniques adopted by the researchers in order to minimize the damage. The first point on your screen is the selection of the optimum operating variables. So, the first point itself is very very clear; we have to be judicious in the selection of the operating variables. Now I can put a very simple question to all of you; that what are the important operating variables in the drilling operation? Very easily you can answer, it is cutting speed, feed rate; we can also control the tool; geometry we can control the tool, diameter. So, those are the control variables that are in our hand; so, these are the variables that we need to judiciously select; intelligently we need to select these variables so that the damage occurring in the composite is minimized. We can have a cutting speed, an optimal cutting speed, an optimal feed rate, a optimal tool point material, an optimal tool point geometry. So, all these things will help us to avoid the damage.

So, first is optimum operating variables, second one is tool material selection; it is also equally important. Now, in tool material selections; we can have a high speed steel tool, we can have a solid carbide tool, we can have a diamond grid coated tool, we can have any other hard material coated tool; which can minimize the effect of tool wear. So, we

have to select a tool material, which does not wear out very fast. If you remember, in the last session; we have seen that some of the fiber that are used to reinforce the polymer matrix are abrasive in nature.

Now, abrasive fibers will abrade the tool material or the tool point. So, if the abrasion of the tool takes place; the tool will wear out, the tool wear rate will be very high and if the tool wears out; it will lead to increase in the thrust force the torque. And if the forces will increase, subsequently the material damage will be more or the damage in the polymer matrix composite will be more. So, the selection of the tool material is also very very important; then the third point that is tool point geometry.

So, tool point geometry is also very important; we will see in today's session that there are number of tool point geometries that have been used, that have been researched, that have been investigated by researchers in order to avoid the damage. Usually as engineers we know only one tool point geometry; as I have discussed in the previous session also that is the twist drill. We prepare the twist drill, we try to draw the diagram of twist drill number of times in order to just understand that what are the various geometrical features of the drill point; also from the examination point of view we try to remember what is the point angle and all.

But it is not the only that exists; there are number of other tool point geometries which have been investigated for making damage free holes in composite materials and specifically polymer matrix composite materials. So, we need to judiciously; intelligently select the tool geometry also. So, the three important things that we have to select; that we have seen today are, first one is the selection of the operating variables; that is cutting speed and feed rate, then the tool material whether it should be HSS or solid carbide or diamond grid quoted solid carbide or maybe the specific tool material for drilling of composite.

So, third that we have seen was in the tool geometry; it is not mandatory that we have to use the same geometries that we are using for metals. Because the conditions and requirements for making holes in composite materials are entirely different from that for metals. So, tool geometry, tool material, cutting speed, feed rate all these important variables we have to select and then only we will able to make a good quality hole in a composite material.

So, next is the selection of the appropriate process. So, it is not mandatory that we have to use a conventional drilling process only, where we use a tool, we use of spindle, we use a fixture and we mount our composite in a fixture and we make a hole. There are number of advanced manufacturing processes that have been developed, which can be used for making holes in composite materials. So, we will see in our subsequent sessions that what are the modifications suggested in the processes so, that our damage in the hole is or damage around the whole is minimized.

So, selection of the appropriate process is also very very important and one of the processes which we have successfully developed and tested for glass fiber epoxy composite materials is; the ultrasonic machining process. That process we will see; that what modifications have been done in the conventional ultrasonic machining process, in order to make good quality holes; specially in polymer matrix composites.

So, then there is a another that is dedicated machine tool. Now, dedicated machine tool means that the machine tool or the machine that we are using for making a hole must be dedicated for the purpose of making holes in polymer matrix composites. Because, we require a very very accurate and precise machine for making holes in composite materials; here again I am emphasizing. But it is not important that we use the same machine tool for making holes in metals as well as for composites.

For composites, the order of magnitude or the forces that are generated are maybe one tenth of the forces that we get in case of metals. Suppose for metal, we get a thrust force of 700 Newton with the drill point diameter of 8 mm; in case of composite material for same diameter drill that is 8 mm, we may get a 70 Newton force. So, which means the order of difference will use approximately maybe 8 to 10 times than that for metals maybe 1 by 8 to 1 by 10th time.

So, the force is that we get in case of composite materials are very very very very less as compared to the metal; same thickness of the metal, same drill point geometry, but the forces are less. The heat generated is also very less in case of composite materials; therefore, it is advisable that we should have specific dedicated tools for making of holes in composite materials.

Similarly, selection of the cutting fluid is also one of the important strategies to avoid drilling induced damage. In cutting fluid if we see, it acts both as a lubricant as well as a

coolant. Now, in case of composite materials if you remember in one of the slides; we have seen earlier also, that there are cracks developed around the hole wall. Now, these cracks may seep in or water may flow in these cracks because of the capillary action and this water I am taking as a lubricant as well as a coolant.

So, when our coolant or cutting fluids enters into this cracks; it may cause even severe damage to the composite laminate. Therefore, it is advisable that we should select the cutting fluid also very very intelligently so that it does not affect the performance of the composite part which has drilled holes in it. Because when in service, we will be using this part and there is maybe; a layer of water or a layer of fluid inside will certainly affect the performance during the in service conditions. So that we need to avoid under all circumstances and therefore we have to be very very careful while selecting a cutting fluid during the machining operation of polymer matrix composites.

And the last method that has been used worldwide by different researchers for minimizing the damage are the development of special methods. Now, this special methods are the woodpecker cycle, the use of baking plate; so, these I am not going to explain today; just I have tried to summarize the overall methods or summarize the overall strategies adopted by the scientist worldwide in order to avoid the drilling induced damage. So, this is a broad; we can say picture of the various methods, tools, techniques adopted by the researchers.

One by one we will try to understand that what is a woodpecker cycle? What is the use of the backing plate during the drilling operation? What is the step drilling operations? We will see then in the subsequent sessions, but as a learner; as a student or as a maybe a candidate who is under taking this course; I think this slide is very very important. That there may be a question; somebody may question any learner that; you have attended a course on processing of polymer and polymers composites, what are the challenges during the secondary processing of polymer matrix composites?

Very easily, you can emphasize that the drilling induced damage or the machining induced damage is one big challenge. Then the joining of composite materials is another big challenge and somebody may question next that how we can avoid the damage that takes place around the hole. So, you can answer with the help of these points that in order to avoid the damage around the drilled hole, we can adopt all these strategies, we

can judiciously select the operating variables, we can select the tool material accordingly, we can select the tool geometry also accordingly, we can be very very careful during the selection of the cutting fluid, we can have a dedicated machine tool for making holes in composite materials as well as we can modify our process in order to minimize the damage.

So, maybe at least you can frame four or five sentences on your own and can answer these question that; how the damage in case of polymer composites can be avoided? Specifically, the drilling induced damage or the machining induced damage. So, one by one we will try to understand or we will try to have a overall picture of the methods adopted to avoid the drilling induced damage.

First thing is; we need to understand that how the drilling action takes place, then only we can propose certain methods which can help us to avoid the damage. On your screen, you can see this is a thrust force signal obtained during the twist drilling of composite.

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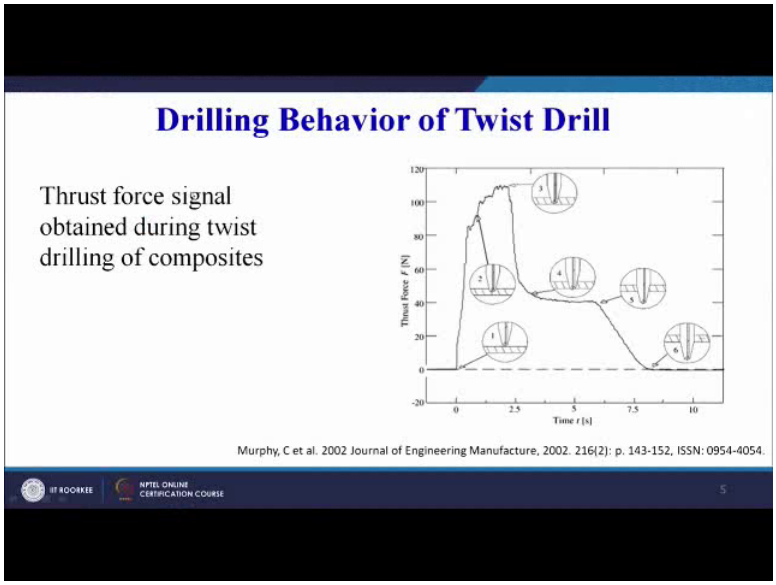

So, twist drill is used for making of holes in the composite material; this is the plot of the thrust force. Now if you can see, from where the plot has been generated; now some of you may be wondering that all of a sudden from where this plot has come into picture. If you go back to our previous sessions and specially the yesterday session, in which we discuss the drilling of polymer composites. The first; I think slide or the second slide

show the experimental set up; in which there was spindle, there was a drill point, there was a dynamometer, there was a computer system, there was a to d card.

So, a complete drilling system was shown; which is not only dedicated to making holes in composite what can be used for making holes in metals also, but in that system there was a dynamometer . So, the dynamometer is used to record the forces and it gives us the signal of the forces with time. On X axis, we have time; on Y axis we have the magnitude of the thrust or the torque. So, this signal basically has been recorded using the dynamometer. And this is the thrust force on your Y axis and on X axis; we have the time. So, how the thrust force is varying during the hole making operation is depicted by this figure.

So, here you can see this stage one; the drill is just coming in contact with the work piece. When the drill is just coming in contact with the work piece, we have this point; there is no force recorded. But as soon as the drill starts to enter the work piece or the composite laminate, there is sharp increase in the thrust force. Here you can see the drill is entering the laminate; now at this stage, stage 3; the drill is in complete engagement with the laminate and it is performing the drilling action and this is the maximum force that is recorded during the drilling action.

Now, after sometime the drill will start to exit the laminate and the force will start to come drop down and at this stage; the drill has completely exit from the laminate and the hole has completely been drilled or it has been made. And finally, the drill comes out and there is just rubbing action of the drill against the hole wall and the thrust force crops down. So, this is a variation of the thrust force with time during making of hole in a composite laminate.

So, why such type of study is important? Such type of study is important in order to understand that what type of drill geometry we should use? Because it will help us to judiciously select the drill point geometry; because signals thrust force as well as torque signals when vary when you will change the geometry of your drill. And when you are able to change the geometry of your drill, you are able to control the forces that are generated. So, if lower forces are there; so, lower forces mean that there will be layer lower damage around the hole. So, that is an important point that needs to be taken into account.

So, three things are there; one is the process, then the drill point geometry that we select; that drill point geometry will affect the forces as we can see here and these forces will subsequently affect the damage. So, if we are able to control the forces, we are able to minimize the damage. So, here again this is the same thing that is the torque signal that is the movement components. So, there is a thrust force and there is a torque, so this is a torque component; the torque signal obtained during the twist drilling of composites and this is a variation I will just move the arrow on the torque signal.

This is a torque signal and here the drill is just touching the laminate and finally, at stage six the drill has come out of the laminates. So, if you are able to understand these signals and relate them with the drill point geometry, we are very easily able to design our tool accordingly. We need not choose the twist drill for making holes in composite laminates; very easily we can redesign our tool which will manipulate the forces and these forces will subsequently affect the damage that is taking place because of the drilling action.

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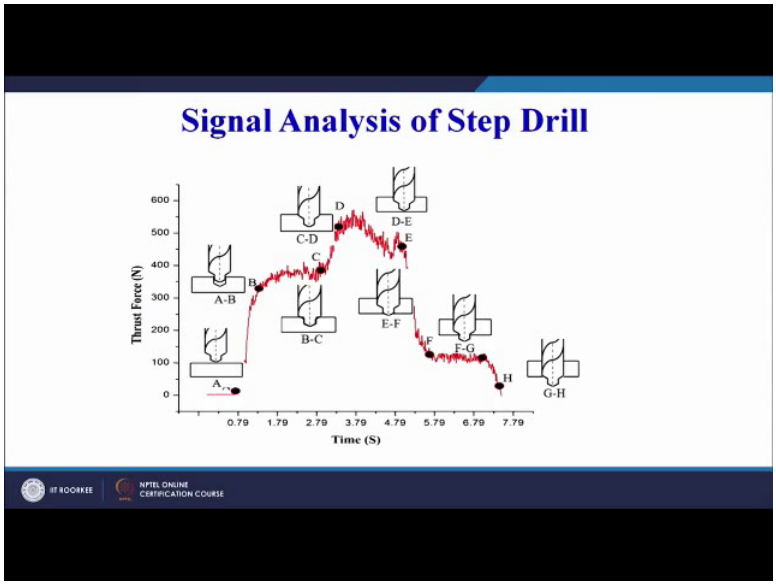

Now, this is another maybe representation; same representation for thrust force with varying with time; A stage drill is just coming in contact, A, B stage drill is entering the laminate and here we can see; this red color is the variation of the thrust force with time. And this is specifically a step drill; so, it has step. So, initial section is making a hole and the outer section is enlarging the hole.

So, drill has a step; this is a step. So, stepped drill will perform the drilling action in two stages; the inner portion will just pre drill a hole and outer portion will enlarge the hole. So, the inner portion will pre drill the hole and the outer portion will enlarge the hole.

So, you can see the signal is also varying accordingly; so, the signal is different from the signal that was recorded using the simple twist drill. So, this way we can say that the drill geometry is an important parameter which governs the drilling induced damage.

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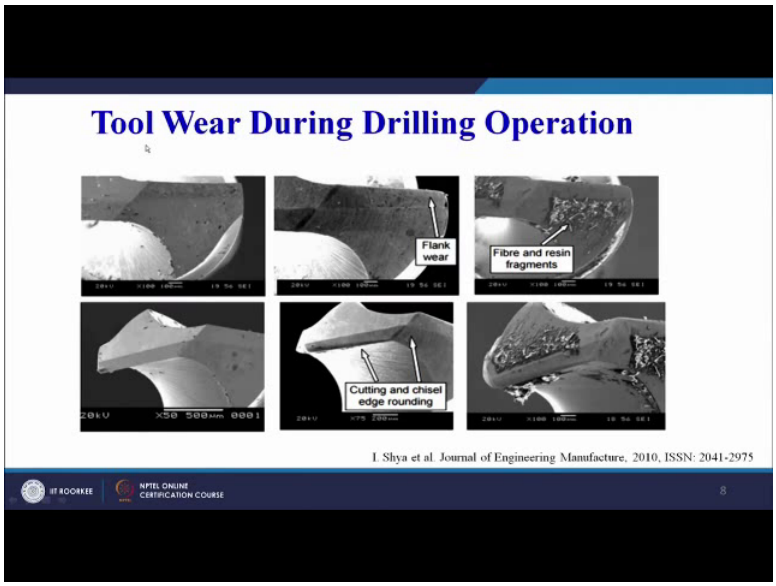

So, this is the tool wear; during the drilling operation, different flank wear can take place. Cutting and chisel edge rounding can take place from here, you can see the damaged fiber and the resin fragments are present on the drill surface; they get stuck to the drill surface. So, tool wear is also one big challenge in case of drilling of composite materials.

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Again this is tool wear; you can see this the new drill completely new drill, but after making maybe more than thousand holes; we can see the tool wear or the drill wear has taken place. So, this is another maybe chisel edge wear is shown here; this is a bright portion depicting the chisel edge wear. Then the flank wear is also shown here dark portion showing the flank wear. So, corner edge rounding has also happened, so maybe different forms of wear can be observed during the drilling operation.

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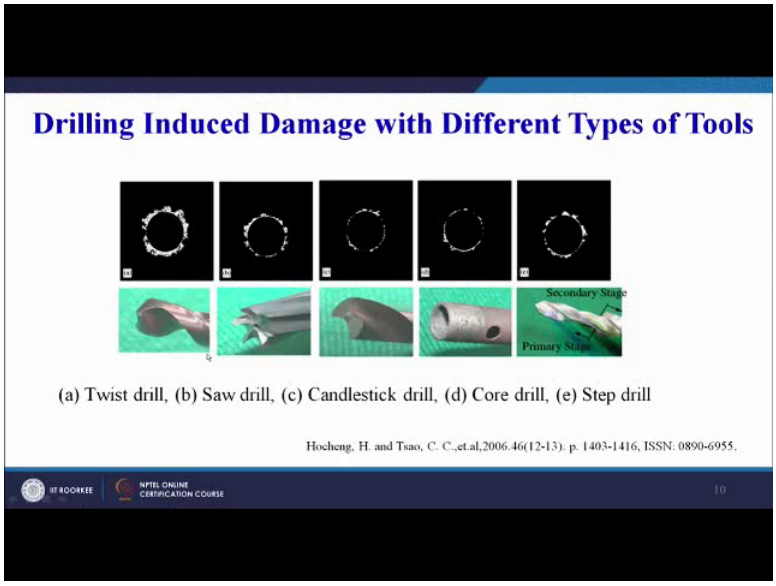

Now, here we can see this is the last slide that I want to discuss today. You can see 1, 2, 3, 4, 5 different types of drill; this is the twist drill most commonly used twist drill, saw drill, candle stick drill, core drill, hollow drill and then this is step drill. So, we have already seen the signal that is recorded for the step drill and we can see the damage around the hole; this black color portion inside represents the hole and the white portion is depicting the damage around the hole. So, you can see in case of twist drill; maximum damage has been reported around the hole; whereas in case of core drill, it is less similarly in step drill also it is comparatively less.

So, we can very easily now understand the importance of tool point geometry; specifically in case of making holes in composite materials; more specifically in case of polymer matrix composite materials. So, by now I think we have understood that what are the important tools and techniques that can be adopted to minimize the damage around the drilled hole in case of polymer matrix composites.

And one important fact that I have established today is; the importance of tool point geometry in minimizing the drilling induced damage. We will continue our discussion and try to see what are the other methods techniques developed by the researchers in order to minimize the drilling induced damage.

Thank you.