Processing of Polymers and Polymer Composites

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Lecture – 39
Intelligent Drilling of Polymer Matrix Composites

[FL] friends, welcome to session 39 in our course on Processing of Polymers and Polymer Composites. Just to have a brief review of what we are covering in the current section of our course or in the current phase of our course. We are currently focusing on the secondary processing techniques for polymer matrix composites. We are seeing that what are the challenges in the secondary processing of polymer matrix composites, we have identified 2 important processes which are important to realize any composite product.

These 2 processes are the joining of polymer composites, as well as the machining of polymer based composites. So, in joining we have seen that we can join the polymer parts or polymer composite parts using the adhesive joining, we can join them using mechanical fastening, microwave joining or using induction welding or the resistance welding technique. There can be other techniques also which can be employed for joining of polymer matrix composite parts. But since we have paucity of time, because of the limited time available with us we have emphasized only on the most important processes that are used for joining of polymer composites.

In our discussion we realized that in mechanical fastening, we require holes in order to do the nut and bolt type of fastening or for our location to put our fasteners. For hole making we have seen that there is lot of damage that takes place during the hole making operation. If you see, if you realize we have seen that pileup type of delamination may take place, push down type of delamination may take place. Then out of roundness is another type of error, matrix burning fibers pool outs spoling, chipping. There are different types of damage that can be seen while making holes in polymer matrix composites.

Then we have tried to identify that what modifications are suggested for reducing this damage. We have seen that we can modify the conventional drilling process, with slight modifications or innovative modifications. There we have seen that we can use a

woodpecker cycle, we can use a backup support method, we can use a helical feed method.

So, modification in the conventional drilling hole making approach has resulted in minimizing the effect of damage. Also, we have seen that there are advanced machining techniques that can be used, and one of them we have focused that was the vibration assisted drilling or ultrasonic assisted drilling.

We have seen that this ultrasonic assisted drilling approach also has got number of variants in which we have seen that very vibration assisted twist drilling is one technique, ultrasonic machining is second technique, as well as rotary ultrasonic machining is third technique. Although we could have covered abrasive water jet machining, water jet machining as well as laser beam iron beam machining methods, but we have at least understood that hole making in composite material is a difficult task. And we need to avoid this damage at any cost.

In the last session if you remember, we have seen that how simulation approach can help us to minimize over experimental efforts. And in order to establish that how much damage will take place because of a particular boundary condition, or because of a particular cutting speed feed rate or dual point geometry. So, we have seen that we can model the geometry, we can model the composite plate, we can apply the specific boundary conditions, we can execute the program and we can observe that how the drilling action is taking place. Not on the machine, but on the screen. And in on screen we can have a plots of the thrust force as well as of the torque. And then we can compare the different operating conditions; that is the cutting speeds of feed rate, as well as we can compare the drill point geometry; that which drill point geometry will give us the better results as compared to the other drill geometries. So, till now we have appreciated we have highlighted we have outlined, the importance of damage free hole making in composite parts.

Today our topic is intelligent drilling of polymer matrix composites. Now you can see there are lot of literature available, there are may be 200 research articles that have been published in the area of drilling of polymer composites. So, there is lot of information available, but it is all scattered. Now a company supposed starts to use composite

materials for a specific applications in their product, or they want to convert from a knit polymer products to a polymer matrix composite product, and it requires hole making.

The company needs to search lot of literature and find out; that how the whole can be made without damage. So, therefore, there is a eminent need to develop a system, which can predict the performance or predict the drilling performance for a specific type of composite material. Or which can club the information, which can assimilate the information, which can combine the information, in such a way that there is a single platform on which a user can login give his requirements in put his details, and the out and the single platform gives the output in terms of the forces there are going to be generated, the damage that is going to be recorded for that specific set of input parameters. And we have developed one such platform which is generic in nature in which the user can give input based on his requirement. And the system will generate an output which will be the cutting force; that is stork, the thrust force as well as the delamination or the damage around the drilled hole.

Now, based on the output that is generated from the system the user can take a decision. Either he can select the variables that he has input, or he can modify the variables accordingly. And he can fine tune his input in such a way, he can tweak his input in such a way that the output is desirable.

Desirable means the forces are below the critical level of the forces. The damage is within the limit or within the control limits. And then he can choose those best optimal parameters, and do the drilling operation without looking for the available literature across various generals, across various website. The system itself can be used by the user for solving his problem.

So, today we are going to see briefly have an overview of the system; that is the intelligent drilling software or intelligent drilling knowledge base for damage free drilling of composite parts. Specifically, polymer matrix composite parts.

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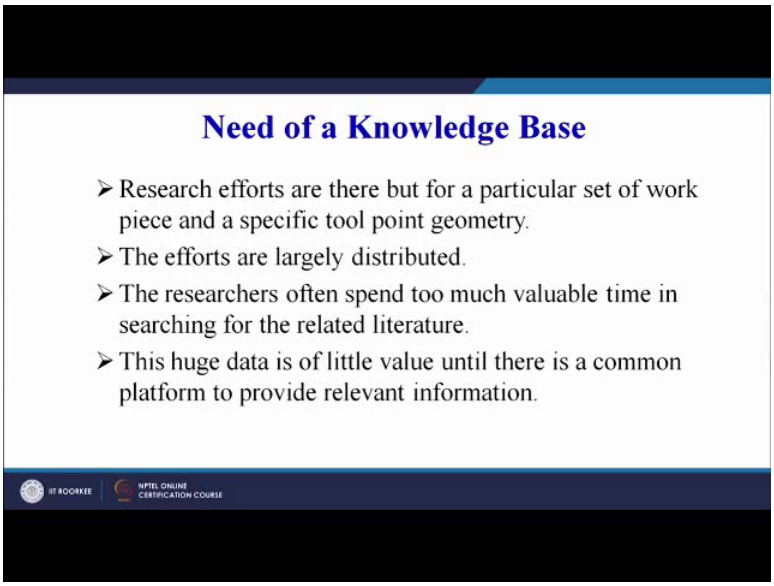

So, let us see that what is the importance of this particular platform. This is the need or the objective. Research efforts are there. There are lot of research articles maybe 200, more than 200 research articles focusing on the drilling behavior of polymer matrix composites are available published by various researchers, various publishers, various journal. So, there is lot of information available. But there is no particular set of work piece and specific tool point geometry. So, these articles are specific to a particular tool. If you remember in the previous, to previous session, we have seen there are different tool point geometries that have been investigated for making holes in composite parts.

So, the research article will focus on 2 or 3 geometries, then a workpiece material. A workpiece material can be glass fiber epoxy composite, glass fiber polyester composite, or it can be carbon fiber epoxy or carbon fiber polyester or carbon fiber with polyetheretherketone, depending upon the specific work piece material there will be a work piece. There will be a tool, there are few conditions, may be cutting speed in a particular range feed rate in a particular range. And then there will be output in which they will show that how the geometries are behaving, what kind of damage is going to happen, or which geometry is giving the minimum damaged, or what are the optimal cutting speed and feed rate for making damage free hole. But mind you that that is going to be a specific result for a specific set of tools, and a specific type of work material. There is no generic tool that is available which can help the engineers and scientists in making wise decisions regarding damage free hole making in composite parts.

So, the first point is very, very important; that research efforts are there yes articles have been published, but these articles have focused on a particular set of tool, and particular set of work piece material. And the efforts are largely distributed may be globally in different parts of the word, people have published different research article focusing on specific work piece material and tool geometries.

So, the researchers often spend too much valuable time in searching for the related literature. I must mentioned that it is not only the researchers who spend valuable time in looking for the literature, even these days composites are being used by industry in a very big way. So, the engineers working in the industry also look for literature looking for the optimal conditions for hole making in composite parts that they plan to use in their product. So, the user phase has widened. The number of users has increased the user's spectrum has increased, and it has widened. But the information available is still segregated and distributed. Therefore, there is a need to develop a common platform on which any user can login and can get his desired piece of information. So, the huge data is of little value, until there is a common platform to provide relevant information.

So, the data is existing, but the common thread is missing, a link is missing, where anybody can go or visit that platform or visit that website, or visit that algorithm and can get the information as per his input parameter as per her input parameters. So, that is with this back grounds, we tried to develop once software when knowledge base in which I we will see in the subsequent slide, user can give an input and he will get the desired output.

We have also try to incorporate the artificial intelligence tools; that we have covered in the last session, in the last 2 slides we have seen artificial neural network. We have seen ANCIS, ANFIS sorry, we have seen ANFIS we have also seen genetic algorithms.

So, there are different artificial intelligence tools; which have been incorporated into this software. Now why they have been incorporated? Because we cannot get specific data for each combination of work piece; that is each combination of composite material, and the tool geometry as well as the cutting parameter. So, the family is wide. If you remember we have seen, there are there is a large family of polymers. Similarly, there is a large array of fibers. So, each fiber can combine with different polymers, and we can make a composite material as per the requirement.

So, drilling experiments have not been done, but have not been done for each and every combination of a fiber and a polymer. So, the information is limited in that contest.

This software has used intelligent algorithms; that is artificial intelligence tools to predict the performance based on the information that is available with available with the researchers are which is available in the literature. So, based on the data that is available, this artificial intelligence tools have been trained to make a prediction, make a wise prediction make a intelligent prediction regarding the output.

Output in our case here is the you can very easily, now tell me what can be the output in case of drilling of polymer matrix composites. So, the output will be the forces, the drilling forces in terms of thrust force and torque as well as the damage in forms of delamination. So, we can very easily predict based on these artificial intelligence tools.

So, basically the need is to provide a common system in which any user can login give his inputs and he can get the output, whether the output is desirable or undesirable. Suppose it is undesirable, he can find tune his input parameters to get the desirable output. And the software is not only based on the knowledge that is available, it has got the predictive capability also based on the artificial intelligence tools.

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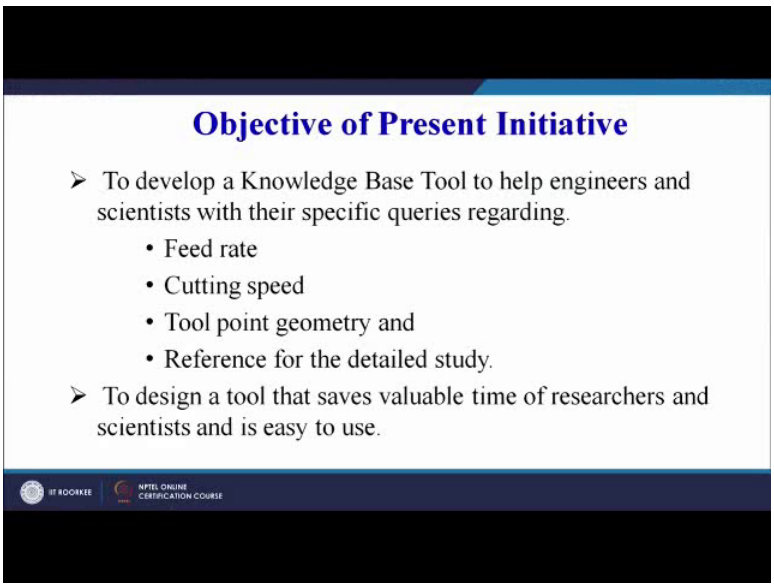

Now the object objective for developing this type of a system was to develop a knowledge based tool to help engineers and scientists with their specific queries

regarding the feed rate, the cutting speed, tool point geometry, and reference for the detailed study.

So, basically our focus was, that a user must be able to select his feed rate cutting speed based on the output; that is the forces the damage that is going to be occurring or that is going to happen because of the drilling action. So, to design a tool that saves valuable time of researchers and scientists and is easy to use. That was the major purpose to -provide a common platform which can work on certain set of inputs, and give a desirable output. And what is in the knowledge base the knowledge base has got a huge amount of data in the background, through which it will do the predictive modeling.

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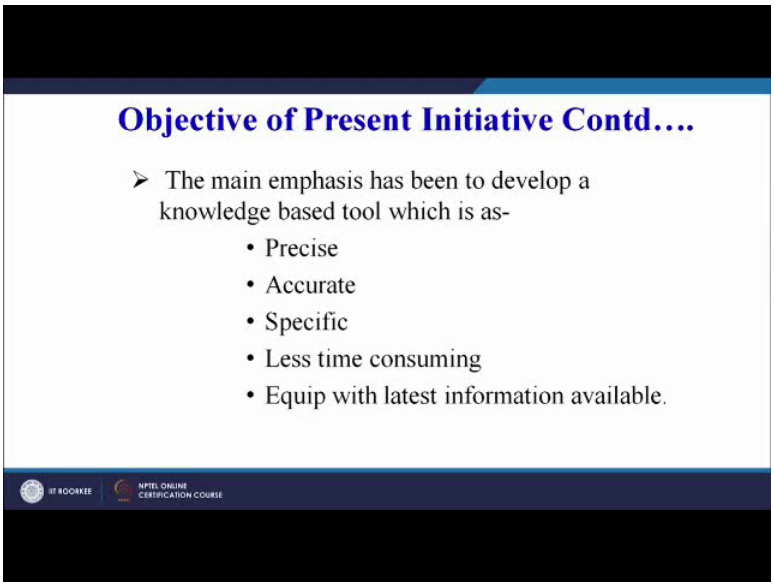

The main emphasis of the knowledge based tool is that it must be precise; means it must give the accurate results. It must be specific that if we are asking for glass fiber epoxy composite, it must give results for glass fiber epoxy composite only. The time taken for prediction or time taken for running a program must be reasonable, it should not be too large. And it must be equipped with the information available.

Now here you can see, this is the general outline of the intelligent software or intelligent knowledge base.

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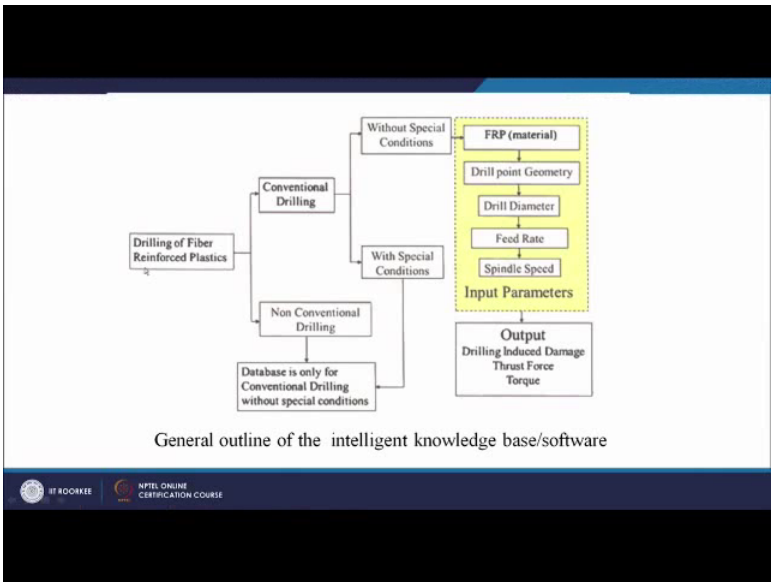

So, this is drilling of a FRP's or polymer matrix composites. We can go for conventional drilling. We can go for non-conventional drilling. So, it means that we can either have conventional drilling, that we have seen, and we can go for unconventional in terms of ultrasonic assisted or it can be ultrasonic machining, or rotary ultrasonic machining, or water jet machining, abrasive water jet machining. So, unconventional drilling also can be done. So, we can we can choose in the software that whether we are whether we are interested in conventional drilling, or we are interested in non-conventional drilling.

Then in conventional drilling; further we have choice, that without special conditions that is it is purely conventional hole making approach or purely conventional drilling that the tool will be in direct contact with the work piece, or with special conditions. Now special conditions can be that we are using a backup plate or it is a woodpecker cycle, or we can use a helical feed method. So, we can do the conventional drilling, with special conditions also and the software will prompt us to give this information. That whether we want a special condition or it is going to be a conventional drilling.

The input parameters then will be the material; that what is going to be the fiber, what is going to be the polymer, what is going to be the drill point geometry. If we do not know that there are different drill point geometries available, the system will prompt us may be 15 to 17 different drill point geometries that have been used for making hole. So, out of then we can select one, and see what is going to be the effect of the drill point geometry,

on the forces as well as the subsequent damage. We can select the drill diameter that is very well known to us, because we know that we want to make a hole of for 4-millimeter diameter, or 8-millimeter diameter, or 10-millimeter diameter.

Now, diameter also we know, and we can make a choice of feed rate and spindle speed, why? Because we know that which type of machine we are having, what is the capability in terms of foreign context of the feed rate? What is our capability in terms of the cutting speed, because each machine will have different combination of speeds and feeds. So, a user can input a particular speed, a particular feed rate, he he can input the drill diameter, he can input the or he can select the drill point geometry, he can input the material for which in which the hole has to be created. So, this is the input parameters.

When finally, we execute the program, the output will be the drilling induced damage, here you can see. This is the output. The output would be drilling induced damage, the thrust force and the torque.

So, based on the input provided by the user, the system or the software will make a prediction, related to the thrust force the torque and the drilling induced damage. We will try to understand this by taking one or 2 examples, because this is a very important tool which helps us in minimizing the drilling induced damage; which is a big challenge in case of hole making in specially in context of the polymer matrix composites.

Now, how this will work? Let us see step by step there are not many steps only 4 steps in which the system will work.

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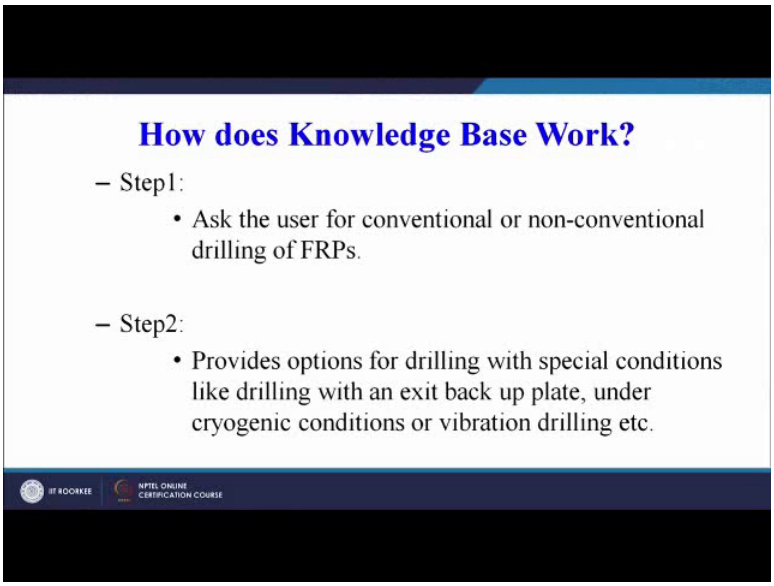

In step 1 the system will prompt the user or it will ask the user for conventional or nonconventional drilling of fiber reinforced plastics.

So, the first question that the system will prompt is that whether you want to go for conventional drilling, or you want to go for unconventional drilling or advanced machining method.

Step 2, provides options for drilling with special conditions, like drilling with a exit backup plate, under cryogenic conditions or vibration drilling. So, there will be questions are prompts, that will ask whether you want to go for conventional drilling only or you want to go for a modified version of conventional drilling or using a backup plate, or using a helical feed method. Then in step 3, the process is now known to the system; that the software or the knowledge base knows; that this user wants to use this process.

Now the next stage is the material, the system would like to know from the user that which material you want to use. Now it will take input in form of the fiber; that what is your fiber it can be carbon fiber it can be glass fiber it can be aramid fiber, then the system will prompt you to input your matrix material. Now matrix can be epoxy polyester polyetheretherketone acrylonitrile butadiene styrene, it can be polyethylene, it can be polypropylene it can be a thermosetting and thermoplastic depending upon the requirement you will put your matrix material or you will input your matrix material. Then it will prompt you regarding the tool point geometry.

Now, suppose you know, that for this type of material I have fair amount of idea, that out of these 2 3 drill point geometry is one is going to give me the best results. So, you will select that drill point geometry suppose you do not know, you can make a guess work that let us try with this drill point geometry.

In step 4, the system will display based on the information that we have provided. Now what type of information you have provided the information as a user has been first that rather it is a conventional drilling, or advance drilling then whether the conventional drilling with some modifications in the process or standard conventional drilling only.

Third you have input the raw material, or the composite material; that you want to drill, you have input the fiber, you input the matrix and then you have also input the drill point geometry that you want to use. Now based on the input set, that you have given to the system, it will display most relevant result to the user regarding his or her query with the references.

Now, with the references means; that suppose your data matches very closely with any of the research articles or the research work already done, by any researcher in any part of the word. Now this system will prompt that article that your work is or your requirements are similar to this work which has already been reported by this researcher in a particular year. So, you can directly be confident; that the work that or the drilling that I want to do has already been done in this part of the world and these are the results and then you can refer to that article and further get into the details of the process carried out by that researcher in his research work. So, this way the software is going to help us.

Now suppose you whatever information you have input in terms of the work piece material, in terms of the drill point geometry, in terms of the cutting conditions or the drilling process, do not match with any of the standard literature available in the database. Even then the system will give you the results based on the artificial intelligence involved in the prediction process.

You have you can select that, whether you want your prediction through artificial neural network, you can input you want your prediction from genetic algorithm based intelligence tool, or you want your prediction from ANFIS. Now depending upon the type of intelligent tool that you have input, the system will prompt you based on that

intelligent tool only and it will give you the prediction. Even you can do the prediction using all 3 4 intelligent software or intelligent tools, and you can compare the results.

Now, suppose first you do your prediction using artificial neural network. You get thrust force torque and damage value. Second time you can try with genetic algorithm; that do the prediction you tell the system do prediction using genetic algorithm. Again, it will predict thrust force torque and damage or delamination. Then you can use third may be predicting software, or third you can say intelligent tool, and it will again give you thrust force torque and your delamination factor. So, then you can compare that which one of the predictive method is better for you, and which particular parameter or output response you may choose for your further investigation. So, this is the important versatility of this system.

Now, the output of the knowledge base, can be in case of conventional drilling now you know that what is the feed rate that is giving you the optimal result, similarly cutting speed thrust force critical thrust force, if your data is matching a particular research article it can even predict the critical the torque the surface roughness of the hole The damage factor or the delamination factor, relevant critical thrust force model can also be predicted.

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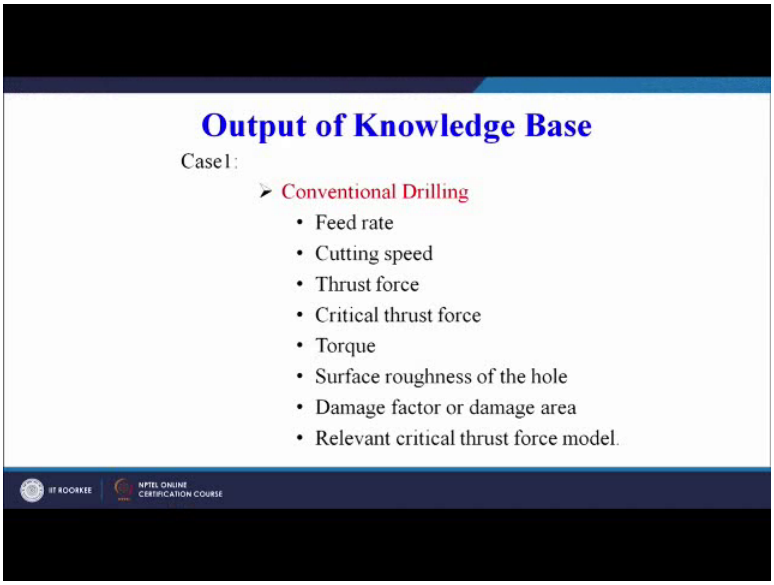

This all this is the overall, this is the overall result that you can get. This models surface roughness, critical thrust force, this may be possible only if your data or your input data

is very closely or is exactly matching to any research article which has already been published. In that case only you will get this complete list of information. If your data is not matching, then the predictive results may be in terms of thrust force torque and delamination factors only will be predicted up, but I feel that is also very, very important because our main objective is to minimize the damage during the drilling process.

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Now, non-conventional drilling specifically if we have choose ultrasonic drilling, you can choose abrasive size the output will be in terms of abrasive size input current feed rate, volume concentration surface roughness and hole clearance repetition rate you do not depending upon the process, that you have chosen you will get output accordingly.

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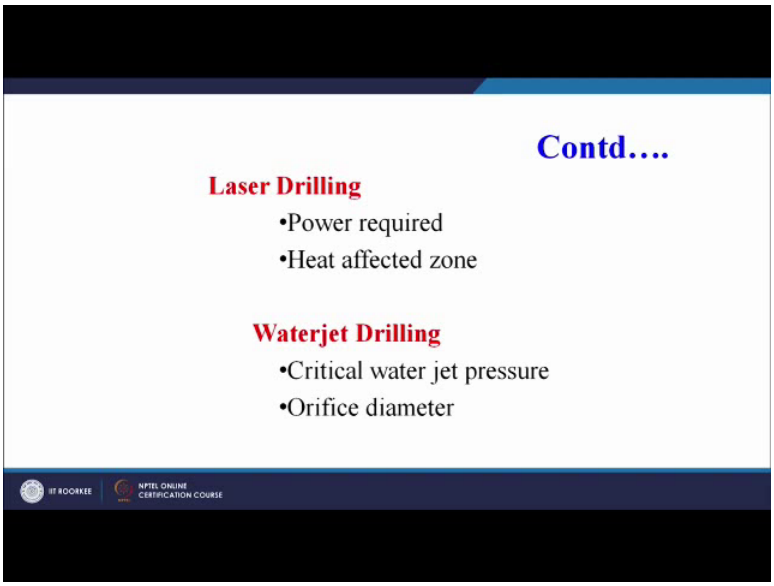

In laser drilling you may get what is the power required, what will be the heat affected zone? In case of water jet drilling, you can get the critical water jet pressure or the orifice diameter. Based on your input you will get an output, if you select conventional drilling you will get the specific output. If you choose laser drilling you will get a specific output.

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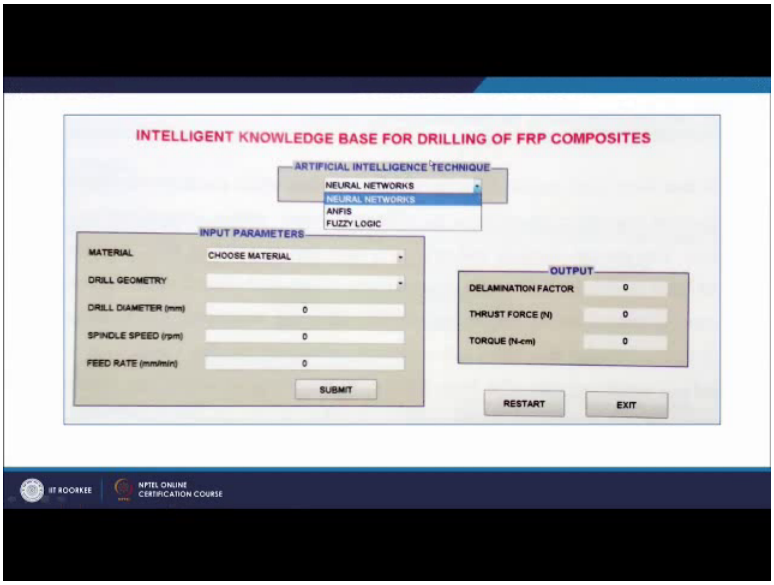

Now, this is the main graphic user interface, the intelligent knowledge base for drilling of FRP composites. Here you can see I think it may not with that clear on the screen, the

artificial intelligence techniques it is neural network ANFIS fuzzy logic. The input parameters that you can specify material, there will a drop-down menu from that you can choose your material. And you can similarly there is a drop-down menu in which you can choose your drill point geometry. Then the drill diameter you can specify spindle speed feed rate you can specify and you can submit it.

So, the input is in terms of the work piece material, drill geometry drilled diameter spindle speed and feed rate. And the output is in terms of the delamination factor, thrust force and torque. So, when you start it when we give this input and your submit it you will get your output. Now suppose you want to change it you can click on the restart button again change the input parameter, again you can choose the artificial intelligence technique, you may choose from neural network to ANFIS. Again, when you submit you will get the output. The output will be in terms of delamination factor thrust force and torque.

This is one example here. The artificial intelligence techniques chosen is fuzzy logic. Material is woven glass fiber reinforced epoxy, which has been made by hand layup technique. Drills geometry chosen is carbide parabolic drill, drill diameter is 8-millimeter. Spindle speed is 720 rpm feed rate is 10 millimeter per minute. When you submit it, you will get the output, the delamination factor will be 2.4, thrust force will be 34.4 Newton and torque will be 10.22 newton centimeters. So, this is one set of input parameters, and the related output parameters.

So, this is some results of the knowledge base, the process suppose selected is conventional.

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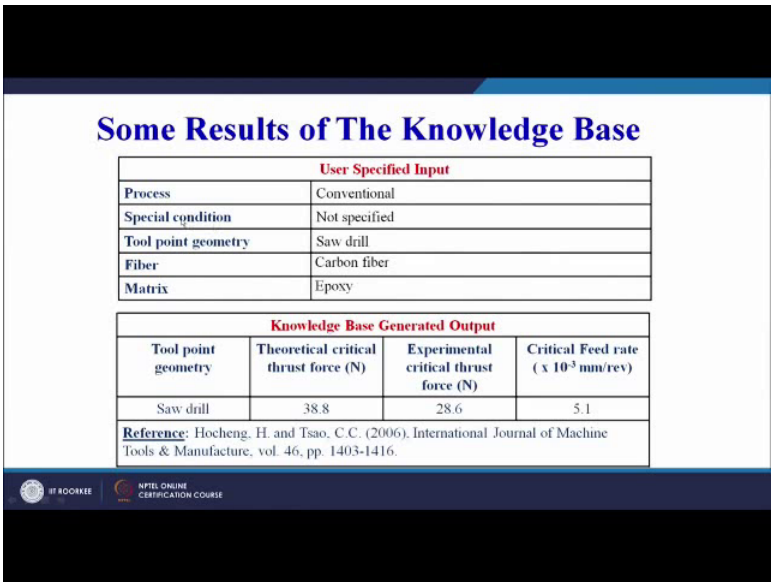

There is no special conditions specified. Tool point geometry short drill, fiber is carbon fiber matrix is epoxy. Now knowledge base generated output is giving you a tool point geometry that you can you can use this short drill your choice is correct.

Theoretical critical thrust force is 38.8 Newton. Experimental critical thrust force is 28.6 newton, and critical feed rate is 5.1 into 10 to the power minus 3 millimeter per revolution.

Now, why such specific information is available? Because your input data is clearly matching the data provided by this research article; that is H hochang and C C Tsao they have published one research article, and the data that we have input is clearly matching the data provided by these researchers. So, our we can get additional information from the research article, and we can refer to this research article for further investigation or for further understanding of the data.

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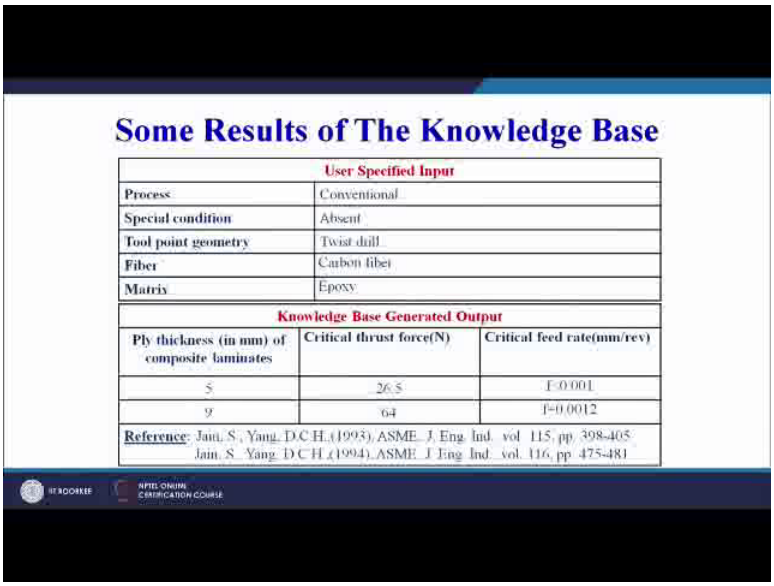

Similarly, this is another case study. So, I will skip this case study. So, the summary that we get from this is that the code that is the developed as part of this study saves valuable time of the researchers and scientists.

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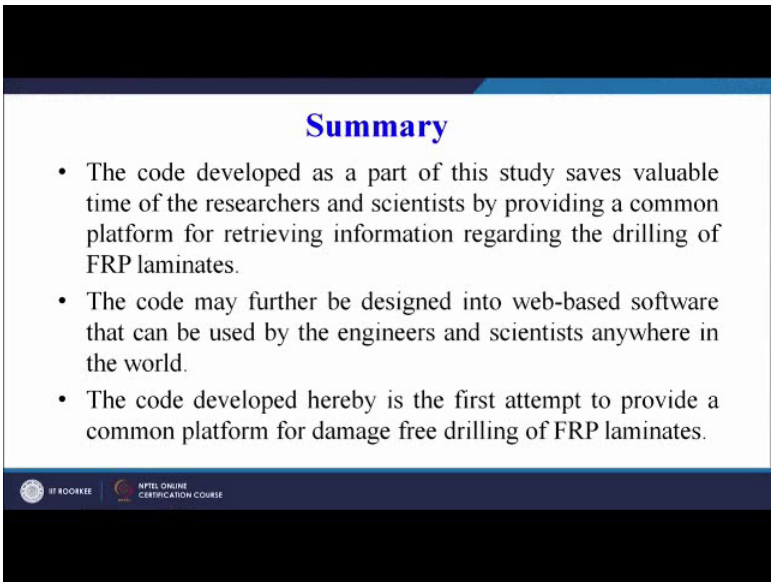

How? It by providing a common platform for retrieving the information regarding the drilling of polymer matrix composites or FRP laminates.

The code may further be designed into web based software; that can be used by engineers and scientists anywhere in the world. The code developed hereby is first

attempt to provide a common platform for damage free drilling of polymer matrix composites. Now this system is very, very useful and it can be developed into a web based system, in which anyway anyone can log in from any remote location anywhere across the globe, and just input the parameters regarding the whole making. And definitely he will get some help in terms of output; which is the cutting forces and the drilling induced damage. And then even he can refer back to a specific article, and get the specific information that he is desiring off or that is going to be useful to him in deciding the parameters for making damage free holes in polymer matrix composites.

So, with this we conclude today's session. And in next session we will focus on some other tools, which are helpful for the engineers and scientists, who are working in the area of polymer matrix composites.

Thank you.