Processing of Polymers and Polymer Composites

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Lecture – 32
Microwave Joining

[FL] friends welcome to session 32, in our course on Processing of Polymers and Polymer Composites. As you are well aware that currently we are into the third phase of our course, in which our focus is primarily on secondary processing of polymers and polymer composites. And we are focusing much on polymer based composites, but that is the current trend; that most of the composite products these days are an additional development in context of the polymers. Although we see so many polymer products or plastic products also all around us, but the joining technologies for plastics are more or less developed.

Moreover, the plastic parts are generally made to a near net shape and then they are assembled using any simple standard method that is; like adhesive joining, simple example can be the toys that children play with. Most of the joints you will see; will be either adhesively bonded joints or there will be hole and they are fastened by nuts and bolts; plastic nuts and bolts as fasteners are used. So, for plastic parts; the technology more or less is developed, but for composite parts when you add additional element that is the reinforcement.

So, the complications arise because the 2 phases have to be considered. We have to consider the reinforcement also; we also consider the polymer also. And on top of that; we have seen in our previous sessions, there are process based implications also. For example, we have seen in adhesive joining; surface preparation is one of the major limitations. Similarly, we have seen in case of mechanical fastening hole making is one of the major limitations. So, limitations are there on account of the constituent materials, similarly limitations are there on account of the processing technique or the joining technique that is used for joining these materials.

So, problems may arise due to the materials, problems may arise due to the technique and we have to overcome all these challenges. Now, the 2 major challenges that have come forth during our discussion are; the joining or preparation of the surfaces for adhesive joining and making of holes for mechanical fastening. So, we will try to see another method which does not require too much of surface preparation, as well as does not require a hole making technique or hole making procedure for joining using a nut and bolt.

So, today we are going to discuss the third method of joining the polymer composites. And must I address here that; this is not a commercially applicable technology for joining of polymer composites. If we talk of the 2 techniques which we have already discussed, which we have already studied during our course; that is adhesive joining and mechanical fastening, both methods have been universally applied for joining of polymer based composites. But the microwave joining, some of you may not be able to appreciate today the importance of this technique, but what I believe with more research efforts in this direction; this can be one of the most important rapid green technique of joining the polymer based composites.

It is fast, it is quick and it is one of the; maybe is going to be one of the most important methods for joining of polymer based composites. But currently this technique is at the research stage and researchers worldwide are trying to find out the means and mechanisms, the mechanisms of joining the polymer based composites using the microwave joining technique. So, the equipment; the requirements are not much different as we use microwaves for heating our food.

Similarly, we can say; we have to cook our thermoset or thermoplastic based composites using the microwave so that a joint is formed between the 2 joining members or between the 2 adherents or between the 2 composite components or parts. So, basically the mechanism will remains same, the equipment will remains same but the application will change. We will be using the microwaves for joining of 2 parts together and the applicator or the microwave oven can be a simple oven as we use in our domestic applications.

So, we will try to understand that how the microwaves can be used for joining purposes. Now, if you remember the very basic definition of joining; we have seen that there are 2 major inputs that are required. The first major input is; I think you should always try to relate what we are discussing; what are the 2 major inputs? So, input one is heat and the input 2 is pressure. So, our major focus is to ensure that our joint has got some temperature, some heat should be the input and then there must be some pressure.

So, in case of microwaves; we will be using microwaves as our source of heat. So, the 2 adherents or 2 joining members or the 2 composite parts that we have to join together will be subjected to heat. So, from where this heat will come? This heat will come from the electromagnetic radiation or the microwaves. Microwaves must heat the joint overlap area and since the plastics have a glass transition temperature, so the heat should be able to make them sufficiently viscous at the interface so that a joint can be formed with the application of pressure.

So, we have to subject our joining members, our adherents to the electromagnetic radiation so that a joint can be developed. Definitely, some of you may be wondering; that how a specific area can be exposed; why not the complete member or the complete adherent will be exposed to the microwaves; maybe that is a very valid question. When you are putting your adherents inside the microwave cavity and you are exposing this assembled portion or assembly of these 2 adherents inside the microwave oven, you are subjecting it to the microwave; the complete assembly will get the heat.

How you can focus your heat on that area where you want? Or how you can have that focused heating of the joint area where you want to attain the joint? That is what we are going to understand, we are going to establish today that; how that can be achieved? How masking has to be done? So, that only the required area gets the heat and a joint is formed at that area.

So, I think I have introduced the topic of microwave joining in our last 8 to 10 or 15 sentences and we have also seen that the 2 joining methods that we have already covered; that is the adhesive joining and the mechanical fastening, both have limitations. And microwave joining tends to overcome both the limitations of the adhesive joining, as well as the mechanical fastening.

So, let us try to understand the fundamentals of microwave joining; we may not be able to establish the complete science and technology of microwave joining in half an hour session, but definitely we will try to just understand that; microwaves can also be used for joining of composite materials and specifically the polymer based composite materials.

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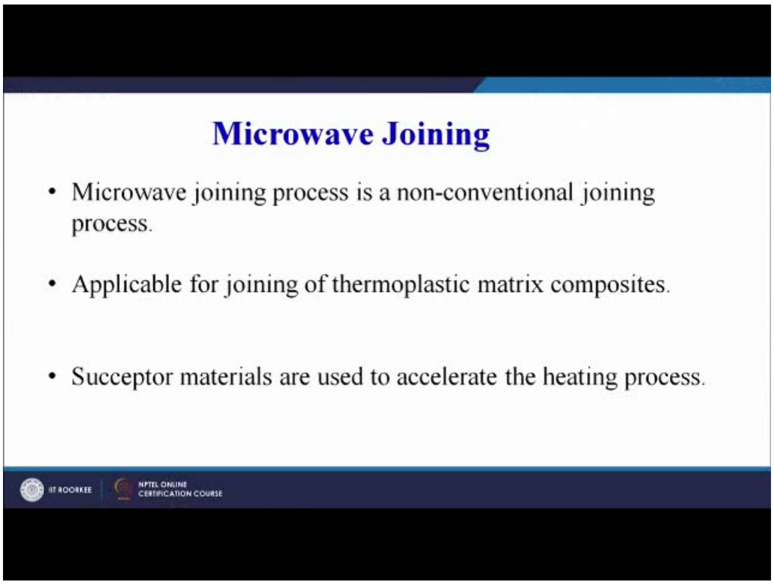

So, let us now start our discussion; you can have on your screen; microwave joining process is a non conventional joining process. I have already highlighted, emphasized outlined in the very beginning in today's session that adhesive joining and mechanical fastening are the 2 most important joining techniques which are used for joining of polymer based composites. But microwaves can also be used and it is an unconventional way of joining the 2 composite parts together.

It is applicable for joining of thermoplastic matrix composites. Now, if we go back to our initial discussion on polymers, we have classified the polymers into 2 major categories. What are those 2 categories? I think your answer is correct; it is thermosets and thermoplastics. Now thermoplastics can be remolded whereas, thermosets cannot be remolded. If you heat thermosets again, the three dimensional structure which is formed during the curing process or the polymerization of process of the thermosets; this three dimensional structure, it is difficult to break that and if you try to break it forcibly with the application of heat; the polymer may burn.

So, you cannot remold a thermoset, but yes you can remold a thermoplastic and therefore, thermoplastics are more; you can say applicable to the microwave joining. So, microwave joining on the contrary; we can say has been found to be more applicable in case of thermoplastic based composite. With some modifications, some additions, some control parameters; we can try microwave joining of thermosets also.

But it is relatively difficult to control as compared to the joining of the thermoplastic based composite materials. Now, the third point on your screen you can have; so succeptor materials are used to accelerate the heating process. As I have told you, that when we are going to join the 2 adherents together; this is adherent 1, this is a adherent 2; we bring them together and there is a overlap area. We wish that only this overlap area is subjected to heat or subjected to the electromagnetic radiation.

The other area; this is the other part of the adherent and this is again the other part of the adherent. This 2 adherent areas; we do not want to expose to the electromagnetic radiation. Now, what we believe should happen ideally is; that all microwaves that are being emitted from the emitter or from the; we can say source, should focus on one point only. Now how we can do that? It can be done by adding a succeptor material.

So, succeptor acts as a concentrator and has the ability to attract the electromagnetic waves. So, it helps us to focus the electromagnetic energy on a specific location. So, the succeptor materials are used to accelerate the heating process, so they try to converge the waves at particular location so that the heat is developed at a specific location inside the microwave cavity.

Now, some of you may be wondering that; when heat only has to be supplied for joining of 2 adherents, what is the difference between a conventional heating or a microwave heating? So, we can see from the diagram on your screen; this is the heating element in case of conventional heating process.

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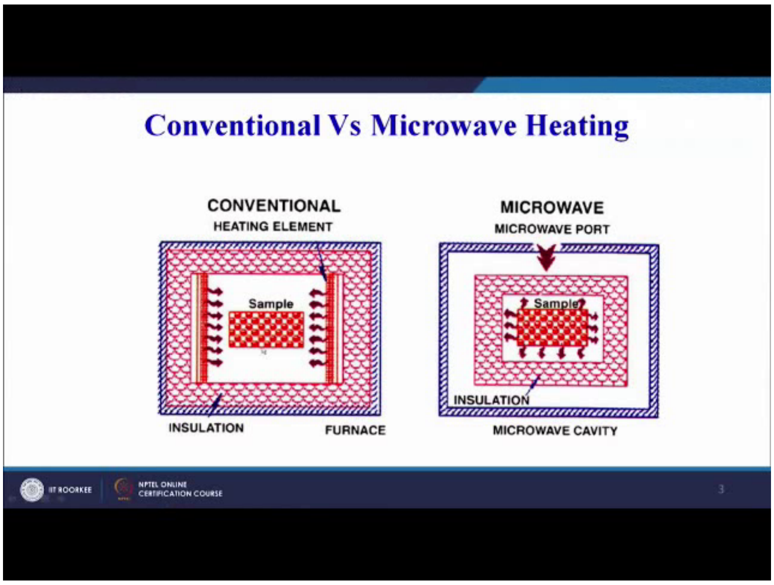

And this is our sample that we want to heat. So, our heating element will first become hot and then it will try to heat the sample by supplying heat to the sample, which is kept inside the furnace.

So, heat is not being generated inside the material; there is no source of heat generation from within the material. But the heat is being developed at the periphery because of the heating elements and then the heat is being supplied to the material and the material then develops heat or it gets heated. On the contrary, in case of microwaves; there is a microwave port, which I have called as the source. So, we have a source here from which the microwaves will enter into the cavity and microwaves will go and hit the sample. I am saying hit; h i t; it is not h e a t, we can also say h e a t; it will heat the sample.

What is going to happen? We will try to understand in the subsequent slides, but we will see that the heating is focused, it is volumetric, it is within the sample only. And because of the molecular rearrangement, the heat is developed within the material. So, here in case of microwave; it is volumetric heating, all across the sample heat will be developed and that heating can be utilized for the joining of the 2 adherents. Whereas, the other method can also be used, but may not be that effective and efficient; this induction method we will see in our subsequent sessions that what is the induction heating method of joining the thermoplastic based composites? What is the resistance heating method for joining of thermoplastic based composites?

But here; the microwave has got additional advantage that the heat is generated from within the material and that heat is used for joining of thermoplastic based composites. So, it has got slightly more advantage as compared to the outside heating. So, we can classify them into two; this conventional heating is heating from outside and then the material heat is being transferred to the material. So, in case of micro the heat is generated within the material and then that heat is used for joining of the composite parts or components.

So, the mechanism is slightly different; now whatever I have tried to explain, I think I have used my own terminology for explanation, but scientifically we have put it into the slide that what is the heating mechanism in case of microwaves?

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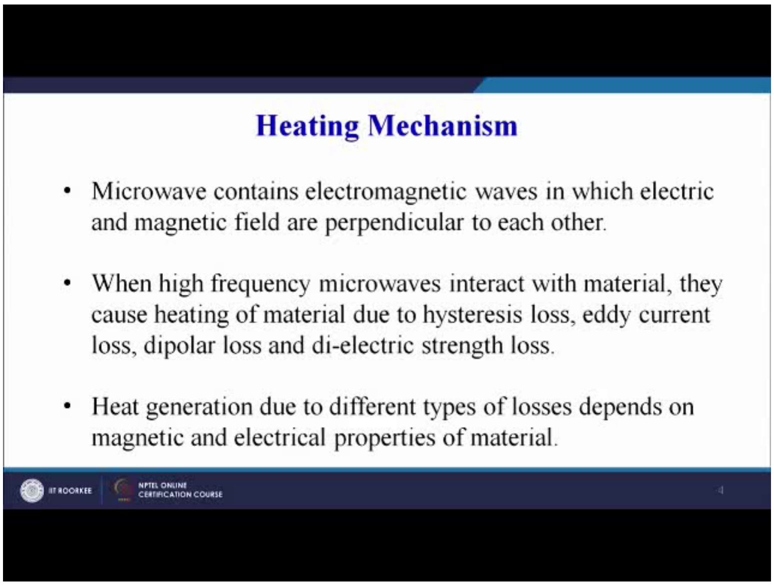

So, microwave contain electromagnetic waves in which electric and magnetic fields are perpendicular to each other; more scientific way of explaining what is a microwave? When high frequency microwaves interact with the material, so we have a applicator in which you have kept our sample. We have a port from where the radiation is being input into the microwave, into the applicator or into the cavity. So, when high frequency microwaves interact with the material. So, from the source the microwaves are coming; they are interacting with the material; they cause heating of the material.

So, the material will get hot, why it will get hot? Due to the hysteresis loss, eddy current loss, dipolar loss and dielectric strength loss. So, these are the four major reasons of increase in heating of the sample or the adherent or the joining member.

So, whatever component or bulk that we want to heat, we will use microwave as a source of energy and when this source of energy will interact with the material; different types of losses will take place. And there are equations, scientific background of these type of losses when a material is subjected to the microwaves. So, hysteresis loss is one loss, eddy current loss, dipolar loss and dielectric strength loss. So, all these type of losses will happen which will lead to increase in the temperature of the adherent, as well as increase in the heat in the or maybe development of heat inside the material.

So, definitely it will be a volumetric heating; all across the material there will be a development of heat. And that heat we want to use for joining of our thermoplastic based composites. So, we are not going to focus on; what is hysteresis loss? What is eddy current loss? What is dipolar loss? What is dielectric strength loss? But we need to understand that when the material is subjected to the microwaves; because of these reasons there will be heat build up inside our material and that heat we want to use for our joining purposes.

Now, heat generation due to the different types of losses; depends on the magnetic and the electrical properties of the material. Now, whatever material because if you see; we have different types of food items that we use and we use microwave to heat them, always we have to change the setting. Usually, in our home based or domestic microwaves; we have control on the time. We may heat it for 10 minutes or maybe 10 minutes is on the a longer side, usually we use 1 minute, 1 minute 30 seconds, 2 minutes, 2 minutes 30 second, so that kind of setting is there.

So, the power is fixed, the material we keep inside the microwave and then we just set the timing. So, for different types of material; different timing is required, even sometimes you take out a material or a food item from the refrigerator and you put it inside the microwave oven; you have to set the time accordingly. So, the magnetic and electrical properties of the material that you want to heat using the microwaves, play a very dominant role in deciding the heating that or the heat that is going to be developed inside the material.

So, the heat generation due to different types of losses; depends on the electrical and the magnetic properties of the material. And therefore, different materials will behave differently to the exposure of the microwaves. Now, this is again the heating mechanism being explained with the help of a diagram.

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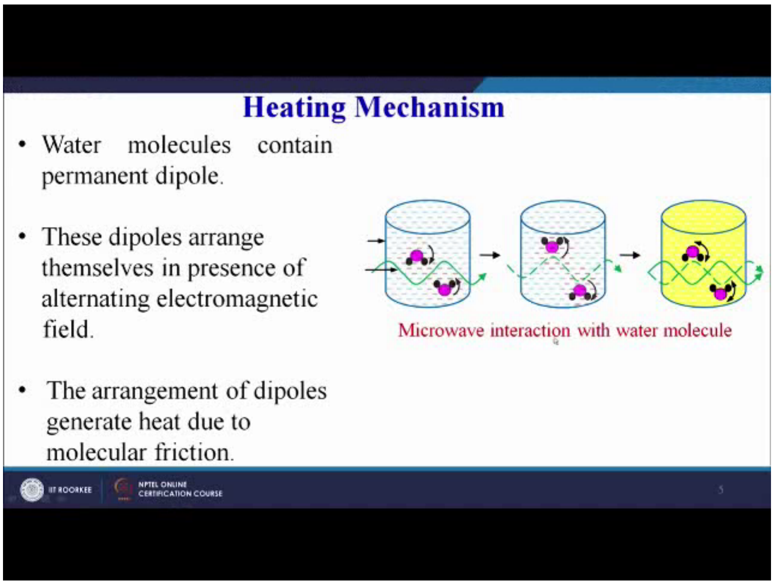

And this is the example of a water; so, water molecules contain a permanent dipole. These dipoles arrange themselves in presence of the alternative electromagnetic or alternating electromagnetic field. The arrangement of dipoles generate heat; due to molecular friction.

So, they have permanent dipoles in water and when this green color depicts the microwave. So, we have a microwave which is entering into the water and then it is leaving. So, sometimes we heat water also inside our microwave oven; so, how heat is developed? So, that is a simple example given that because of the molecular dipole rearrangement, the heat is developed. So, once again we can try to understand that when we heat water inside our microwave cavity, how the heat is developed?

So, the water molecules have a permanent dipole; these dipoles arrange themselves in presence of the alternating electromagnetic field. The arrangement of dipoles generate heat or rearrangement of dipoles generate heat; due to molecular friction, so that is the source.

Now, any other material which has got permanent dipoles and which dipoles arrange; rearrange themselves due to this microwave radiation will definitely generate heat. So, therefore, it is not only water which gets heat or which gets heated or which gets hot; on the application of microwave or on the exposure of microwave, there are so many other materials which get hot due to the exposure of the microwaves. And one of these materials is the thermoplastic based composites or the thermoplastics. Since there are 2 phases, we have a polymer or a plastic and we have a fiber.

So, our focus here primarily would be the polymer because polymers have lower; we can say temperature at which we can process them. And therefore, using microwaves also we would focus on polymer so, that we can make a joint between the 2 adherents; by remolding the polymer. Since we are emphasizing again and again that; microwave energy can be used for joining of thermoplastic based composites only.

So, thermoplastic has got the property of remolding and therefore, we should focus or we must focus on the polymer only so that; we are able to make a joint, the polymer will gets softened on the application of microwave. And if you are able to apply the pressure, it will form a joint between the 2 adherents.

So, this is a simple mechanism to explain how heat is generated in a water or in a glass of water, on application or on exposure to the microwave. Same mechanism can be used for developing heat or for generating heat in a polymer also. And that heat can help us to form a joint between the 2 adherents or the 2 joining members or the 2 composite parts.

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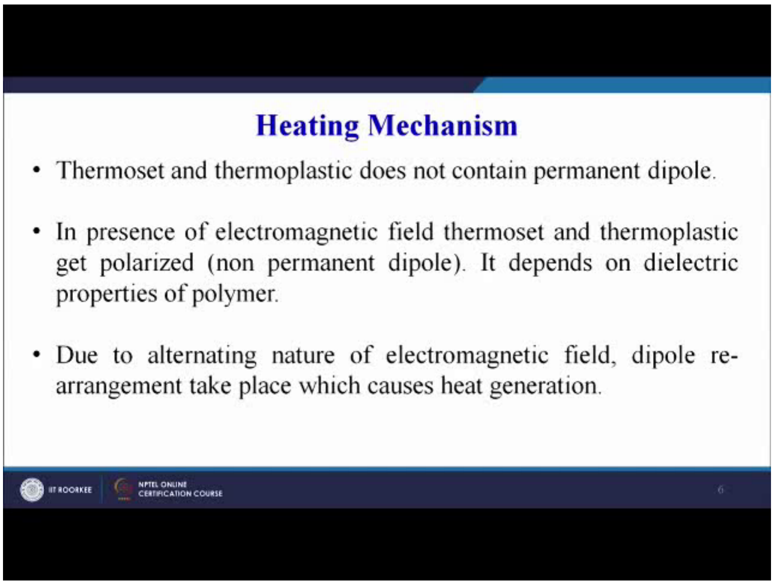

Now, thermoset and thermoplastic does not contain a permanent dipole; that is may be one challenge; so, they do not have a permanent dipole. But in the presence of electromagnetic field, thermoset and thermoplastics get polarized; they are means although they do not contain permanent dipoles, but yes non-permanent or semi permanent dipoles can be there or they can be generated on exposure of the electromagnetic fields.

And that depends on the dielectric properties of the polymer. So, we have already told or we have already discussed that how much amount of heat or how the material will react to the exposure of the microwave, it depends upon the electrical and the magnetic properties of the material.

Similarly, it also depends upon the dielectric properties of the material; specifically in case of polymers because they do not contain the permanent dipole. So, we can generate non permanent dipoles or we can polarize them in presence of the electromagnetic field. So, due to alternating nature of the electromagnetic field, dipole rearrangement takes place which causes heat generation. So, many times we will see that lot of heat is not generated because we do not have a permanent dipole in case of polymer, so what is the solution to this issue?

So, therefore we sometimes use succeptor materials to attract the microwaves so that sufficient amount of heat is generated. So, once again I will quickly read through what is given on this slide. So, thermoset and thermoplastics does not contain permanent dipole which must be always clear to all of us. But in the presence of electromagnetic field, thermoset and thermoplastics get polarized that is; they have non-permanent dipoles, it depends upon the dielectric strength of the; or dielectric properties of the polymer. Due to alternating nature of the electromagnetic field, dipole rearrangement takes place which causes heat generation.

So, there may be a query or a question that how heat is generated in the polymers on application of microwave? So, we can say that they do not have a permanent dipole, but have a tendency on application of electromagnetic radiation, they may develop or they may get polarized and that how much they will get polarized will depend upon the dielectric properties of the polymer. And due to the application of alternating electromagnetic radiation, dipole rearrangement may lead to generation of heat in the polymer.

So, we should know in water it is simple, but in case of polymer; we must be able to understand that what is the mechanism of heat generation in the polymer due to the application of microwaves? So, once we know the basic mechanism heat itself will be able to remold the thermoplastic. And when we have a adherent, we have a specific area which we are exposing to the microwave; definitely a joint will be formed, once the we are able to heat the polymer at that particular location.

So, focused heating at a particular location that is a joint lap area or we can say span of lap joint. If we are able to focus our attention or focus our microwaves on that area and heat is generated because of the mechanism explained on this slide. Once heat is there, adherents are there, we have a pressure which we can apply through a tape; very easily you must be able to form the joint. And one more thing which I have not emphasized till now in today’s session is; that in case of thermoplastic based composites, we can join them without the application of an adhesive; what we are trying to achieve here is, that there is no third party in between the 2 adherents.

This is adherent 1; in which we have a thermoplastic polymer reinforced with the fibers. This is adherent 2; thermoplastic polymer reinforced with fibers; we are joining them together. So, there is no need of edge preparation, there is no need of applying any adhesive; we are just bringing them together, we are wrapping them so that they do not get deformed on heating.

So, we wrap them; this assembly we put it in the microwave. So, no need of a adhesive material and when we expose the microwaves; due to the heat generated in the polymer, because of the heating mechanism explained here; the remelting or remolding of the material will take place at the interface and when it will solidify again; a joint will be developed.

So, that is a very simple way of joining but we need to understand that how much heat has to supply? What is the; has to be supplied, what is the duration for which the microwaves must be exposed to this material? Or on the contrary, this material is exposed to the microwaves. So, all these decisions need to be taken; it is easier said than done, but number of iterations are required to develop this type of a successful joint. Now, you can see no edge preparation is required, no adhesive is required, no hole making is required. So, the joining technique is much better and the joint strength sometimes that is achieved is even higher than the adhesively bonded joints.

Comparable sometimes to the mechanically fast and joint and it has been found experimentally that mean many cases the adherent itself has failed, but the joint has been intact due to microwave joining or in case of microwave joining. So, sometimes the joint strength achieved or is achievable is more than the strength of the adherent itself; which is a very advantageous position from the joining point of view. So, therefore this technique has the potential and can be used and must be used for joining of thermoplastic based composites.

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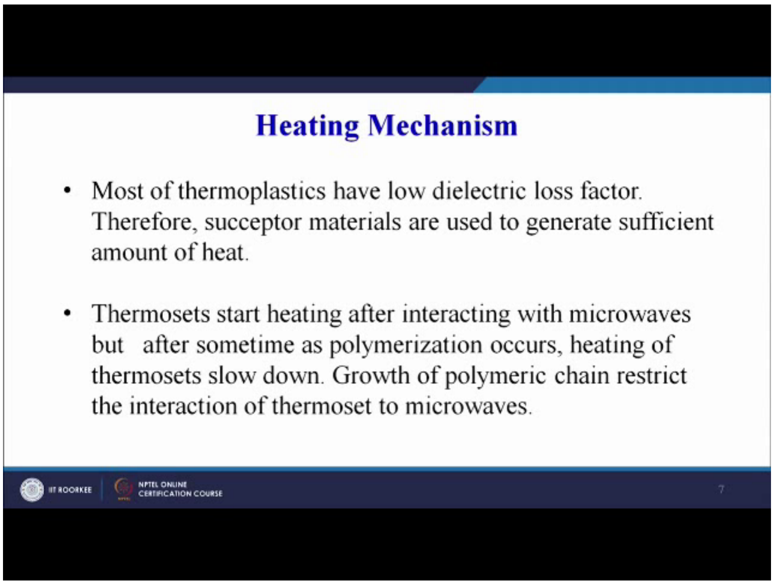

Now, heating mechanism I have already explained this is just in continuation. In most thermoplastics; low dielectric loss factor is noticed. Therefore, succeptor materials are used to generate sufficient amount of heat; already I have told you that because they do not have a permanent dipole, there are challenges but succeptor material can help us to focus the microwave energy at a specific location. And therefore, must be; are able to and that heat at a specific location helps us to make a composite joint.

So, thermosets start heating after interacting with the microwaves, but after sometime just polymerization occur, heating of thermoset slows down. So, this growth of polymeric chain; restrict the interaction of thermoset to the microwaves. So, this is just an explanation that microwaves are more advantageous in case of or microwave heating mechanism is more advantageous in case of thermoplastic based composites and is not that successful in case of thermoset based composites; because of the reason given in the point number 2.

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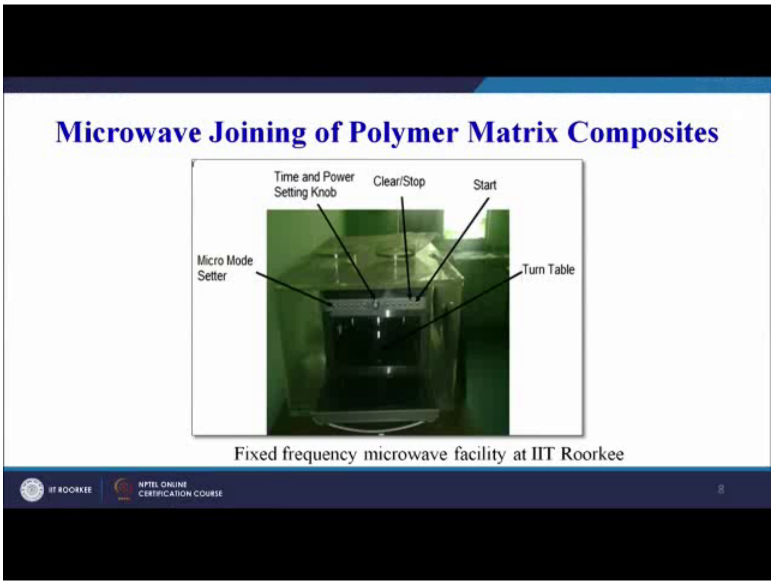

Now, just from the practical point of view; so, the microwave joining of polymer matrix composite, this is a microwave facility available at IIT, Roorkee. So, we have a micro mode setter here on the screen then there is a timer and power setting knob, as I have told you in our domestic microwave ovens; usually we can set the time also. But in industrial scale microwave ovens; there is flexibility, versatility that we can change the power setting also, we can change the time setting also. And then there is a turn table inside on which we can put our adherents and make a joint.

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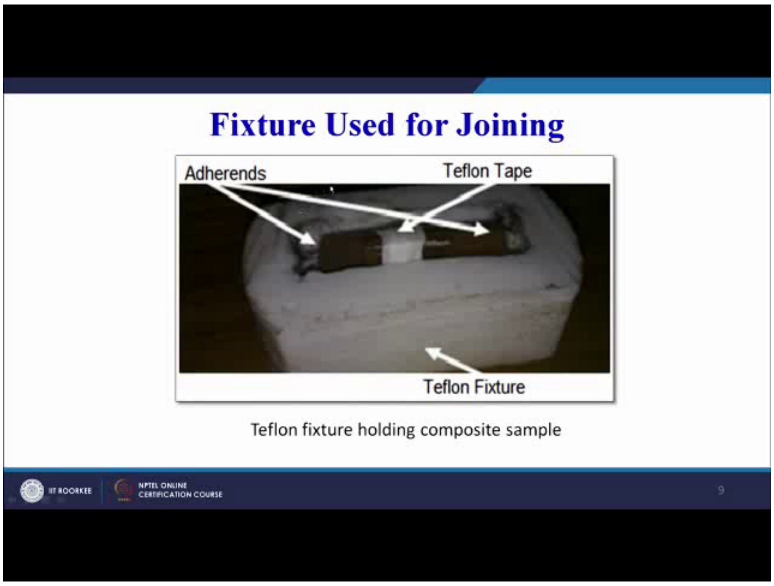

Now, this is a fixture that is used for joining; these are our own experimental findings. So, this is a adherent number 1 on your screen, this is adherent number 2 and this white color teflon tape is used to join the 2 parts or to bind the 2 parts together or to keep the 2 parts intact or 2 adherents intact at the joint overlap area. And this is a fixture which is used, now what is ideally required is that these 2 parts must join successfully.

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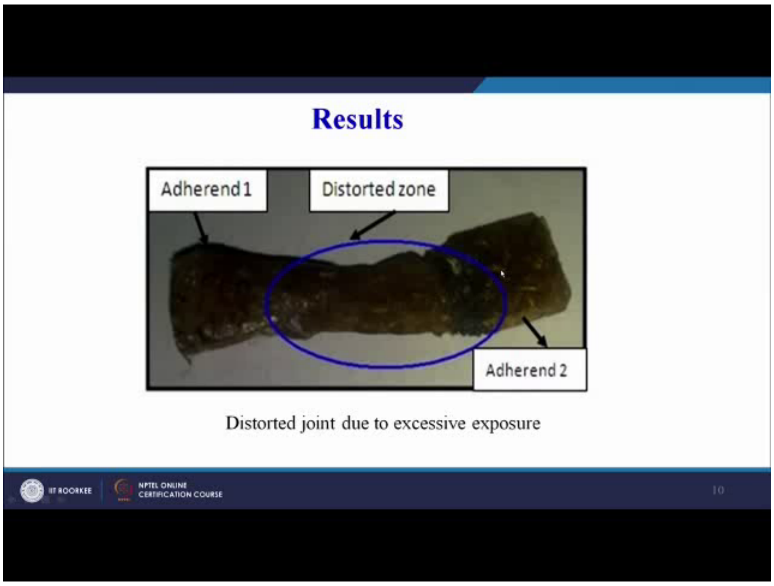

But that is not possible because of number of iterations, number of combinations of power and time that we have to see. And even sometimes, we have to see that; we have to find out, we have to establish that where we must keep our assembly. Because within the microwave also; there is interference of the microwaves happening and there are chances of the development of hot spots inside the material that we are keeping.

So, the location of the assembly; this adherent assembly inside the microwave cavity is also very very important. You cannot just keep it anywhere you feel like; that must also be optimized. So, the adherent 1 and adherent 2 were joint, but there was lot of distortion happening inside the joint. And therefore, dimensionally our joint was not stable, but due to the changes in the timing or the exposure time, due to the changes in the power setting, due to the changes in the location where we are keeping over assembly of the 2 adherent; we were able to successfully form the joint.

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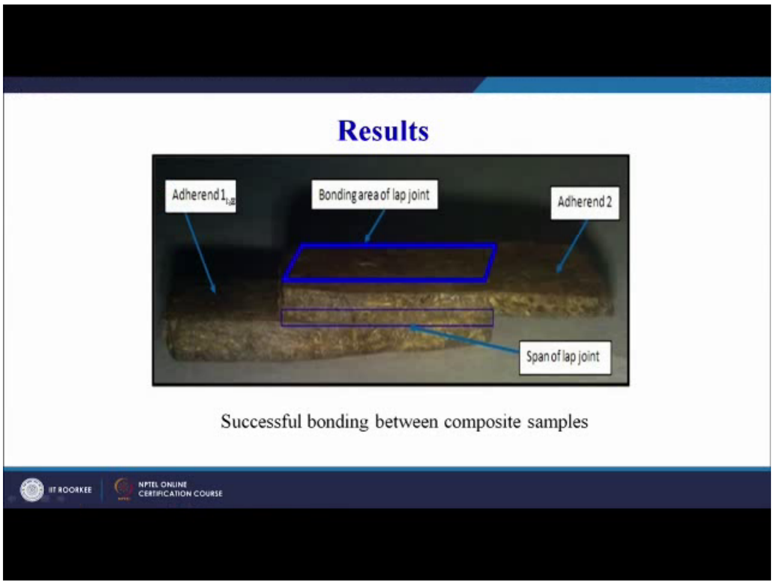

So, you can see these are the results; we can see here this is the finally, successfully formed joint, this is adherent 1, this is the span of the lap joint; this rectangle here and this is adherent 2. So, we have a adherent 1, adherent 2 and this is the lap joint or bonded area of the lap joint; which has been formed, this area has been joined at this joint interface; this is showing the lap area; represent the lap area, this joint has been developed here. So, we can see that if we select the things or the parameters or the exposure time, exposure duration; we select the power, we select the location within the microwave cavity.

We are able to form a good quality microwave based joint. So, with this we come to the end of today’s session on microwave joining. In today’s session, we have tried to see that the microwave energy is a good source of energy, which can be used for joining of thermoplastic based composite materials. We have tried to understand, very basic issues related to microwave joining; although this requires a very elaborate discussion, but we have just tried to understand that how microwaves are able to generate a heat inside the material. Then we have tried to see that; what is the basic mechanism of heat generation by taking the example of water or heating of water under microwaves?

Then we have seen the same principle can be used for heating of polymers and finally, we have seen a case in which microwave energy has been used and 2 adherents made up of short fiber reinforced composite materials have been joined together. We have seen that joining is not that easy, there are parameters that we need to control; otherwise we will get a distorted or a failed joint.

We have to seen that; image or a actual experimental picture of a failed specimen and currently on your screen, you see a successfully joined composite part or a composite assembly in which 2 adherents were there and they were kept together with the application of a teflon tape and due to the exposure of the microwave, due to the focused exposure of microwave; we were able to form the joint.

So, with this; we come to the end of today's session, in next session we will see another method of joining of the thermoplastic based composites.

Thank you.