Manufacturing Guidelines for Product Design

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Lecture-34
Microwave Joining

Namaskar friends, welcome to session 34 of our course on manufacturing guidelines for product design. So as we are aware we are currently in the 7th week of our discussion and today is the 34th session that we are discussing and the title is well clear on your screen that is microwave joining. So in the 6th and 7th week of our discussion on this important course that is manufacturing guidelines for product design.

Our focus primarily has been to focus on to emphasize on to highlight the importance of joining when we are designing a product. So if you remember in the 6th week we focused on reviewing the various joining strategies, joining processes which are used for joining of different types of parts or products. Now depending upon the type of raw material whether we are going to join metals or we are going to join plastics or we are going to join advanced materials like ceramics or polymer composites, different joining strategies have to be adopted.

And the 6th week our focus primarily was on metals and we have seen that welding can be done for metals what are the different types of design guidelines that must be kept in mind when you are joining metals. We have talked about soldering and brazing we have talked about hole making that is mechanical fastening in metals we have talked about riveting with different types of rivets. And then we have seen fastening using the different types of screw fasteners.

So, 6th week focused primarily on joining strategies which are well established then we focused on the advanced joining strategies. Because many a times when we are designing a product we are not able to design a product or a geometry or a material which can easily be processed by the conventional joining roots that is adhesive joining or welding or riveting or brazing or soldering. So, we have to go for the advanced joining strategies.

And there are different advanced techniques specifically designed for specific set of material. So, we have broadly classified materials into metallic non-metallic. And in non-metallic we can talk about plastics. And in this week if you remember if you have gone through the previous sessions you will appreciate that we already seen the induction welding of plastics. We have already seen ultrasonic welding of plastics.

We have seen vibration and spin welding which is specifically we can say used for plastic materials. Although these processes can also be used for joining of metals also we are not ruling out this process is for metals. They can be used for metals also but the conventional joining strategies such as welding maybe a gas welding or arc welding or brazing or soldering is sometimes not suitable for plastics. So these are the processes which make themselves available for joining of plastic materials.

So in this week we have already finished 3 sessions, session number 1 was focused on induction welding of plastics, session number 2 was dedicated towards ultrasonic welding. In session number 3 vibration and spin welding, that is session number 31, 32 and 33 in our course. And session number 1, 2 and 3 for the 7th week of discussion, today we are going to discuss another important technique which is currently in research stage many places it is being utilized also commercially for joining of different types of material.

And this technique is microwave joining, so as a product designer when I am designing a product and I have to ensure that the different parts of the products have to be joined together at a later stage to get the complete assembly. I must know that what are the various joining strategies that can be adopted to realize the complex product which is made in different parts. So one of the processes which is these days gaining significant importance is microwave joining.

So in today's session our target will be to have a brief review of the microwave joining of different types of materials. And try to understand the basic mechanism of joining and try to see it with the help of an example with the help of a case study towards the end of today's session maybe for briefly for 5 minutes. We will discuss on one case study in which the microwave joining has been used to join the different types of workpiece materials.

And the case study specifically based on polymer matrix composite materials. In the next session also when we will discuss session number 35 which is dedicated to hole making we will be discussing the case studies related to hole making in polymer matrix composites. Because these are the materials which are going to be use in numerous application where plastics are being used in the current scenario.

So plastics in future may get converted into polymer composites or may get converted into biopolymers, keeping in mind the environmental concerns about the use of plastic materials. So, let us quickly now have a brief review of the microwave joining process. So we will first start with the introduction, let us try to understand that what microwave joining actually is.

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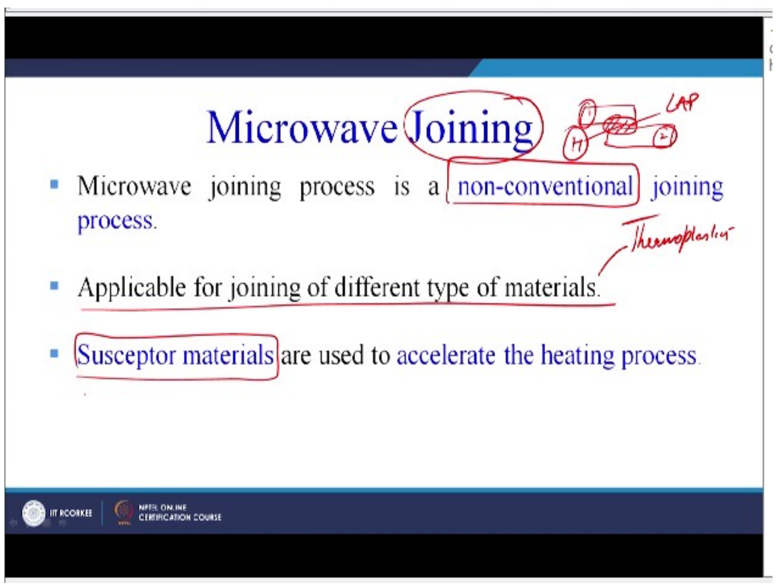

Now joining word is absolutely clear to all of you that we have to join the 2 pieces together at maybe in the lap configuration here. So this is my adherent and second adherent have to be joined here as a lap configuration now how to join them as I have already I think in each session joining I have talked about basic definition of welding. Now welding as again I will emphasize that it is a joining of two similar or dissimilar material.

Similar or dissimilar materials with the application of heat with or without the application of pressure. So here again heat is required to join these 2 pieces together from where the heat will come the source will vary and we have seen that in induction welding the source will be electromagnetic induction effect. In case of vibration welding we rub the mechanically we rub the work pieces against each other and frictional heat is produced because of the rubbing action.

Similar is the case with ultrasonic welding, so in conventional welding we use the heat of electric arc. In gas welding, we use the flame for producing the heat, so here again the source of heat is a microwave energy in microwave joining. So when we have to join the 2 pieces together the source of heat in case of microwave joining is the microwave or the electromagnetic radiation. So let us see now the microwave joining process is a non-conventional.

Now non-conventional itself says that its mechanism is different from the conventional methods of joining the 2 materials. It is applicable for joining different types of materials, so at IIT Roorkee we have been able to join the thermoplastic composites using this technique and a research group with professor A K Sharma in the lead their working towards joining of different types of metallic materials also using the concept of microwave joining.

So, susceptor materials are used to accelerate the heating process now when we have to produce heat in this zone. So this heat can be accelerated with the help of susceptor materials now materials are the materials maybe one of the examples can be charcoal. So if we are going to join these 2 pieces together. This is one adherent and this is another adherent and on the top of the 2 joint surfaces we can put charcoal as the susceptor material.

The charcoal has the tendency to absorb the radiation or the microwave radiation, so the heat will be focused in the joint area only. And a specific area will get heated and joint will be form, so susceptor materials are used to why they are used to accelerate the heating process, source of heat here is the microwave radiation. So basic difference between microwave joining and the other forms of joining is basically the way in which we produce the heat which is used for joining the 2 pieces together. Here specifically we use the microwaves to produce the heat.

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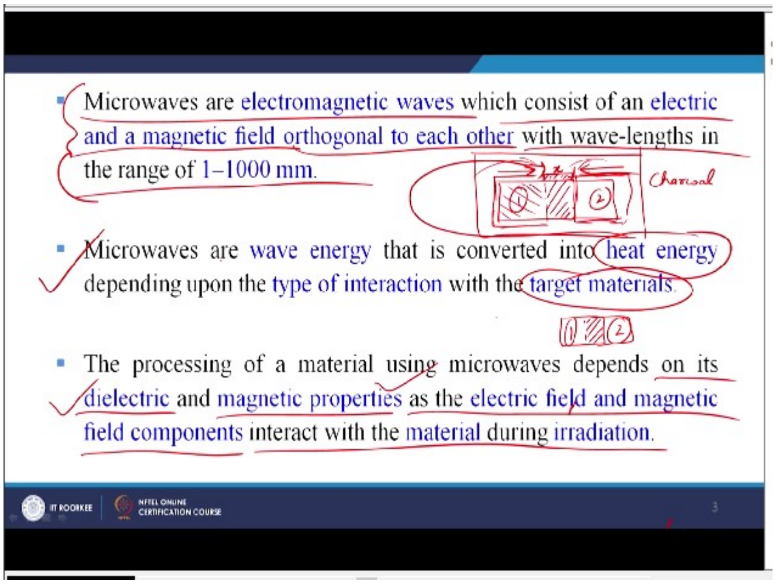

Now microwaves what are microwaves now, microwaves are electromagnetic waves which consist of an electric and magnetic field orthogonal to each other with wavelengths in the range of 1-1000 millimetre. So this clearly gives us an idea that what microwaves actually are? and these are the same microwaves that we use for heating or cooking of our food in our domestic ovens or the domestic microwave ovens.

So same microwave oven can also be used for joining the polymeric parts. But there are certain precautions that we have to ensure that we have to only expose the joint area only to the microwaves. If we expose the complete polymer product to the microwaves the melting of the polymer may take place at in totality means the complete product will be melted whereas we want to only melt the areas are selectively melt the area where we want to produce the joints.

So that is the catch, so selectively we have to do the heating at the localized area. So that the joint can be formed, how to do that selective heating one of the strategies is that you put as susceptor material at the point. For example let me draw a diagram this is one part and suppose this is the other part, now this is the area that we want to join this is the top part this is the bottom part this is the lap area.

Now what we can do we have to heat only this area that is the length x we want to heat. So, what we can do we can put the susceptor material here which can be charcoal. And then we can place this complete assembly into the microwave cavity or the microwave oven. Now the electromagnetic radiations will be attracted by this charcoal material because it is a susceptor it has the tendency to absorb the microwaves.

So this is the one strategy, now we do not that this portion of the material be exposed to the microwave. So we have to do the masking of this material up to here and similarly the masking of this material up to this place. So this masking can be done with various patented material masking means that we will cover this portion with a material which is opaque to the microwaves which is not transparent to the microwaves.

So, once we are covering it with the material which is opaque to the microwave. Microwave will come heat this opaque material and reflect back. So they will not heat the portion or the section which we do not want to get heated. So using these 2 strategies first is focusing the microwaves at the area of interest and then masking away the other portions we can very easily make a joint your plastics using the microwave energy.

So what are microwaves actually it is explained in the very first sentence, microwaves are electromagnetic waves which consist of an electric and magnetic field orthogonal to each other with wavelengths in the range of 1-1000 millimeter. Microwaves are wave energy that is converted into heat energy, already I have explained it with the help of diagram that we convert the heat energy depending upon the type of interaction with the target materials.

Now target materials, what are the target materials these are the 2 target materials which we want to form this is the joint interface area. So this is the these are target materials 1 and 2 and depending upon the type the nature of the target materials whether they are electrically conducting they are magnetic or not there will be interactions and the dipoles in the material and it will be generated.

So microwaves are wave energy that is converted into heat energy depending upon the type of interaction with the target material. Now depending upon how microwaves interact with the material we will get whether it is opaque, whether it is transparent material, whether it absorbs the microwave, whether it reflects the microwave, so that the interaction we will define that whether a particular material can be joined using the microwave energy or not.

And we will see in the subsequent slides examples where we will be able to be understand that microwave is not a vanish is not cure for all types of issues. It is also selective in the type of materials which can be processed using the microwave energy some of the materials may not be possible for us to join them using the microwave energy. So there are a specific set of materials which can be processed using the microwave energy.

But in other types of materials also research is undertaken and the research is going on to find out that how microwave energy can be use for joining of other materials also with little modification in the materials as well as major modification in the process. So let as now go to some specific areas where microwave energy can be utilized. The processing of material using microwave depends on its dielectric and magnetic properties as the electric field and magnetic field components interact with the material during the irradiation.

So very very important point as I have told you in the previous point that is point number 2 that microwaves are not you can say universal in their heating mechanism, universal means that they do not heat all the materials in a common manner or in a uniform manner, depending upon the dielectric properties of the materials, depending upon the magnetic properties of the materials. We will be able to differentiate the different types of materials that these materials can be processed by microwave energy, these materials cannot be processed by the microwave energy.

Now this electric field and magnetic field components in the material interact with the material during the irradiation. So these components as we have already seen here microwaves are electromagnetic waves which consist of an electric and magnetic field. So these fields interact with the material and produces heat, so if a material is maybe it has a good dielectric properties maybe is poor in the magnetic properties.

It will behave to the exposure of microwaves in a different manner on the contrary the material is poor having poor dielectric properties. But good magnetic properties it will interact with the microwaves in a different manner. So depending upon the dielectric and magnetic properties of the materials they will interact with the microwaves and that will define that how the heating will take place.

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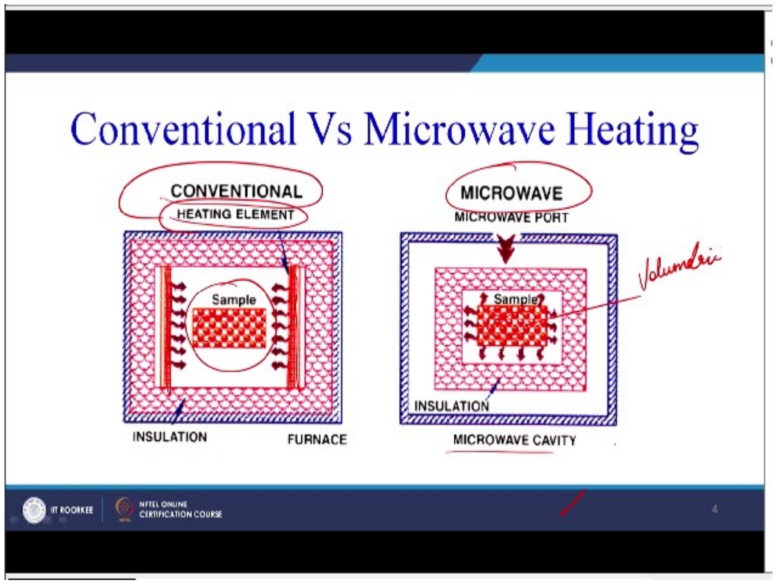

Now this is the very very important diagram or figure because many of us usually confuse that what is the difference between the heating using the conventional methods and what is the heating mechanism in my microwaves. And we have seen the previous slide also there are number of words that are quite catchy but difficult to understand, for example the dielectric property of the material, the magnetic properties of the material, the electric and the magnetic components of the electromagnetic radiations.

So all these are quite complex terms to understand in a very brief period of maybe 20 to 25 minute. So this diagram clearly explains that in conventional heating process this is the heating element already shown in red colour. And this is a sample, so it is heated in a conventional manner from outside. So maybe the heating may start from the periphery and then the heat front will travel towards the centre.

So the temperature will maybe higher at the outer periphery of the job or the workpiece or the component that we are heating and slowly the temperature will increase towards the centre, whereas in microwave heating the heating will be from the there will be a volumetric heating, so the all the component will start getting heated at the same time. So this is the insulation, so here we can see that you get the heating from the centre.

So, you can see heat is being liberated here because it is the material is that producing the heat it is not that the where the heat is coming from outside. So, there is no outside heating element there you can see there is a heating element here this portion and this portion whereas here you do not see any heating element the microwaves go the different components of the microwave enter into the material.

And they interact with the material and internally only heat is produced and that heat you can see is liberated out. So that is the microwave way of heating the materials. Similarly you can see when you use the domestic microwave oven you do not see any heating elements around there are microwave port through which the microwaves are irradiated on the food that we want to heat and then the food gets hot .

Because of the movement or because of dipole movement reorientation, so there is a mechanism which we will try to understand in the subsequent slide that what happens inside the material when it is exposed to the microwaves and what types of heating takes place. So let us quickly now move to that. Now before going to that mechanism of heating let us try to see the microwave material processing.

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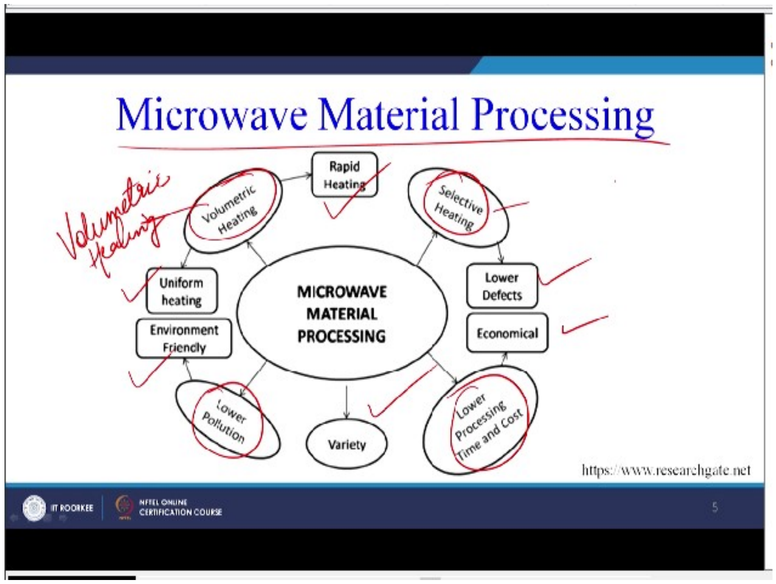

There are number of advantages, so already I have highlighted this part which I am again writing that it is an important characteristics of microwave that it leads to volumetric heating. So the everywhere in the product or the component or the joint that we are making the temperature will be more or less constant. So which is an example of the volumetric heating, so when the volumetric heating takes place the heating process is fast, uniform heating.

Because everywhere the temperature is more or less same it causes lower pollution, environment friendly, a wide variety of materials can be processed lower processing time and cost. You can see how quickly you can cook your food in a microwave cavity or how quickly you can warm your food in a or heat your food in a or heat your food in a microwave oven. It is economical lower defects are there and selective heating is another important characteristics.

As I have try to explain that when we are going to join 2 pieces we can selectively heat the joint interface area by putting a susceptor material there. So these are the broad characteristics of microwave joining process, now what are the various heating mechanisms because once you are able to produce the heat at the joint interface automatically the joining will take place. So, what are the various heating mechanisms in microwave processing let us try to see

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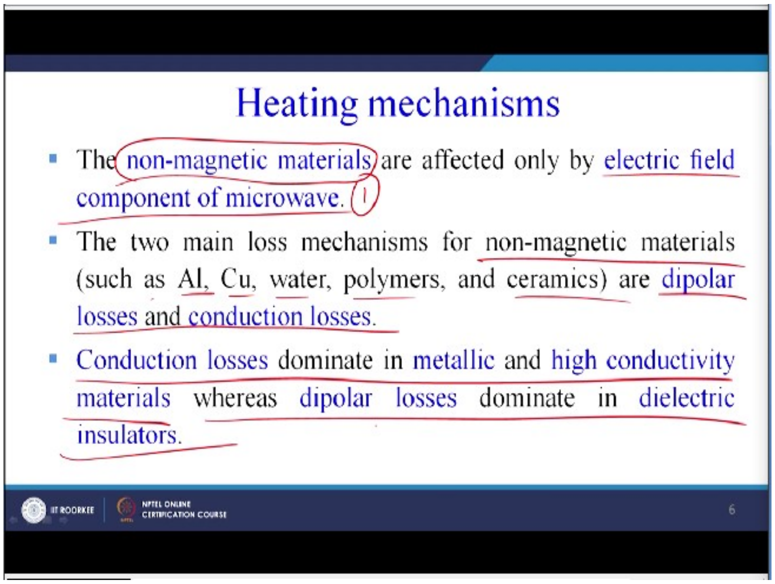

We have seen that the different types of materials will behave differently on exposure to the microwave radiation. So, the non magnetic materials let us take the first case the non-magnetic materials are affected only by the electric field component of the microwave. So, in the very beginning maybe 2 slides before this we have already seen that the electromagnetic radiation or the microwave radiation consists of 2 components electric component and the magnetic components.

So the non-magnetic materials are affected only by the electric field component of the microwaves. The 2 main loss mechanisms for non magnetic materials such as aluminium, copper, water, Polymers and ceramics non-magnetic materials or dipolar losses and conduction losses. So these 2 will lead to production of heat bipolar losses and the conduction losses, conduction losses dominate in metallic and high conductivity materials whereas dipolar losses dominate in the dielectric insulators.

So for in order to understand these terms in much more detail for example the dielectric insulators, then dipolar losses. We need to understand I will give a reference you can go to that reference and study these terms in much more detail. But basic understanding that we can develop during this short time with your spending on microwave joining is that the electromagnetic radiation the microwaves or the microwave radiation consists of 2 different types of components.

One is the electric component another one is the magnetic component and these 2 components interact with the material with having different dielectric properties different magnetic properties different types of conductivity. And because of this interaction between the various components of the radiation and the various properties of the material heat is produced. And this heat is used to heat the material. And this heat we can also used to join the 2 materials together, now this is a very important slide the dipolar loss.

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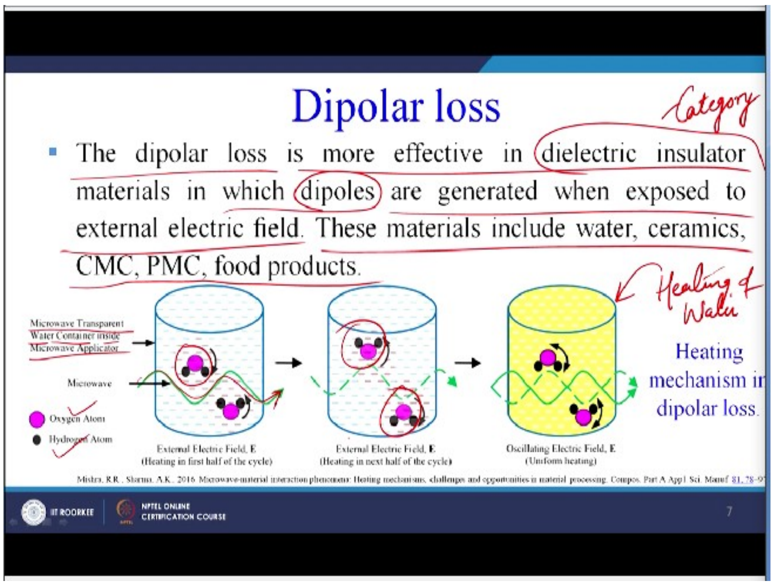

You can see the dipolar loss is more effective in dielectric insulator, so this is again a category of a material, some materials will dielectric insulators in which dipoles are generated when exposed to external electric field. So dipoles we can see the dipoles here in the diagram are generated when exposed to the external electric field. These materials include water ceramic, ceramic matrix composites, polymer composites and the food products.

Now let us try to see this is the green portion you can say is the movement of the microwave. So, microwave transparent water container inside the microwave applicator, so this is a microwave transparent water container inside the microwave applicator. So microwaves enter, so there is a because this is water, so there is a oxygen atom and hydrogen atom external electric field is applied heating in first half of the cycle.

Then this is a heating in the next half of the cycle, the dipole movement is there heating mechanism is dipolar loss. So this is the heating of heating mechanism for water, so this is heating of water with the microwave. So we normally we see that in microwave when we keep our glass of water we can easily heated, so how what happens inside you can see here, this is hydrogen and oxygen molecules which forms the dipoles.

And dipoles are the source of heat which produces heat from internal sources only or from internal movement or reorientation of the dipoles only.

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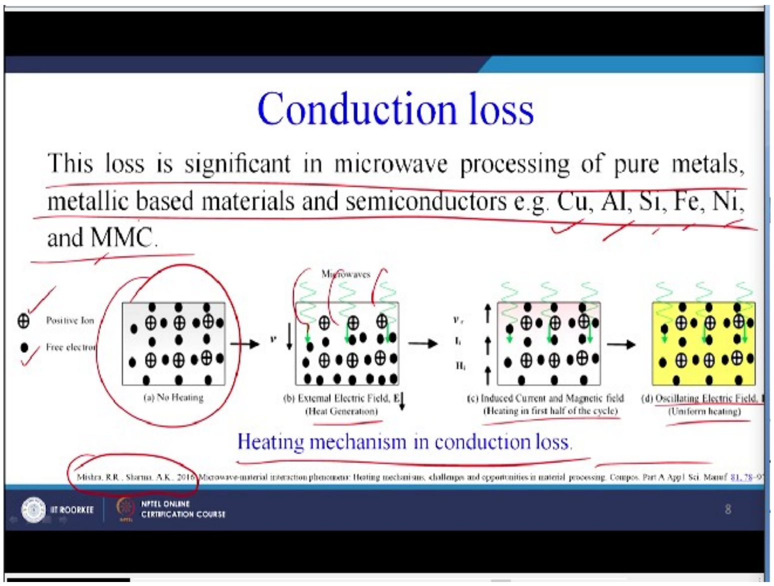

Now conduction losses is this loss is significant in microwave processing of pure metals metallic based materials in semiconductors. So and metal matrix composites, so there is a positive ion here, there is a free electron here. So, these are the microwaves again green portion microwaves shown here, the external electric field E heat generation takes place you can see. There is this is a no heating area and this is when the microwaves are irradiated on the material.

There is you can say change in the position of the positive and the ions and the free electrons which causes heat induced current and magnetic field heating in the first half of the cycle, oscillating electric field which causes the uniform heating. So, you can see that there is a transition between the positive ion and the free electrons which causes the heating that is the heating mechanism by the conduction loss.

And the details are given in a article or review article a very very comprehensive review article published by Radha Raman Mishra and professor A.K Sharma that is microwave material interaction phenomenon heating mechanisms challenges and opportunities in material processing. The article is published in composites part A applied science and manufacturing page number is also given volume 81 page number 78 to 97 a very very comprehensive article which explains the complete mechanism of heating for different types of material.

We have only taken 2 example conduction loss, loss and the previous one are the dipolar loss but mean the much more detail the comprehensive details are given for different types of material with different case studies I have been explained in much more detail. So, we can see here that dipolar losses are cause of heating in case of water and the various other materials which are dielectric insulators and for the other type of materials.

For example conduction loss takes place in copper, aluminium, Silicon iron, Nickel or metal matrix composites. So these are the 2 maybe mechanism for heat production of heat or generation of heat in different types of materials. So 2 different families of materials we have seen in the previous slide dipolar loss is the we can say dominating mechanism of heat generation here the conduction loss is the dominant mechanism of heat generation. Now heating mechanisms in polymers because we are talking in this week on polymers.

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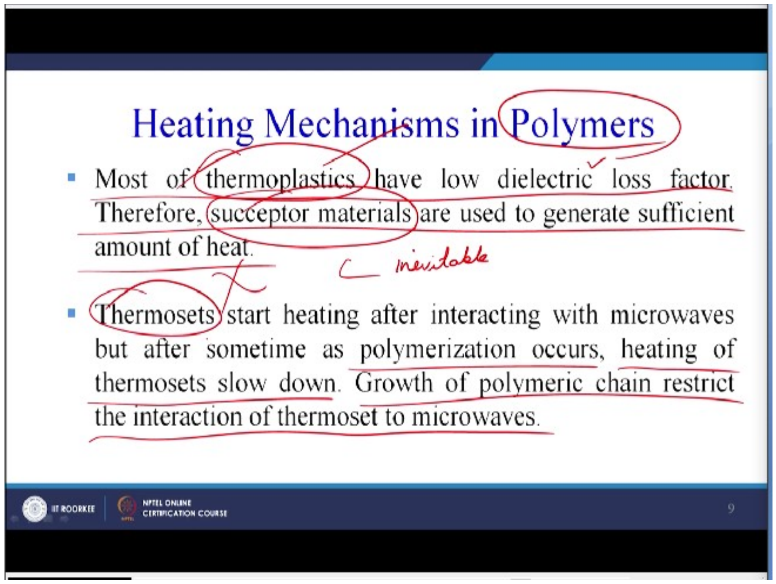

So most of the thermoplastics have low dielectric loss factor, therefore susceptor materials are used to generate sufficient amount of heat. So we can see here the depending upon the dielectric properties of the polymers we may not be able to produce or sufficient amount of heat and therefore the need of the susceptor materials becomes inevitable. So we are able to produce sufficient heat in case of polymers by using the susceptor materials.

Because of the low dielectric loss factor of the polymers, thermoset start eating after interacting, so this is another case thermosets this is related to thermoplastics. So, in thermoplastics we can use a susceptor material, in thermosets they start heating after interacting with the microwaves. But after some time as polymerization occurs heating of thermosets slow down growth of polymeric chain restrict the interaction of thermoset to the microwaves.

So, which means that thermosets are not that good materials which can be processed with the help of microwaves. So thermoplastic yes we can process them using microwave energy but with the help of a susceptor material.

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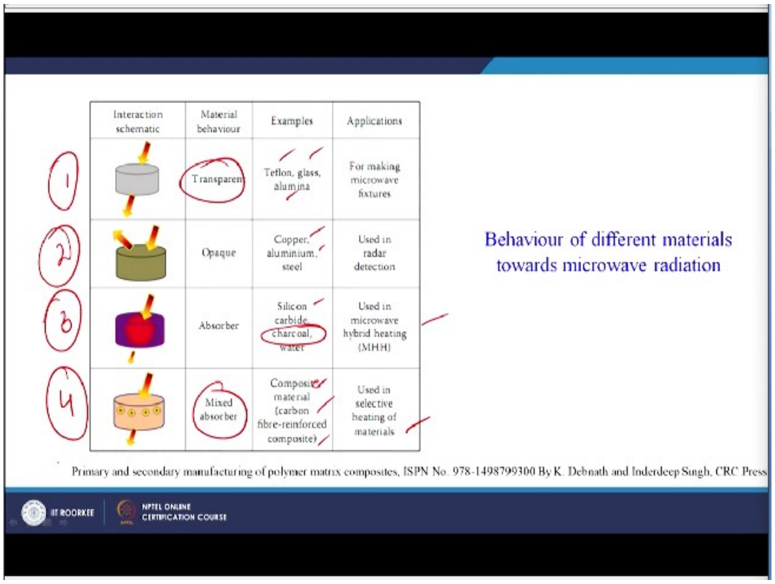

Now this is a summary of the materials different types of materials, depending upon the interaction of the microwaves with the material as well as the properties of the materials for example the dielectric loss factor or the dielectric properties of the material, the magnetic properties of the middle. They will behave differently to the exposure of the microwave radiation, so we can see here interaction mechanism material behavior, sometime it will be transparent.

so examples are Teflon glass alumina which are transparent to the microwaves opaque, copper aluminium steel or opaque to the microwaves, absorber silicon carbide. I have already told charcoal is use as susceptor material these are absorbers of microwaves then mixed absorber composite material carbon fibre reinforced. So they are mixed absorbers used in the selective heating of materials used in microwave hybrid heating this absorbers.

So depending upon now we have maybe category number one, category number 2, category number 3, category number 4 we can broadly classify the engineering materials into 4 categories on how they react to the microwave radiation or how they behave on exposure to the microwave radiation. We can have fully transparent materials, we can have opaque materials, we can have a absorbers of the microwave, we can have mixed absorbers also.

Now depending upon the type of material we can choose our strategy that how the material can be processed using the microwave radiation.

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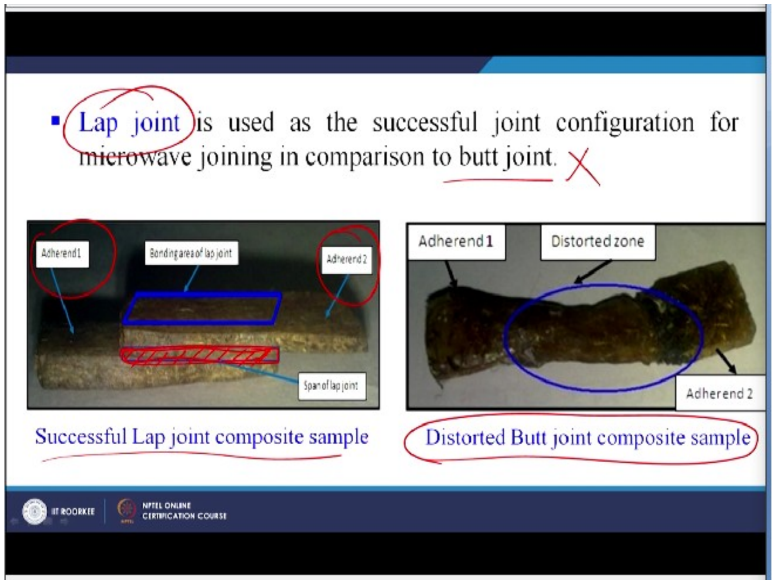

Now this is just one case study that we have done at IIT Roorkee, a lap joint is used as a successful joint configuration for microwave joining in comparison to butt joint. So this is maybe lap joint is more suitable as compared to a butt joint in case of microwave joining. So, this is a joint which was formed using the microwave energy and this is adherend number one, this is a adherend number 2. So, 2 adherend joints like this in this case it is like this.

This is first adherend number 1, adherend number 2 and at the interface in microwave energy was used to produce this joint. This is the span of the lap joint this is the bonding area of the alp joint and this is the adherend 1, this is distorted but composite sample. So, we have tried using but joint configuration also we tried using lap joint composite also. So, lap joint was successful we were able to successfully form a lap joint in a composite material using the concept of microwave energy.

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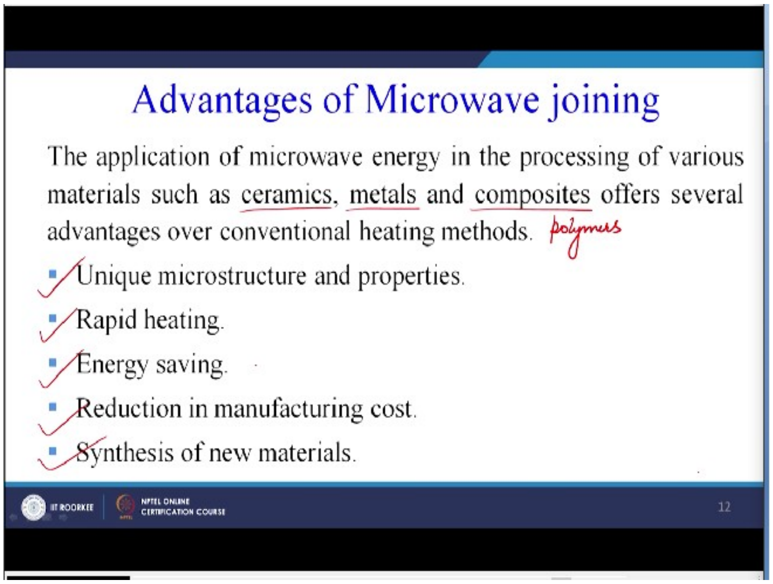

Now what are the advantages of the microwave joining, the application of microwave energy in the processing of various materials such as ceramics, metals and composites offers several advantages over conventional heating methods. So they can be use for ceramics, metals and composites or we can also say polymer based composites what are the advantages unique microstructure.

And properties of the final product rapid heating, energy saving, reduction in manufacturing cost, synthesis of new materials maybe one material can be joined to a different material using the microwave energy depending upon the dielectric properties or as well as magnetic properties of the materials that are being joint.

So we have different types of advantages that we can derive out of microwave joining of materials. So with this we can conclude the today's session, I think we have not gone into the design complexities involved just one guideline we have seen that lap joint to better to process as compared to a butt joint in case of joints for microwave joining. But we have been able to address that microwave joining is an important joining technique which can be use for joining similar or dissimilar materials, rapidly quickly without harming the environment as well as without much energy.

So it is a energy efficient process which can be easily used for joining of different types of materials. So for basic mechanism as well as the various properties that a material must possess if it has to be processed using the microwave that is still left to be discussed. But because of the capacity of time we are concluding the discussion here I have given you are very good reference written by professor A K Sharma.

If you can go through that reference and try to understand the basic mechanisms of heating in the material when it has got a good dielectric loss factor or when if it has got a poor dielectric loss factor. So all those details can further studied and the knowledge can further be developed in the area of microwave joining of materials. But certainly in his last 25 minutes we have been able to address an important joining strategy for different types of materials.

In our next session we will talk about hole making in different types of materials and what are the various guidelines which must be kept in mind when we start making holes in the materials, with this we conclude our session number 34.
Thank you.