

Processing of Polymers and Polymer Composites
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Lecture – 33
Induction and Resistance Welding

[FL] Friends, welcome to session 33 in our course on Processing of Polymers and Polymer Composites. We are currently discussing the secondary processing of polymer composites and in this series we have discussed 3 important processes already. Again I will emphasize very briefly that why secondary processing is required, secondary processing is required to a certain the structural integrity of a complex composite product from sorry from complex I mean intricate product, a big size product, a shape complex product, which has got a very complex shape.

So, we cannot make that product in a single go or we cannot adopt a near net type of manufacturing for that product. So, what we do actually we divide the product into individual parts and we manufacture each and every part independently and then we combine these parts together using certain assembly operations or using different joining strategies. In that series we have seen that primary forming processes are primary manufacturing processes for composite materials, usually yield simple parts for example, Pultrusions, we will get long parts continuous parts, but with uniform cross section.

Similarly, in filament winding we will get large axis symmetric part which may have or may not have a cylindrical cross sorry circular cross section. So, depending upon the shape of the mandrel we will get a filament wound product, but certainly when that product has to actually be realized, we need to do some additional operations on that product. Sometimes we may require some cutting, sometimes we may require joining of that structure with some other structure in order to make it a tangible product.

So, basically in primary manufacturing processes for polymer based composites, we have certain limitation of the shape as I have taken 2 examples you can yourself think as an assignment that what is the shape limitation for compression molding product? What do a shape limitation for a injection molding process? What is a shape limitation for a resin transfer molding process? What is a shape limitation for a hand layup process? What is a shape limitation for a spray layup process? So, any process that you see that falls under

the category of primary processing of polymer based composites definitely you will see that there is the shape limitation.

Now, when you require a complex shape you will divide the shape in 2 3 4 different individual parts and for those individual parts definitely surely there will be some processes which can be used in the primary manufacturing domain of composite materials. Now individually you can make these parts and finally, you can assemble them together to make a complete products and these assembly operations will require certain operations to be done on this composite parts or may require assembly using different joining strategies and in that series we have seen we have taken, I think 2 or 3 sessions on the introductory part for regarding secondary manufacturing.

And then we have understood the very fundamental issues related to 3 different joining strategies, if you remember the first one that we saw was adhesive joining, the second one that we discussed was the mechanical fastening, the third one that we discussed was the microwave joining of the composite products today we our target our focus would be on induction and resistance welding.

Now, induction and resistance are the 2 words that you have already I think discussed may have heard every engineer knows about the induction heating effect everybody knows about the resistance heating effect. So, these 2 effects we are going to make use of in joining of our composite parts, our topic will be restricted to the basic approach of joining the composite parts using the concept of induction heating, using the concept of resistance heating.

Now, induction word definitely you may have heard when we have furnaces we have induction based furnaces, which are used for melting the metal prior to the casting operation. Similarly resistance word has also common to all engineers because resistance heating is one form of basic fundamental for resistance welding technique, which we use for joining thin sheets or sometimes you do spot welding that also falls under the resistance welding, we have sometimes the seam welding that is also falling under the resistance welding technique.

So, you have heard that resistance heating can be used for certain application specifically in welding. Similarly induction heating effect can also be used for generating heat which can be used for melting the metal, but in our case we are not going to use the induction

effect for heating of metal, but we are going to use the induction effect for heating of the polymer, why because in our composite materials or the composites that we are discussing in this series of lectures are polymer based composite material.

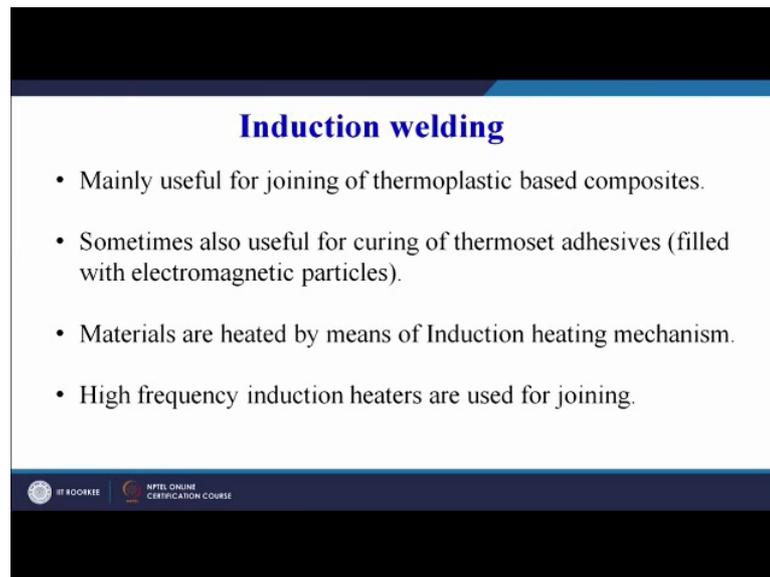
So, we have to melt the polymer or we have to heat the polymer beyond the glass transition temperature of the polymer. So, that we can mold the polymer again and a joint can be formed between the 2 mating parts or between the 2 adherents. So, we will try to understand that what does the configuration that can be used for joining using the induction effect, what is the configuration that can be used for joining of members or joining of composite members using the resistance welding effect.

So, let us start I think with this background and this introduction we can just look at few diagrams and try to understand that what is the induction heating, effect in case of polymer matrix composites and how resistance welding can be used for joining of composite parts. So, these 2 processes are not that widely practiced for polymers and polymer composites, but the previous 3 processes that we have discussed out of the 3 the first 2 that is the adhesive joining and the mechanical fastening are the most commonly used joining strategies joining processes for polymer matrix composites as well as for polymers or plastics.

Microwave joining, induction heating, resistance welding all these are also being used, but for very specific application and still they require lot of understanding, lot of study, lot of research, lot of development, for them to be applicable to each class of composite material. Because as we have already discussed composites is a very big family, there is a long list of fibers that can be used as reinforcement, there is a long list of polymers which can be used as the matrix. So, a process that we develop may not be applicable to each combination of fiber and matrix.

So, therefore, we have to very cautious while proposing a specific joining strategy for a specific class of composite materials and today we will just like to have a overview of induction welding as well as the resistance welding, specially in context of the polymer matrix composites. So, let us start our presentation. So, this is a brief introduction regarding induction welding or induction based joining.

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Induction welding

- Mainly useful for joining of thermoplastic based composites.
- Sometimes also useful for curing of thermoset adhesives (filled with electromagnetic particles).
- Materials are heated by means of Induction heating mechanism.
- High frequency induction heaters are used for joining.

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It is mainly use for joining of thermoplastic based composites, now again yesterday also in the session 31 I think or thirty I have emphasized that thermoplastic and thermosets are different, thermoplastics can be remolded where as thermosets cannot be remolded or reheated.

So, therefore, in this case when we have already made a composite material using a thermoplastic as a matrix material so there is a probability or there is a chance or there is a opportunity with us that we can Remelt it at a specific location and we can form a bond between the 2 composite parts at a specific location usually we call it as a joint overlap position. So, thermoplastics can be remolded and therefore, all these processes yesterday we have seen microwave, joining technique in our session number 32 we have seen microwave joining is mostly applicable for thermoplastic based composites.

Similar is the content here similar is the context here, where we use induction welding and resistance welding majorly for thermoplastic based composites, why because they are remoldable they can be brought back to their regional shape by application of heat and therefore, we can again remold then we can heat then they will become viscous at above a glass transition temperature and then at that point we can form a joint by the application of pressure and allow them to solidify or cool and then we will get our joint.

So, this thing we have to always keep in mind because sometimes we learn by our mistakes, some of you after learning this may try to use the process without giving it a

thought that only thermoplastics can be used for in the for induction welding and resistance welding as well as microwave joining. Sometimes you start joining the thermosets also using the microwave heating or using the induction heating or using the resistance heating and in that case our polymer will burn and we will not be able to form a successful joint.

Therefore we have to be careful while selecting a manufacturing sorry a joining technique for joining of polymer based composites. For Thermosets we can use since no heating is required we can go for adhesive joining, we can also go for mechanical fastening, but specifically for thermoplastics we can choose resistance welding technique, we can choose induction welding technique, we can choose microwave joining techniques.

So, it is the processes are also material specific. So, first thing we should keep in mind is that for thermoplastics we can use induction welding and resistance welding. Sometimes it is also useful for curing of Thermoset adhesives filled with electromagnetic particles. So, specifically when we are applying a adhesive material in case of thermoplastic composite these are the 2 adherents, in between if we apply our adhesive which is a Thermoset, we can use the induction effect to heat that particular adhesive in order to accelerate the rate of curing, but we will not raise the temperature or we will not supply too much heat to the adhesive, otherwise it may there are chances that it may over cure or it may even burn.

So, we have to be very very cautious while applying the induction heating and the resistance heating to the thermosetting type of resins or thermosetting type of adhesives, but yes in some cases special cases we can use it for use the induction effect as well as the resistance effect for heating the adhesive which may be a thermosetting material . So, when we want to form a joint materials are heated by means of induction heating mechanism.

Now, induction heating mechanism we are not going to discuss in detail today all of us know the effect of induction heating and how heat is developed, high frequency induction heaters are used for joining purposes. Now the basic mechanism in this case is fusion bonding so it is a type of fusion bonding where material is heated at their glass transition temperature. So, each polymer will have a TG that is the glass transition

temperature for amorphous polymer we will have a TG and for crystalline materials we will have a melting point that is T_m for semi crystalline polymers.

So, if you remember in our first phase of discussion when I think again I am repeating the same thing again, we have divided the course in to 3 phases, phase one was related to polymers, phase 2 was related to the polymer composites, but focus was on primary manufacturing or near net manufacturing of composite product and phase 3 is the secondary processing or the machining and joining of the polymer based parts.

So, in phase one we have and try to understand that what is amorphous what is crystalline and how we can how the specific volume changes with the heating effect and which is a in case of amorphous polymers where the transition starts and in case of crystalline or semi crystalline type of polymer where the transition will start. So, these are the 2 important quantities which we have to keep in mind for any polymer processing technique, that is what is the glass transition temperature of the polymer and what is the melting temperature of the polymer. Because these are the 2 things that will help us to decide our operating variables that may be operating variables may be the holding time, the injection temperature or the temperature in the barrel.

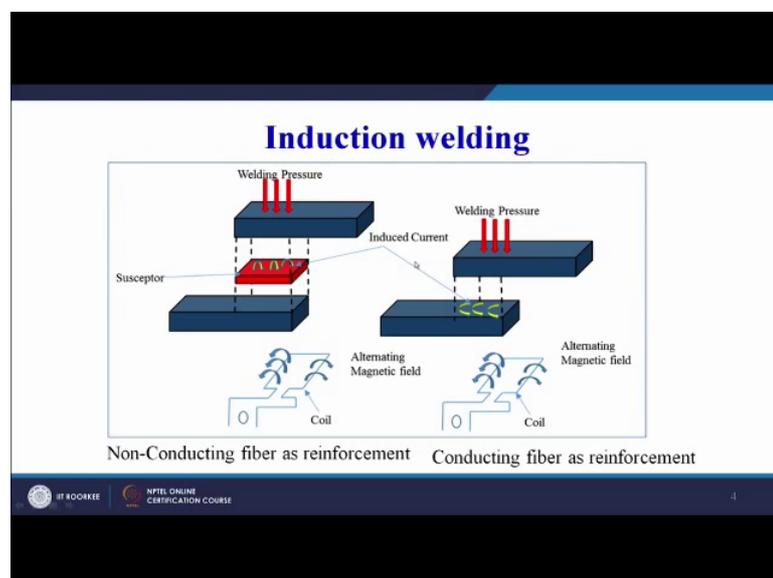
So, these are the 2 important things that we have to keep in mind and for joining using the induction effect again we need to keep in mind the glass transition temperature as well as the melting temperature in case of the semi crystalline type of polymers why. Now why these are the 2 important quantities that we have to keep in mind, as I have tried to give a hint I have try to drop a hint, that in case of processing of polymers we need to understand these 2 quantities specifically in context of polymers, because we have to set our parameters accordingly, because for remolding or for molding of the plastic we need to heat it we have to bring it to that state where it is moldable. Otherwise our plastic may be available in small pallet us form and we want to make a product out of it.

So, we need to heat it we need to bring it to that state where we can mold it as per the desired mold or the die or the desired shape. Again drawing the analogy from the casting of metals, we have a scrap metal available with us, we heat it in the furnace we melt it and then we pour it in the mold, which can be a sand mold or a permanent mold and the molten metal takes the shape of the mold and we get our casting.

Similarly, in case of polymers also we have a TG and the TM beyond that the polymer will become moldable and therefore, we need to understand and for joining also there is an important criteria that when you want to join at a particular place, the heat must be sufficient enough to remold the polymer at that point. It will be solid these 2 products that I want to join together or these 2 parts or components of composite that I want to join together, like this maybe solid not maybe they will definitely be solid before I bring them together and I heat them at the joint interface. When we supply heat at the joint interface this TG and TM will come into picture the glass transition temperature and the melting temperature.

And since the temperature will be more than a glass transition temperature we can easily mold them and then we can apply the pressure and we can form the joint. So, for joining using the heating effect of induction or resistance, we need to understand and we need to first see what is the glass transition temperature and that melting temperature of that particular polymer. So, thermoplastic composites having non-conducting reinforcement is heated by using the susceptor at the joining interface this, we will try to understand with the help of a diagram.

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Now, here you can see in Induction Welding this is the one composite part the blue color and this diagram we have seen earlier also in our introductory session towards secondary processing of composite materials in that session we have seen the same diagram. So,

here again we have trying to understand the mechanism once again this is our composite part one this is our composite part 2. So, we have 2 composite parts and we want to join them using the induction effect or the induction heating effect.

So, if the fibers that are there in the composite are non-conducting. So, it is clearly written for non conducting fiber as reinforcement, when the fibers are non conducting we need to add a Susceptor, this blue color plate or sheet we can say is the Susceptor, which will facilitate the heating effect because if you see our fibers are non conducting. Polymers all of you are conducting or non conducting most of the polymers are non conducting there are very very few polymers which you can say are conducting and their also made conducting synthetically or maybe artificially.

So, we have most of the polymers that we use are non conducting polymers, you can see yourself you use the if there is a current carrying conductor we cover it with a jacket of polymer why do we cover it because it is non-conducting and it provides the insulation. And if you remember we have studied in this course only the extrusion process for plastics and there we have seen different variants of the extrusion process and there we have see in the jacketing extrusion.

So, the all those things the polymer is being use or plastic is being used to cover the electric wires because it is non-conducting in nature. So, the polymers are also non-conducting, the fiber is also non-conducting, then how the joint will be formed how the heat will be developed. So, therefore, we put one Susceptor which is conducting and then we pass the current and the because of the heating effect induced at the Susceptor point the 2 parts can be joined together. So, this is the first case where the fiber is non-conducting.

But in case the fiber is conducting, now we can say what can be the example here it is thermoplastic based composite that we want to use very easily you can give me one example; the fibers can be yes glass fibers which are non conducting, then what can be the other polymer the polymer can be polypropylene or it can be polyethylene. So, you have a thermoplastic based polymer and you have a non conducting fiber and it is a composite material and therefore, in such a situation we need to put a layer of Susceptor which will help us to develop the induction heating effect and the heat can be used to remold the polymer and form the joint.

But in case of a conducting fiber reinforcement for example, we have carbon or graphite fibers and which are used to reinforce our thermoplastic matrix, in that case we do not need a Susceptor material directly we will take our 2 composite plates this is composite number 1, this is composite number 2, and we will induce the current at the joint interface we will apply the pressure and we will be able to develop the joint.

So, therefore, it is a very very important for us to understand that what are the constituents of the our material, whether we have a conducting reinforcement, whether we have a conducting polymer or we have a non conducting polymer and a non conducting reinforcement or what is the combination of the fiber and the matrix and accordingly we have to choose the process for joining the composite material and if it is non-conducting then we have to use a Susceptor in order to induce the induction effect.

Now, very briefly we need to understand that how the heat is developed. So, very briefly I will try to read out the material or the content written on this slide.

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Induction heating mechanism

- Joule loss by fiber heating
- Junction heating-dielectric hysteresis heating
- Junction heating-contact resistance
- Hysteresis or eddy current loss

Conducting Fiber as reinforcement

Non-Conducting Fiber as reinforcement (Susceptor is used)

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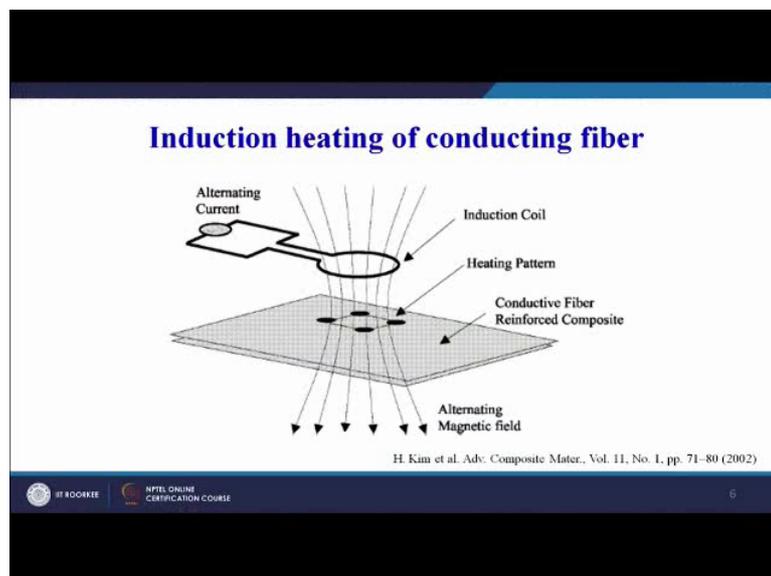
So, induction heating mechanism where we have conducting fiber as reinforcement, we have the joule loss by fiber heating, then we apply the induction effect the heat will be developed because of the joule loss in the fiber, then junction heating that is a dielectric hysteresis heating may be there are 2 or 3 or there is a array of fibers and there can be a dielectric hysteresis heating effect developed because of the array of the fiber than the

polymer which acts as the bulk of the material and finally, there can be junction heating or the contact resistance heating effect.

So, because there can be fibers adjacent to each other very close to each other there can be a contact resistance effect between the 2 adjacent fibers which may also lead to the heating in the composite material. So, in case of the conducting fiber how the heat is developed because the joule loss and leading to the fiber heating it can junction heating junction heating again due to contact resistance or the dielectric hysteresis heating.

So, these are the 3 major mechanisms of development of heat inside the composite due to the induction heating effect and in case of non conducting fiber. So, there will be in fiber is non-conducting. So, joule loss will not happen in case of non conducting type of a fiber. So, the heat may be developed because of the hysteresis or the eddy current loss. So, we have to see that what is the combination of fiber and polymer in order to understand that how the heat is going to develop inside the composite material, if it is a conducting fiber top 3 mechanisms of heat generation may come into picture, if it is a non conducting type of fiber the hysteresis or the eddy current loss may lead to heat generation inside the composite material.

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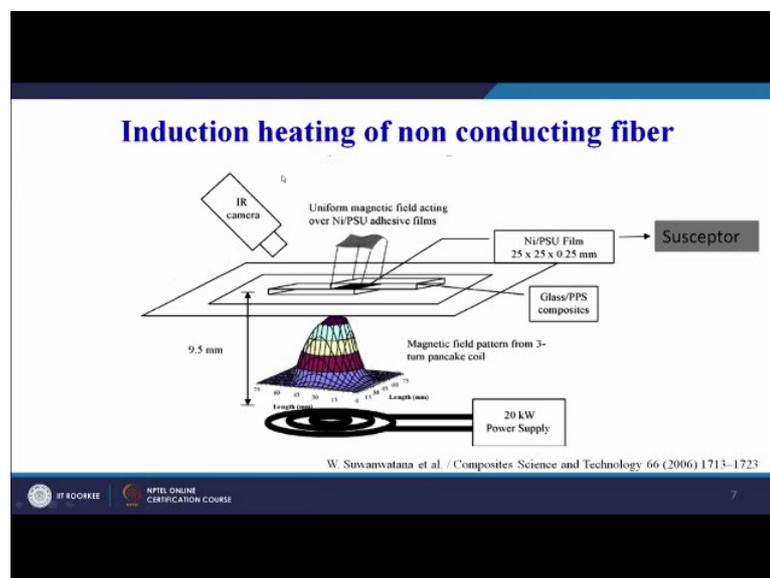
Now, this is the induction heating just an example this has been taken from H. Kims article published in advanced composite materials.

So, here we can see this is our conductive fiber reinforced composite this through this plate this is a conductive fiber reinforced composite, this is our alternating current this is a induction coil and this is the because the current is flowing the magnetic field is developed this is the induction coil. So, this is the heating pattern and once you have the induction heating effect it will what it will do, because the fiber is conducting in this case it is a conductive fiber reinforced composites what will happen?

In the previous slide, we have seen 3 major type of effects due to the induction heating will come into picture joule loss and then dielectric heating and the last one let us see it again dielectric hysteresis heating as well as the contact resistance heating will take place. And it will lead to heat generation in the composite material which will bring the temperature of the composite or not the composite, but the polymer beyond the glass transition temperature and we may be able to form a joint.

This is the induction heating of a non conducting fiber you can see here.

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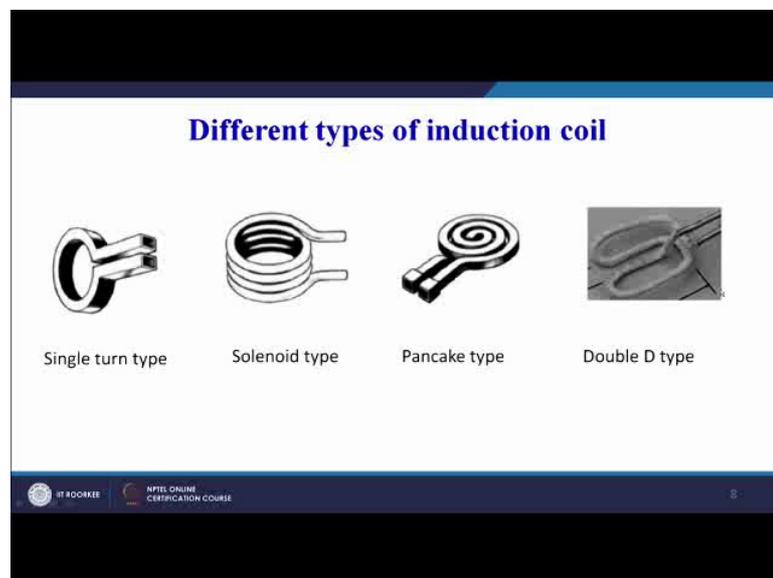


If you remember in non conducting fiber what we need to add in order to make a joint we need to add a susceptor material in order to make a joint. So, example has been taken here this is this Blank, Portion, Depicts, the Glass, PPS composite this is the other Glass PPS composite and in between this black portion, black layer is the Ni PSU Film and the dimensions of the film are also given 25 into 25 into 0.25 millimeter.

So, we have a film in between and in the top and the bottom we have the composite plates or sheets that we want to join together. Since it is glass as I have already taken an example glass is a non conducting fiber. So, therefore, we require a additional film in order to make it make the joint possible or in order to induce the induction heating effect. So, this is the susceptor material as highlighted here which is use for joining the 2 parts together the top glass PPS layer and the bottom glass PPS layer or the laminate.

So, we have uniform magnetic field acting over these adhesive films and because of this there is a infrared camera here and this is the power supply, this is our induction coil which is used here to induce the heating or the induction heating effect.

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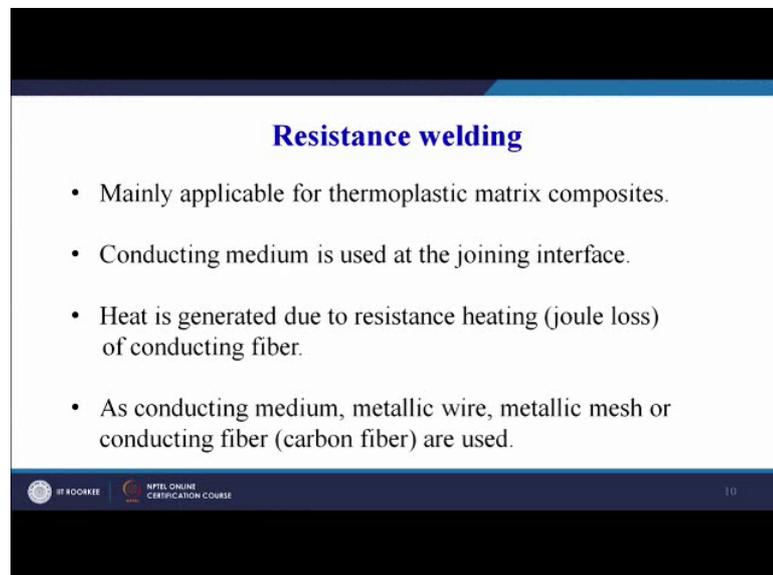
Different types of induction coils can be used we can have a Single turn type, Solenoid type of induction coil Pancake type, Double D type. So, if students who stay in hostel may have seen the solenoid type of coil which we which is used for heating the water in the in our domestic applications.

So, we can have different types of coils for inducing the induction or for inducing the induction heating effect in the polymer based composites. So, we can see that the major purpose is to supply heat or to apply heat at a specific location where we want to form the joint and different mechanisms can be used. So, till today we have seen 2 different mechanisms in the yesterday's session on microwave joining we have seen the

electromagnetic waves or electromagnetic energy is used to heat a specific area of the composite material and from the joint.

In today's session we have seen induction heating effect can be induced at the specific location in the composite in order to form the joint between the 2 composite parts similarly the resistance effect can also be used for inducing heat at a specific location. So, very quickly as the time is running out we will try to understand the resistance welding effect in case of composite materials or fiber reinforced plastics or polymer matrix composite materials.

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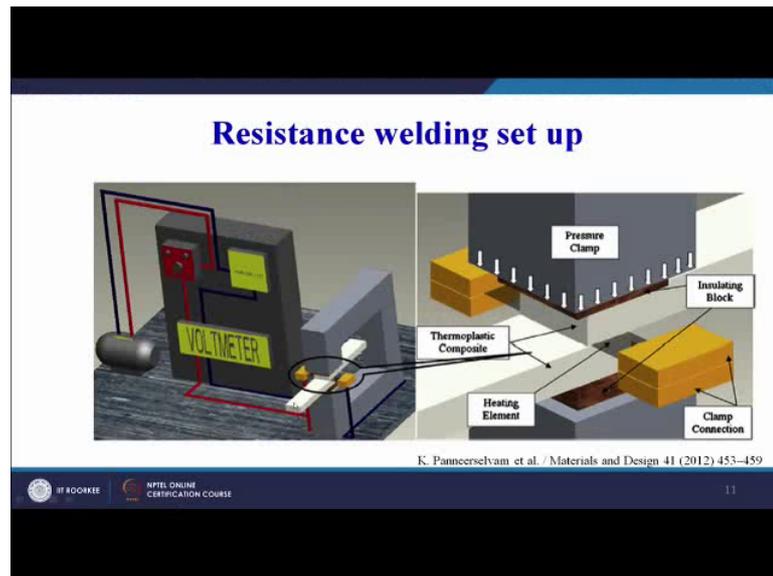
Resistance welding

- Mainly applicable for thermoplastic matrix composites.
- Conducting medium is used at the joining interface.
- Heat is generated due to resistance heating (joule loss) of conducting fiber.
- As conducting medium, metallic wire, metallic mesh or conducting fiber (carbon fiber) are used.

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So, it is mainly applicable again for thermoplastic matrix composites because we can Remelt or remold the thermoplastics, Conducting medium is used at the joining interface. Now suppose this is the these are the 2 parts that I want to join together, I will bring them in the lab condition like this and in between at the joining interface we require a conducting medium through which we can pass the current and heat can be generated. So, the conducting medium is used at the joining interface, heat is generated due to resistance heating effect or the joule loss effect of the conducting fiber, as conducting medium we can use metallic wire metallic mesh or conducting fiber that is as I have already given an example carbon fiber has the capacity to conduct. So, we can use carbon fiber also for resistance welding effect.

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Now, this is a diagram we can see here these are the 2 parts, this is white part one first adherent or composite adherent, this is second composite adherent in between we are passing the current here. So, this a lap joint configuration and when we pass the current heat will be generated here and we will be able to form the joint.

So, here we can see enlarged view we can see this is thermoplastic composite the top this is a thermoplastic composites, this is a second thermoplastic layer thermoplastic composites layer and then this is the heating element this grey color. You can focus on the arrow, this is the grey color heating element and this heating element will provide heat between the 2 mating parts of the thermoplastic composite, this is the top layer, this is the bottom layer or this is a top adherent, this is the bottom adherent, and in between the top and the bottom adherent we have a conducting coil or a heating element through which we will be able to pass the current and generate the heat due to the resistance effect and therefore, we will be able to selectively heat the joint overlap area and there because of the heat the temperature will raise above the glass transition temperature.

And because of the pressure we are applying the pressure here the top this is the pressure clamp because of the pressure also acting the 2 adherents will not deform because of the pressure they will be at their place only, but at the interface there will be heating effect and because of the heat and the temperature going beyond the glass transition temperature. We can reload the polymer at that point and form a joint, but certainly there are number of parameters that need to be that need to be observed or control, the first one can be the type of polymer rather it is thermoplastic or thermoset mostly we have already

told it is used or thermoplastic based composites, then we have to see whether it is a amorphous type of a polymer or it is semi crystalline type of polymer. We have to see whether the fiber that is used for reinforcement or is a conducting fiber or it is a non conducting fiber, then we have to see how much heat is required what is the glass transition temperature of the polymer, what is the melting temperature of the polymer, what is the thickness of the composite laminate.

So, all these parameters we have to keep in mind while we decide a process that we are going to use for joining of the polymer based composites. So, with this we conclude the today's session and I would like to briefly summarize that now we know 5 different processes that are used for joining of polymer based composite materials or fiber reinforced plastics and all these 5 sessions we have already completed, we have seen the adhesive joining technique, we have seen the mechanical fastening technique, we have seen the microwave joining technique in today's session, we have tried to cover the induction effect or induction heating effect for joining of polymer based composites as well as the resistance welding technique for joining of polymer based composites.

In our next session we will focus on other issues related to the joining or the assembly of the polymer based composites.

Thank you.