Processing of Non-Metals

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Module - 7
Secondary Processing of Composite Materials
Lecture - 4
Microwave Joining of Polymer Matrix Composites

Very warm welcome to all of you in this lecture number four in module seven. This particular series of lectures are dedicated towards processing of non-metals, in which we have covered six modules. In module number seven, our focus is on secondary processing of composite materials, which is one class of advanced materials. So, we have already seen different aspects of secondary processing; we have seen why secondary processing is required in lecture number one.

We have seen that there are so many processing techniques for processing of advanced materials. In which, we can make a composite or we can make product in a single shot, but once a product is ready for larger scale product, for big assembly or for big complicated or interact product, we make small, small sub product. And this small, small sub product have to be assemble together to get the final product. So, final product if it is very complicated, if it is huge in size, and it has got certain degree of intricacy, we need to make the product in parts. And each part would be made by any of the process is which we have already covered. If you remember in the past five or six modules our focus has been on the processing aspects of different types of materials.

In which, we have seen processing of plastic, processing of ceramics, processing of polymer matrix composite, processing of ceramic matrix composite. So, we have seen the processing aspects of different type of material, and these particular processing can be huge for processing these material into the products. Now if this products have to be finally assembled into the complicated product, the assembly operation have to be preformed. And these assembly operation necessitate certain times in some of the specific cases - the drilling of holes or the trimming of the corner or sometimes the joining of the various parts processed by this process which we have already covered with different techniques of joining.

So, as I have already introduced in lecture number one in module number seven, that we are going to basically focus our attention on two important aspects that is the machining aspects of the composite materials, and the joining aspects of the composite materials. If you remember in lecture number one, we have seen the drilling aspects of the composite materials and our area of specialization or our area of discussion was polymeric matrix composites. So, we have seen that if we make a hole in a polymeric composite, how the damage takes place and how the damage can be avoided that was seen in lecture number one. In lecture number two, we have seen what are the various advanced techniques or what are the process variants which have been developed researcher by worldwide to reduce the drilling induced damage.

In lecture number three, we have seen that if you want to join two composite materials together, what are the issues and challenge in the mechanical fasting as well as the adhesive joining of the composite adherents. Or two composite parts when they are joined to gather either mechanically using the bolts and the fasteners, bolts or other type of fasteners or if they are joined using the adhesive bonding, what are the various issues and what are the various problem areas, and how this problems areas can be addressed.

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Today, we are into the lecture number four, in which our focus would be microwave joining of polymer matrix composites. So, basically in this brief overview, where this lecture fits into our total feature that have been given that we are discussing the series of

lecture on the course processing of non metals. In which we are discussing module number seven, in which our focus is on secondary processing or secondary operation on advanced materials such as composite. And today we are going to discuss the microwave joining aspects of polymer matrix composite. So, in this lecture, we will see that what are the disadvantages of the mechanical joints, what are the disadvantages of the adhesive joints because the advantages is and of both the mechanical joints and the adhesive joints we have covered in the previous lecture.

The disadvantages is the also covered, but today I would again like to revise that what are the disadvantages of the mechanical joints and the adhesive joints which can be overcome by the microwave joining of polymer composite. So, microwave are being used worldwide today in large number material processing application, and here the microwave the use of microwaves is advocated for the joining purpose is in case of polymer matrix composites.

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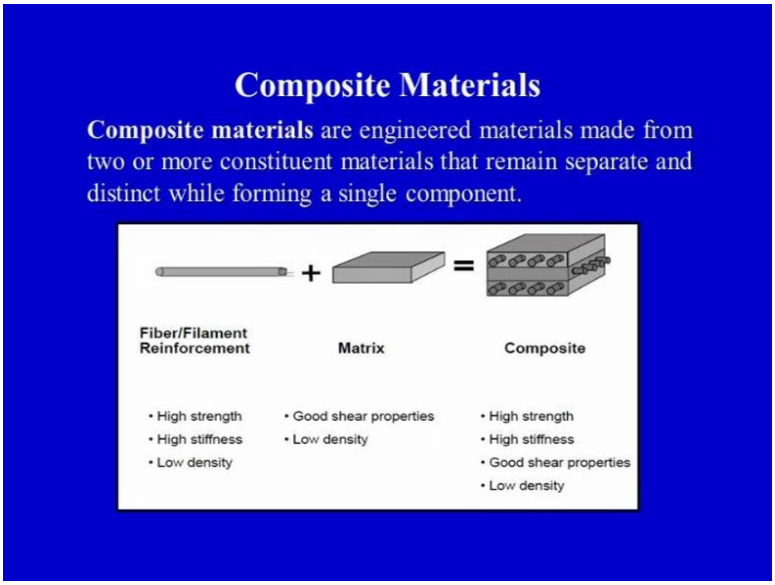

So, on your screen, you can see again I want to revise because the two terms are there microwave and the polymer matrix composite. Again, we will just briefly revise what is the polymer matrix composite. Suppose anybody is looking at this lecture independently and has no idea about what we have discuses in the previous lecture, in order to make this lecture actuality we will see what is the polymer matrix composite. A composite

materials or engineered materials made from two or more constituent materials that remain separate and distinct while forming a single component.

So, on your screen, you can see we have formed a single component, but it is made up of two components; one is the matrix, another one is the rein; sorry this is the fiber or the reinforcement and this is the matrix, so we have a matrix. In our lecture, our focus is on polymer matrix composite. So, this matrix is a polymer and the fiber can be a fiber or a filament reinforcement. So, we have a matrix materials which is a polymer or in other term we can call it is as a resin. So, we have a resinous matrix material or a polymer matrix material and which is been reinforced with a fiber or the filament. And finally, when these two are added or these two are combined together or blended which we have already seen that how these two things are blended together in our module five. In which, we have seen different processing techniques for polymer matrix composite. So when these two are combined together we get finally, a composite material. So, this is a composite.

So, just I think it is visible on your screen. The fiber has high strength, high stiffness and low density, which result in a low weight finale products. So, finale products has less weight. Why? Because of the density of the fiber is comparatively less. Matrix has good shear properties and low density. So, density is low in both the cases, therefore the polymer matrix composites, the use of the polymer composite is advocated in light weight application or in the on the other hand, we can say that polymer matrix composite are use for light weight application.

So, the resulting composite has high strength, high stiffens, good shear properties and low density. So, the combination of properties of the reinforcement and the matrix, we are getting in the composite material which we are making by combining in the reinforcement and the matrix together. The reinforcement in case of polymer matrix composite is in form of fiber or filament. And the matrix is the polymer, the polymer can be thermo set or it can be a thermo plastic. Within thermo set and thermo plastic also there is a wide verity of polymer which are available, among which we can chose that which polymer we want to combined with which fiber and what type of composite we want to design for specific application. So, this gives a brief over view of the word polymer matrix composite that it is a material which is a made up of the fibers and the matrix.

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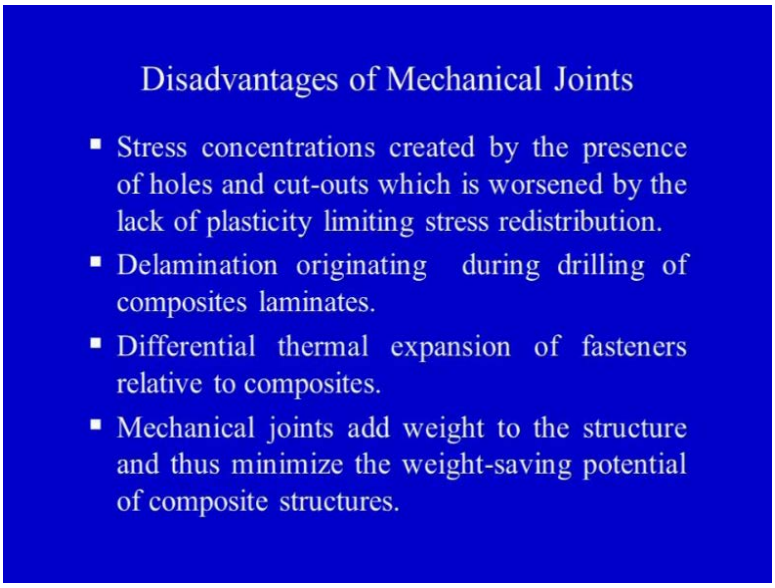

Now, coming on to the disadvantages of mechanical joints this we are discussing specially in context of the polymer composite. That if we are using the polymer composite as the material and we are joining two polymer composites together what can be the problem areas if we are using the mechanical joints. So, on your screen, first point which is common in any case when we are making a mechanical joints. Stress concentrations created by the presence of holes and cutouts, which is worsened by the lack of plasticity limiting stress redistribution. So, the point is very very clear, just to emphasize that this discontinuities in terms of hole. So, basically in case of mechanical joint, how we are going to make a joint. Suppose we have two members which have to be joint together, we will simply make a hole in the two members and use the mechanical fasteners to make a joint.

So, initial or one of the primitive requirements is to make hole, in which we can do the fastenings process or the mechanical fastening process. So, when a hole is generated, all designers know that it would act as a sight of stress concentration. So, stress concentration created by the presence of holes and cut outs, whatever holes and cut outs have been generated for the fastening process is a worsened by the lack of plasticity limiting stress redistribution. Those stress redistribution is limited, and it can act a stress concentration sight and loading this member, which has holes and different type of cutouts, this particular sights may act as the failure sights under different type of loading condition. Loading can be compressive loading tensing loading feting loading or impact

loading different types of loading may result in the failure add this particular stress concentration sights.

What is the another disadvantage delamination originating during drilling of composite laminates. So, problem of the delamination which we are already seen in lecture number one that, when we try to make a hole inside of a laminated composite in which different layers of fibers imprangreted with resin or the matrix we get a laminate. So, this particular laminate when a hole is being made in this laminate; there are chance is delaminate if you remember in lecture number one in module seven, we seen that three can be fill up type of delamination at the entry of the drill. And the push down type of delamination at the exit side of the drill, even the diagram is very simply represented in the in the presentation in diagram.

We have seen that when that drill tries to exit the laminate or it is at the exit of the laminate the bottom most layers of the laminate tries to open up, which is called the push down type of delamination, and when the drill tries to enter in the beginning of the hole making process the drill tries to fill up the top layers of the laminate, and it is called the fill up type of delamination; it was also discus that what are the factors on which the fill up type of delamination depends to just review it is a tool point geometry, and the operating variables which dictate that how much fill up delamination will take place.

And the push down delamination depends upon the thrust force, which is being generated as the cutting action. So, delamination take place while making holes in composite laminate suppose we have not to different composite laminate, and we want to join them using the mechanical fastening process for that we require a hole, and when we try to make a hole and when we go about making a hole in the composite laminate damage take place all around the hole in the form of push down type of delamination or fill up type of delamination. And there are other forms of damage that may take place in composite laminates on account of the drilling operation the matrix burning may take place fiber full out may take place micro wards may be formed; there are number of types of damage forms which have been reported word wide while making hole in composite laminates or while drilling in composite laminate.

So, when we are using the composite laminates in a very big structure and we have to fasten them together we require a holes and hole making damage takes places. So, this

damage has to be avoided that we have seen in the very first lecture that, what are the metallurgy or techniques suggested for minimizing the drilling induced damage, but still we cannot avoid the damage in totality. So, when the composite two composite are fastened together using the nuts and the bolts other mechanical fastening feature, there is bound to be a of the risk of the failure of this laminate why, because there is certain damage which has taken place while making holes.

So, on your screen you can see the first point is holes act as stress concentration point that is very valid point second point delamination originating during drilling of composites laminates. So, when we are going to make a hole inside composite laminates it is going to damage the laminate, and when you are using the same laminate with a drilled hole as a structural member in a very big structure, this particular hole with damage around the hole may act as the failure side of the hole structure.

This is another disadvantage when we want to joining the composite material using mechanical fastening third differential thermal expansion of fasteners relative to composite. So, composite have different thermal expansion as well as fasteners will have different thermal expansion because the fastener may be made up of metals, and the composites are made of specifically polymer composite are made up of polymer matrix which has been reinforce with glass carbon or aramid fiber. So, we have two different material systems one being composite; other one is metal the fastener being the metal and there for they have different thermal expansions which may act as a disadvantage in case of mechanical fastener join.

Mechanical joints add weight to the structure and thus minimize the weight saving potential of composite structure. So, basically our focus for using the composite materials is as we have seen in the very first slide in which we have seen what is composite material actually we have understood that the basic purpose of using a polymer matrix composite is light weight, but if we use the fasteners which will has certainly have weight for example, the nuts and the bolts will have some weight and if we have a large number of nuts, and bolts going into the structure that would certainly add into the weight of the structure.

So, mechanical joints add weight to the structure and thus minimize the weight saving potential of composite structure. So, do not want to add to much of weight now this

weight can easily be over come if use the adhesively bounded joints, but adhesively bounded joints also have got there on specific limitation that we are going to discussed in the subsequent slide.

So, right now before advocating the use of microwave joining for polymer composite, let us first try to understand that what are the disadvantages of the mechanical joints as well as of the adhesive joints, then we can propagate or we can propose the use of microwave joining in certain specific applications. So, we have seen certain points which are not in fever of the mechanical joints certainly, there are few points in fever of the mechanical joints which have seen in the previous lecture, that is lecture number three in module number seven.

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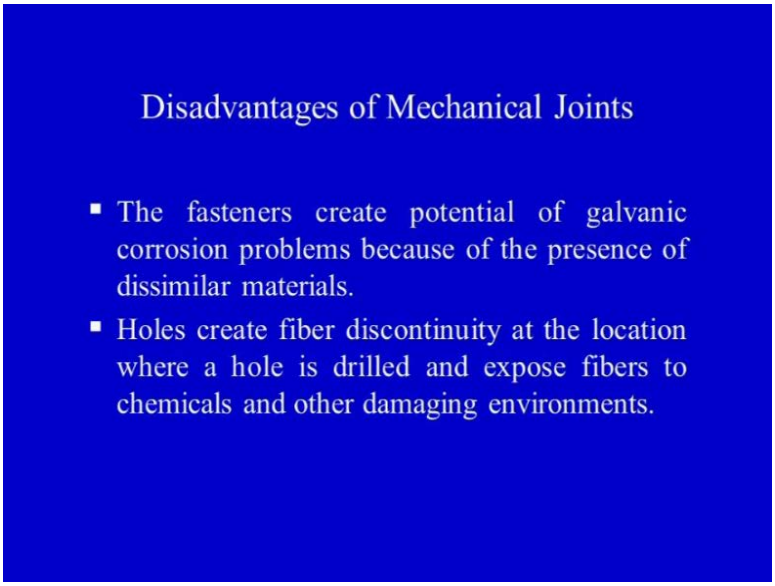

What are the other disadvantages of mechanical joints? The fasteners create potential of galvanic corrosion problems, because of the presence of dissimilar materials which is already we have discus that the adherents are made up of or the structural members are made up of polymer composite, and the fasteners are made up of some other material may be an metal and when two dissimilar materials are there; there are chances that the corrosion may take place or specifically galvanic corrosion may take place, which is another disadvantage in case of mechanical fastening of composite of materials holes create fiber discontinuity at the location of the hole expose fiber to chemicals and other damaging environment.

So, when we are making a hole inside a composite material the place, we are the hole is made, we will have fiber discontinuity and some micro wards may formed and in case of specific environment this micro wards may result as sight, we are the moisture up take may take place or some chemicals may seep in into this point, we are the fibers and the matrix has de bounded during the drilling operation when composite laminates are drilled at the hole wall damage takes places and the damage may be particularly severe in case of damaging environment such as chemicals or were we can say the moisture is the very, very high.

So, basically in case of mechanical joints, if you summaries our discussion what we have discus it relation to the disadvantage is a mechanical joints; there are two or three important points that we can summaries first point is from the design point of view, that we are making a hole in any structural member, it will act as a sight of stress concentration. Secondly, in case specifically for polymer matrix composite if we are trying to make a hole, it has got its own disadvantages in terms of the damage that may take place all around the hole or in case of micro wards may form because of the drilling action.

And here the moisture up take or in case of damaging environment, such as chemicals is chemical may peak into the side in to this fibers, and the matrix at the hole wall, and may alter the mechanical properties of the composite laminates through the summary is that four mechanical joints; there has to we have to excises a lot of question before advocating the use of mechanical joints for the assembly operations of polymer matrix composite. So, now we will again see the disadvantages of the adhesive joints because adhesive joints certainly will overcome some of the disadvantages of the mechanical joints, but they still have got their own set of issues, and then when we have seen the disadvantages associated with the mechanical joints disadvantages associated with the adhesive joints, then we will see how the microwave joining is better than the two or how it can be used as an alternative certain specific requirements.

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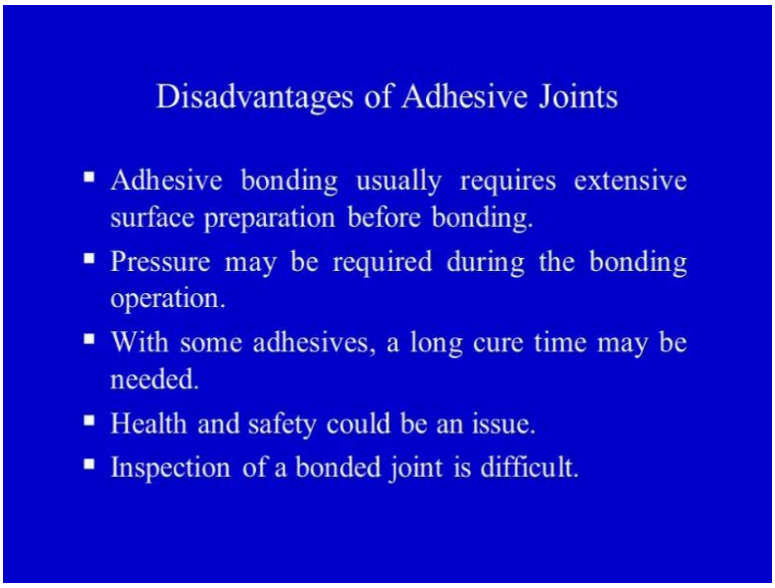

Now, what are the disadvantages of adhesive joints adhesive bonding usually requires exten extensive surface preparation before bonding what does it mean, suppose this is one adherent or one composite plate. And when I have join this two composite plates together in this particular area, where I want to from the joint I have to do the surface preparation before adhesive is applied. So, that we get good bonding between the adhesive and the two composite plates or composite laminates.

So, one of the disadvantage adhesive joints is that it requires extensive surface preparation before the bonding to take place or before the adhesive joining to take place second important point is pressure may be required during the bonding operation. So, when we are bonding we may be required to wined this particular joints for a certain period of time, and after the adhesive has we can say solid applied or has from the joint after the we can open that winding, and we can get the plate or a composite joint.

Third disadvantage with some adhesives a long cure time may be needed, which also important, because of in case of adhesive the curing has to take place we have to apply the adhesive, and weight for a particular time depending upon the curing time of that adhesive finely to take its desired straight. So, with some adhesives we have to weight because of the long curing time of the adhesive next health and safety could be, and issue with a adhesive, because this are chemical substances. So, we there can be certain issues associated with the health and safety inspection of a bonded joint is difficult why

because the bonded joint form a permanent joint, and if we want to disassemble them the joint has to be broken. So, if in certain cases a periodic maintenance has to be carried out or we have to frequently check that what is happening inside the structure and the structure is bounded adhesively the adhesively.

It be it is not advisable where as incase of mechanical joints, we can just use a this assembly operation we can check what is happening inside again, we can assemble using the nuts and the bolts. So, mechanical fastening has certain advantages as compare to the adhesive joints, but today our topic of our discussion is the microwave joining and before we advocate that what microwave joining is we need to understand, that what is the logic behind the proposing the use of microwave joining, when we have two very well established techniques of joining that is mechanical fastening and adhesive bonding.

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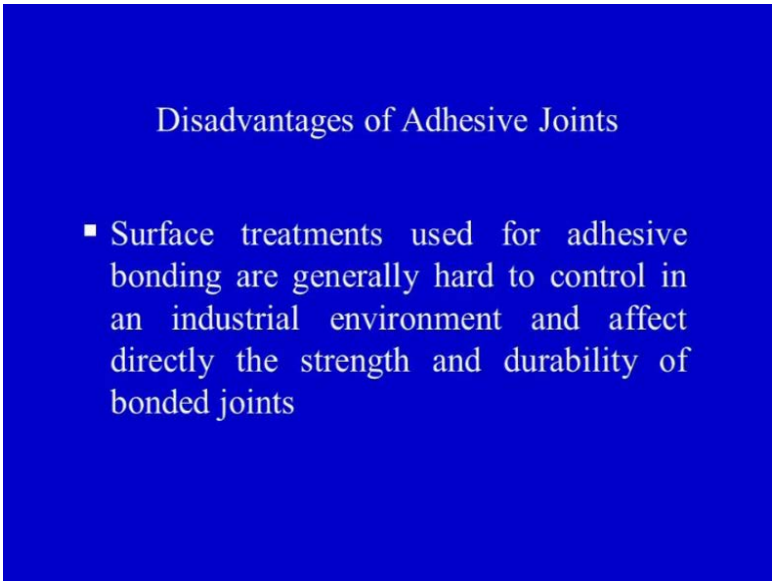

Another disadvantage surface treatments used for adhesive bonding are generally hard to control in an industrial environment, and affect directly the strength and durability of the bonded joints. So, again surface preparation the strength of the joint and safety and health issue or some of the important points which limit the use of the adhesively bonded joints.

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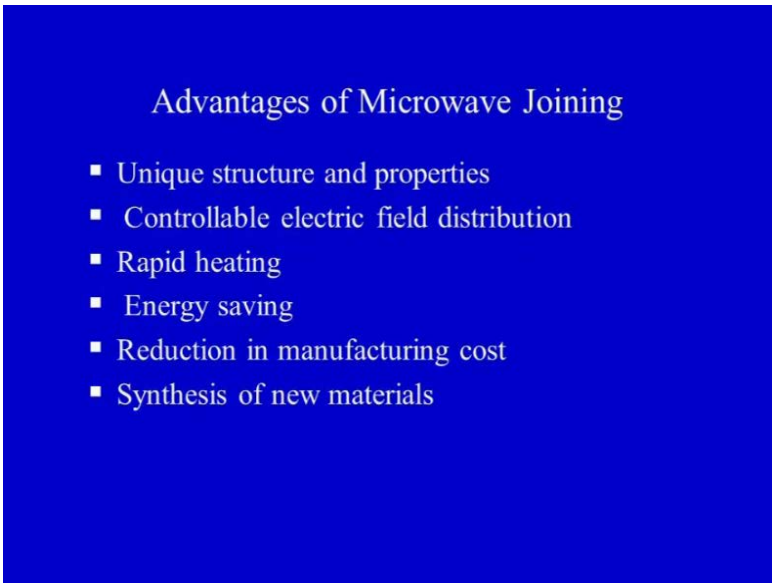

Now, we have seen what are the disadvantages of mechanical joints what are the disadvantages of the adhesive joints, now we will see what are the advantages of the microwave joining process as compared to or in comparison to the mechanical fastening and the adhesive bonding; first is unique structure and properties the joint that will we will get will have unique structure, and unique properties we will see in the subsequent slides, that in certain experiments it has been shown that the microwave joint is more stronger and have can bear more load or more tensile load under same conditions.

So, as compare to the adhesively bonded joints, because once we are comparing comparison comparison has to between two or three different members or two or three different techniques. So, when we compare the microwave joint specimen with with a adhesively bonded specimen, it has been found that microwave joining provides better bond strength as compare to the adhesively bonded joint. So, because why it is happening, because it provides unique structure and properties to the joint controllable electric field distribution. So, we the control over the process is also better the control of the heating is also better in case of microwave joining and electrical field distribution is also controlled very well within the microwave oven.

Than it is a rapid heating process the time required to form the joint is less as we have seen in case of adhesive bonding that when we apply the adhesive, we have wait for a long duration of time in case of certain adhesives which may take a long time of curing.

So, depending upon the curing time sometimes the use of adhesives may be limited in relation to the microwave joining. So, in certain cases we may purpose the use of microwave joining because it is a rapid heating process.

Energy saving that is another advantage reduction in the manufacturing cost. So, certain time certainly microwave joining is would be cheaper as compare to the other techniques of joining synthesis of new materials, because there are certain materials which we find difficult to join when we are using the adhesive bonding process, but here it is not. So, difficult different types of materials can be join using the microwave joining and this is a the microwave joining of polymer composites is still in the development stage a lot of research work is being done and efforts have been put to find out the applicability of microwave joining in context of the polymer matrix composite because there are. So, many problems as we have seen associated with the mechanical joining or mechanical fastening of the composite plates or the adhesive joining of the composite plates.

So, microwave joining certainly provides an alternative to the mechanical fastening and adhesive bonding although there would be certain important limitations of the microwave joining also, but today we want to see that what are the advantages of micros wave joining, and it is one of the processes or technique which can used to join the composite adherents or the composite plates or the composite laminates.

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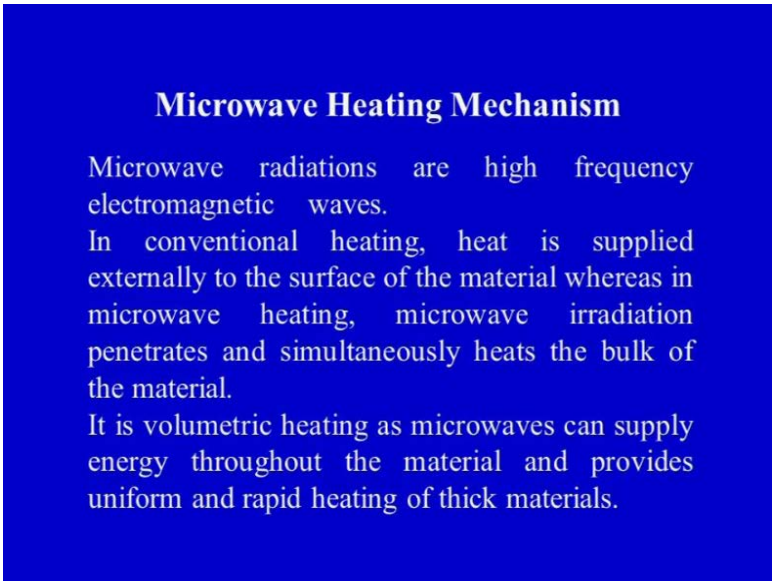

Now, what is the microwave heating mechanism? Microwave radiations are high frequency electromagnetic wave, which is known to everybody these are high frequency electromagnetic waves. In conventional heating, heat is supplied externally to the surface of the material, whereas in microwave heating microwave irradiation penetrates and simultaneously heats the bulk of the material. So, this is important point that in microwave heating the whole material gets heated uniformly it is volumetric heating as microwaves can supply energy throughout the material and provides uniform and rapid heating of thick materials. So, may heating mechanism in case of microwave is different from the conventional heating mechanism, it performs bulk heating or volumetric heating in which the whole bulk gets heated uniformly.

So, this is one advantage which helps us to form a join, because when we have to join a lap join we want that the whole lap area should be heated uniformly and a good bond should be found between the two adherent. So, because it performs heating in all directions and volumetric heating is perform it perform it can be used as a viable alternative two deferent types of joining techniques which we have already seen the disadvantages of now microwave joining has been done.

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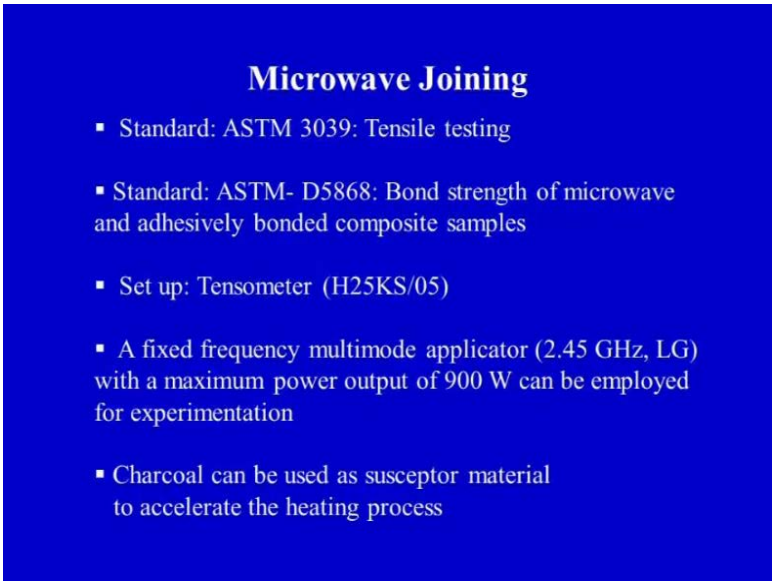

Now, what are the preparations required for microwave joining. So, once we purpose the use of microwave joining, we need to test the applicability of the microwaves for the joining purpose with the conventional methods of joining.

So, for that we may use a tensile testing (( )) tensile testing method that we make one joint using microwave another joint can be made by using a mechanical fastening in the lap area, we can make a whole do the fastening and then test the strength and in another case we can apply the adhesive on the two plates or laminates which have to be joined together and then see the bond strength that how much load, they can take and in s a simple comparison can be done on the basis of the tensile testing. So, when we are comparing this process of joining.

We can compare this using the tensile testing specimens. So, standard ASTM can be used for bond strength of microwave and adhesively bonded composite samples. So, we can check the bond strength of the composite samples. So, we can use these samples we can make the joints using the adhesives or we can make these joints using the microwave. So, now, we are coming to the application point that, if we want to purpose that microwave heating should be used to form a joint in case of polymer matrix composite.

How to compare its performance with the other methods of joining, such as the adhesively bonded joints and a machine can be use such as a tensometer can be used one make of tensometer is also given a fixed frequency multi mold applicator which is the microwave simple in simple terminology we can call it as a microwave oven a fixed frequency multimode applicator may be gigahurtz is given with a maximum power output of 900 watt can be employed for experimentation. So, this type of a setup there is a diagram for this setup in the subsequent slide we will see.

Microwave oven can be use to make the microwave joints charcoal can be used as susceptor material to accelerate the heating process, which is another finding were researchers have found out that charcoal is a material which can act as a accelerator to accelerate the rate of heating specifically in case of microwave joining. So, fixed frequency applicator can be used charcoal can be used, and this we can say we can make the joints by using a adhesive, we can make a joint using a microwave and compare the performance of the two.

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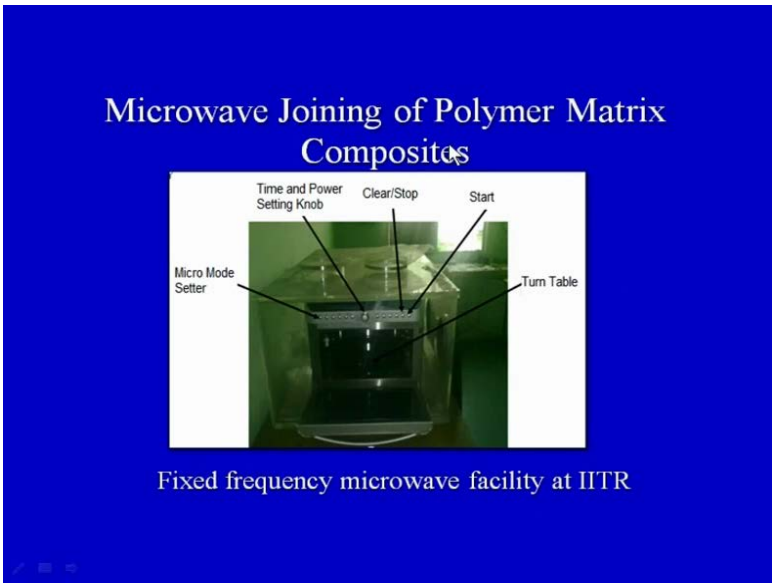

This is a typical microwave joining of polymer matrix composite on your screen, you can see there is a time and power setting knob time and power setting knob in which we can fix the exposure time, and the power, as we have seen that in the previous slide the power can be 900 to a maximum of 900 watt there can be other high end microwave ovens where the power powers can be even higher, but we can set the power according to the requirement.

And we can even set the exposure time therefore, how much time the microwave irradiation would radiate the material or joint in side, and then there are other setting which can be there, there is the start button; there is the stop button and there is the turn table on which we can keep our specimens, and there is a micro mode setup. So, basically it is the fixed frequency microwave facility at IIT Roorkee. So, in this particular oven we can make a joint in the subsequent slide we will see how a joint or lap joint is made and how it is placed inside the microwave oven.

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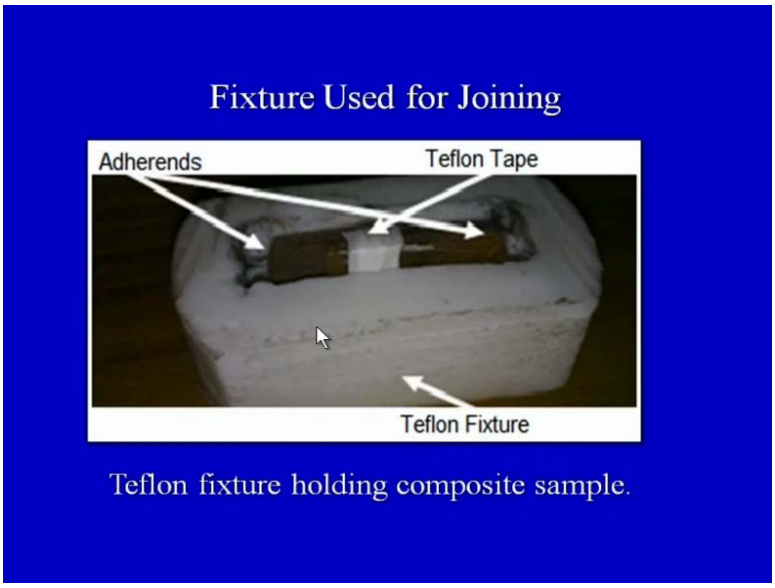

On your screen you can see we have a teflon fixture, this is the teflon fixture white colour fixture, this is teflon fixture within this fixture the adherents adherents basically are the composite laminates which we want to join together. And we a teflon tape is use to apply the pressure. So, we have two adherents which have to be joint together and at the bond area or at a distance, we can wind them using a teflon tape. So, that do not get distorted while the heating or microwave heating takes place. So, teflon fixture use for holding the composite sample. So, composite samples are the adherends in this particular case. So, we have two different adherents which have been made in the form of a lap joint and microwave irradiation would increase the temperature or would heat the joint area and would (( )).

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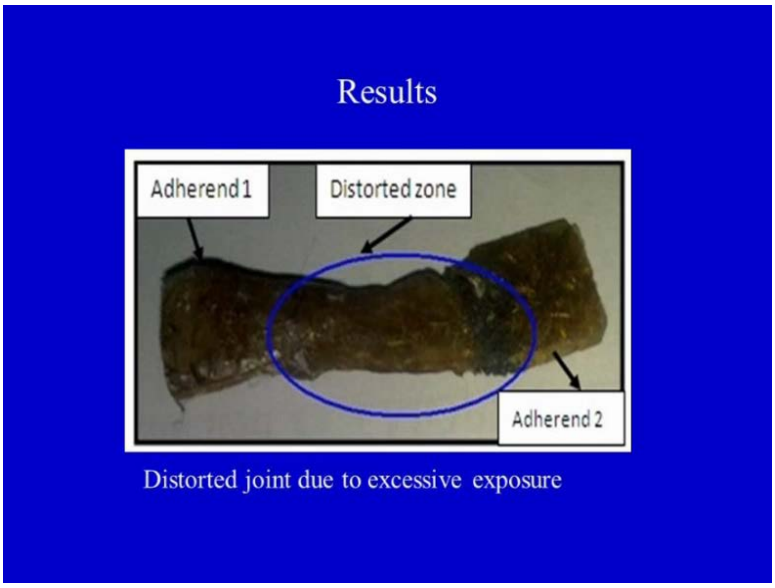

Your can see a failure in which the two adherents of composites were tried using the microwave heating process, and the joint got distorted why it got distorted distorted joint due to the excessive exposure more heat was given as compared to the required heat. So, we have to find out that how much exposure time for how much period of time the set up should be on or the work piece polymer matrix composite should be exposed to the microwave race or microwave irradiation and what should be the setting of the power. So, there are two important control variables that is the power and the exposure time and we have to judiciously select these two para operating variables that is the exposure time and exposure time and the voltage. So, when we have to a control these two parameter trial and error can be done we can find out that at what voltage and that how much exposure time we will get a good joint. So, that is important point

So, here we can see there is distorted joint why this distortion takes place, this is adherent one this adherent two, and this is the joint area, and the bond area in the bond area distortion takes place. And this distorted joint has been made, because of the excessive exposure may be within one 60 seconds the joint may form, but because of the long exposure till three hundred seconds or 350 seconds or may be four fifty seconds the distortion in the joint has taken place. So, the optimization of the two parameters has be done which have I already told no, but this are these two important parameter that is the exposure time and the power the power in terms of volts.

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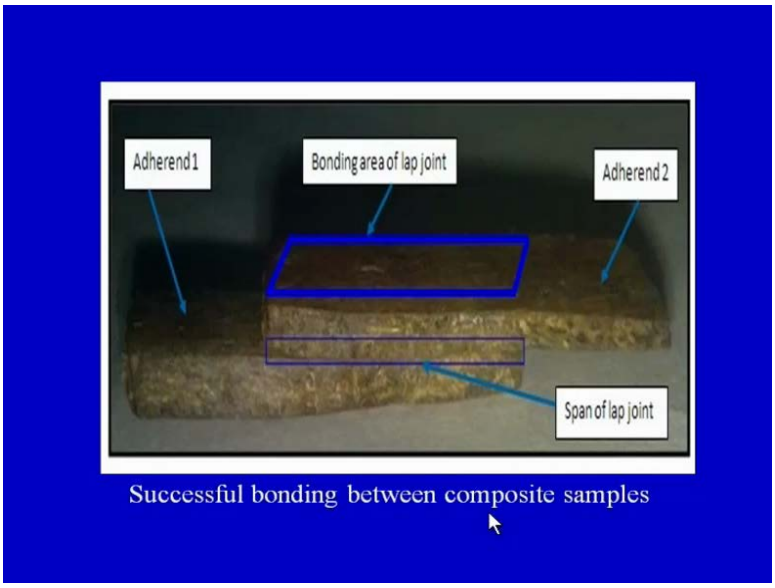

If we are able to control to these parameters and optimize these parameters we would be able to generate a very good joint which is here on your screen. So, this is the joint area this is span of lap joint on your screen this blue rectangle is the area where joint has been formed using the proper combination of the voltage or the power and exposure time. So, this is the bonding area of lap joint this is total bonding are in this direction, this is the you can say the length of the level span of the lap joint, this is the adherent number two or composite number two, and this is the composite number one and this is the area where the joint has been formed after the microwave irradiation of the joint.

So, successful bonding between the composites sample has been done using the microwave joining process. So, we have adherend one we have adherend two these two have been place in the lap joint, and in the lap joint this lap joint has been subjected to the microwaves, and these microwave have been generated at a particular power level and the exposure time of these microwaves at this particular joint has been optimized.

So, when we optimized the two important variables in the microwave joining process that is exposure time and the power, we can very easily get a very good joint, buy before that trial and error has to be done in which we have to find out that what are the optimum levels of the exposure time. And power of generation of the micro wave which would give us a very good joint, as we already seen that sometimes the failure may take place in case of composites where over heating has taking place due to overexposure or giving

more voltage for given less period of time. So, depending upon the different operating variables sometimes it becomes difficult to find out the optimum levels, but with regress experimentation and using judgment it is very easy to find out that, what are the various combination of parameters at which a very good composite joints can be made.

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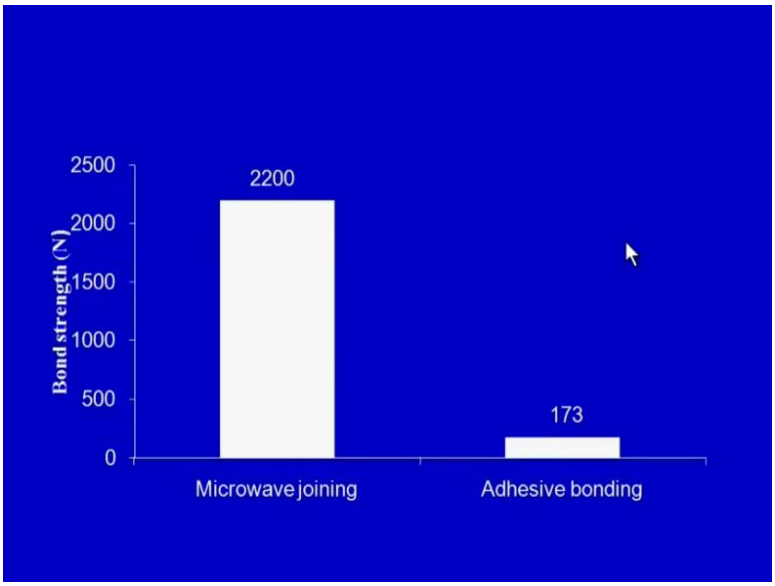

Now, on your screen you can see a comparison of bond strength you can see the bond strength is there on the y axis it is given in terms of Newton on axis, we have two different iso bonding first one is the microwave joining this is the microwave joining and there is the adhesive bonding. So, we can see that more load to failure has been taken by the microwave joint composites adherent and less load to failure has been taken by the adhesively bonded composite adherent. So, this is in one particular comparison. What needs to be emphasized here is that microwave joining has been done on two composites adherent the material of the adherent the time of exposure the voltage levels of the microwave oven, all these are the parameters which will governed the bond strengths of the microwave joints passively.

On the other hand, in case of adhesive bonding the surface preparation the type of adhesive use the interfacial characteristics between the adhesive and adherent and the mechanical properties of the adhesive, and adherent will play a very important role in dictating the bond strength. So, if we are using a particular type of adhesive and we are not getting a very good bond strength what we need to do is we can try another type of

adhesive to improve the interfacial bonding between the adhesive and adherent and in a way we can increase the bond strengths. So, this particular comparison is just an over view of the initial findings which have been carried out and it has been found that microwave joining can provide as an alternative or can provide an alternative to the other methods of joining the composites adherents or composite pates that is the mechanical fastening, and the adhesive joining although the microwave joint specimens have not been compared with the mechanically fastened specimens, why?

Because the mechanical fastening the mode of failure is entirely different as compare to the microwave joints specimens. So, microwave joint when we are joining that two plates together the reason where the joint has to take place their localized heating forms the joint between the two components adherents the polymer, that is present inside the two we can say composite adherents at the joint interface that is heated, and it forms the joint between the composite adherents incase of microwave joining, where as there is the third party that enter into the picture in case of adhesive bonding there are two adherents and in between we do the surface preparation.

And we applied the adhesive know the adhesive bonding becomes a three party system in which we a one adherent a layer of adhesive and another adherents, so two adherents and an adhesive. So, three party systems where as the microwave joining is the two party system only in which we have one adherent second adherent, and at the joint we are doing the localized heating in which the polymer forms the joint between the two adherents together.

So, this particular should have the property of warming the joint on heating, because of in case of thermo sets even on heating they may not be able to form the joint. So, this particular microwave joining is most suitable in case of thermo plastics. So, that a joint can be form by the polymer in the lap area or at the joint area, so in this particular slide it is very, very clear that if we compare the two different techniques for joining of polymer matrix of composites microwave joining certainly provides a viable alternative.

And in certain cases may even as in the present case outperform the adhesive bonding of polymer composites, so but still this is in the development stage and lot of research and lot of efforts have to go in to the we can say bringing out the true benefits of the microwave joining, but since the joining has been initiated in this direction was

important that the budding engineering then the scientist should have an idea about the we can say potential application of microwave joining in the material processing technology. So, basic aim of today's lecture was to acquaint the audience or the engineers with the application and potential of the microwave joining in the field of materials processing.

A very wide over view of the process has been given although a lot of details can be discuss in the field of microwave joining of advanced material. So, be we this come to the end of today's lecture and to summarize what we have covered, in today's lecture we have seen that there are few disadvantages associated with mechanical joints as well as the adhesive joints specifically in case of polymer matrix composites, and we have seen the basic heating mechanism of the microwave. And we have tried to discuss that microwave joining can act as a potential alternative to the conventional methods of joining of polymer composites in the last lecture in this particular module on secondary processing of composites our would be on latest tools and techniques which are used for forming or for facilitating the secondary operation of polymer composites or the total composites in general.

Thank you.