Processing of Non-Metals
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Module - 7
Secondary Processing of Composite Materials
Lecture - 2
Hole Making Techniques for Polymer Matrix Composites

Good morning to all of you, I welcome all of you to this second lecture in our module seven, that is secondary processing for composite materials. As all of you are well aware that we are discussing for the last few weeks lectures on the course processing of non metals, and within processing of non metals. Now, we have reach to the end of our course with the module number seven that is secondary processing of composite materials.

We have already discussed lecture number one in which we have seen the drilling of polymer matrix composites. So, before we start lecture number two let us first revise what we have covered in lecture number one, and we will also see that what is the need of secondary processing for composite materials, as we have seen in our previous lectures and previous modules most of the materials can be made using the primary processing, that is near net manufacturing in which we are able to generate the shape of the product, but sometimes when this particular product or a component has to be assembled with another component or a product in order to get the complete assembly or a complete structure or a complete body of a complicated product.

All these individual components needs to be assembled together, and when these individual components have to be assembled together we have to undergo or we have to perform the assembly operation, and for assembly operation secondary operations are required. And these secondary operations we have already classified that in our module seven we are going to discuss only two important aspects, that is the machining aspect as well as the joining aspect. So, joining aspects we would be covering in lecture number three and four, but primarily now in lecture number one and two our focus is on the machining aspects and more specifically on the drilling aspects or hole making aspects in polymer composites.

So, in our previous lecture that is lecture number one, we have seen that what are the important factors that have to be taken in to account, what are the important challenges that are there, when we try to make a hole inside of a composite material or inside a laminated composite material, now what is a polymer matrix composite which that we have already discussed in module number five, that it is made up of a reinforcement and a matrix and when we try to machine or drill up this particular laminator, this particular composite material there are a large number of issues that are involved. So, all those issues we have covered in lecture number one today we are going to focus our attention on a specific techniques or some of the developments that have taken place in the drilling of or hole making, we should say in case of polymer matrix composites.

We stopped our last lecture with a discussion on the different drill point geometries. So, that is one of the important points that has to be taken care of while we are trying to make a hole inside a composite laminar, again I want to emphasize a drill point geometry not only influences the forces that are generated during the drilling process or drilling action, but they also influence the damage that takes place around the drilled hole, if you remember in the previous lecture number one module number seven we have seen that there is a damage that takes place, because of the drilling action in the polymer matrix composites we have seen what are the different types of damage that takes place

So, therefore whenever we are going to make a hole inside a composite material there is bound to be or there is every chance that the damage may takes place around the drilled hole. So, therefore, there is a need that we should think or we should propose some of the processes which may avoid this damage around the drilled hole. So, one of the important points is the geometry of the tool that we have using to make a hole. So, today our first focus would be the modified drill point geometry and we will see try to understand the working or the performance of one typical drill point geometry that is called as a step drill and another name can be the jo drill. So, we will see the performance that how it makes the hole and how we can modify the geometry. So, that the damage can be minimize.

Then we will see different types of techniques which have been proposed by the researchers worldwide to reduce the drilling induce damage or to minimize the drilling induce damage. So, our focus would be primarily on vibration assisted drilling we can also see the helical view we will also see the helical feed method we will also see the use of a backup plate. So, different techniques we will see with the help of diagrams which are used worldwide to minimize or reduce the drilling induced damage in polymer matrix composites.

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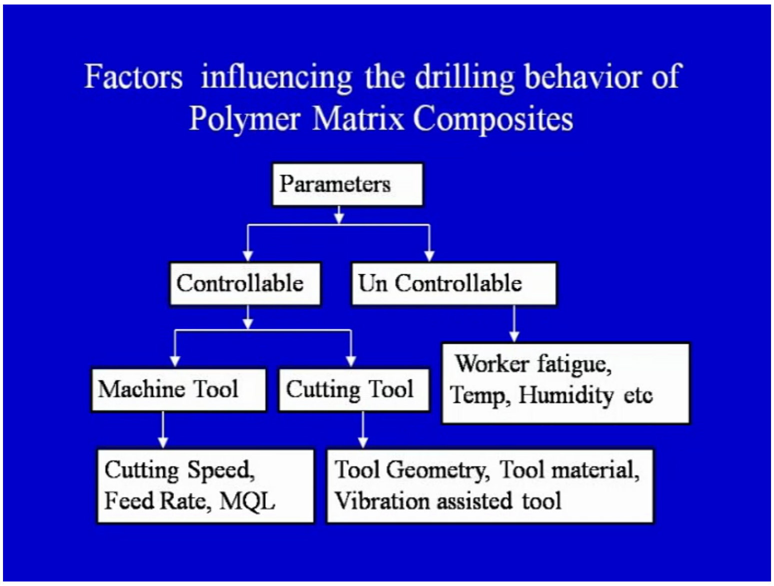

So, let us first see the factors influencing the drilling behavior o polymer matrix composites now, what are factors that govern the behavior when we are trying to make a hole using the drilling operations. So, these parameters can be broadly classified into two categories as on your screen you can have an idea that we can have controllable parameters and we can have uncontrollable parameters. So, controllable parameters are within our control, and we can select the machine tool that is the machine that will provide the relative motion between the tool and the work piece. So, we can decide on the machine we can control this decision that which type of machine is required for the specific purpose of hole making in polymer matrix composites. So, one important controlled decision that we can exercises the selection of the machine tool.

Another important decision is the cutting tool the tool, which is actually going to perform the hole making operation in context of the machine tool, we can further control the cutting speed we can control the feed rate of the machine also we can control the amount of lubrication that m q l minimum quantity of lubrication. So, m q l quantity of lubrication can be control whether we want to go for lubrication that is can also be control, what cutting speed that we want to use can be control speed rate can be control in totality there are many parameters related to the machine tool that can be control.

Similarly, in relation to the cutting tool there can be few controlled parameters that we can decide. So, what we can decide we can decide on the tool geometry that what type of tool we are going to use for making a hole, we can decide on the material of the tool, because there are large number of tool materials that are available which can be used for making holes in metals as well as in wood or incase of composite.

So, we can choose whether to go for high speed still or cemented carbide tool or a diamond coated tool or diamond tib tool. So, we have we can decide what type of tool material can be use what type of tool geometry can be use also sometime, we can use a vibratory assisted tool the tool along with the rotation is all can also be made to vibrate in order to improve the performance of the hole making operation. So, there are few controllable parameters or few decision variables that will help us to make certain decisions in our and ever to reduce the drilling induce damage or the damage, that is all around the hole.

There are few uncontrollable parameters also on your screen, you can have an idea we can have worker fatigue; that is one uncontrollable parameter although that can also be somehow controlled by shifting the workers after a particular interval of time, we can control the temperature and humidity, but usually as a engineer most of the controlled variables are machine tool and the cutting tool other variable are the management decision making. So, when we are making the hole these are the important variables that we can control, that is the machine and the cutting tool.

So, we can very easily see it is very clear from this particular slide that our focus today would be towards the controllable parameters, that is how the machine tool can be modified in order to make a damage free hole and how the cutting tool should be selected. So, that we get minimum drilling induced damage in drilling of laminated composites those are falling in the broad category of polymer matrix composites. Now, this is the one of the important setups which is used for doing research in the area of drilling of polymer matrix composites.

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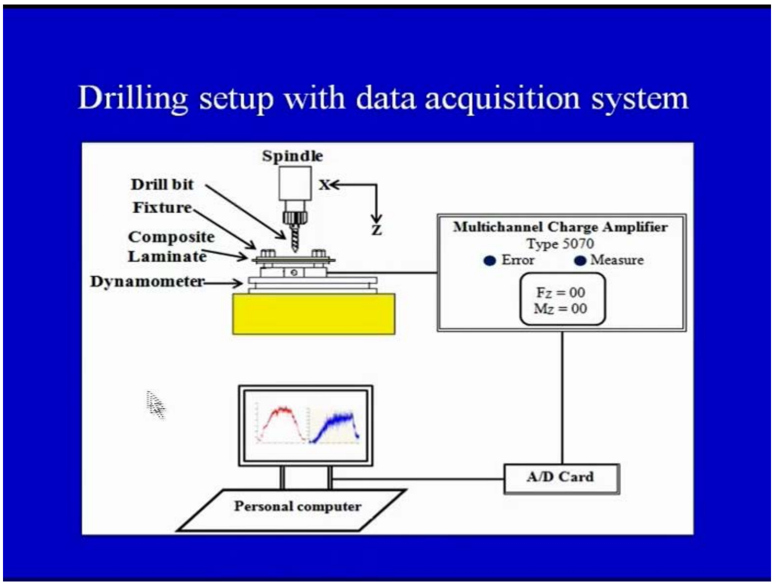

So, here on your screen you can see there is a machine head or a spindle, we have a drill bit or a drill jo twist drill or any other kind of drill can be used, we will see the performance or the signal analysis for one particular type of drill in the subsequent slide. So, we can have a drill this is a cutting tool this is a cutting tool drill bit, then we have a fixture a composite laminate is placed in which the hole has to be made and then there is a dynamometer which will record the forces. So, dynamometer is connected to the multichannel charge amplifier and this charge amplifier through the analogue to digital card is connected to the personal computer or a machine, where the signals are getting recorded. So, on your screen you can see a red signal you have we have y axis we have x axis on x axis, we have the time and on y axis we have the magnitude of the forces, it can be torque it can be force in x direction y direction or z direction.

Similarly, we have another signal in which on x axis, we have the time and on y axis, we can have the force it can be again to emphasize, it can be the force component in any direction. So, this is a generalized setup which is used for doing research in the area of hole making in case of polymer matrix composite. So, basically thus behavior is recorded in the form of signals and then it is analyze to see what changes can be done in order to minimize the damage that is accompanying the drilling action. So, basically we want to reduce the drilling induce damage, and therefore we need to investigate that what type of machine tool should be used, what type of cutting tool should be used.

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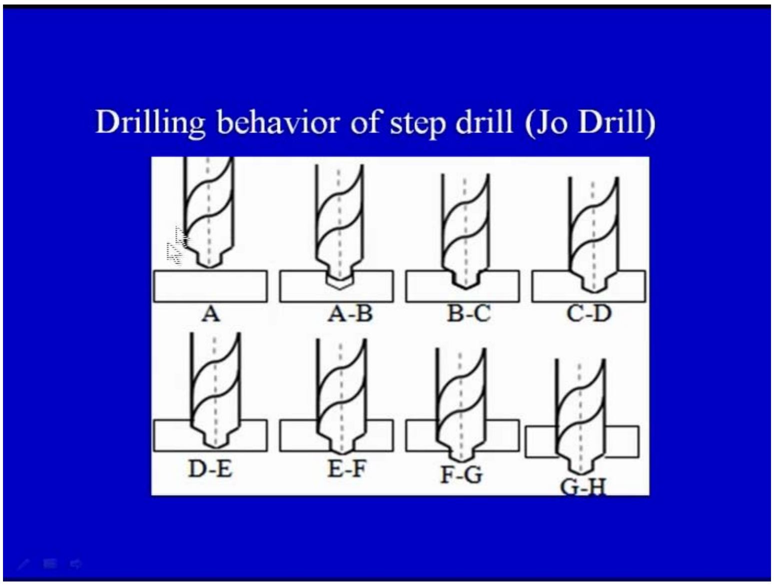

Now, here we can see the drilling behavior of a step drill or we can also call it as jo drill. So, this particular drill has a step here otherwise this line could have directly joined at the centre, but here we have a step. So, this is a step drill a A B, this is going down the central portion has started to make a hole then further it goes down these are the different stages, that we will try to understand in the subsequent slide with the help of a force signal that how the thrust force is generated and how it is related to the varies stages.

So, this is stage a where the drill is just touching the composite laminate stage A B, where the inners circle or the central cutting edges have entered the laminate or the primary cutting edges have started to perform the drilling operation or the hole making operation, then it further goes down the secondary cutting edge is have also entered the laminate and the drill. Now, is an incomplete engagement with the composite laminate finally, it is going down and performing the hole making operation e f stage the primary cutting edge is have started to come out of the laminate and the hole making process is going to be completed, and finally the total drill will come out still the secondary cutting edges are doing the cutting in the lower lamina of the laminate, and finally the total drill point comes out of the laminate and the hole making process is complete.

So, we can see that the hole making in a composite laminate can be explained with the help of different faces in the hole making operation important point to understand, here is that we have taken one type of a drill point geometry, there can be other types of drill point geometry, and their behavior their response to the different types of composite materials may be different their cutting mechanism, may be different their cutting characteristics, may be different. For example, if we have a hollow drill it will not start the cutting operation from the central point, if it is hollow it will start the cutting operation from the periphery.

So, the total cutting mechanism will change. So, important point to emphasize, here is that the drill point geometry plays a significant role in defining the cutting forces as well as the drill induced damage. So, we will see now that how a force signal can be correlated with the cutting being performed by a different drill point geometry, because there can be a large number of drill geometries and each type of geometry will generate a different type of a force signal.

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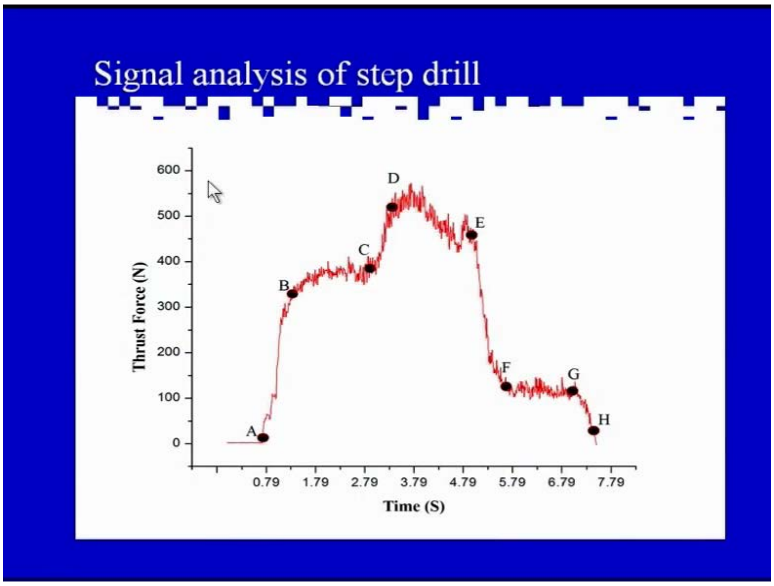

So, on your screen you can see a force signal this is a thrust force signal, as I have already told it is not recorded with the composite laminate it is recorded for a metal why because the magnitude of forces are very high, which are very uncommon in case of laminated composite. So, this particular force signal is for a drilling of hole in a metal and it is one form of a signal if we change the drill point geometry certainly this particular signal will change on the x axis, we have time on y axis, we have the thrust force.

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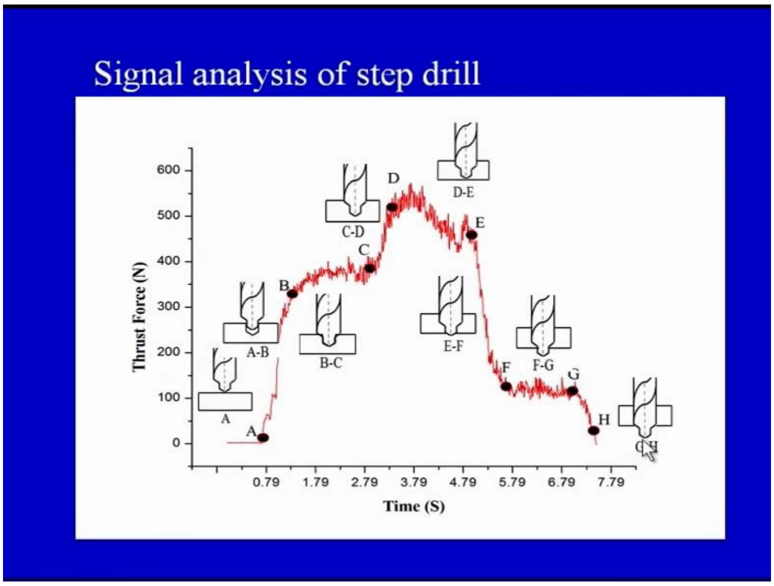

So, we will see this is the point a where the drill point is just touching the laminate, and no drilling is taking place, then the inner or the primary cutting edges have started to perform the cutting operation and from A to B the force rises and from b to c further the force rises and the outer cutting edges are also, now in touch with the laminate c to d the outer cutting edges are now incomplete engagement with the laminate and the (( )) force rises from C to B. And finally, from d to e there a complete engagement of the drill and the inner cutting edges start to come out and the drilling operation is going to be completed from e to f.

Again there not much difference between d to e and e to f, we are recording a reduction in the force why because a drill is, now going to come out and mo the amount of material removal in this particular stage is considerably less as compare to the initial stages these stages why because the inner or the primary cutting edges have already generated a hole and the secondary cutting edges are now finishing the hole and removing the minimum amount of material.

So, already a feed drill hole is existing, because of the primary cutting edges and therefore, from stage d to stage f through e d to e and e to f, the forces are reducing and from f to g, we can see the primary cutting edge has already come out. And only the secondary cutting edge is performing the cutting operation, and finally we can see from g to h the drill has come out of the laminate the hole making process has been completed.

So, with this diagram we have try to understand that if we are able to record the forces that are being generated, because of the drilling action or the hole making action and correlated with the drill point geometry, we would be able to design the drill geometry in such a way. So, that we get minimum forces and when we get minimum forces it can be understood that the damage associated would also be less it has been proved that if the thrust force is very high the pushdown type of delamination is extremely rampant and the damages more towards the exit side of the drill.

So, if we are somehow able to control the forces that are generated drooling during the drilling action we would be certainly able to reduce the damage, and this particular slide explains that if we are able to select an optimal drill point geometry, which minimizes the forces both the thrust force and the torque, we can very easily feel or we can very easily observe and record that the damage associated is also minimum. So, first and foremost important point for minimizing the damage in laminated composites of polymer matrix composite is to optimize the drill point geometry.

So, just to review what we have covered our major focus is to minimize the damage in laminated composites, and we have seen that if we judiciously control the controllable parameters that is the machine tool and the cutting tool, we can very easily control the damage therefore, we have seen that tool point geometry play the significant role in dictating the drilling behavior of polymer composites. And more specifically the damage characteristics, we have to understand that how a drill makes a hole, and there are different stages in hole making which can be correlated with the signal, which is generated or recorded during the drilling action and we have focused on the thrust force which is very, very important in case of laminated composite.

So, till now we have seen the damages important, we have to minimize the damage and tool point geometry can be used as one of the important control variables to minimize the drilling induced damage, because it affects the drilling forces which subsequently dictate the drilling induce damage. So, we have focused on one control aspect that is the tool or the cutting tool aspect, and we can modify the geometry in order to achieve our objective

The other important aspect is the machine tool aspect and in machine tool aspect we would somehow try to modify the machine tool. So, that we are able to minimize the drilling induced damage. So, what are the varies parameters that we can controlling the machine tool and what are the process variants of the hole making operation that we are going to see in the subsequent slide.

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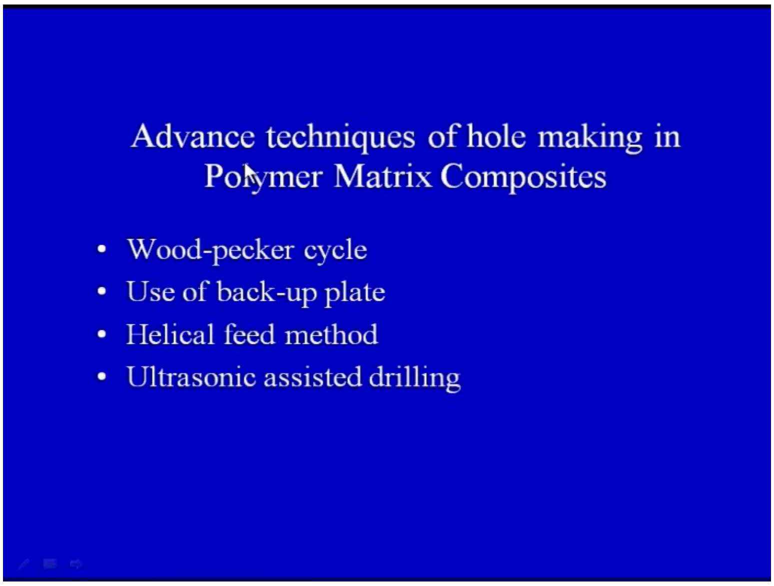

So, on your you can see the title is given advance techniques of hole making in polymer matrix composites. So, these are some of the techniques which have been adopted worldwide to minimize the damage that is associated with hole making operation in case of laminated composites or polymer matrix composites. So, one of the methods is woodpecker cycle, it has two variants we can use a back up plate below the laminated composite there is a helical feed method, and there is ultrasonic assisted drilling or vibrated assisted drilling. So, we will see one by one.

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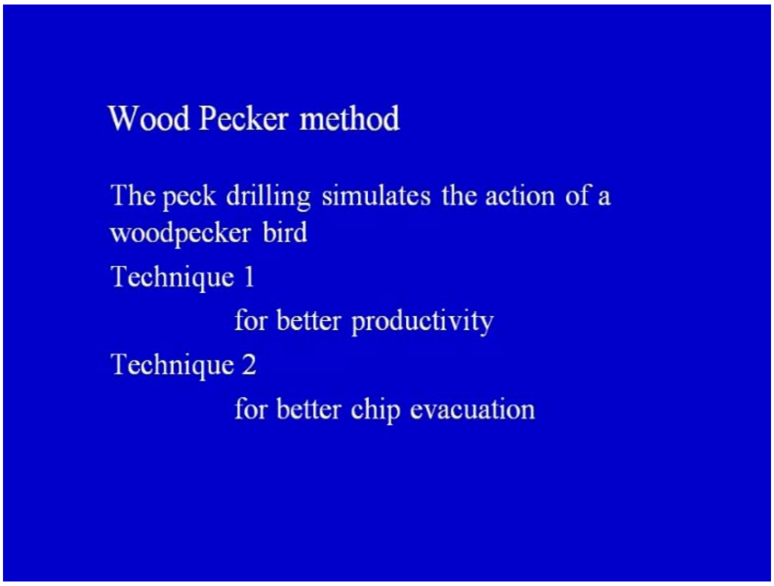

Wood pecker method the peck drilling simulates the action of a woodpecker bird most of us might have seen the action of the woodpecker bird how it tries to make a hole inside wood. So, similar method or similar technique can be utilized in case of laminated composites also. So, there are two variants of the woodpecker method that is technique one and technique two. So, for technique one it is for better productivity for minimizing the time required for making a hole and technique two is for better chip evacuation or better chip removal we will try to see both of these techniques with the help of a diagram.

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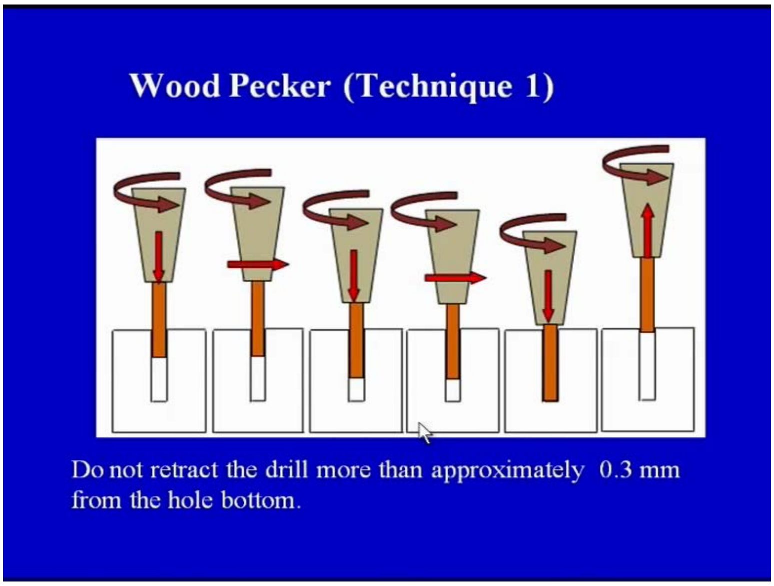

So, on your screen you can see, this is woodpecker technique or woodpecker method which is technique one in this technique, we can see this is the spindle and this is suppose the drill. So, it is rotating and it is being fed in the laminate this is our piece material. So, it goes down and makes a hole and suppose this is the hole final hole that we want to make this is the blind hole, this is a total depth that we want to achieve. Now the drill will go inside to a particular depth, and then it would be stopped it would be made stationary there, but it would still be rotating it would be rotating, but it is not going down it is stationary.

Now again it will go down to a particular free defined depth, and it will again be made stationary, and finally it will go down to the bottom of the hole or to the point up to which we want make a hole finally, it would be taken out. So, in this we have seen that the total depth of the hole or the total we can say height of the hole has been generated not only in a single go, we have made it in two or three different stages now what is the purpose of this two or three stages, because we wants sometimes in certain machine tools there is a provision that we can modify the feed rate during the drilling operation.

As I have already emphasized that thrust force is the main parameter or the major parameter which governs the drilling induced damage in form of pushdown type of delamination. So, when we have different layers stacks together and when drill goes down and makes a hole towards the end of the end of the laminate or towards, the last layers of the laminate, there is the tendency that this layers may open up, because of the thrust being generated and this is call the pushdown type of delamination.

So, if we can somehow control the feed rate that the drill instead of going down with a constant feed rate, it should initially go down may be at a slightly higher feed rate, and later on this particular feed rate can be reduced. So, that towards the end the feed rate is extremely slow and there is no pushdown type of delamination. So, this type of woodpecker cycle is very important and can this very useful can be used in those circumstances, where we want to maneuver or where we want to manipulate the feed rate during the drilling operation. So, here we can see that once the feed rate is set the drill is not performing the total operation in one go it is going down, then it is stationary then further it goes down again it is stationary, and finally it goes down and comes back

So, once it is stationary somehow we can manipulate the machine tool. So, that the feed rate is reduced and in the final go the feed rate may even be reduced further. So, this particular technique is very help full in controlling the drilling induce damage it has been proved, but may be true for a certain set of material and under certain circumstances, but the researchers have found that if we are able to manipulate the feed rate during the drilling operation or the hole making operation, we would be certainly able to reduce the forces as well as we would be able to reduce the associated damage.

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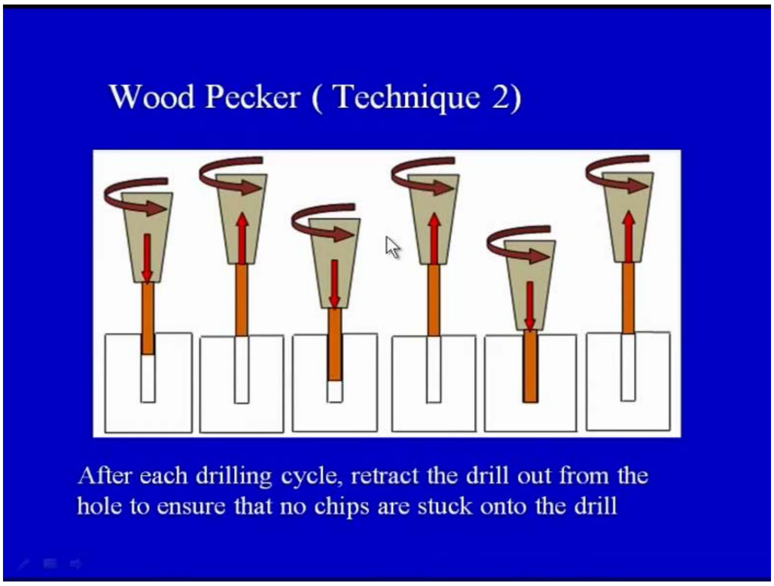

This is another woodpecker method with technique number two here, you can see the drill is going down, and again it is coming back again to the surface of the laminate again it is going down, but to a depth which is greater than the depth it has gone initially. So, this is hole is generated to this much depth comes out again goes, goes inside hole is generated to this much depth again, it comes out goes in. And finally, completes the hole making operation or the total depth, that we want to achieve is achieved in the final pass or in the final hole making operation and finely it goes out.

Now, what is the advantage of this after each drilling cycle retract the drill out from the hole to ensure that no chips are stuck onto the drill. So, we can get better surface finish in this case because sometimes the chips also may be coming out with the drill and these chips may be rubbing against the wall of the hole, which is already been generated and some kind of honing action may takes place, and because of this honing the surface finish may be better. So, we can see that instead of the tool going at a constant feed rate and making the through hole in a single go the hole can be made as the woodpecker makes a hole in the wood. So, it can be made in a series of steps and these series of steps would certainly lead to some advantages.

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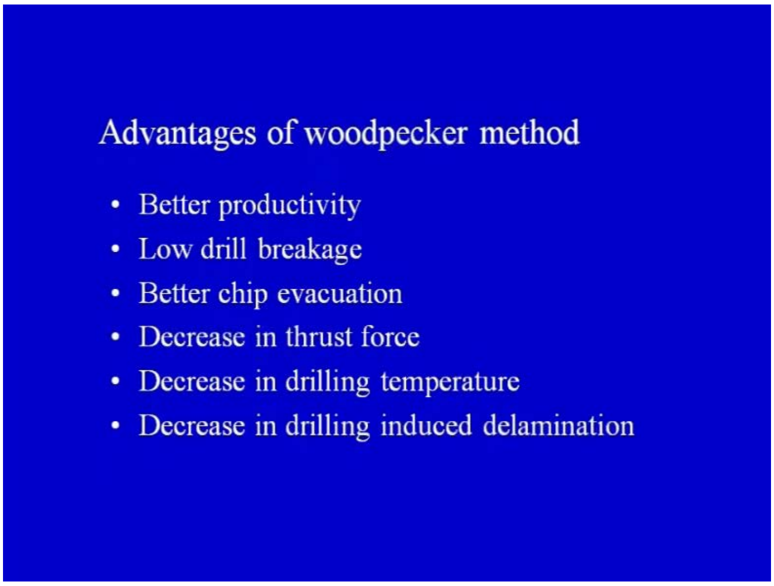

Now, what are these advantages, we can see the advantages of woodpecker method are better productivity, it is obvious that in normal drilling operation there damage will takes place and lot of holes are rejected. So, in case of woodpecker cycle if the damage can be minimized the number of holes, which are accepted is more and the we are we can say that we are more productive as compare to the conventional hole making operation drill breakage is also less better chip evacuation chips can be easily removed, because again and again the drill is coming out decrease in the thrust force, because we are not using a constant feed rate here decrease in the drilling temperature, because the drill is now not in constant engagement with the work piece for a longer period of time suffuse, it is a thick laminate.

And the drill is going inside at a very slow rate and for a large period of time if the drill is in constant engagement with the work piece the temperature may rise which may lead to matrix softening, because matrix is a polymer and if matrix softening takes place there is bound to be damage accompanying. So, accompanying damage would be severe when we are going to use this laminate with the hole in certain application.

So, we want to control the temperature also and in this method we have a better control over the temperature as compare to the conventional drilling process. So, decrease in thrust force decrease in drilling temperature, and finally our major objective is to minimize the drilling induce damage inform of delamination which is considerably reduce, because we are manipulating the feed rate during the drilling operation or during the hole making operation and towards the end of the operation the feed rate is extremely low and therefore, there is no excessive thrust force that is generated therefore, the pushdown type of delamination is minimized, if we use the woodpecker cycle to make a hole.

So, once again i will read out the advantages of the woodpecker method, we can get better productivity drill breakage can be minimize chip (( )) evacuation is better thrust force is are less drilling temperature is also less. And finally, the major objective of reduction in the drilling induced delamination is also there is also achieved.

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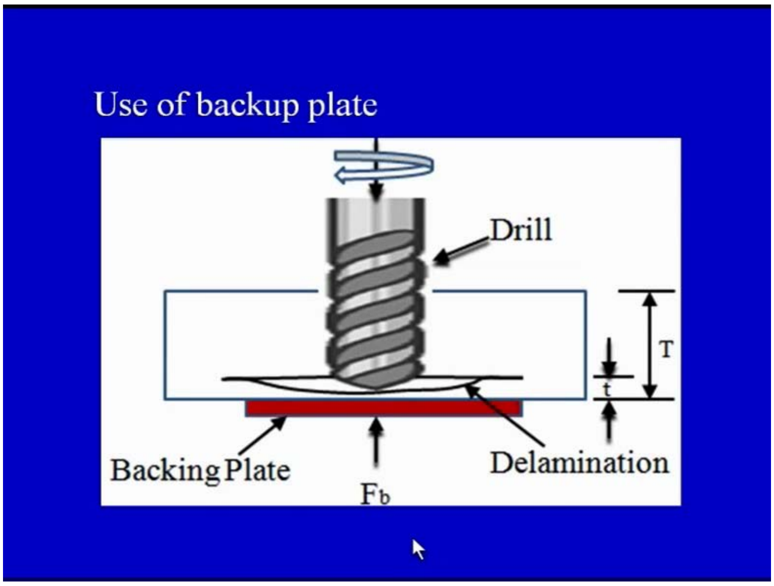

Second important modification in the process is the use of the backup plate. So, on your screen, there is a very simple diagram in which we have shown a drill the drill is rotating this is the composite laminate rectangular block in which there are different layers and one particular layer suppose is shown on the exaggerated scale this is one layer. So, we have a laminate suppose it is made up of ten layers. So, this ten layers have a total thickness of capital t and this last layer has a thickness of small t. So, when the drill is rotating and it is going down at a constant feed rate it tends to open up the bottom layer and delaminate, the bottom layer this is a bottom layer which is getting delaminated, because of the feed rate with which the drill is moving down the drill is rotating as well as it going down. And suppose we have a very high feed rate the chances of this delamination are even more specifically in case of the laminated composite. So, when this is going down this stands to delaminate or open up the bottom layers and causes push down type of delamination. So, this delamination can be arrested to a particular amount with the use of backup plate this red rectangular block on your screen represents the backing plate.

So, when we put up backup plate below the laminate which is being drilled, we can somehow arrest some of the push down type of the delamination. So, backup plate method has been used to minimize the push down type of delamination in many cases and it has been proved experimentally that when we compare the performance of the hole making in case of composite laminates without a backup plate, and with the backup plate the performance with the backup plate is much better as compared to the hole making or drilling with a backup without a backup plate. So, with backup plate the performance is better, but in certain circumstances in certain complex geometries it is not always possible to put the backup plate below the laminate and therefore, the push down delamination cannot be avoided totally, but certainly wherever possible a backup plate would certainly not allow the bottom plies to delaminate and would arrest the push down type of delamination.

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So, back use of backup plate has got certain advantages. So, that those advantages are listed on your screen that it decreases the drilling induced damage is specifically in terms of push down type of delamination, and the quality of hole produced is comparatively good to those holes which are produced win with the without the use of backup plate. So, use of backup plate is advocated, wherever possible when we are going to perform the hole making operation in the laminated composites why, because the plate tends to arrest the push down type of delamination and does not allow the bottom most layers of the laminate to delaminate under the cutting tool action.

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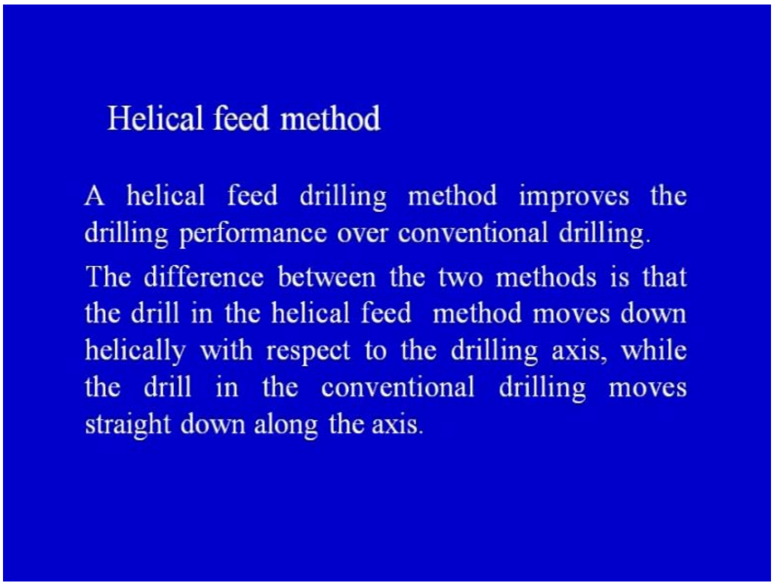

Then we come on to the helical feed method a helical feed method is a modified hole making operation in helical feed drilling method drilling performance improves over the conventional drilling. So, first point is very, very obvious that whenever we purpose a new method of hole making it should certainly be advantages related to the conventional method at least in some of the important aspects. So, a helical feed drilling method improves the drilling performance over the conventional drilling.

Now, what is the difference between the two will try to understand with the help of a diagram also the basic difference between the two methods is that the drill in the helical feed method moves down helically with respect to the drilling axis now suppose we have a drilling axis the drill would move down helically, where as in conventional drilling the drill goes down straight along the drilling axis. So, in conventional drilling we have a straight movement or a linear movement of the cutting tool or the drill where as in helical feed method the drill moves down helically.

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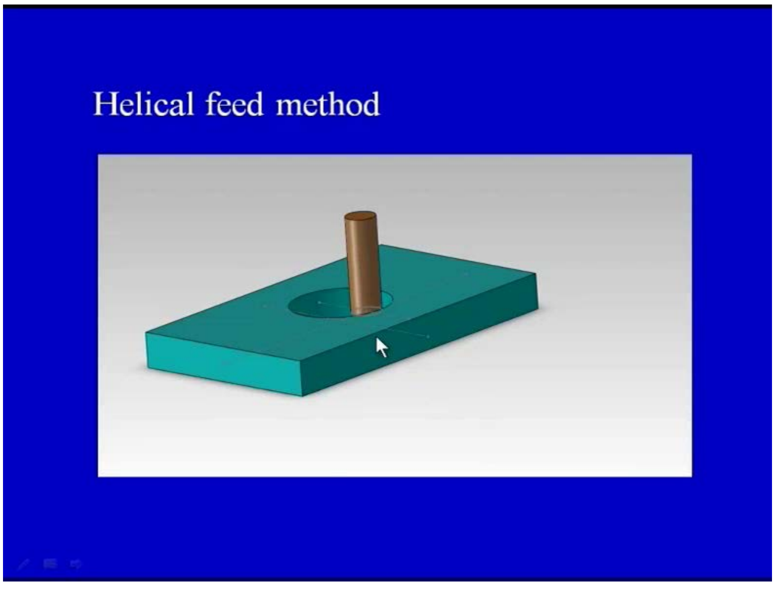

So, we can see the helical feed method this is the drill point geometry and this is the composite laminate in which the hole is being generated. So, the drill would moved on helically and it would certainly lead to certain advantages which are not possible with the conventional drilling method.

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Now, what are those advantages now the advantages of helical feed method are chip removal is better because the drill moves it on helical chips can come out easily, if we have a conventional drilling the drill is going down, and the chips may come out of the flutes which are present in certain drill point geometries, but we are performing operation with a modified drill point geometry we may certain times not be able to evacuate or remove the chips in a convenient manner. So, in case of helical feed method the chip removal is better that is number one point.

Number two point flow of coolant is better that is another point because it gets an open axis to the area where the actual drilling is taken place thrust force is minimized drilling induced damage is minimize, and high quality of hole is produced, and the temperature produced is also less which decrease is the matrix burnout problem. So, matrix burning can be reduced when we are using the helical feed method.

So, primarily if we see this process variants the major focus is on three aspects, that is the reduction in the forces and more specifically the thrust force because the thirst force is the prime cause of push down type of delamination. So, whatever process variants have been suggested the focus is on minimization of the thrust force generated during the hole making action or hole making operation when the thrust force is minimized, it leads to subsequently the reduction in the drilling induced damage and more over the process variants are also giving one, one another advantage that is the temperature generated is less and if the temperature generated is less the polymer matrix will not soften or matrix burning may not take place which is advantageous, because it is also related to the damage. So, other forms of damage or also not possible or also can be controlled if we are using the process variants as we have seen in the previous slides. So, we will see another process variant that is the vibration assisted drilling in vibration assisted drilling the drill is rotated also and it is vibrating also.

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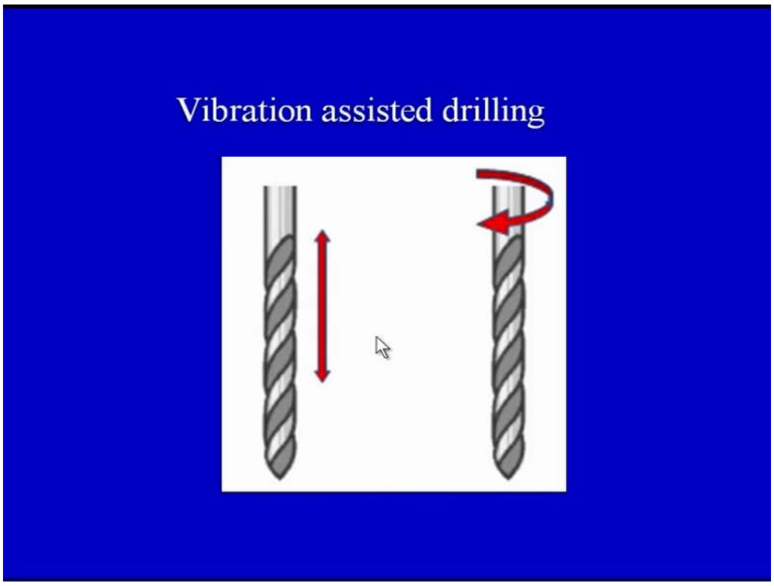

On your screen you can see that there are two motions in the drill now otherwise in conventional drilling the drill is only rotating, and it is being fed into the laminated composite at a specified pre determined feed rate the drill is rotating, and it is fed into the work piece at a specific federate, but in case of vibration drilling the drill is rotating as well as it is vibrating also at a certain frequency. So, we have a vibrating drill which is rotating also, and it has been found that this vibratory assisted drilling certainly leads to lower forces and lower damage in case of the laminated composites.

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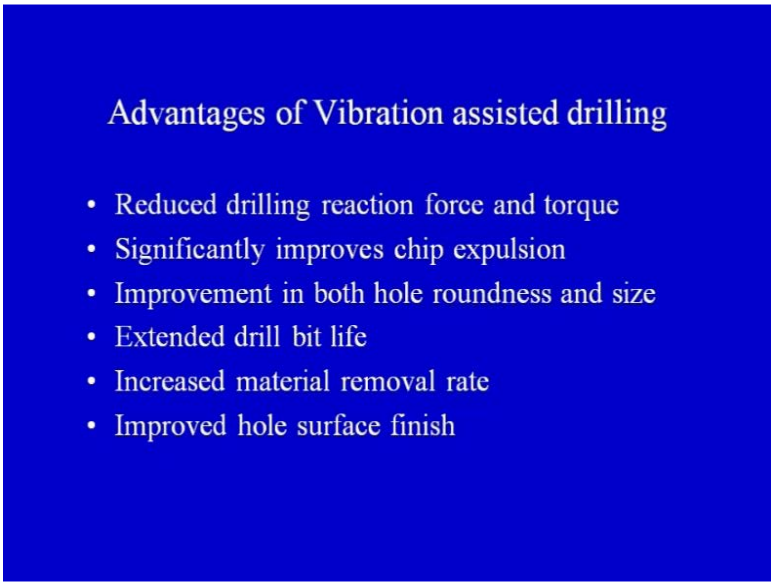

So, now what are the advantages of the vibration assisted drilling on your screen you can see reduced drilling reaction force and torque. So, the forces is are less significantly improves the chip expulsion that is also possible in all the process variants that we have studied today improvement in both hole roundness and size. So, basically the quality of hole in terms of roundness and size is considerably improve, when we make a hole using the vibratory assisted drilling. So, the quality of hole made is also better in case of vibratory assisted drilling and the drill life is also more. So, the tool wear is minimize and we get a extended life of the drill tool or the hole making tool material removal rate is also high means the productivity is more, we are able to make large number of holes in less amount of time or quickly, we are able to make large number of holes.

And finally, the hole surface finish is good. So, the geometrical features of the hole are also good the quality characteristics of the hole are also good the forces, that are generated are also minimized, and the damage in terms of push down or fed up type of delamination are also is also less. So, over all we can see that if we modify the process slightly to shoat to the specific requirements of the laminated composites certainly we can achieve our major target of minimization of the forces and minimization of the drilling induced damage and maximization of the quality of the drilled hole. So, in today’s lecture we have seen that there are few process variants, which are available with the engineers out of with they can choose accord depending upon the availability and the cost effectiveness of the various process variants a engineer can very easily choose that which process variant will give him the desired characteristics of the hole.

So, in today’s lecture our focus primarily was on certain important techniques which can be used for minimizing the drilling induced damage, we started our lecture with focus on the tool point geometry as one of the important tools for minimizing the damage, we have seen that how the force generated can be correlated to the geometry of the cutting tool and the geometry of the tool can be minimize to reduce the foresees. So, that when the foresees are less the damage is also less. Secondly, we have seen a woodpecker type of technique in which a better quality hole can be generated we have also seen the use of backup plate as a effective tool for minimizing the drilling induced damage, then few process variants in terms of the helical feed method, and the vibrated assisted drilling was discussed and we have very briefly out lined the advantages of these processes.

So, in our subsequent lecture, we would be focusing on the joining aspects of the polymer matrix composite, we would see the mechanical fastening the adhesive joining and as well as the microwave joining of the polymer matrix composite just to conclude the today’s lecture in a two or three sentences; the important point to note is that the process variants can be developed specifically dedicated to the laminated composites wear a hole can be made to a better accuracy with a better quality and with minimum damage using this process variants, but one of the major limitations can the cost because whenever we develop a process variant the cost would certainly be more than the conventional hole making techniques, but depending upon the applications and depending upon the usefulness of these particular laminated composite sometimes we may be able to justify the higher cost of the set up in relation to the quality of the hole that we are getting. So, with this we conclude the today’s lecture of hole making techniques in polymer matrix composites.

Thank you.