Processing of Polymers and Polymer Composites
Dr. Inderdeep Singh
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture – 37
Non-Conventional Drilling

[FL] friends, welcome to section 37 in our course on Processing of Polymers and Polymer Composites. As we are in the last phase of our course, we are focusing on the secondary processing of polymer matrix composites. So, majorly there are two processes that are common in secondary processing; that is the joining as well as the machining.

We have already seen the joining processes; if you remember five different types of joining processes we have seen in context of the polymer composites. Very easily we can remember if you have gone through the previous session, you will be able to recall that we have seen the fundamental or the basics of the basic joining process for polymer composites. We have then seen the mechanical fastening process, the microwave joining process, induction welding as well as resistance welding process.

Finally, we shifted our attention towards the machining of fiber reinforced plastic parts. Now, if you see the overall production cycle or overall product development cycle for polymer matrix composites, you will see that initially we make the composite parts using the standard primary manufacturing processes; such as hand layup or spray layup filament winding, pultrusion, vacuum bag molding, resin transfer molding; there are number of processes well developed for making of composite parts, specifically polymer matrix composite parts.

But when we shift to intricate products, when we shift to larger structure; we cannot make larger structures using the primary manufacturing processes. And therefore, we make individual parts using the primary manufacturing processes and then we shift to the secondary manufacturing; that is joining as well as machining of these individually manufactured parts, using the primary manufacturing techniques. And this joining and assembly of these parts usually requires different types of techniques.

So, five techniques; I have already highlighted or outlined for joining of polymer composite parts and today we are going to focus on machining aspects. If you remember in the last session; last I think two or three sessions, we have focused on the problem areas associated with machining. We have seen that hole making is an unavoidable machining operation in case of polymer matrix composites; why? Because as I have told you that microwave joining induction, welding; resistance welding are in the process of development, so these process have been developed for some set of composite materials are not equally versatile or not equally applicable to all family of composite material.

So, whenever you change the polymer; you change the fiber the joining technique will also automatically change. But the two techniques remain very very important and are not much specific or not much relevant or not much dependent on the type of material of the fiber as well as the matrix. So, these two types of joining strategies are the adhesive joining technique and the mechanical fastening technique. In mechanical fastening, you can make a hole and use the fasteners to do the assembly operation.

Similarly, in adhesive joining; you can do the surface preparation and use a adhesive to make a joint. So, therefore, major focus of industry is towards these two techniques that is adhesive joining as well as mechanical fastening. And in mechanical fastening the major challenge is the hole making operation in the composite parts and therefore, we have emphasized in detail, but what are the issues related to hole making in polymer matrix composites.

And in the last two three sessions, our focus has been on this operation only which is inevitable operation for making a composite structure. And we have seen that in conventional drilling, we can avoid the damage or we can minimize the damage by certain guidelines. So, the guidelines were that we can optimize our operating variables, we can control our operating variable such as the cutting speed, the feed rate, the drill point material, the drill point geometry; we can even modify the process.

If you remember, in the last session we have seen that we can modify the conventional machining process or conventional drilling process. If you remember, we have seen that we can go for a woodpecker cycle for making holes. We can go for support or the backup support just below the composite laminate in which we are going to make a hole. And finally, we have seen that modification in the process can lead to reduction in the damage.

So, we have seen the three methods that are the modifications in the conventional drilling technique; that were the first one was the helical feed method, the second one was the woodpecker cycle and the third one was the backup support method. So, we have seen; I think in the sequence, we have covered first the woodpecker cycle, the second one was the backup support and the last one was the helical feed method.

So, these three methods are the modifications in the conventional hole making or conventional drilling approach; specifically applied to polymer matrix composites and more specifically to the composite laminates. So, three methods that is the first one being the woodpecker cycle, the backup support being a second method and the third method being the helical feed method are; I think modifications in the conventional drilling process.

Again and again I am emphasizing so that can come to your mind and very easily, you can remember that somebody may question you that what modifications can be done in the conventional drilling in order to avoid the damage. So, very easily you can count on your fingers that; these are the three methods which have been established worldwide through research and which minimizes the damage around the hole.

But must I address; that these are not the only three methods which have been investigated. There are other techniques also which people or researchers have adopted to minimize the damage due to hole making operation. Now, what are these methods? Now these methods we are going to cover today, we are going to cover the non conventional hole making approach today.

We are going to cover the non conventional drilling techniques that have been developed, in order to minimize the effect of damage deduct happens or that occurs due to the drilling operation. And there are number of such techniques; which have been adopted which, but we are going to cover maybe two or three important methods that fall under the non conventional hole making of polymer matrix composites.

So, very quickly we will go through these techniques and try to understand the importance of each one of them in minimizing the drilling induced damage. Just to have a brief review of what we have discussed till today; we have seen that there are challenges in the conventional drilling. Again, I am emphasizing conventional drilling means that the tool is in direct contact with the workpiece. So, there is a challenge then we make a hole using the conventional drilling; then in the previous session we have covered that we can use a helical feed method, we can use a backup support method or finally, we can use a helical feed method in which we can we can try to minimize the damage.

So, we can different techniques can be done; that is woodpecker cycle, helical feed method, backup support method; all those are modifications in the conventional drilling in order to avoid the damage. So, the damage is still not avoided; still there is damage, but it is minimized if we use these three techniques. But finally, there are other techniques which have been developed, which try to completely eliminate the damage that happens due to the drilling operation.

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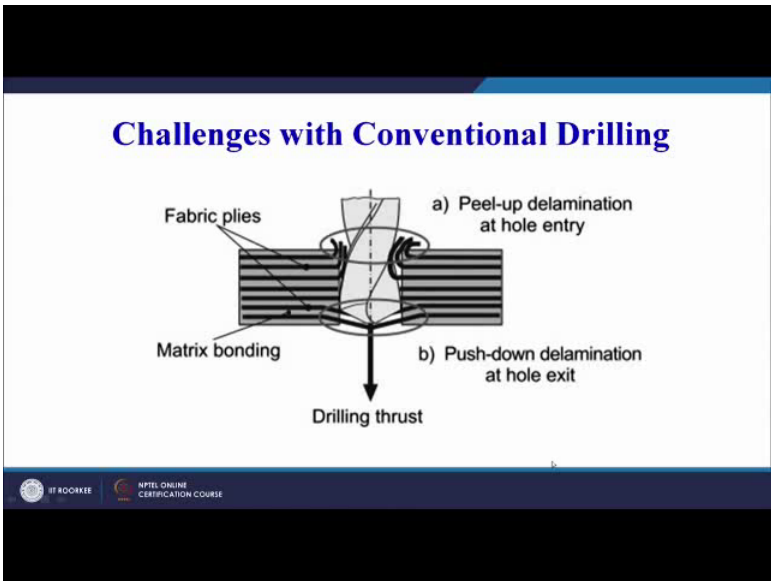

So, this is one form of damage we can see here on your screen; this is a push down type of delamination, this is because of the thrust force generated during the contact of the drill with the laminate. Then there is a peel up delamination these fibers; these fibers represent the peel up delamination, this is the pushdown type of delamination towards the exit of the drill; then there is matrix de bonding also, sometimes the matrix may fail.

So, major damage forms are the peel up delamination at entry and the pushdown delamination at hole exit. And this is not new, I think in the last two three sessions we have seen different figures, diagram, schematics representing the peel up delamination and pushdown delamination. And our endeavor has to be to minimize these two types of damage forms; this is another damage from you can see.

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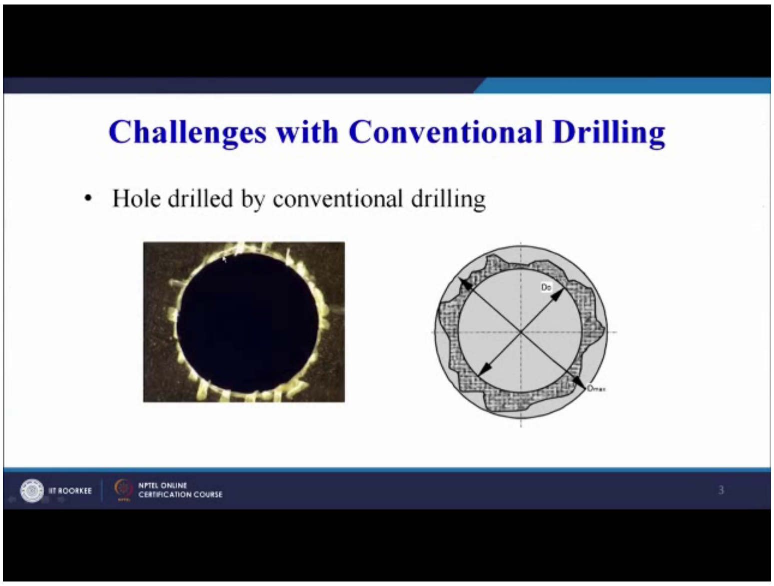

Around the hole; this white portion represents the damage to the fibers and the matrix. And schematically it has been represented here; D A represents the original diameter of the hole that is our objective, our goal and this shaded portion represents the damaged area around the hole. And we have also seen the delamination factor as f d is equal to d max by d o in one of our previous sessions.

So, here also d max is shown; these arrow represents d max; that is the maximum diameter up to which the damage has been reported or recorded or quantified. And this is the D O; that is our original diameter that we have planned. So, our ratio of d max by D O is called the delamination factor; now our objective is to minimize this damage.

Let us just reinforce what we have covered till now, whatever I have spoken in today's session.

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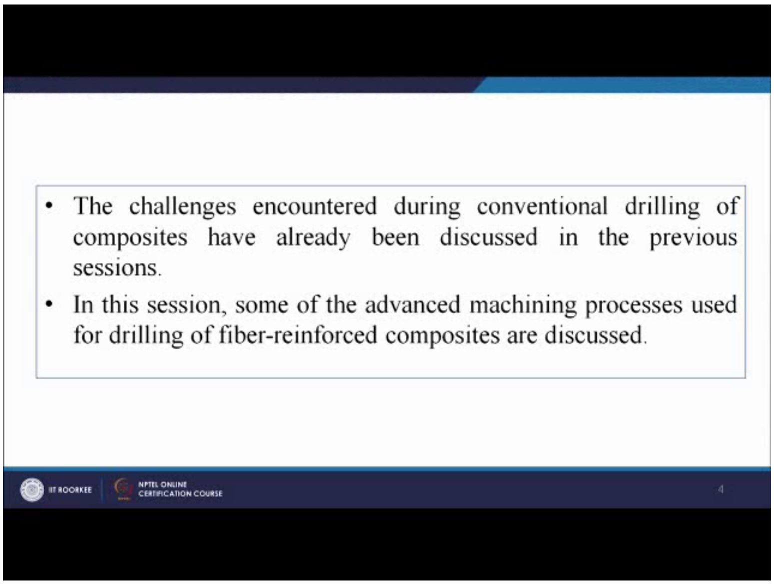

The challenges encountered during conventional drilling of composites have already been discussed in the previous session. We have seen what are the different damage forms that are reported; or that occur during the drilling of polymer matrix composites. In this session, some of the advanced machining techniques used for drilling of fiber reinforced processes will be discussed. So, our focus today will be advanced machining methods.

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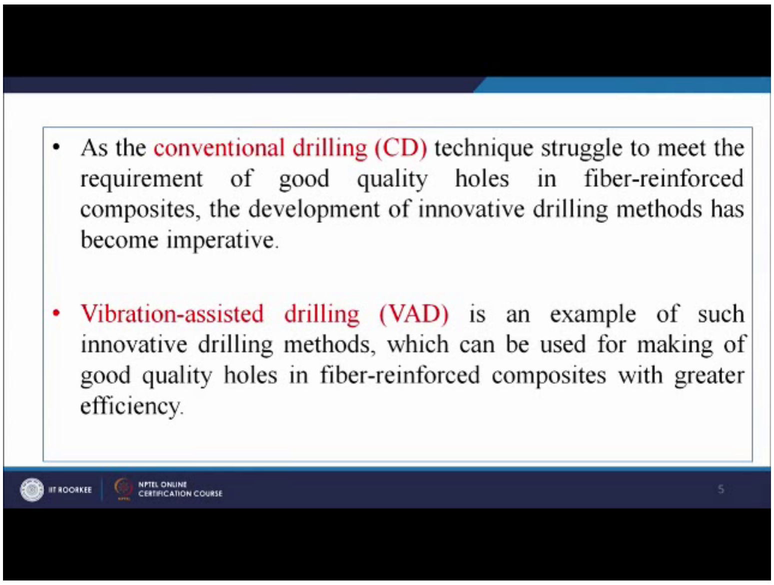

As the conventional drilling technique struggle to meet the requirement of good quality holes; so, we have seen that there are different forms of damage that takes place and conventional drilling leads to this form of damage in fiber reinforced composites. There is a eminent need to develop innovative drilling method, that can reduce this effect of damage.

And we have seen little bit of innovation in our previous session also; that there was a problem like initially the same method that is used for making holes in metals or isotropic material or homogeneous material were used for making holes in composite materials; which are in homogenous and an isotropic.

So, those methods were not found to be suitable in case of composite materials. So, when these methods were not found suitable for composite materials; innovative methods need to be developed. So, people focused or researcher focused on the conventional drilling approach only. And in conventional drilling, they found out that yes let us derive some knowledge from the nature and woodpecker cycle was in investigated and it was found to be partially successful in reducing the damage.

Then backup support method was innovated or maybe innovation was done or maybe some creativity was used to support the laminate from bottom so, that the plies do not open up and then the backup support method was developed. Finally, a helical feed method was developed; just a modification of the conventional drilling to minimize the effect of damage.

So, conventional drilling had issues; creativity and innovation was used to modify the conventional drilling approach to reduce the effect of damage. Then finally, the vibration assisted drilling was developed, it is an example of innovative drilling method which can be used for making of good quality holes in fiber reinforced composites with greater efficiency.

Now, today we are going to cover this vibration assisted drilling technique, which falls under the unconventional method of hole making. So, conventional method we have seen a few innovations in conventional method we have already seen. Now, we are going to focus on the vibration assisted drilling; that is unconventional method. On your screen you can see; that vibration assisted drilling, we can give vibration to our drilling tool.

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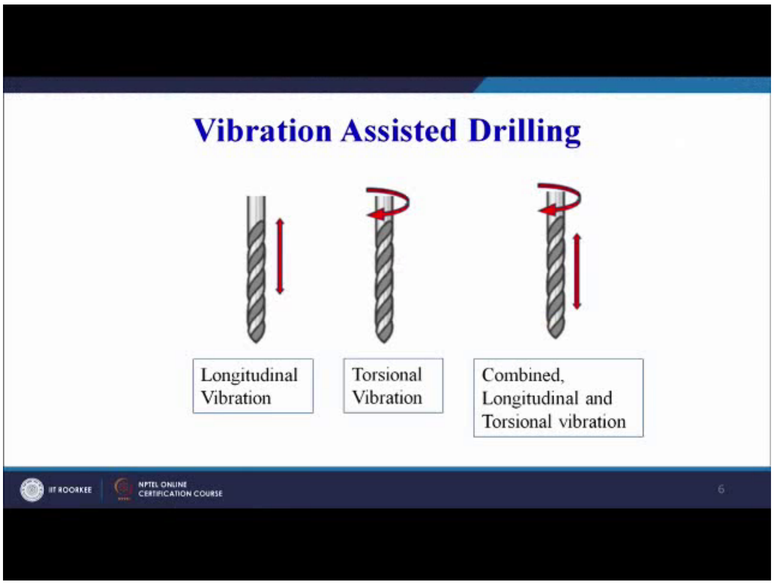

So, we can see, we can give longitudinal vibration; the drill tool is rotating or a twist drill is rotating, as well as it is vibrating at ultrasonic frequency. So, we can give vibration as per our requirement, so in ultrasonic vibration; we will have ultrasonic range only. So, in vibration assisted drilling we can give longitudinal vibration, we can give torsional vibration also, we can give combined torsional and longitudinal vibration.

Now, depending upon via vibration is given because in conventional drilling; the major problem arises when the tool is in constant contact with the workpiece. And when the tool is in constant contact with the workpiece, it may lead to fiber pull out, it may lead to delamination either at the entry in the form of peel up delamination or at the exit in the form of pushdown type of delamination.

So, the delamination is major issue and this vibration assisted drilling will lead to intermittent contact maybe; it will not be a continuous contact between the tool and the workpiece, it will be a intermittent contact; the tool will be coming in contact with the workpiece at a time interval. The time interval may not run into minutes and hours, but that will certainly be in the range of microseconds or picosecond. So, it is vibrating as well as coming in contact with the workpiece s, that intermittent contact will certainly reduce the thrust force generated between the tool and the workpiece.

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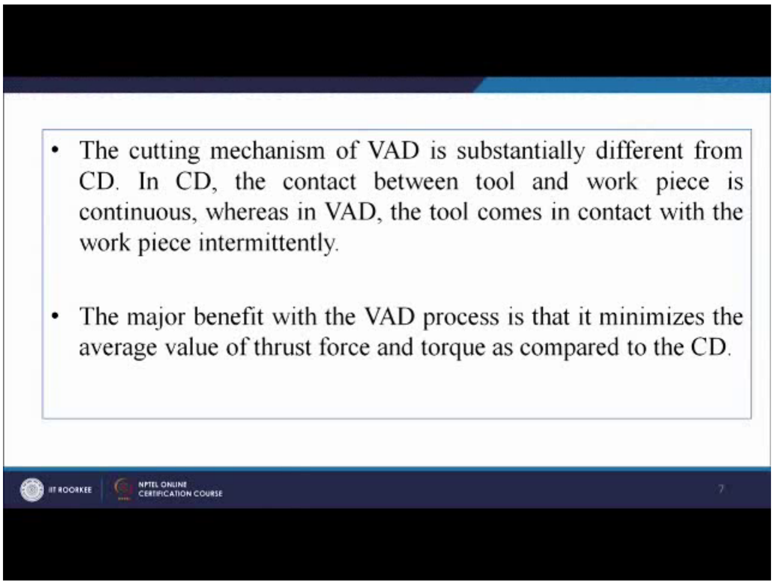

The cutting mechanism of vibration assisted drilling is significantly and substantially different from the conventional drilling. In conventional drilling, the contact between the tool and the workpiece is continuous; whereas in vibration assisted drilling, the tool comes in contact with the workpiece intermittently, which I have already explained. The major benefit with vibration assisted drilling process is that; it minimizes the average value of thrust force and torque as compared to the conventional drilling.

Now, if you remember in our broad summary of tools and techniques that are used for avoiding the damage; we have seen that one important technique is the dedicated machine tools for avoiding the damage. And this vibration assisted drilling is one example of this dedicated machine tools. As I think, we have discussed that in most of the cases; engineers use the same machines for making holes in composite material as they use for metals.

But here we can see; that if we modify our machine tool now one modification that is suggested here is that the tool must vibrate in order to minimize the damage. Whereas in conventional machines, the tool will not vibrate it will rotate and it will be fed into the workpiece and it will be in continuous contact with the composite laminate and therefore, it will lead to higher values of thrust force and torque leading to damage.

If we modify our machine tool, we are able to induce vibration into the tool material or into the tool it will result in reduction in average value of the thrust force and torque;

thus leading to minimum damage around the drilled hole; in case of polymer matrix composites laminates, this is one research article which has been published by Makhdum et al.

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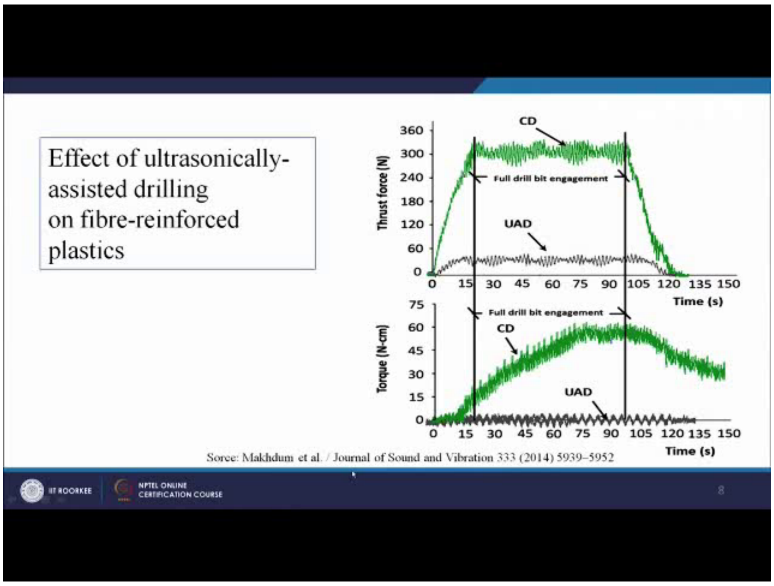

It has been published in 2014; Journal of Sound and Vibration; you can see 2014 is not far ago; maybe it is hardly 2 years back; which means that people are still doing research and trying to find out innovative methods for making damage free holes in composite materials. So, these materials are the materials of the future and are going to be used in numerous applications; maybe leading from high and aircraft applications to domestic applications in our household, as well as in sports equipment as well as in marine industries.

So, the materials have got application in a wide range of engineering products, but the problem is of hole making. And here this particular article reports; that the ultrasonically assisted drilling is better in context of the force is generated during the drilling operation. So, you see the effect of ultrasonic assisted drilling on fiber reinforced plastics; here the effect is very very clear. This is the thrust force; you can see in conventional drilling the green signal is a thrust force signal for conventional drilling and the black signal is for the ultrasonically assisted drilling. So, you can see the order of difference between the thrust force generated during conventional drilling and generated during ultrasonic assisted drilling.

Similar is the case with torque; we can see the torque in case of ultrasonic assisted drilling is very less, whereas in conventional drill; drill is quite high. So, this is the full engagement if you remember in previous sessions, we have seen that how the signal varies when the drill enters the composite laminate. If you remember some of you; who may have missed that session may also recall or today I am again emphasizing that these are the signals that are recorded using the dynamometer; which is used for recording of the forces. And four component drill dynamo meter is used for recording these forces.

So these forces gives an idea that how the process is progressing and when the drill is touching the laminate? When it is under full engagement? When the drill has come out of the hole? So, here you can see on X axis is time; so, this signal is time bound. So, as soon as the drill starts making the hole, till the time it comes out of the laminates after completing the hole making operation; this signal is recorded online using the drilling dynamometer.

So, here very easily we can compare using these signals recorded from the drilling dynamometer; their conventional drilling is producing more force as compared to the ultrasonic assisted drilling, more torque as compared to the ultrasonic assisted drilling. So, the conventional drilling more forces, higher magnitude of forces, more damage. Ultrasonically assisted drilling; less magnitude of forces, less damage so, very easily it can be concluded that if we use ultrasonically assisted drilling, our performance will be better.

Mind you, one thing I must address here that this particular results that are established here may be for a specific family of composite material, it may not be true for all types of composite materials. Maybe ultrasonically assisted drilling may find suitable results or may lead to suitable or optimal results in case of synthetic fiber; maybe glass fiber, carbon fiber, aramid fiber; reinforced composite materials.

But these results cannot be directly applied to natural fiber reinforced composite material, where we have natural fibers maybe grewia, optiva, sisal, nettle, hemp; wherever we have natural fibers, we need to again investigate and find out that whether these results are valid for the natural fiber reinforcement also or not.

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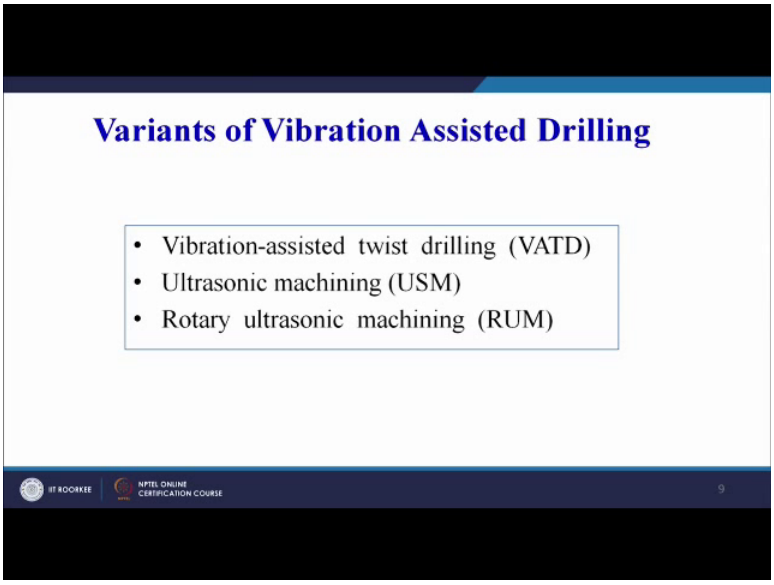

Now, different variations or variants of vibration assisted drilling are investigated in research. Vibration assisted twist drilling, where the drill that is used is a twist drill, standard twist drill, ultrasonic machining, then rotary ultrasonic machining. So, whatever we have seen it is ultrasonic assisted drilling UAD, we can have the same variant is the vibration assisted twist drilling.

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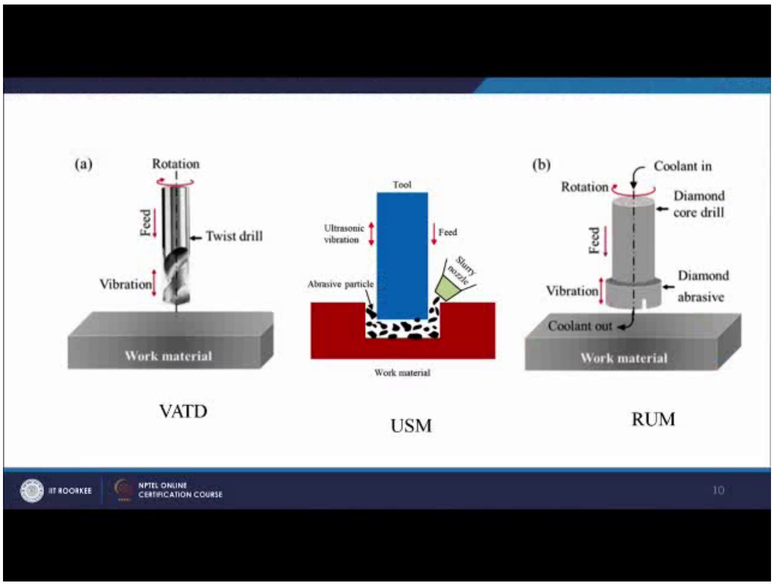

So, this is our vibration assisted twist drilling with the help of diagram, we have tried to explain. The first one is the vibration assisted twist drilling; VATD; vibration assisted, this is a work material; a twist drill, standard a twist drill. This is the feed rate; the vibration is given in the longitudinal direction and the tool is rotating also.

So, this is VATD process; conventional drilling process only addition is the vibration given to the drill in the longitudinal direction. Then there is ultrasonic machining, there is no rotation of the tool; here we see there is the rotation of the tool. In ultrasonic machining, there is no rotation of the tool; only ultrasonic vibration is there, the feed is given in this direction that is the axial direction of the tool. And there are abrasive particles in this slurry; this is a slurry nozzle through which the slurry containing the abrasive particles will be present between the tool and the workpiece.

And because of the ultrasonic vibration, the tool hits the abrasive particle and abrasive particles in pinch; the composite laminate and removes the material from the composite laminate. Then another modification is the rotary ultrasonic machining; here we can see there is a rotation given to the tool. Even if we use a hollow tool, we can put the coolant also through the hollow tool towards the machining zone. So, the coolant can also be given and vibration is given; which is common in all these techniques. So, we have a vibration, we have a rotation given to the tool and there is a diamond core drill which can be used we give feed in the axial direction; this is the axis of the tool, this is a vibration.

So, the difference between vibration assisted twist dealing and ultrasonic machining is that in ultrasonic machining, there is no rotation only ultrasonic vibration. In case of vibration assisted drilling, there is rotation also and here in rotary ultrasonic machining; the recombination of rotation and the vibration. And then the tool does not come in direct contact with the workpiece, but it just impinges the workpiece with the help of slurry particles.

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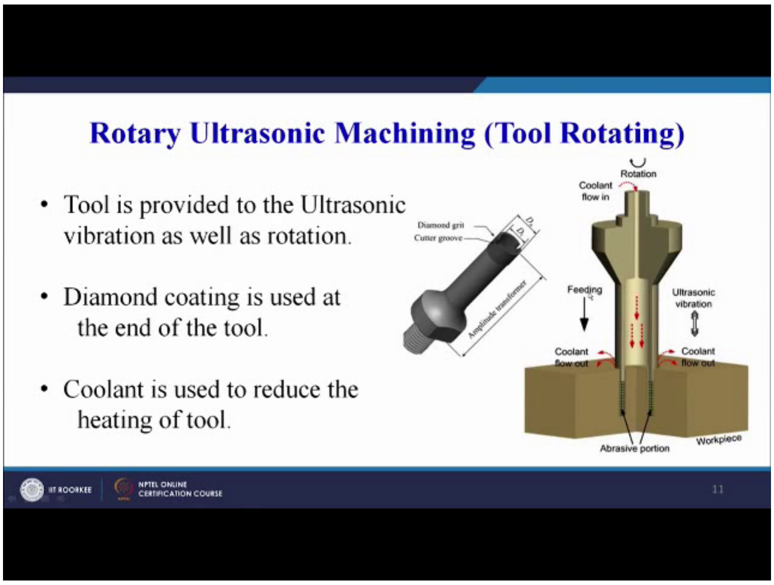

This is rotary ultrasonic machining, the tool is rotating; tool is provided the ultrasonic vibration as well as rotation; as I have already highlighted. Diamond coating is used at the end of the tool, coolant is used to reduce the heating of the tool.

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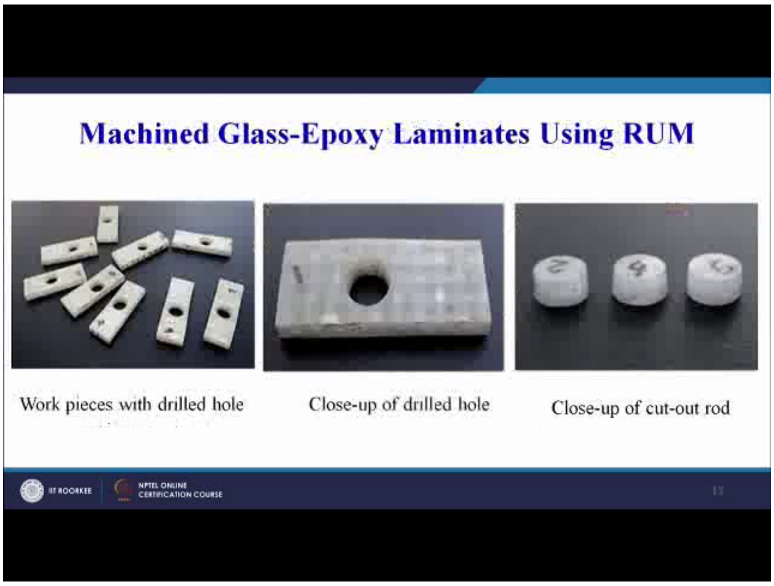

So, this is the result; we can see this is a glass fiber reinforced epoxy composite, these are the hole successfully made without much damage; workpecies with the drilled hole. So, so many work pieces have been drilled using the rotary ultrasonic machining technique. And this is a close up of the cut out rod; so, if you use a hollow tool; it will only cut the workpiece material; that is coming below the hollow tool and the central portion will be removed as the cut out rod, which is shown here.

So, this glass fiber reinforced epoxy laminate has been cut or has been drilled using the hollow tool and therefore, we are getting a close up of the cut out rod.

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Again you can see the holes drilled by the rotary ultrasonic machining and conventional drilling; this is conventional drilling, you can see the fiber pole outs and clean cut hole has been cut using the rotary ultrasonic machining. So, the hole quality that we get in case of rotary ultrasonic machining is better as compared to the conventional drilling approach.

Now, what can be the advantages of vibration assisted drilling? So, we have seen different variants of the vibration assisted drilling process, we have seen vibration assisted twist drilling, we have seen ultrasonic machining, we have seen rotary ultrasonic machining. So, the different variants lead to advantageous situation for us as compared to the conventional drilling approach.

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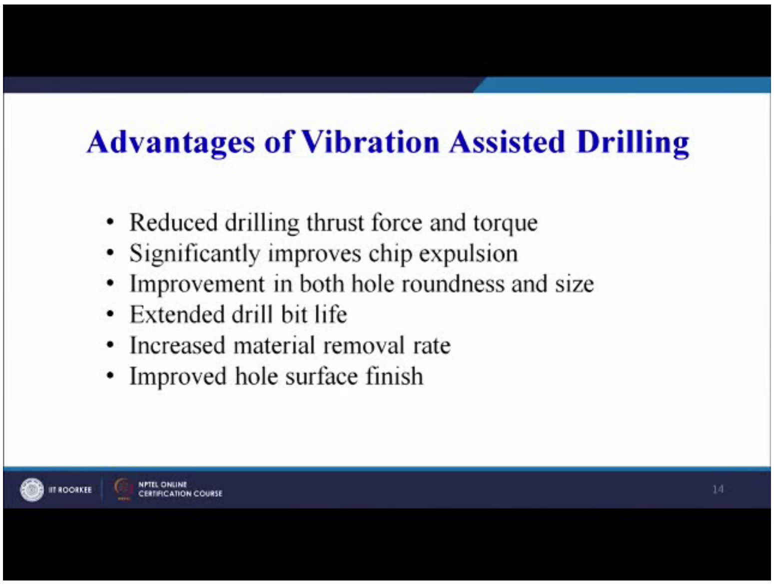

So, what are the advantages? The advantages are reduced drilling thrust force and torque which we have already seen with the reference of one of the research articles.

Significantly improves the chip expulsion or chip removal is better in especially in case of a hollow tool; from center we can easily remove the chips. Improvement in both the hole roundness and size; out of roundness error is reduced in ultrasonic assisted drilling. Drill life is more because the drill is not coming in direct contact with the workpiece, it is coming in intermittent contact with the workpiece. Then increased material removal rate is there; increased hole surface finish is there.

So, we can very easily conclude that if we use vibration assisted drilling in making of holes in composite laminates, we are going to get good quality of holes. So, with this we conclude today's session; we have seen different variants of advanced machining method for making holes in composite materials. In our next session, we will focus on some research tools which are used specially in context of the polymer matrix composite materials.

Thank you.