Processing of Polymers and Polymer Composites
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Lecture – 38
Process Simulation of Secondary Processing

[FL] friends, welcome to our session 38, in our course on Processing of Polymers and Polymer Composites. So now, I can say with confidence that we are towards fag end of our course, and we have to learn so many new things related to the polymer and polymer composites. So, which establishes that low course can be completed, may be in 10 hours, 20 hours, 40 hours or 80 hours the knowledge is enormous and vast, and we can keep on learning the finer nuances of any topic or any subject, if we have that will to learn. And today I am going to introduce a completely new dimension related to the polymer matrix composites; which is the process simulation.

We have seen that so many process is are used for processing of polymers, processing of polymer matrix composites. And when new and new materials are developed, new and new polymers are developed, new and new polymer matrix composites are developed by choosing a different type of a polymer in a different type of a fiber. It becomes difficult to experimentally investigate the process behavior of each and every combination. Therefore, sometimes simulation is helpful to us that we can develop some simulation models, we can develop some simulation platforms, on which we can give the input we can change the material, and we can try to establish the behavior or the processing behavior of that combination of polymer and the fiber .So, simulation tools are very, very important.

Now let us take an example. Now we have seen that drilling of polymeric composite materials is a challenging task; all of you have understood that and I have emphasized overemphasized, rather I should say the importance of drilling in polymer composites. So, many different techniques we have seen for making of holes. If you remember we have seen conventional drilling approach. We have seen the modification in the conventional drilling in the form of wood packer cycle, the helical feed method the backup support method.

Then we have seen the advanced machining techniques for making of holes in composite laminates. We have seen the vibration assisted drilling, ultrasonic assisted drilling. Then we have seen rotary ultrasonic machining, ultrasonic machining. There are number of other processes; which due to time constraint we could not it study or we could not discuss. For example, water jet cutting, abrasive water jet cutting, laser cutting, electron beam cutting, electro discharge machining also. But some of these techniques are in the research stage. But whatever have been established successfully, we have tried to cover that.

Now, I have told in the previous session that ultrasonic assisted drilling process, may be applicable to one set of materials, or one class of composite material. May not be equally applicable or equally advantageous for some other class of composite materials. Now suppose we want to check the validity the versatility the applicability of this process which is well established for one family of composite for some other family of composite. Again, we need to do the exhaust experimentation; which will lead to lot of time, lot of manpower lot of resources, and sometimes we may not get the adequate results.

Therefore, when the material is changing the process mechanism if remaining the same, or the process mechanism remains the same what we can do we can develop a model, and validate that model for a successful process or for a process, for which it has it can be validated. And then we can use the same model by changing the input parameters, and see whether the process is going to be feasible or versatile or not.

So, the modeling approach is help full for all classis of materials. For example, why to talk about polymer composites only. Why not to understand it for metals. Now suppose we can drill a hole easily in case of an aluminium alloy. Now we want to check that what can be the terms and conditions or requirements for making hole in steel. Suppose we validate our simulation model for making of hole in aluminium, or aluminium alloy that model is available with us. What we can do? From the same model we can change our input material properties. We can input the properties of steel now, and see how the process will behave for a change in the material. And certainly, we will get our results, that what will be a thrust force generated, what will be the torque generated for making a hole in a steel plate. From the model which has been validated for making of hole in a aluminium plate.

So, the models are simulation tools are very, very important to us. Some time they act as the pilot also, for which we can get some input from for regarding the process behavior from the simulation. And then for that inputs we can use it in the experimentation and make use of this input for minimizing our number of experiments, or for minimizing our experimental efforts. Because we can see that the process is behaving nicely, the process is behaving accurately, or precisely in these range of parameters. Then those parameters only we can select from the simulation, and use them for experimentation and validate the 2 results; that is the simulation results as well as the experimental results.

So, simulation tools these days have become very, very important. And everybody must at least know the basics of these simulation tools. So, we will try to understand a basic concept with taking example of 2 or 3 process is specifically relevant to polymer matrix composites. And I believe that if you attend may be if you or may be able to assimilate the information that we are going to discuss today. You will be better prepared maybe you will be using you are mental faculties to simulate more as compared to experimentally establish the process because simulation these days is the catch word. And people are using different softwares, different tools, different platforms for simulating the process behavior in comparison to the experimental effort.

So, the may be focus currently is on simulate, we see so many simulation so many teacher tv channel shows process simulation or may be impacts simulations or may be flight simulation. And many results are established by the simulation approach only, and then maybe one or 2 experimental tests are done to establish the veracity or the truth fullness or the application of the simulation results. So, today our focus primarily would be to understand the process simulation in context of the polymer matrix composites. I think, I have highlighted the importance of simulation. Now we will see the case studies related to the process simulation of the secondary processing.

Now, if I put a question that what are the secondary processing techniques that are employed for polymer matrix composites. You can very easily answer the question that these are joining of the polymer composites, as well as the machining of the polymer composites. So, these are the 2 processes that we have seen in our sessions or in our previous sessions or in our course. So, we will try to see that how we can simulate these 2 processes, and get our results and how these results are going to be advantageous for us.

So, let us try to understand the simulation of 2 of these processes; that is the machining as well as the joining. So, first case or case study that we are going to see today is the finite element model for drilling of polymer matrix composites.

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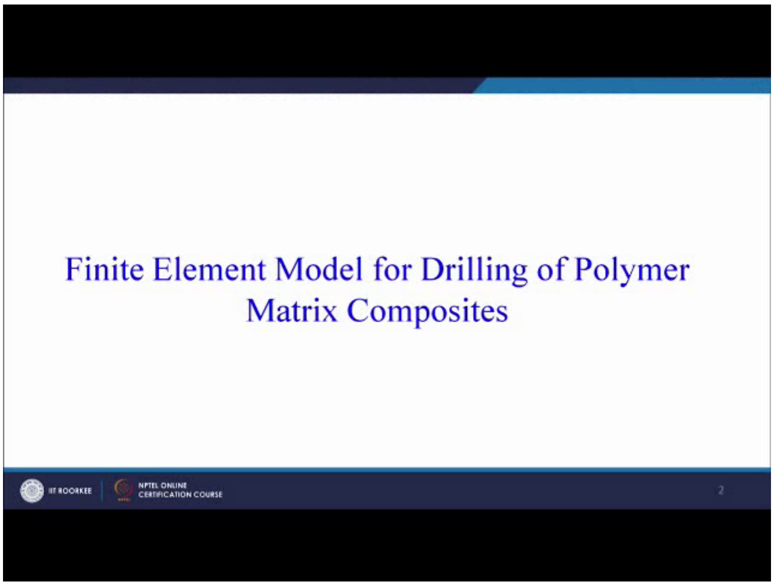

So, we can see in the last session we have seen 3 variants of the vibration assisted drilling that is vibration, assisted twist drilling than we have seen ultrasonic machining, than we have seen rotary ultrasonic machining RUM process.

Previous to that we have seen 3 variants of the conventional drilling process; that is the woodpecker cycle method, the backup support method, and the helical feed method. So, we have we know that how experimentally we can make a hole in a composite material. Today we will try to establish that how we can simulate that behavior and try to establish that whether the damage can be minimized using the simulation or not. And the approach that we are adopting is a very fundamental very common approach with which the topic is also covered in many use curricular in many collages this topic is taught that is finite element method.

So, we are not going to go into the basic no one sees or basic basics of finite element method. But we are going to see how finite element method can be used to simulate the drilling behavior of the polymer matrix composites.

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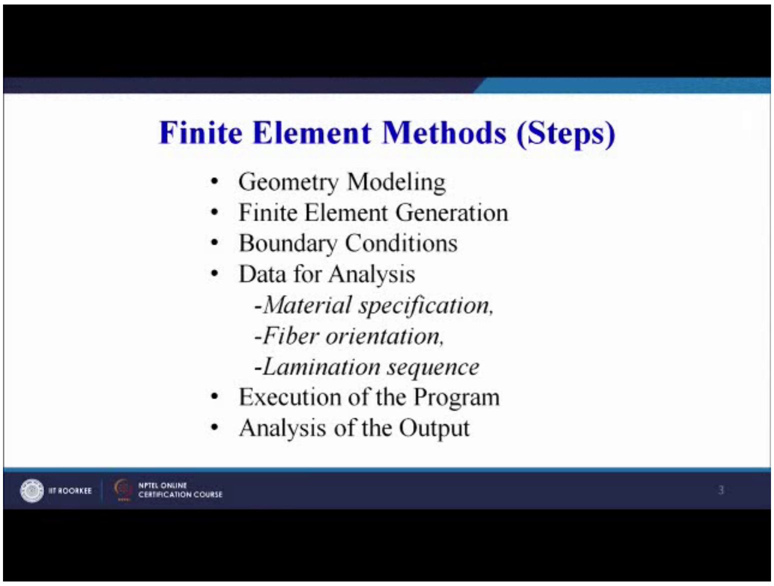

So, let us see now the finite element methods in there are different steps involved. So, first is the geometric modelling. So, we have to create a geometry of a composite plate in which we want to make a hole. We have to create a geometry of the drill that we want to use for making a hole. Then we discretize the plate and the drill into finite elements. Then we apply the boundary conditions, now boundary conditions basically are that is this is the plate in which we want to make a hole. So, this late will be fetched from bottom may be clamped from the top also.

So, these boundary conditions that it cannot move in x y and z direction. It cannot rotate in this direction. So, these are the boundary condition. We will fix this plate and then this is the drill this drill will rotate also; drill geometry and it has to move down in order to make the hole, the rotation of the drill the feet of the drill towards the work piece. These are all boundary conditions; that at what rotation it will rotate or at what speed cutting speed. It will rotate it may rotate at 20 meter per minute, it can rotate at 30 meter per minute that is the cutting speed. Then the feed rate also maybe 0.5 millimeter per revolution or 0.05-mile meter per revolution. So, this feed rate and the cutting speed are the boundary conditions that we have to give. More over for the plate in which you want to make a hole we have to see that it is constrained all degrees of freedom are constrained for the drill.

So, these all are the boundary conditions for the process simulation of drilling of polymer matrix composites. Rather I should say for any drilling operation. Even if we are making a hole in a steel plate we will give similar type of boundary conditions, only that the plate is fixed it cannot move the drill is rotating as well as it has a feed rate at which it is going to make a hole. So, the boundary conditions for drilling operation or the process remains same. Only difference will be when we will input our data for analysis. So, first thing is the geometric modelling we have to create a geometry of the drill, as well as of the work piece. Second is discretise the tool geometry and the work piece into finite elements then we have to apply the boundary conditions.

Now, our basic model is ready now we have to give the data. This data will differentiate between machining or drilling of a steel plate, and the drilling of a polymer composite plate. Now in data you can see we have to give the material specification. Now material specification means that we have to specify. What we have to specify? We have to specify what are the different layers, or what is the material of the different layers. We have to see that what is the angle of orientation of the fibers. We have to see what is the thickness of the individual layer. So, the material specification we have to give in the data. We have to give the fiber orientation. We have to give the lamination sequence. Now lamination sequence will be a new word I think for most of the learners.

So, let me take an example of a glass fiber reinforced epoxy composite laminate. Glass fiber reinforced epoxy composite laminate. Now glass fiber means it is reinforced the epoxy matrix is reinforced with glass fibers. Now suppose we take the woven glass fiber, and we have 4 layers, in these 4 layers. Maybe we may have first layer of glass fibers, second layer of glass fibers, third layer of glass fibers, forth layer of glass fibers. And this 4 layer of glass fiber are being used to reinforce the epoxy matrix.

So, in lamination sequence we will specify each layer. Layer 1, glass fiber epoxy. Layer 2, glass fiber epoxy. Layer 3, glass fiber epoxy. Layer 4, glass fiber epoxy. So, that will make a power lamination sequence, and the software will get an idea that this is a 4-layered composite laminate in which all 4 layers are glass fiber epoxy layers.

Now, if we have a hybrid type of composites. We may have different materials in different layers. Sometimes metallic sheets are also there, in the layers and that we can specify it during the material specification stage of finite element modelling. So, the data for analysis will incorporate what is the material, what are that how many layers are there, what is the material of individual layer, what is the fiber orientation in the individual layer, whether all fibers are in one direction or there is a woven mat of fibers used as the reinforcement. So, all this will be a input which is more specific to the polymer composites.

If in case it is a isotropic material, it is an alloy. For example, it is an aluminium alloy or it is steel or an iron alloy, maybe it is isotropic material. We only need to specify the mechanical properties. We may specify the modulus we may specify the UTS, we may specify the poisons ratio we can directly specify the material properties. And the software will do the calculations accordingly, but when we are modelling a composite material there is a challenge. We have to specify many other details numerous other data is required to completely specify a composite materials. We have to make the software understand that what is our material. And our material suppose it is a composite material we can very safely say today we are discussing polymer matrix composites. So, we have to be very, very careful in specifying our material. And softwares have this capability they will prompt you to enter this information or enter this data.

So, we have to specify the material. Basically, for may be to summarize suppose we have to specify the lamination sequence, we have to specify the; how many number of layers? What is the material of each layer? What is the thickness of each layer? And what is the fiber orientation in each layer? So, this will suffice our information for the software, and the software will do the calculations according to this data that we have input in the material specification stage of the finite element method.

Finally, now we have told the software. Now we have input this information, that what is the geometry of the drill, what is are the dimensions and shape of our work piece material suppose it is a plate. Now in that composite plate how many layers are there, what is the material of individual layer, what the thickness of individual layer, what is the fiber orientation in the individual layer. Then now the software knows that based on the boundary conditions, based on the shape of the material based on the material of the work piece it will perform the simulation. And we will be able to see that how much forces are generated, and how much damage is been created or how much damage is happening because of the drilling action of the tool. And once you execute our program these days the graphic user interface is very, very solid is very, very we can say versatile. We are able to see the complete simulation that the drill is rotating. It is moving down into the laminate the chips are getting removed, and force is are being recorded on xy plot.

So, that kind of versatility that kind of strength today is possible, or that kind of strength is available with the numerical modelling tools or simulation tolls; that the that have been developed by the engineers worldwide. So, once you execute the program you can see the complete simulation. And finally, we can analyze our output. Now one of the analysis can be that if we use 3 different drills, we can see in which particular drill point geometry or for which particular drill point geometry, we are gusting the maximum thrust force or the maximum torque value. And very easily we can perform a comparative analysis of the drills; that we are using. For example, we use a twist drill or a step drill or candlestick drill or maybe we can use number of other drills matrix are there. Suppose we take 3 geometry only very easily, we can conclude that based on the simulation results, this particular drill point geometry is going to give us the minimum forces as well as the minimum drilling induced damage.

So, that is the overall beauty of this technique; that without even going to the machine without even going to the experimentation, we can very easily do the simulation and find out the optimal values. Not only for the drill point geometry, we can also find the cutting speed the feed rate which is going to give us the best output in terms of a good quality hole in a composite laminate.

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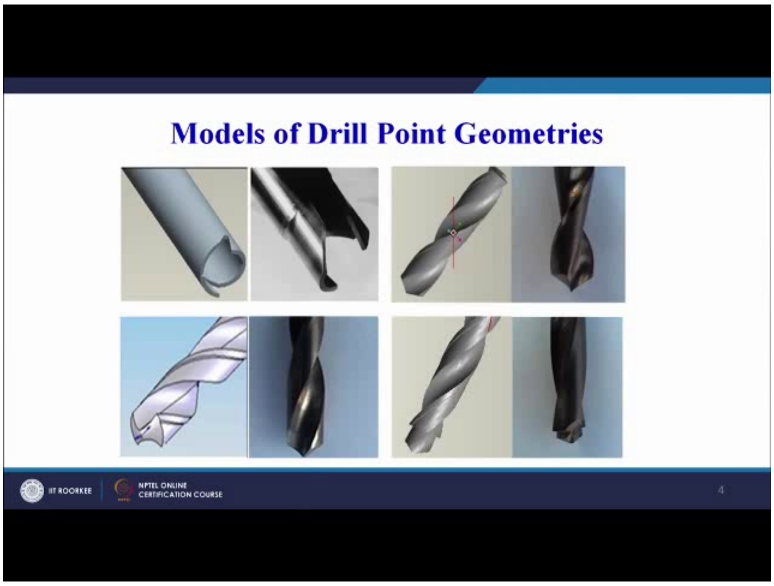

On your screen you can see the different models of drill point geometry. You can see this is a trepanning tool, trepanning tool, t r e p a double n i n g trepanning. This is a hollow tool, and it has 2 cutting edges. Then we can see a standard twist drill here. This is a parabolic point sorry, parabolic point. You can see the cutting edges, having a parabolic shape. This is at standard twist drill, the third one standard twist drill. And this is a step drill you can have a focus on this area you can see. It performs the drilling operation in it is 2 stages, and if you remember in one of the previous sessions, where we have seen the thrust force signal that was for the step drill only. And I have emphasized there very clearly that the inner portion of the drill generates a hole, and the outer portion of the drill and large is that hole to the specified diameter.

So, this is a step drill, actual step drill, actual parabolic drill, actual trepanning tool and the actual trepanning tool. And the actual twist drill and these 4 are the modelled geometries using the software. The model of the trepanning tool, the model of the parabolic point, the model of the twist drill and the model of the jo drill or the step drill.

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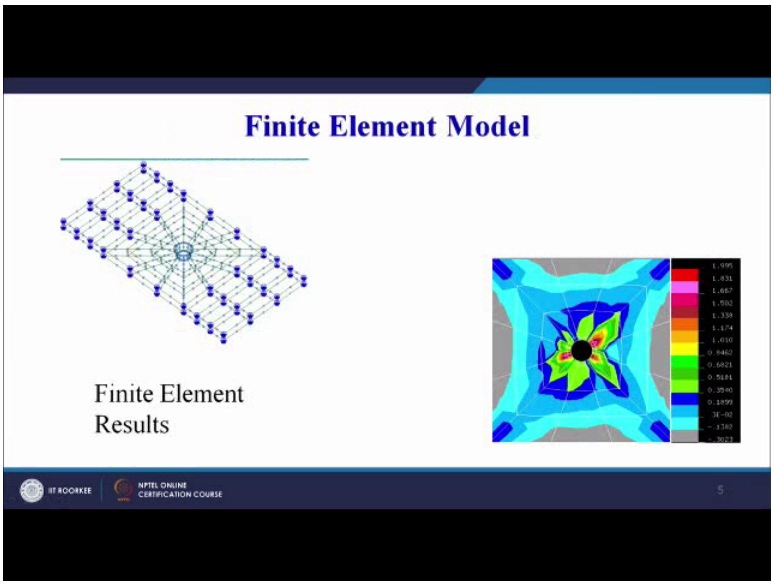

Then we can see this these are the boundary conditions. This is the plate in which we want to make a hole. In many cases we can assume that there is a pre-hole, that is existing and we can enlarge that hole using the drill, and here we can see this is a boundary condition, which shows that the plate or the composite laminate has been fixed in this area. X y and z movement or displacement are restricted.

Similarly, this side also x y and z displacements are restricted. Only this portion is free to move under the application of the drilling action. And these are the typical results that we get after running our finite element program. And it is showing that area around the hole till the red pink and the dark pink color; this is the area that has been damaged around the hole. This is (Refer Time: 22:17) plot which is a kind of a failure criteria, specifically designed for polymer matrix composite materials.

So, we are not going to get into the failure criteria, we are just trying to understand that how the process can be simulated, instead of going for experimentation. We can simulate the process also and try to understand the process behavior. In this way we can see using this failure criteria plot. We can understand that what is the area around the hole, that has been damaged or how much area around the hole has been damaged. So, this is the output or the result of the finite element approach; which gives a fair amount of idea about the area around the hole that has been damaged because of the drilling action. These are again the finite element results, we see that around the hole.

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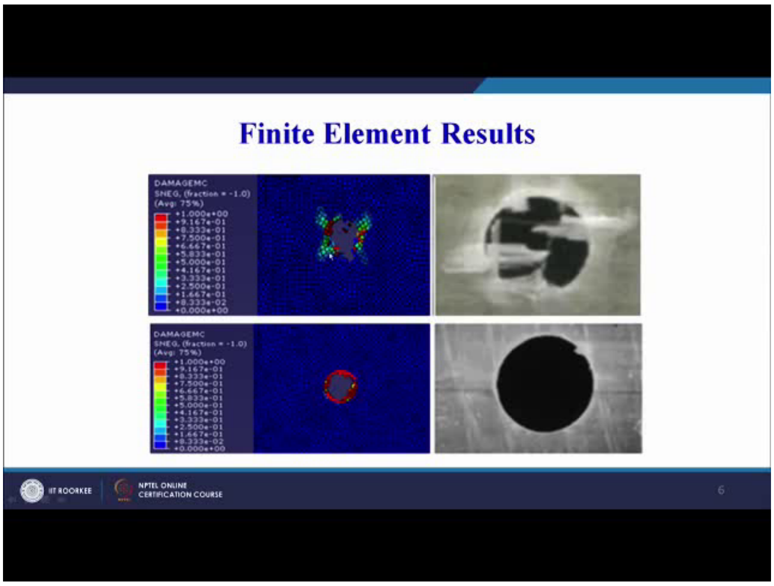

There is damage which is because of the drilling action. And this is the actual experimental result, which shows the area around the hole has been damaged.

Similarly, here also this is with the hollow tool, and we get a better-quality hole. And simulation also predicts that the damaged area is less because of the change in the drill point geometry. So, similar type of results are possible, when we use a composite material, and when we use a simulation process for understanding the behavior of the composite material under the machining action.

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The next part is the finite element model, for microwave joining of polymer matrix composites. So, previous section that we have seen is focusing on the simulation of the drilling behavior of polymer matrix composites. The next session very briefly we will try to see a simulation behavior of the microwave joining process for polymer matrix composites. Must I tell you here, that it is not that only microwave joining can be simulated the adhesive joining as well as the mechanical fastening can also be simulated using the finite element approach. And the results can be experimentally validated, at our lab also we have done the simulation of adhesive joining also, as well as the mechanical fasting also. But I am trying to explain the microwave joining because this is the latest and research is going on in this direction. Some of you can just try to use a software and try to simulate the microwave joining behavior of the composite materials in your bachelors of the masters or a PhD project.

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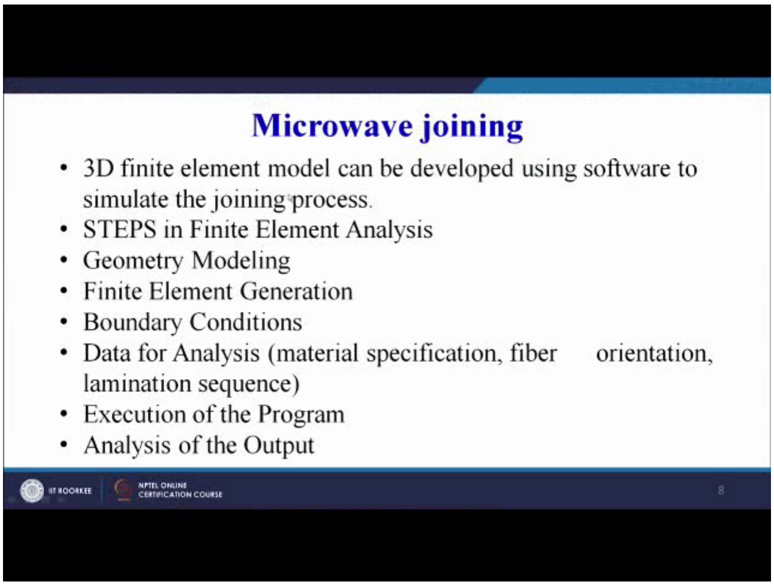

So, just the most of the steps remains the same. Very quickly I will read the steps or 3-dimensional finite element model can be developed using software to simulate the joining process. Steps in finite element analysis are again the same. It is geometric modelling, finite element generation it is same as we have seen for the drilling behavior, or the simulation of the drilling. Behavior boundary conditions are applied although now here we have to heat the joint area. So, the boundary conditions will change, but the steps remains the same. Data for analysis is specified we execute the program and then we analyze the output.

So, the basic finite element steps remain the same. Now this is a simulation results that we can get.

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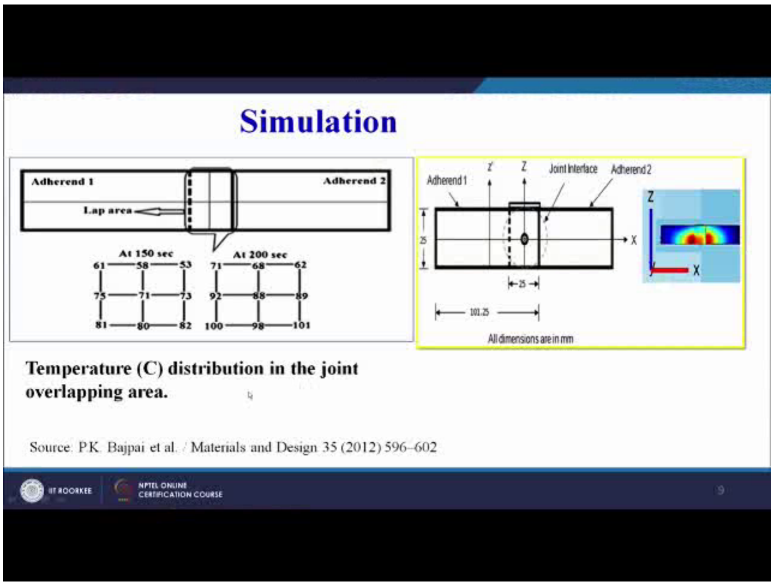

We can see the temperature distribution in the joint overlapping area. Now adherents are there this a adherent number 1, this is a adherent number 2, or very we can say precisely, we can say that these are the 2 composite parts that we want to join together. And the joint configuration or the joint type that we are using is a lap joint. So, as per the lap joint there will be a overlap area, and this overlap area we can simulate and find out what is the temperature at the overlap area.

So, this is at 150 seconds. 150 seconds means that exposure time in the microwave oven is 150 second. We can see at 200 seconds the temperature is further increasing. Now because of this simulation results we can see that what is the exposure time in which we are getting the temperature in the overlap area; which is above the glass transition temperature of the polymer or the melting temperature of the polymer. Because we have seen that for joining we need to raise the temperature. We need to increase the temperature beyond the glass transition temperature or the melting temperature depending upon the type of polymer that we are using.

Now, depending upon the polymer we have to find out that what is the temperature required. And simulation will give us the temperature profile in the joint overlap area, and after simulation we get a fair amount of idea that what is the exposure time. What is the wattage that we should give or what is the power that we should input so that we are able to make our joint. So, the input parameters can be wattage. The input parameter can be the exposure time that we can very easily find out from the simulation results. So, this again shows the joint configuration this is adherent one adherent 2 the 2 composite parts that we want to join together, and this is a joint interface area. And on the top we have a susceptor as we have already discussing microwave joining, that there are materials which have a tendency to attract the microwaves, and these microwaves are helpful for heating the joint overlap area for developing the joint.

So, this is one simulation plot the temperature profile shown on your screen.

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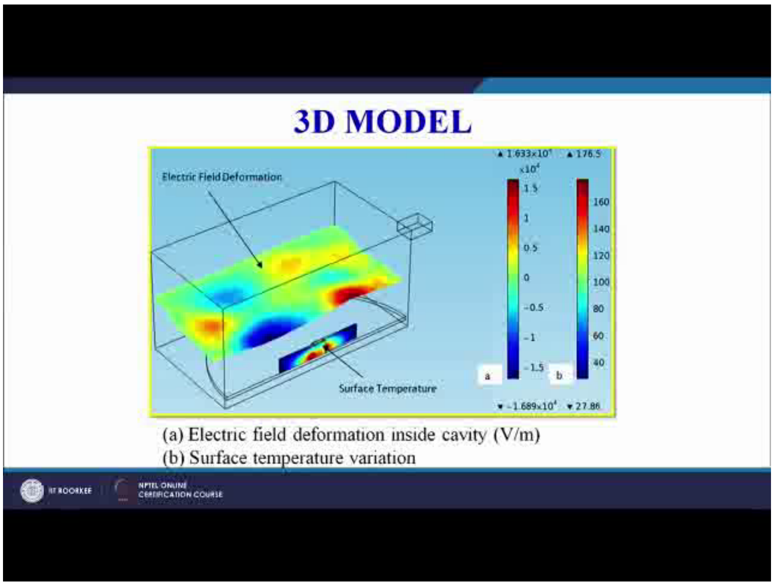

This is the again the temperature profile, these are the 2 adherents in the microwave cavity. This is one adherent this is second adherent. And since we can assume the symmetry only half portion has been modelled. Here we can even get electric field deformation inside the cavity plot for electric field deformation, but more importantly we are interested in finding out the surface temperature variation. Because we have to see that what is the temperature in the part that we want to join together. And if the temperature is matching with the glass transition temperature as well as the melting temperature of the polymer or not.

Way if where we are able to match the temperature we will be able to form a joint. This type of simulation of joining of polymer matrix composite parts is also possible.

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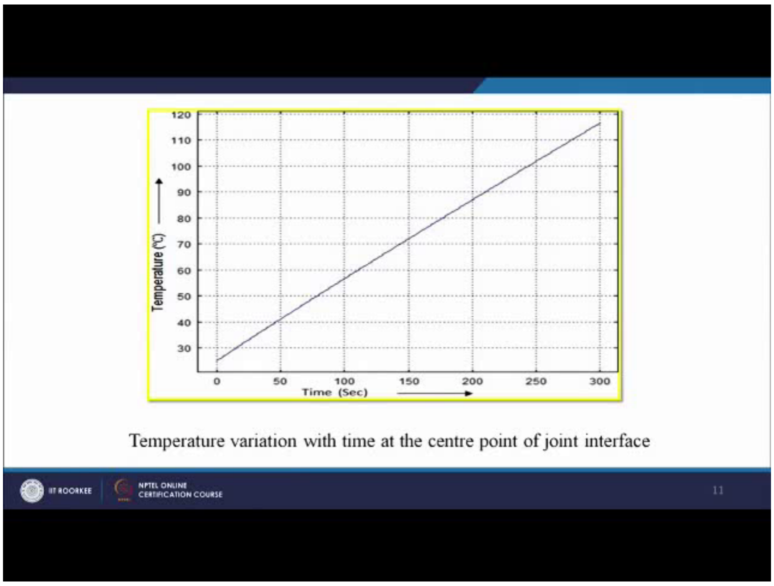

This were temperature variation with time at the center point of the joint interface. So, we can see with the time of the exposure time of the microwave is increasing, the temperature is also increasing linearly.

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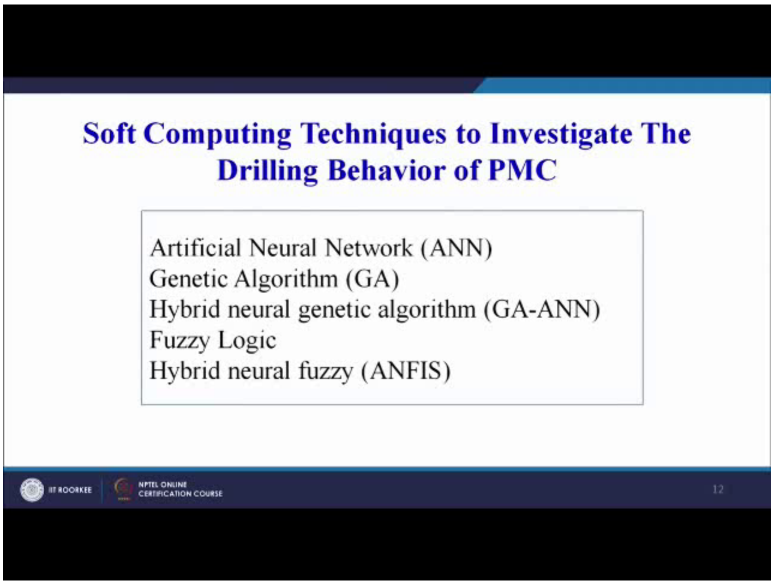

Now, the last 2 sections in the todays session that we are covered today are; the process simulation tools for simulating the behavior of or the process behavior of processing behavior of the polymer matrix composites. We have seen the simulation of drilling behavior of polymer matrix composites. We have seen the joining behavior of polymer matrix composites, specifically in case of microwave joining. Then there are many artificial intelligence tools also that are used for understanding the behavior or predicting the behavior of polymer matrix composites. It can be the drilling behavior, it can be the joining behavior.

Now, soft computing technique or artificial intelligence tools that can be used are artificial neural network genetic algorithms, hybrid neural genetic algorithms, fuzzy logic, hybrid neural fuzzy algorithm. So, different types of algorithms are used which can help us to predict the behavior of the composite materials. If it is a drilling than it can even predict the force is it can predict the damage we will try maybe in our next session or next to next session. We will try to understand a case study based on this soft computing tools; that how these tools can be used to the benefit of the composite engineer on the engineers were working in the composites industry. Just to have a brief overview of one of these that is the artificial neural network.

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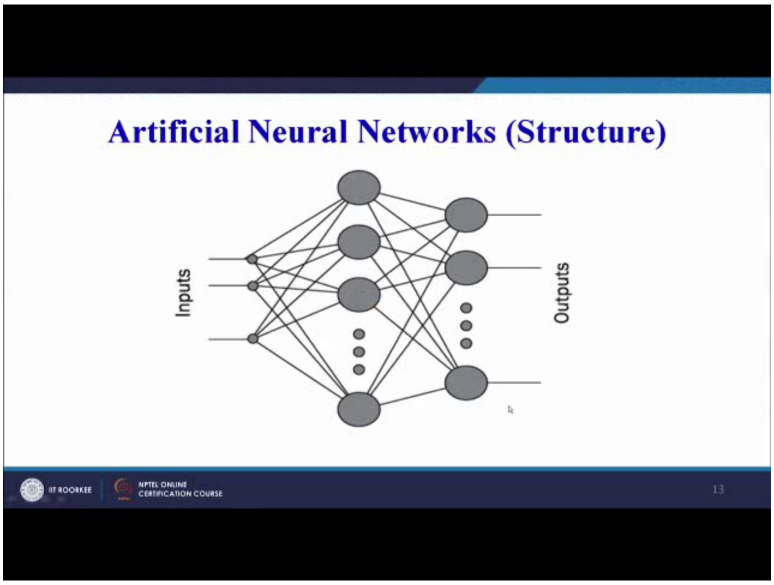

This is a diagram representing artificial neural network. We have the inputs specifically in drilling what will be the input let us take the 3 inputs. One can be the cutting speed another can be the feed rate another can be the drill point geometry. So, these are the inputs and using the artificial neural network, we get the outputs or we can predict the output. Now output can be the first force the torque as well as the drilling induced damage. So, we train this network in such a way that based on any arbitrary input, we can get a desirable output. And we will try to understand a case study based on these soft computing tools also maybe in our next session.

With this we conclude today's session and we have seen today; that how a simulation approach can be used to minimize the experimentation, and how the simulation approach can help us to understand the behavior of the process, more specifically the drilling behavior of the polymer matrix composites as well as the joining behavior of the polymer matrix composites.

Thank you.