Processing of Non-Metals
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Module - 7
Secondary Processing of Composite Materials
Lecture - 5
Research Tools for Secondary Processing

A warm welcome to all of you in this last lecture of the course processing of non metals; as we have been discussing module number 7 for the last 1 week. We have now come to the lecture number 5 of module number 7; on your screen you can see the title of today's lecture that is research tools for secondary processing. If we focus on what we have discussed in this course on processing of non metals; we have seen so many different techniques of processing of wide variety of materials ranging from the ceramics to the polymers to the polymer matrix composites to the ceramic matrix composite. So, we have seen a large number of techniques which are used for the processing of these materials or these specific materials.

But towards the end we have discussed module number 7; in which we have already discussed 4 lectures where we have seen what are the problems? What are the issues and challenges associated with the secondary processing of specifically composites; we have seen what are the problems that arise when we tried to make a hole inside a composite laminate. If you remember we have seen there are so many tools and techniques which have been proposed to avoid this damage, we have also seen that what are the problems associated with the joining of the composite members. And, how these problems can be avoided or the efforts that have gone into research for avoiding the issues associated with the joining of polymer composites.

So, we have seen that how microwave joining is done and how it overcomes some of the limitations of the adhesive joining and the mechanical fastening. So, all these techniques have been discussed. But still a wide gap exists in specifically in the field of secondary processing of polymer composites. Because if you see the overall structure of the course also we have seen 35 lectures; broadly dedicated towards the engineering materials their manufacturability. As well as, towards the manufacturing techniques are processing techniques for a wide variety of materials that fall under the broad umbrella of non metals or those materials which have properties similar to the non metals.

So, we have seen that a large number of techniques exist to produce or to process these materials in a most cost effective and qualitative manner. And, we can have a certain good quality products also. But a lot remains to be done towards the secondary processing; because most of the products made by these materials are put to direct use without any secondary processing. But in our last 4 lectures; in every lecture I have given a introduction that why secondary processing is required. So, just to brief you once again and for those people who are only listening to this particular lecture; secondary processing in advanced materials or composites materials is required.

Because the parts that we make by the primary processing or the conventional methods have to be assembled together to get the complete structure. So, to facilitate the assembly operations many a times secondary processing in terms of drilling or joining is required; so that we get the complete product. So, secondary operations sometimes are completely unavoidable and they are necessary to a certain the structural integrity of a complex composite part. So, basically today our focus would be to see on the research tools that what are the various tools that can be used to solve certain problems associated with the secondary processing of the polymer composites or the total composites family in general.

So, as the time permit we would see 3 important different areas in today's lecture that is we will see the stimulation of or the finite element modeling of the drilling process specifically in case of polymer composite. Then, we will see the microwave joining; how the process can be investigated using the finite element method. And, towards the end of today's lecture I will just give a brief overview of the various methods which can be used to predict the forces and the drilling induced damage in case of drilling of polymer composites. So, basically our focus would be on the tools. And, the application would be the secondary processing of polymer composites. So, we would be just highlighting the tools that which tools can be used and what type of results can be got; without going into the much detail of one particular area.

So, it would be a overview where we will see that what type of analysis can be done in case of secondary processing of polymer composites. So, first of all we need to understand that why we need to go for secondary processing and what are the problem areas associated with it. So, I have already highlighted the need of secondary processing; again I want to emphasize the need of secondary processing is. Because we want to get a complete structure made up of different parts and that parts needs to be assembled together. And, to facilitate the assemble operation secondary operations are required or secondary processing is required.

And, in secondary processing one of the important processes is drilling. So, we will see that in case of drilling; how, why it is important to investigate drilling in much more details. So, we will see that what are the input parameters in drilling, what are the output parameters in drilling and how complex is the whole process. And, why do we need to use this research tools to investigate the drilling behavior of the polymer matrix composite.

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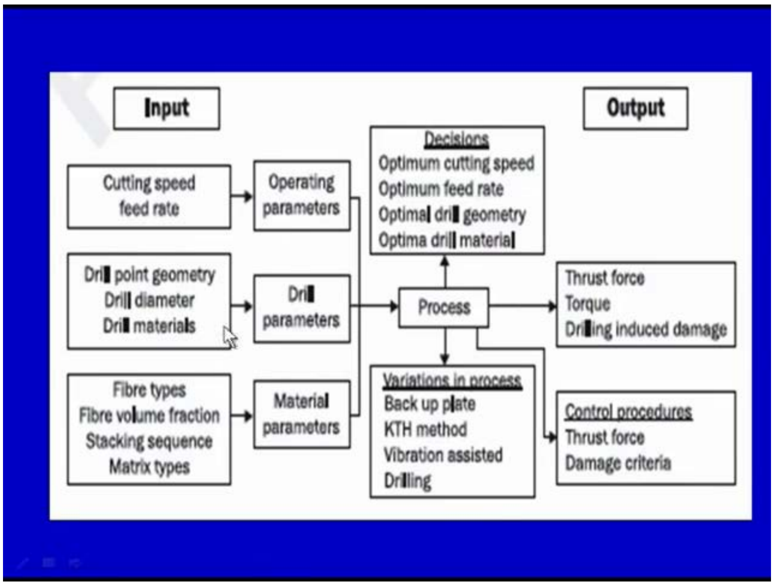

So, with this introduction; now, let us start our lecture today; on your screen you have a simple diagram in which there are 2 broad categories; we have a input and we have a output. Now, what is the input? The input and this particular diagram give us the inputs and the output relationship in case of the drilling of polymer matrix composites. So, drilling of polymer matrix composites means the process is drilling and the material is polymer matrix composite. So, we can see there are broadly 3 inputs going into the process this is the drilling process in the process there are broadly 3 inputs; input number 1, input number 2 and input number 3.

Now, what are these 3 inputs input number 1; is the operating variables. Now, in drilling process what are the operating variables; the operating variables are the cutting speed and the feed rate; there are two operating variables primarily that are going into the drilling process. So, operating variables cutting speed and feed rate, drill parameters. Now, what are the drill parameters; drill parameters are the drill point geometry, the drill diameter and the drill materials. So, there are 3 important parameters those governs the drilling parameter or related to the cutting tool or the twist drill is one type of drill point geometry; you can have different types of drill point geometry.

So, basically the second input that is going into the process is related to the cutting tool first input that is going into the process is related to the machine tool; machine tool basically we have a drilling machine. And, in drilling machine we can control 2 parameters that is cutting speed and feed rate. So, first input is related to the machine tool the operating variables of the machine tools; the second input is related to the tool or the cutting tool that is the drill. So, we can have drill parameter like what is the geometry of the drill; as I have already highlighted twist; drill is one important type of drill which is use for making holes in materials. Then, we can have a diameter of the drill and the material of the drill the tool material.

So, our focus is on tool geometry, tool material and tool diameter; which will be acting as the drill parameter which go into the process. And finally, we have the material parameter that is the material parameters that go into the process. So that material parameter is specifically in case of fiber reinforced plastics are fiber types, fiber volume fractions, stacking sequence and matrix types. So, we have 4 important material parameters which go into the process. Once again we will revise fiber types; we have seen in our lecture on polymer matrix composite that different types of fibers can be use which can be natural fibers also, synthetic fibers also, within synthetic fibers; we have seen there is a category of fibers which can be used to name of few of the fibers both in both the categories we can have glass fibers. Carbon fiber, aramid fibers; we can have hemp fibers, sisal fiber, nickel fiber, grewia optiva within these categories natural and synthetic we can have a large variety of fibers.

So, one important point is the fiber type another is the fiber volume fraction; how much fibers are there in the composite, stacking sequence, what are the different layers in the laminate or the composite laminate, how the various layers have been stacked together to make the composite laminate. And, finally the matrix type broadly the matrix can be classified in to thermostats and thermoplastics. And, within thermostats and thermoplastics; we have a huge variety of other types of polymers which can be used as the matrix materials in order to make the composite material; which we have already seen in module number 5; we have seen large number of processed which are used to combine the matrix and reinforcement to get the final product.

So, input side we have you can see so, many things that we need to control in order to fully characterize the drilling process or to simplify, to fully understand the drilling behavior .So, if we have a one type of fiber, one type of a matrix and at single speed and single feed using a simple tool point geometry made up of the simplest of tool material we make a hole; a slight change in the input parameter would certainly change the drilling behavior of the second hole that we will make by changing the parameters. So, there are so, many input parameters which go into the process. And, then the process gives us output in terms of we can see; what are the various outputs from the process.

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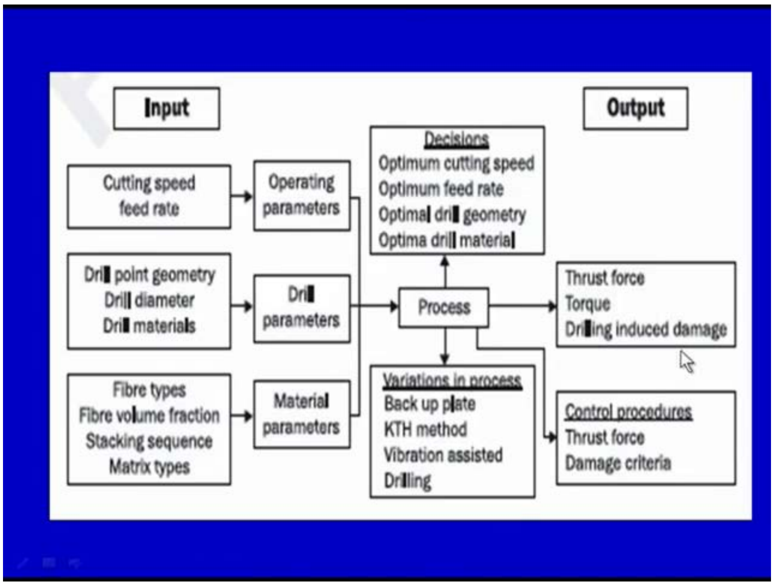

Outputs are thrust force, torque and drilling induced damage. So, basically when we have large number of inputs that go into the process; we get an output the output can be recorded in the form of thrust force and torque. So we need to understand that these input parameters when they go into the process; the process gives us the output. And, the output is has to be correlated to the input parameters; we should know that if this is the setting, these are the operating variable, these are the tool variable or tool geometry or tool material or tool diameter. And, this is the material of the work piece that is suppose it is glass fiber and epoxy matrix; we should be able to understand and very easily tell that this much thrust force would be generated or this much torque would be generated or the damage will be less or more.

So, basically we have a set of input parameters we have a process and finally we get a output. So, this input and the output have to be somehow matched. And, an expert should be there; who should be able to correlate these inputs with the outputs. Now, what are the decisions that need to be taken? Now, we know we have a set of input parameters which will go into the process and process will give us the output. Now, in order to get the good output what should we do always we want the forces should be less, the damage should be less. Now, for minimum forces and minimum damage what are the decisions that we need to take on your screen.

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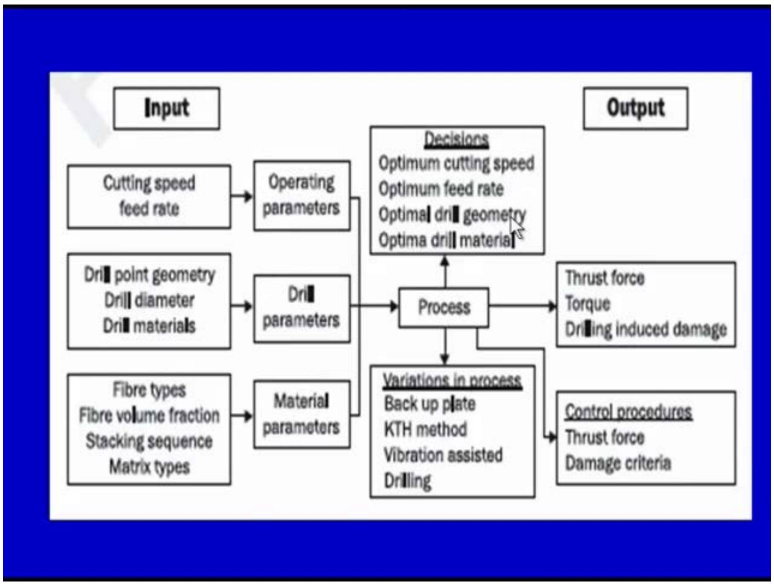

Now, for minimum forces and minimum damage what are the decisions that we need to take on your screen; you can see these are the decisions that we need to take these are the decisions; we should optimize the cutting speed, we should select optimal cutting speed, optimum feed rate, optimal drill geometry. Suppose, we have 10 different geometries which can be used to make a hole; we should select the most optimal one which will give us the best quality hole. And, we should select the drill material also because we have seen in the previous lectures; different types of tool material can be used to make holes in composite laminates. So, we should select the optimal tool material, optimal tool geometry, optimal feed rate and optimal cutting speed so that we get a good quality hole. So, these are the decisions that we need to take.

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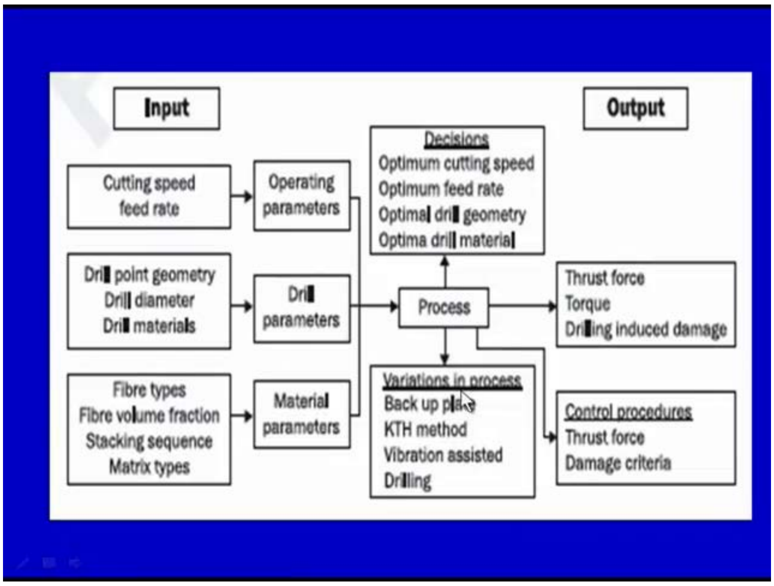

Then, there some variations in the process that we have seen in lecture 2; which are the use of the backup plate the KTH method vibration assisted drilling method. So, there are some process variants like one is simple drilling; in which we have a constant feed rate and the drill is making a hole in the composite laminate. But there are few process variants which helps us to optimize our process by reducing the forces, improving the quality of the drilled hole as well as reducing the drilling induced damage. So, basically we have a set of inputs you can see there is a wide variety of input or the very versatile input that goes into the process and the output is in terms of forces and the damage.

And, then we have to take certain sets of decisions which would help us to optimize our process; so that we get a good quality hole. And, finally we can vary our process orbit so that output is desirable as per our requirement.

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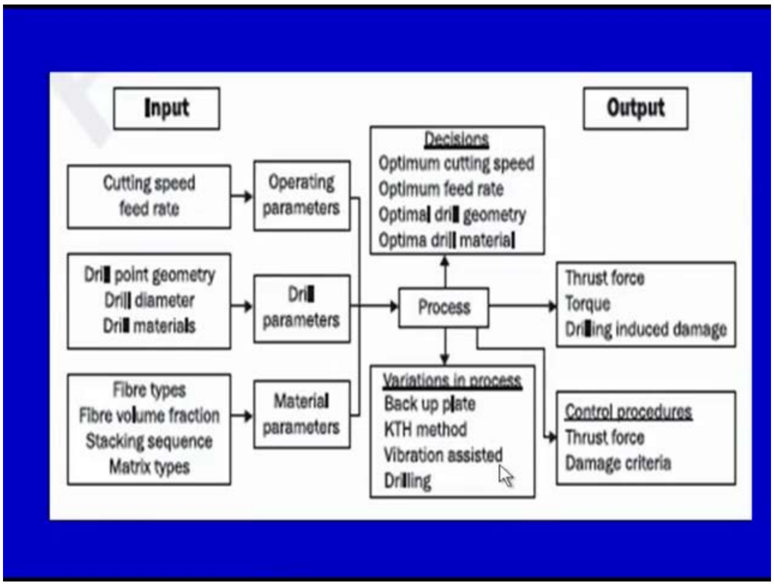

And, finally what are the control parameter, what we need to control? The output we need to control so that we get a good quality whole .So, we can control the thrust force and damage criteria. So, if suppose damage takes place beyond a particular level; we have to fine tune or tweak our process. And, similarly the thrust force goes beyond the particular limit; we need to adjust our input parameters which will resultantly affect our process. And, the process then gives us the output which would be within the limits or within the range. So, this particular diagram if you see this particular figure gives us the complexity of the problem which is; which we need to understand before going into the next step in order to study or to investigate the drilling process using the different research tools.

So, first of all we need to understand the need and the necessity of using the research tools. So, here in order to summaries the things I want to emphasize that even so, many input parameters are there, so, many process variants are there and different types of outputs are there; we cannot do experiments for each and every set of inputs, for each and every materials, for each and every tool, for each and every tool geometry. So, if we need to do this experiment; we can see if you remember in the classification of thermostats and thermoplastics there were so, many polymers.

And, many polymers can be used as the matrix material there were wide variety of the fibers which can be used as the reinforcement. So, there are wide variety of composite materials which are relevant are been used in the industry in various applications. So, there are so many materials speeds and feeds can have a huge range and as well as the drill point geometry you can make your own drill point geometry and we can investigate that how that geometry response to the drilling process. So, there is a large variety of input that exists and the output has to be correlated to this particular input. So, basically we cannot do experiment in each and every case. And, therefore we need to develop certain models which ones validated with the input parameters and gives the desired output can be used to stimulate the behavior of the other types of materials, other types of tool geometries and other types of operating variables.

So, once we develop a model. Now, suppose we develop a model for glass fiber epoxy matrix this is my work piece material I use the high speed steel tool as the cutting tool and I select a particular range of the cutting speeds and feed rate. So, I have somehow made the case out of total diagram that is there on your screen. So one particular case is the material is glass fiber, the matrix is epoxy.

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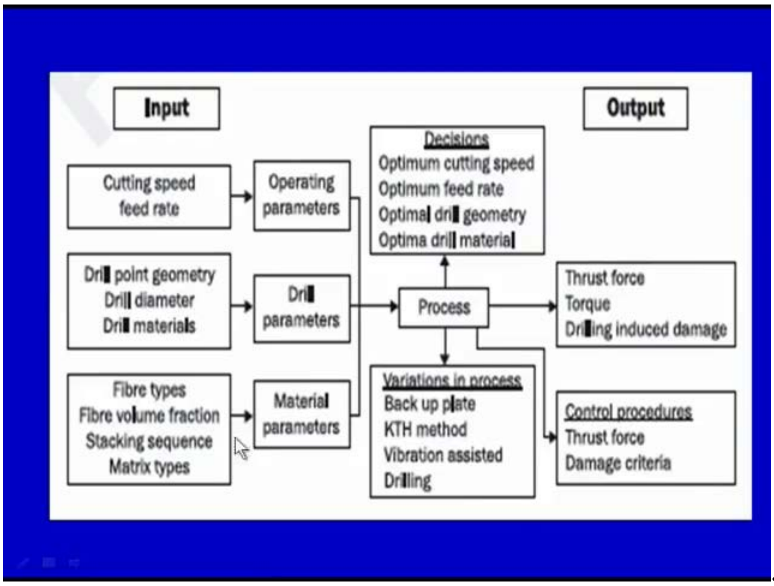

So, my material parameters are fixed fiber type is glass, fiber volume fraction suppose 60 percent, stacking sequence is normal all layers are made up of glass fiber only and the matrix is epoxy. So, glass fiber reinforced epoxy matrix one material; drill point geometry suppose, simple twist drill, drill diameter suppose 8 millimeters, drill materials suppose high speed steel. And, cutting speed and feed suppose I fix a range that cutting speed goes say v 1 to v 3and feed rate goes from f 1 to f 3. So, this is one set of experiment that I will conduct with that conventional drilling process and record the thrust force and torque and the drilling induced damage; one set of experiments. And, the output can be investigated to see that how the feed rate effects the thrust force, how the cutting speed affects the torque, how the we can say the drill diameter; suppose, we vary effects the output parameters such as thrust force torque and drilling induced damage and this is one set of experiment.

Now, suppose the fiber type is different is changed, fiber volume fraction is changed, stacking sequence is changed, matrix type is changed. So, I have wide variety of materials available with me. Now, the drill point geometry can be changed in one of the research paper 17; 1 7 different geometries have been investigated to study their in fluency on the drilling induced damage. So, different types of tools matrix will be there, tool diameters can be there and drill materials can be different. And, similarly there is a wide range speed and feed; why I am emphasizing on this point because you we cannot do experiment for each and every set of parameters. Because there exist a very big family of the composite material and very big family of the tool materials and a very big family of the tool geometry.

So, therefore we need to develop the models which can be used to predict the behavior. But before the model can be used to predict the behavior we have to validate that model with some of the experimental findings. So, we cannot totally outperform the experimentation yes, we have to do the experimentation; we have to do rigorous experimentation and those the results of those experiments then have to be matched with the results of the models. And, then finally, when these models have been validated these can be used for further prediction purpose; then, this models can be used to predict the thrust force, the torque or the damage; without actually going for the experimentation. But for a very good model the back bone is provided by the exhaustive experimentation.

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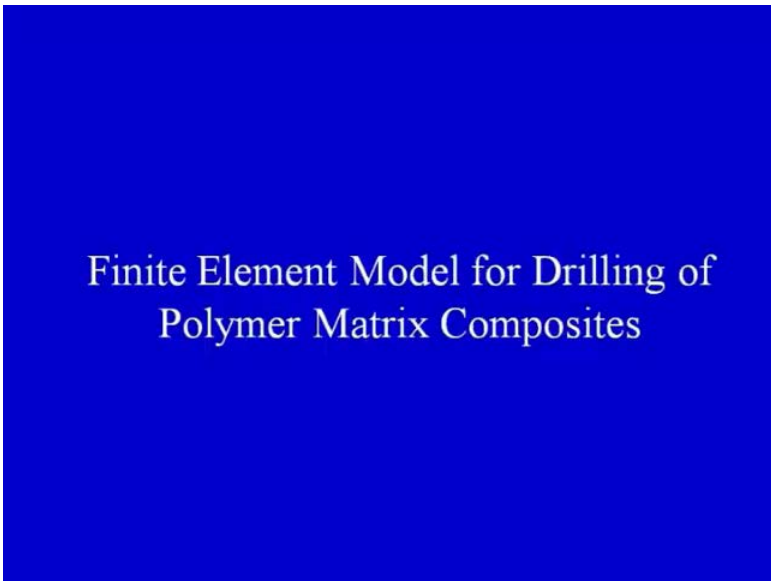

So, now we will see one of the tools which is used in order to develop a model for prediction of suppose forces or drilling induced damage; finite element model for drilling of polymer matrix composites. Now, what are the steps when we want to make a model on your screen? There are 5 to 6 different steps which have been mentioned. And, these steps when executed properly; when performed in a systematical and logical manner we would be able to develop a model which can be validated with the experimental results. And, finally this model can be used for the prediction purposes or for investigating the drilling behavior specifically in case of polymer composite. But these are the steps which are very general in nature; any problem using the finite element method can be solved using these steps; we need to have a platform or a software or a finite element package.

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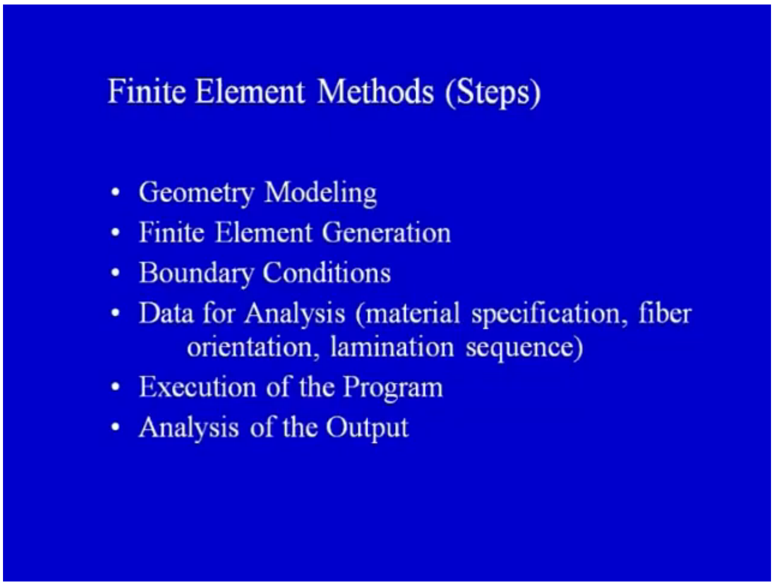

And, in that package we have to first generate the geometry as you can see the very first point on your screen this is geometric modeling. So, first of all we have to generate the geometry of that particular part that we want to analyze. So, in our case as we are investigating the drilling behavior of polymer composite; so, our work piece has to be modeled. So, we will try to see it with the help of diagram; how the work piece can be modeled? So, the first and the foremost point is to make the geometry of the work piece. So, once the geometry has been made then it has to be discretized into finite elements.

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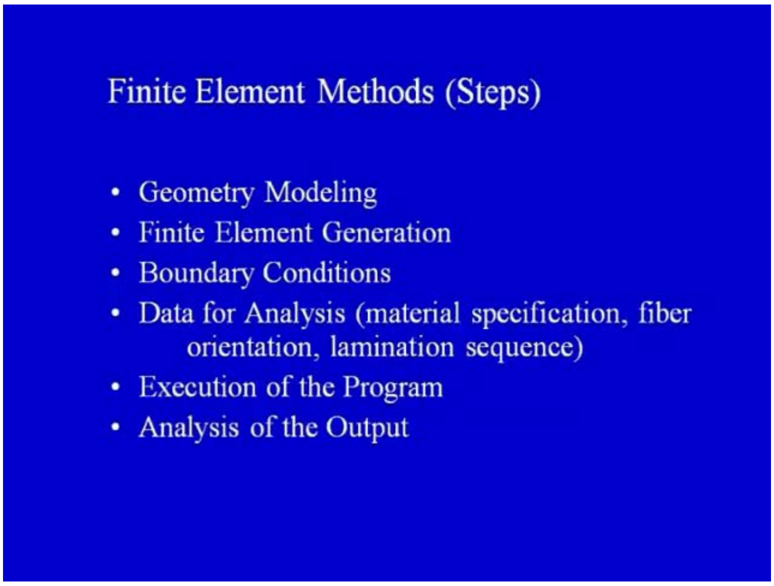

So, the point number 2 is finite element generation. So, we have to then, discretized the complete geometry; it can be a 3 dimensional analysis, it can be 2 dimensional analyses. So, the geometry which has been modeled on the computer screen has to be discretized into different types of elements. Now, this element there is an element library in the various packages from where we have to choose that which type of element that suites our requirement. For example, when we are modeling a composite material; we have to select only that element which is suitable for modeling the composite materials why?

Because in composite we have to make different layers; suppose, the laminate in which I am going to make a hole is made up of 4 layers. So, the element should be such chosen. So that this particular versatility is there in the element or it has the capability to be modeled into 4 layers and it has the capability to be modeled as a thick element. So, during finite element generation few important points have to be taken into account. So, the 1st step is we have to make geometry and the 2nd step is the discretization into the elements. Now, the elements have to be such chosen so that it represents the actual problem and question.

So, the actual problem in our case is; we have model a composite laminate from the element library we have to choose only those elements which are able to take the properties of the composite materials. So that the fiber orientation can be given as we know in case of composite, we can have unidirectional fiber, we can have bidirectional fibers or the fibers can be randomly oriented. So, we should only select those elements which has this capability to be modeled into a composite plate or a composite element. So, finite element generation is done the total geometry is divided into a large number of small, small elements. So, these elements will combine together to depict the total geometry.

So, suppose we have in x direction 100 elements, y direction 100 elements, in z direction another 50 elements. So, we make a plate in which we have X number of element in X direction, number of elements in Y direction, number of elements in the Z direction. So, we have now discretized the total structure or the total the plate or the geometry which we have modeled into various elements. So, first point is geometric modeling, 2nd point is discretization into finite elements; point number 3 on your screen is boundary conditions. Now, we have to make a hole inside a composite laminate; the laminate should not move or the material or the raw material should not move. Because when the drilling action is taking place the plate should be fixed on the table; which is actual requirement when we are making a hole on the machine.

Now, here we are trying to develop a model; in this model one of the prerequisite is that the plate should not move; because it will represent the actual billing which is been done on the machine. Now, we have to fix the plate when this composite laminate or the polymer matrix composite material has to be fixed on the table of the work piece; we have to constrain the movement of this laminate into X, Y and Z directions; moreover it should not rotate. So, the process of providing the constraints to the work piece or to the geometry that we have modeled is falling under the broad umbrella of boundary conditions.

So, we will provide the constraint in x direction, y direction and z direction and it will restrict the movement of the plate in X, Y and Z direction. So, that is the one set of boundary condition that the plate is fixed; another set of boundary condition is that the drill should come down; the drill should rotate and it should come down, it should interact with the material. And, finally it should be removing the material in the form of chips and finally it should be able to generate the hole. So, all these conditions will fall under the boundary conditions; we have to specify the speed at which the drill will rotate, we have to specify how the drill will go down, we have to specify how the drill will interact with the work piece material, how the material flow will takes place. So, all these how the material flow will takes place certainly at a later stage.

But first of all we have to specify the boundary conditions like the plate will not move point number 1, point number 2 the drill will rotate that is rotation has to be provided, point number 3 the drill will translate and it will come and touch the work piece. So, all these conditions when they are given they fall under the category of boundary conditions. So, till now we have seen the 3 very important points of problem building where we are building our problem, where we are trying to model what is actually happening on the machine. So, what we are doing we have a geometric modeling in which we are making the geometry of our work piece, our work piece composite laminate it is a flat plate. So, we have a composite laminate.

Now, we have to discretization into various elements from the element library we are only choosing those elements which correspond to the composite property or which have the property to be modeled as a composite element. And, finally we are specifying the boundary condition that the plate is fixed and the drill is coming from the top and making a hole; the drill is rotating as well as it is coming down. Then, we have to provide the data for analysis in which we have to provide the material specification. Suppose, in finite element generation we have specified that the laminate is having 4 layers. Now, for 4 layers top most layer suppose has glass fiber, layer number 2 also has glass fiber and 3,4 also have glass fiber; so, the task becomes easy.

But suppose all the layers are made up of different materials. So, in data for analysis on your screen the material specification has to be given, fiber orientation has to be given and the lamination sequence has to be provided. So, we have to now provide the data that this particular laminate which have been discretized using this element is made up of this material; the lamination sequence is this different layers are made up of different materials or of same material; the fiber orientation in the different layers is same or different; if different then what is the fiber orientation? All these particular input has to be provided in the data for analysis stage.

And, finally once we have set the problem by setting the geometry, by discretizing the geometry into finite element, by providing the boundary condition and the relevant data related to the material, related to the tool material; when all these data has been provided we will execute the program. And, once the program is executed it would run lot of calculations will be done Matrix multiplication will be done. And, we will get the output in terms of stress plots or strain plots or sometimes displacement or in many cases we may get some specific failure criteria plots; which will help us to find out that whether the damage is taken place or not. So, we will see some of the plots; where we will see the damage has taken place. And, finally once we see the output the stress contriver plots or the contriver of the various parameters; we would be able to correlate what has happened actually when the experiments were done and what has happened when the module has been executed.

So, now we will see how the results can be analyzed; the process of modeling or the process of setting up the problem has been discussed in this particular slide. So, once again before closing down this slide; we can see that these are the important steps to set up a problem and to execute the problem and to analyze the results.

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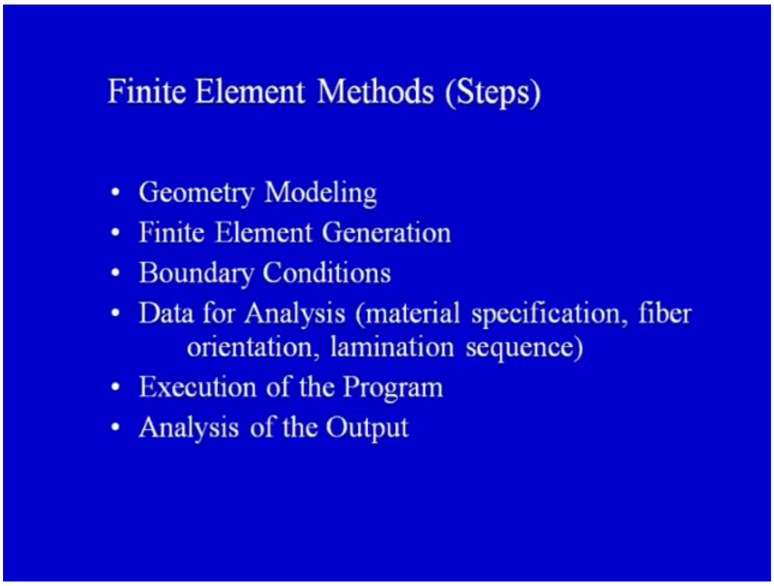

So, the steps involved are the Geometric modeling, Finite element discretization or Finite element generation, Boundary conditions, Data for analysis, now, data material data has to be provided and tool data has to be provided specifically for our case. Then, the program has to be Executed, and the results have to be finally, analyzed.

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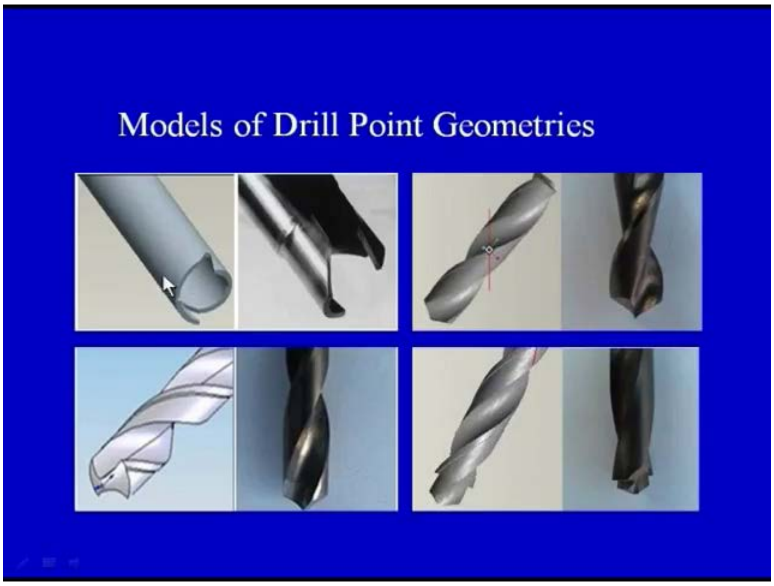

So, here you can see the models of the various drill point geometries there are this is the model; which can be modeled in any geometrical model ling software, this is one model and this is the tree panning tool and this is the actual tree panning tool this is you can see this is the parabolic point, drill parabolic point drill and here is the representation software representation or the model of the parabolic point here; we can see this is the twist drill, simple twist drill, and this is the model of the twist drill and this is the Joe point or the Joe drill and here we see the model of the Joe drill. So, first and foremost we have to make a model. And, any geometrical modeling software can be used for making these models.

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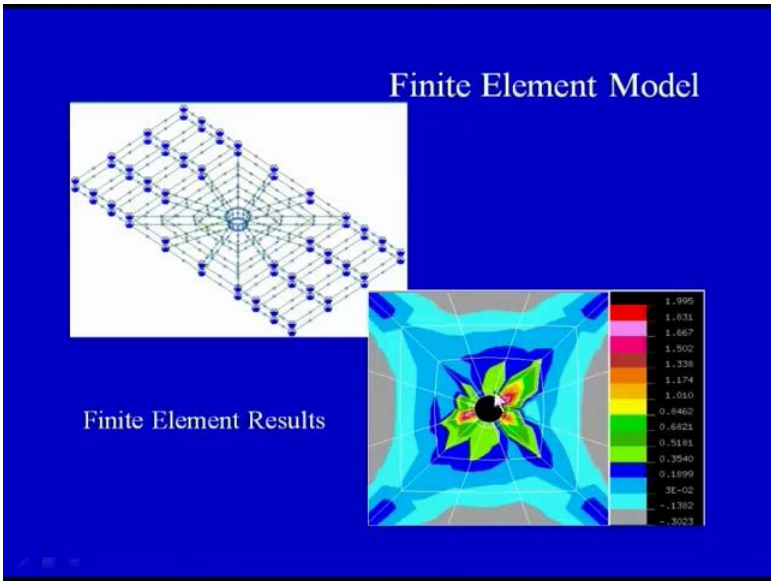

Now, on your screen you can see the output; one of the output is shown here, this red area indicates this is the failure plot and we can see the red portion showing indicating the value which is more than one it is precisely 1.995, and this is red portion and this pink portion is 1.831. So, where ever these red and pink portions are there it means the damage has taken place at that place. So, basically this is the geometric model step number one, this is the geometric model where a hole has to be generated. So, this particular analysis was done with the pre drilled hole; it was assumed that there is a pre drilled hole which already exist in the laminate and this particular hole has to be enlarged depending upon the final diameter requirement. So, the hole has to be enlarged using a standard drill point.

So, this is the geometry of the laminate and these blue point indicate that this particular laminate cannot move in X, Y, and Z direction. So, this particular laminate is fixed it cannot move in X, Y, and Z direction; therefore we can very easily assume that this particular laminate is fixed on the bed of the table and it is not able to move in X, Y, or Z direction. So, it cannot move so, it is fixed and which we have certain by providing the boundary conditions as is visible on your screen. So, this blue dots indicates that this particular laminate cannot move in X, Y, Z direction and then the input or the other boundary conditions are given. And, finally the results or the contoured plots are seen as on your screen where the damage has certainly taken place.

So, the rotations at which the drill was rotating and the feed rate at which the drill was translating or the drill was performing the hole making operation or the drilling operation. So, the combination of the cutting speed and feed rate with that particular drill point geometry which was used would certainly lead to damage in this particular material. So, this material was glass fiber reinforced plastic material. So, for the glass fiber reinforced plastic material yes, there is bound to be certain damage that would take place.

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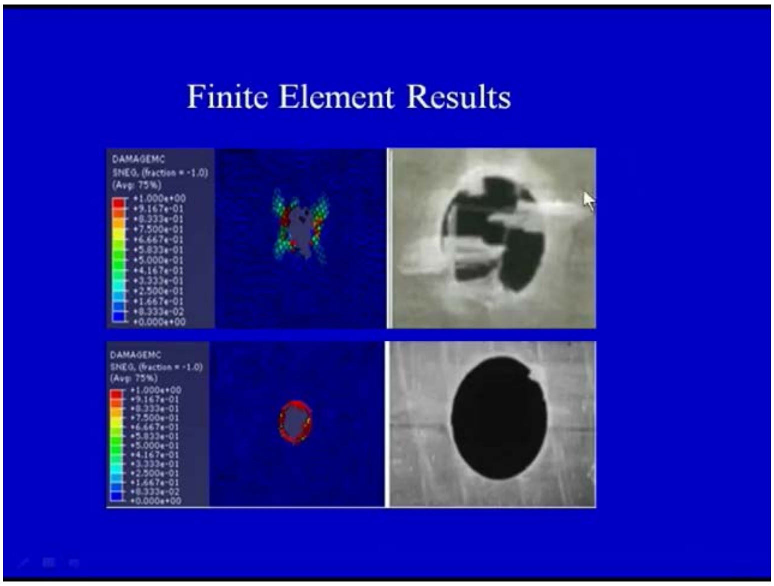

We can see there are few more results of the damage which have taken place. And, here you can see as I have already emphasized on the slide number 1, we have seen that drilling is a very drilling of polymer composite is very we can say complex process in which there are so many input parameters and output has to be governed; so that we make a hole which is good quality. So, here we can see when we have the experimental result this is a result of an experiment. So, we can correlate with the results of the finite element and we can find out that whether the damage which is been predicted by the finite element method correlates with what has been recorded using the experimentation.

So, this has been recorded using experimentation, this has been predicted using the infinite element model and we can correlate the to here also we can see the 2 can be correlated although; this is a magnified view just to highlight the damage area. So, we cannot say one to one matching here. but we can see the qualitatively the areas are damaged around the hole and here also we can see the damage has been reported or predicted using the finite element method; here we can see the damage is there, here also lesser damage, here also lesser damage, more damage has been found experimentally under similar set of conditions, more damage has been predicted using the finite element method.

So, where we can emphasize one important point that when we have a strong experimental base; we have conducted lot of experiments that can be used as input and that we can model the process and the results of the model can be validated with the findings of the experimental results. And, then we can use this particular model by varying the various input parameters and predicting the damage as well as operating variable or the optimal operating variable; that which the minimum damage is taking place.

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Then, we come to another aspect of our module 5 in which sorry, module 7; in which we have seen there are 2 broad categories of processes which fall under the category of secondary processing that is the machining or drilling and the joining. So, now we will briefly overview that how the process of microwave joining be modeled. So that we are able to find out that weather the 2 pieces that we want to join using the microwave energy can be joined together or not. Here, also we can use the software platform to model the process and find out the temperature which is generated at the interface of the 2 composite laminates or the 2 composite adherends that we want to join together.

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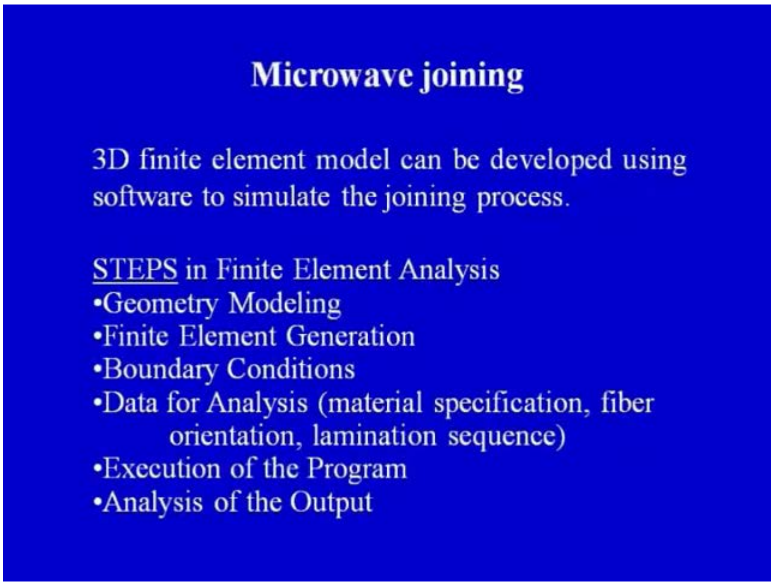

So, in microwave joining 3-dimensional finite element model can be developed using software to simulate the joining process. Now, what are the steps involved? Again to revise the steps involved are same; we can have we can undertake these steps sequentially in order to achieve our objective. So, what are the steps involved I will just read out the steps; because we have already discussed this steps in detail while we were seeing the modeling of the drilling process. So, these steps are Geometric Modeling number one, again the Finite element generation, Boundary conditions have to be specified, then the data for analysis has to be given and finally, the execution of the program and analysis of the output.

So, material specification, fiber orientation or all these has to be specified depending upon the composite adherends that we are using boundary conditions. In the previous case were in terms of rotation of the drill the feed rate was specified, the plate was constrained, here the boundary condition can be in terms of the wattage or the power that we are putting as an input; it can be in terms of the exposure time for which the composite adherends have been exposed to the microwave radiation. So, the boundary condition will change depending upon the problem at hand. Now, whatever problem we have at hand; accordingly we will set the boundary condition. So, here our purpose now is to form a good quality joint or the good quality bond between the 2 composites adherends and the source of energy is the microwave energy.

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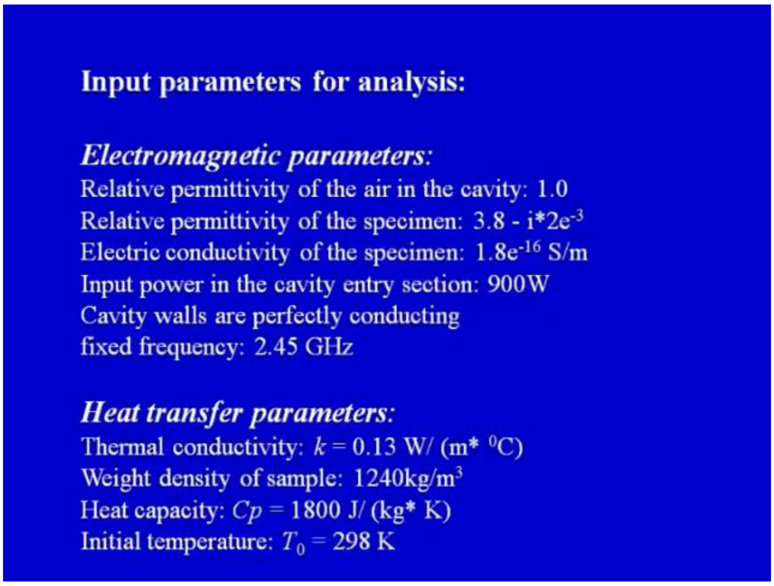

So, quickly we will see the type of output that we will get. Now, in one of the steps we have to specify the data for analysis so, here we have to put electromagnetic parameters and heat transfer parameters as the input into the model. So that the model gives us results which are close to the experimental results. So, we will not discuss these points; these are some of parameters which have to be put as an input into the model, so that we get the desired output.

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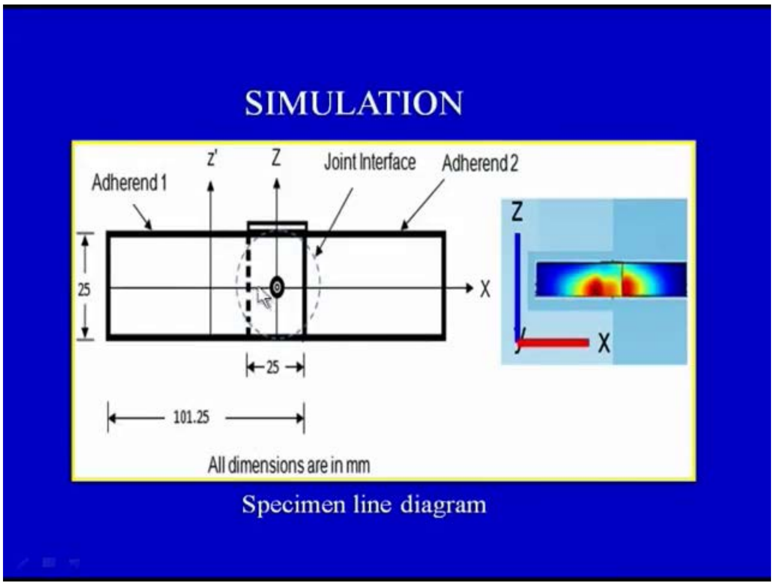

Now, this is actually the simulation process; here there are 2 adherends this is adherend number 1; this dotted portion you can see how the arrow is moving, this is adherend number 1 and this is adherend number 2. So, we have 2 adherends standing end to end like this, we have 2 adherends other view can be like this; this is top adherend this is bottom adherend; we have 2 adherends like this. And, this is the top of the adherend when we have adherend number 1 and this is adherend number2; so, 1 and 2 adherend.

And, finally we have put a susceptor here; to accelerate the rate of heating this is the susceptor. And, the joint will form over this bond area this dotted circle indicates the joint interface where the joining would takes place; on this side also we can see actual finite element result plot or the contriver plot which indicates that the temperature is higher in that particular zone and the joining is going to take place.

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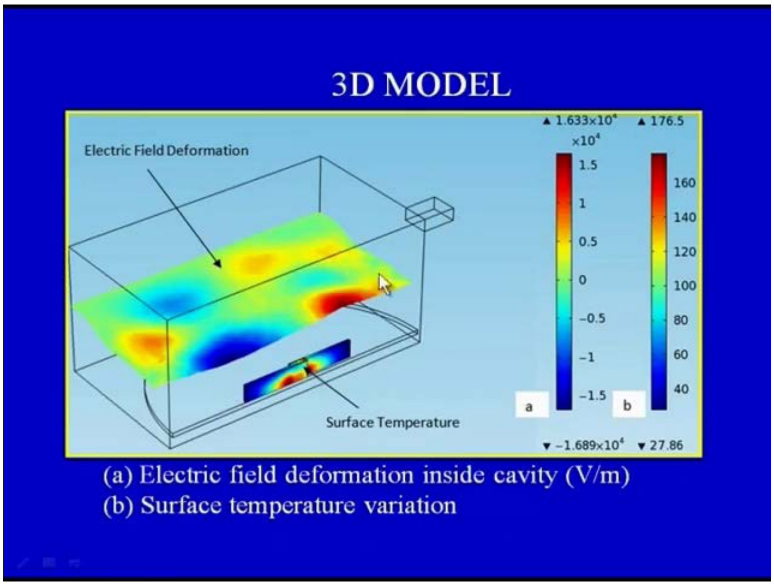

Now, here we can see this is a 3-dimensional model; just briefly we can see what type of output we can get, we can get output in terms of the electric field deformation inside the cavity and the surface temperature variation; this is now the microwave total cavity these are the 2 adherends which have been kept together and this is the input port. And, we can get the output that what is the temperature which is been generated at specific location; inside the microwave cavity. And, if the temperature at the interface or at the joint area or the bond area is more than the critical temperature which is required by the polymer to form the joint; then the joining would certainly takes place.

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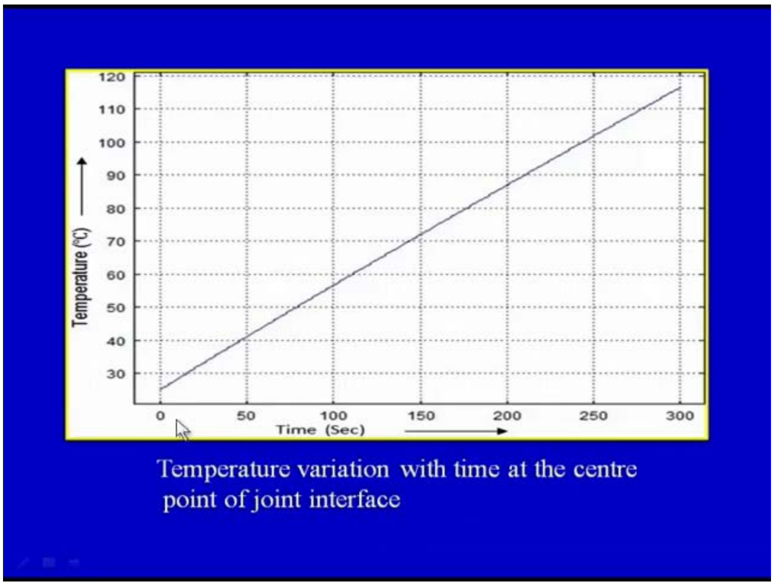

Now, here you can see on your screen temperature variation with time at the center point of joint interface. So, the temperature is unilaterally increasing with the passage of time. But this is the exposure time for which the microwave has been in pinched on the joint area. So, microwaves are in pinched over the whole microwave cavity. But we focus specifically on the bond area by putting some susceptor element which would absorb the microwave and focus the heat at a particular area and the other areas can be made opaque to the microwaves. So, basically we are focused in joining our focus in case of joining is in the area where the 2 adherends are bound to be joined or where the bond has to be formed.

So, in that particular area we have to see that how much temperature being generated because of the microwaves. So, this is showing the temperature variation with time at the center point of interface. So, we can see the temperature is increasing when the exposure to microwave time for exposure to the microwave is increasing. So, at a particular time suppose 250 seconds we have a temperature more than 100 degree centigrade. So, suppose 100 degree centigrade is the temperature at which the matrix material has the tendency to form or to we can say soften a bit and join with the other matrix that is there on the other adherend; when there is the tendency that the matrix is soften and form a joint at suppose 100 degree centigrade; we can say that at 250 seconds of exposure and a particular watt suppose at 900 watt.

900 watt of input setting 250 second of exposure; the temperature is more than 100 which is more than the bonding temperature for the particular matrix, for a particular polymer at which the polymer has the tendency to soften. And, form a bond with the other adherend at that particular temperature the bonding would takes place. So, we can vary easily see we can predict the exposure time at which the bonding is going to take place. So, we can see that finite element method and there are other tools as well at we would be seeing in the subsequent slide or the tools which help us to investigate the various important phases or various important aspects of this particular area of secondary processing of composite materials.

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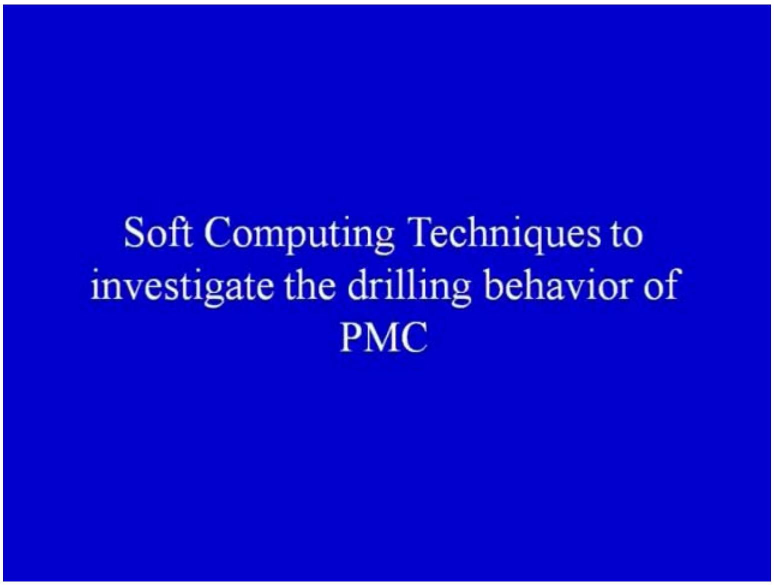

And, finally we come to the last part of our lecture that is the soft computing techniques to investigate the drilling behavior of PMCs. Now, we have seen in the very first slide today that the drilling process there is so, many inputs and so, many outputs. Now, somehow, we have to correlate the inputs with the outputs; so that we are able to predict for a certain set of inputs what would be the output? So, for that there are so, many soft computing techniques; which have been developed worldwide. And, are being used in order to correlate the input parameters with the output parameters.

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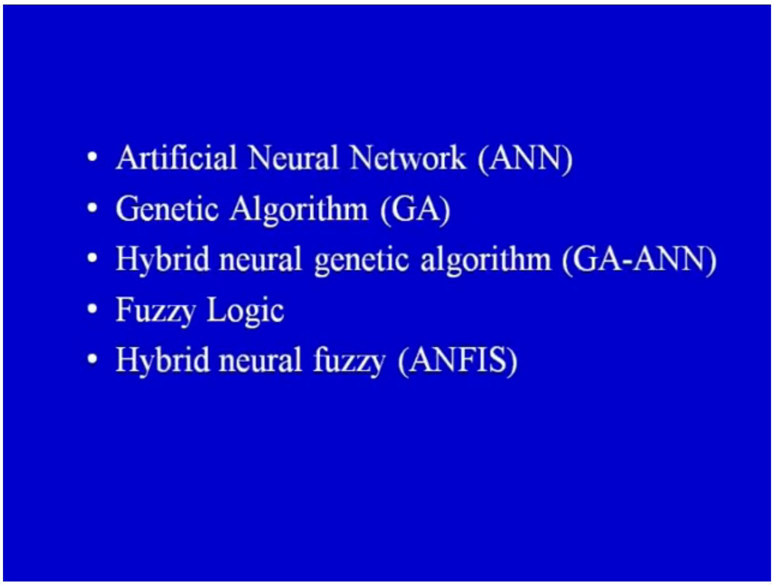

Some of the well known techniques are the artificial neural network, the Genetic algorithm, Hybrid neural genetic algorithm GA-ANN, Fuzzy logic, Hybrid neural fuzzy or the ANFIS system. So, these are some of the soft computing techniques; which are used to correlate the input to the output so that for a specific set of inputs we are very easily able to predict that what would be the output. But certainly these methods or these techniques are based on the experiments results; first we have to undertake the exhaustive experimentation in order to train these methods or to intelligently train these methods.

So that they can further be used or their intelligence can be used to generate the output for unknown set of input parameters. But first we have train them with the known set of input parameters. So that they develop the intelligence which can be further be used for unknown set of input parameters. And, finally we get the desired output out of these intelligence tools.

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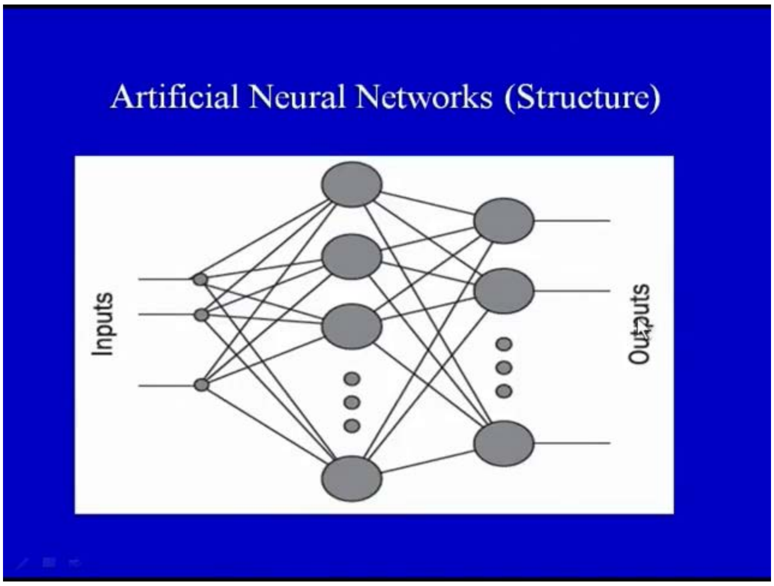

So, this is an artificial neural network. So, in artificial neural network; we can see there are set inputs 1, 2 and 3; there can be other inputs as well more inputs can be used and we get the output. So, this is the intelligence that is inbuilt. So, this is the intelligence that developed by giving a set of input data that data has to be huge that has to be have a wide range. So that the network gets trained better and once the network gets trained better than for unknown data inputs also, specifically within the range it should be able to give us the output.

Now, suppose let me take an example, in our case drilling of polymer composite; we have suppose 4 input parameters, cutting speed, feed rate, drilling point, geometry and the drill diameter. Suppose, these are the 4 input parameters that go into the network; output is suppose the drilling induced damage. Now, for these 4 input parameters we have to take these parameters at different levels and perform lot of experiments; which would be the output has to be found out for these experiments in the form of drilling induced damage. So that we will do large number of experiments and for this experiment we will record the drilling induced damage as the output. And, this data the output, input combination data has given as a input to this particular model.

And, finally when it is trained properly it is we would be able to find out the drilling induced damage for a specific set of input parameter; for which we may not have done the experiment. So, this particular model will help us to find out before doing the experiment that how much damage is going to take place for this set of input parameters; for suppose cutting speed v 1, feed rate f 2, drill geometry d 3 and drill diameter 8 millimeter. So, for these set off these input parameter what is going to be the drilling induced damage. And, these are the 4 inputs which were not taken for the training of the network; the network was trained with different set of inputs. So, we can see once it is done we are very easily able to find out how much damage is going to take place. So, this is just one example of a one particular technique; as we have seen in the previous slide there are large numbers of techniques which can be used to do these types of a work.

So, with this we come to the end of our course that is processing of non metals. And, we are finishing today the module number 7; in which we have seen different aspects of the secondary processing of composite materials; we have seen the drilling aspects, the issues and challenges in the drilling aspects, the process variants of the drilling process or the different tools and techniques which is used to make a holes in composite laminates; which are one or the other process variants of actual drilling process that we have seen. Then, we have seen the joining of composite adherend using adhesive bonding as well as the mechanical fastening; what are the issues and challenges related to the joining of the polymer composites was seen.

In lecture number 4; we have seen the microwave joining of polymer matrix composite. And, finally today in lecture number 5 of module 7; we have seen the finite element method as a tool for conducting research in the area of polymer matrix composite; specifically the secondary processing of polymer matrix composites. And, we have seen that there are some tools; artificial intelligence tools which can be used for predicting the process outcome specifically in case of drilling of polymer matrix composites. I hope you have enjoyed this series of lecture on processing of non metals.

Thank you.