Processing of Polymers and Polymer Composites

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Lecture – 30
Adhesive Joining

[FL] Friends, welcome to session 30; in our course on Processing of Polymers and Polymer Composites. We have started our discussion on the secondary processing of polymers as well as polymer composites and we have seen that what is the need of secondary processing as well as we have tried to understand that what are the intricacies or challenges as well as issues involved in secondary processing. We have also seen that how the different joining techniques can be classified.

Now, just to revise our last session, we have seen the joining of polymer composites in which we have tried to understand that the first type of joining that is a most commonly used joining technique is the adhesive joining. Then, we have tried to understand the mechanical fastening and we have seen that both have their own challenges and the third one which overcomes the challenges is the fusion bonding technique and in fusion bonding technique, there are 3 major processes or techniques that are used in fusion bonding. There was a large classification diagram. If you see a 3 types of welding or 3 types of joining strategies are there and then, with subcategories there are other strategies, but majorly we have seen the 3 types that is the microwave joining, the resistance welding or resistance joining as well as the induction bonding technique or induction heating method.

So, all these 3; the microwave, the resistance as well as induction helps us to form a fuse joint or a fusion joint between the 2 polymer substrates or the 2 composite materials adherents. So, basically there are large types of manufacturing processes falling under the joining techniques that can be used for joining of polymers and polymer based composites, but they vary because of the type of the adhesive, the type of the adherent, the type of the joint, the type or the viscosity of the adhesive.

So, there are number of parameters that have to be taken into account when you are talking of joining the 2 materials or 2 adherents which are polymer based composites. So, we need to understand that what are these processes in detail. In previous session, we

just had a overview of the bonding mechanisms especially in case of fusion based joints and we have seen the basic schematic diagrams of the microwave joining process. We have tried to understand the joining of resistance welding technique, we have seen the mechanism of the induction welding technique or induction joining of polymer based composites.

So, I have told in the previous session that we will be discussing each of these techniques in relatively more depth and detail in our subsequent sessions and today we will discuss adhesive joining which is one of the most important joining techniques for polymers or plastics as well as fiber reinforced plastics or polymer matrix composites. So, adhesive joining is a very important technique and how it compares with the mechanical fastening, we will try to see towards the end of today's session that; what are the advantages, what are the limitations of the adhesive joining technique.

We will try to see what are the different types of joint configurations that we can adopt in adhesive joining technique and we will see that; what are the various bonding mechanisms that can be used up that have been outlined for bonding between the 2 substrates or the adherents together; so, adhesive joining is one of the most commonly used, widely practiced method of joining of polymers as well as polymer based composites and that is the topic of our discussion today.

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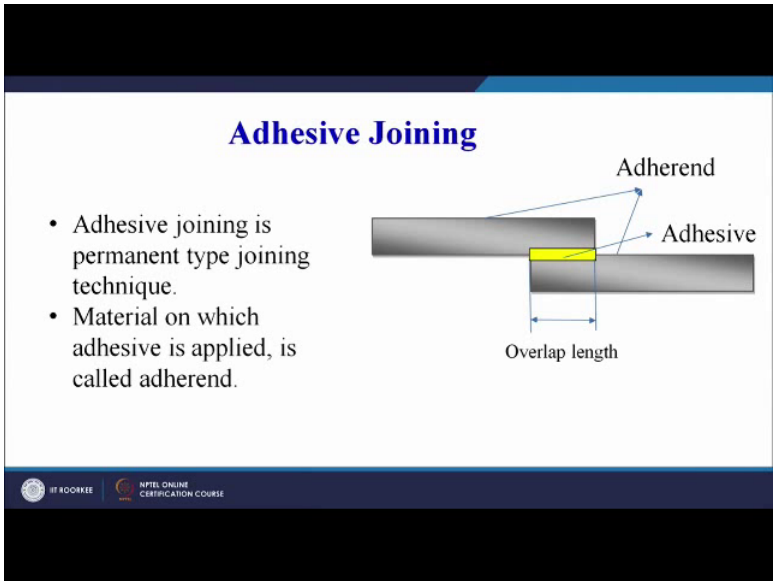

Let us start the discussion. Sorry this is the adhesive joining. You can see the diagram has already been explained in the previous sessions. You can see that adherent are, this is adherent 1 and this is adherent 2. So, the 2 adherents are the materials that have to be joined together or the welded parts or weld parts to be welded or joined together. So, we should not use the word welded because here we are going to use additional adhesive in between and this process is an adhesive joining process. So, these are the 2 adherents which have to be joined together, not welded together and this is the adhesive, yellow color adhesive which is applied between the 2 adherents to join them together.

This is in the previous sessions I have been giving an example like this. So, here we have tried to highlight that what actually the overlap length is. I have told this is the overlap length, this is a adherent 1, this is adherent 2, this is the overlap length between the adherent 1 and the adherent 2 and here this overlap length has been explained or shown schematically. So, this is the overlap length. So, here you can see adhesive joining is a permanent type of joining technique.

So, it is permanent means that once the joint has been made, you cannot disassemble. Only you can break the joint to get your 2 adherents back material on which adhesive is applied is called the adherent. So, this is our adherent 1, adherent 2 and in between we have got the adhesive. Now, some of you may be wondering that when you apply the adhesive, how the 2 adherents are joined together. Now, we all of us use adhesives in our day to day life. If you see a toy is broken, we bring a commercial adhesive from any stationery shop or from any hardware shop and we try to join the 2 broken parts together.

Now, how the adhesive forms a bond between the 2 parts to be joined or 2 joining parts that we will try to understand in our subsequent slides.

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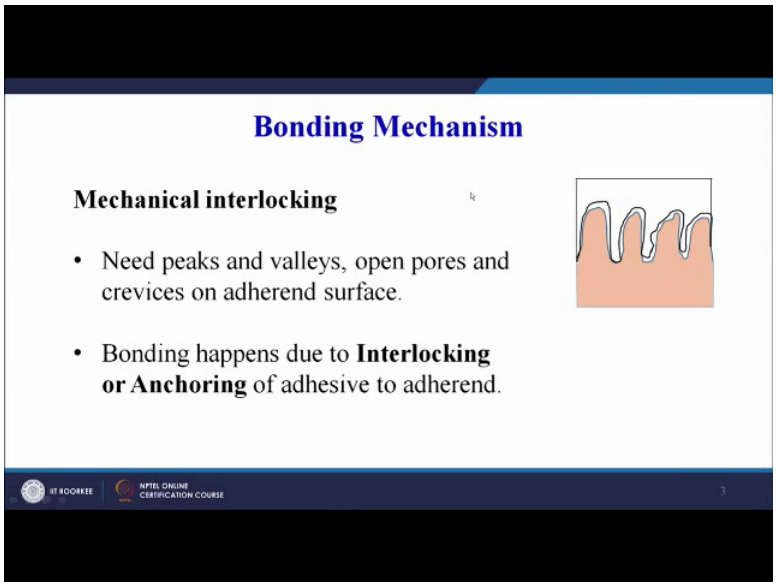

Now, this is the bonding mechanism which usually takes place between the 2 mating parts or 2 parts to be joined together. First bonding mechanism is the mechanical interlocking. Must I tell you that these types of peaks and valleys will not be available on any surface? Surfaces are usually very smooth specially in case of polymers and polymer products.

Let us take the example of a plastic bucket. You just rub your hand against the surface of a plastic bucket. You will never see these types of peaks and valleys. So, this has just been drawn to explain that how the mechanical interlocking takes place. The peaks and valleys will be very small or sometimes indirectly or artificially or synthetically we have to induce a surface roughness on the surface to be joined in order to make that surface ready for mechanical interlocking or for adhesive joining. That is called the edge preparation or the surface preparation.

So, mechanical interlocking between the 2 adherents will only take place if there are peaks and valleys at the surface or open pores and crevices on the adherent surface. So, 3 important things are to be there on the surface if the mechanical interlocking has to take place during the adhesive joining of 2 polymer or polymer composite adherents.

Now, what are these 3 things? First is that peaks and valleys should be present, second is some pores maybe present or third is crevices are present on the adherent surface. Now, suppose these things are not present, how to make a joint? What we will do, we will

artificially create all these things on the surface by rubbing the 2 parts together or by rubbing a additional maybe sandpaper or any other rough surface on the surface of the adherent, so that these 3 things or some of these 3 things are created on the surface to make the surface ready to facilitate the mechanical interlocking when the adhesive is applied on this surface. So, first important requirement for mechanical interlocking is the presence of peaks, valleys, pores and crevices on the adherent surface. Now, if these are present and you have applied adhesive on the surface, how the joining will take place? The joining will take place or the bonding will happen due to the interlocking or anchoring of the adhesive to the adherent.

Now, if some crevices are present, the anchorage of the adhesive will enter into those crevices and it will act as an anchorage point and it will form the joint or if peaks and valleys are present in between, the adhesive will go and it will form a mechanical type of interlocking between the 2 surfaces or the 2 mating surfaces or the 2 adherent surfaces. So, mechanical interlocking is the first mechanism of joining between the 2 types of composite adherents or the polymer or plastic adherents.

Now, second bonding mechanism is the chemical bonding between the 2 adherents. Now, this type of chemical bonding as in case of mechanical interlocking, you require pores, peaks, valleys and crevices. In chemical bonding, you require specific groups at the surface which will facilitate the chemical bonding between the adhesive and the adherent. Now, what are these specific groups that are required to be present on the surface of the adherent that we will try to understand?

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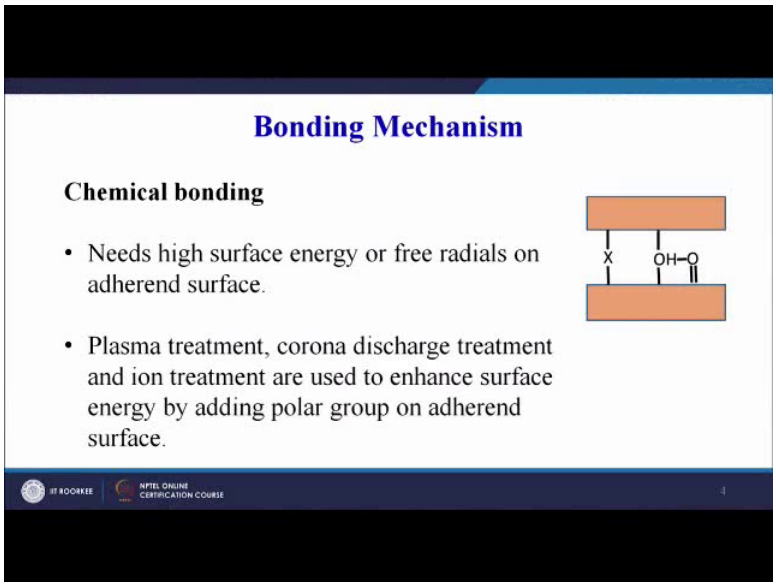

So, first requirement for chemical bonding is that you need to have high surface energy or free radicals on the adherent surface.

Now, when you have prepared your surface, you have made your adherent using any of the techniques for processing of polymers or polymer based composites. You may not be having these free radicals or high surface energy at the surface, now how to form the joint. For forming the joint, you have to induce certain treatment of the surface, so that a surface becomes ready for joining and how those treatments can be done what are those treatments, let us try to see. Plasma treatment is one such treatment; corona discharge is another treatment, then ion treatment of the surface. These treatments are used to enhance the energy and these add polar groups on the adherent surface. These polar groups will help us to facilitate chemical bonding between the adhesive and the adherent.

So, that is a requirement and if these treatments are done on the surface, we can get a very good bonding between the adhesive and the adherent. So, you can see in case of adhesive bonding, the first and the foremost as well as the most important step is to prepare the surface for bonding. If our surface is not prepared for bonding, we will definitely not get a good joint and failure of the joint may take place.

So, the joining mechanisms can be either through mechanical interlocking or it can be through the chemical bonding between the adhesive and the adherent, but both these mechanisms are only possible, can only happen if we prepare our surface accordingly. In

case of mechanical interlocking, simple rubbing of the surface to create a different types of surface roughness, a different types of pores, crevices, peaks and valleys at the surface. So, mechanical type of treatment is required whereas, in case of surface preparation for chemical bonding, we may require corona discharge plasma treatment or ion treatment of the surface. So, that we can add polar groups on the adherent surface and the joining can be done.

This mechanism that you see on your screen, we have covered in the previous session also that how fusion bonding takes place. So, diffusion bonding you can see it happens when the change untangle with one another and here we see the interface, the black dotted line is showing the interface.

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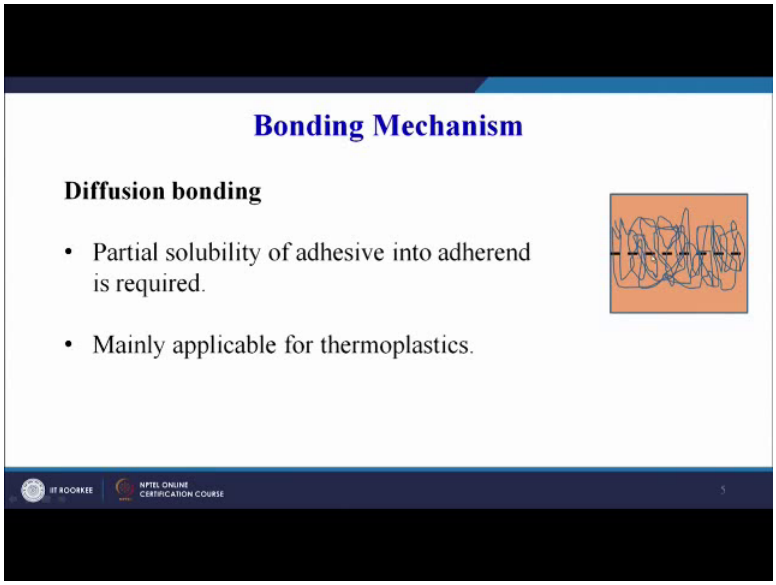

So, this top one is our first adherent, this can be the second adherent at the joint interface, the entangling of the polymer chains or diffusion of the polymer chains at the interface will add to the bonding of the 2 adherents. So, partial solubility of the aggressive into the adherent is required.

So, if we talk of fusion bonding where there is no adhesive directly to surfaces are being joined, the solubility or the diffusion of the change will be from one adherent to the other adherent whereas, in case of adhesive bonding when we are applied the adhesive which can also be a polymer on the surface of the adherent, then this diffusion will be from the adhesive into the adherent and if you remember in our previous session, we have seen

the first diagram for adhesive joining. There was a top substrate, there was a bottom substrate and there was a blue color adhesive layer in between the 2 substrate and between this adhesive and the substrate 1 there was a boundary layer 1.

Similarly between the adhesive and the substrate 2, there was a boundary layer 2 and at this boundary layer, this type of diffusion has to take place that will only happen at because of the partial solubility of the adhesive into the adherent, that is the chains may have to untangle or chains may be diffused into one another. So, this is mainly applicable as we have seen in our previous session also is mainly applicable for thermoplastic materials because of the long chain and when you are supply a heat, the weak bonds between the long polymer chains they break and then, the chains can slide untangle and form the joint.

Now, let us try to see the types of adhesive joints. You can see very common types of joint configurations are shown here for polymeric materials also or for polymer based composite materials also. Similar type of joint configurations are used and just for revision purpose let us see that what type of adhesive joint configurations or joints can be applied or used in case of polymers as well as polymer based composites.

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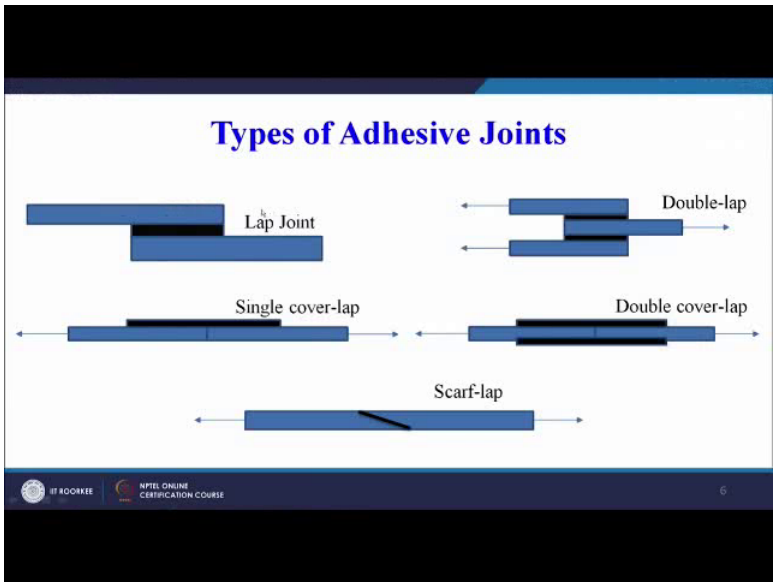

So, we can have a simple most simplistic lap joint configuration, we can have double lap joint, we can have single cover lap. Basically these are the blue portions depict the

adherents. This is adherent 1, adherent 2 or substrate 1, substrate 2 in between black is representing the adhesive.

Here also this is the adherent, second adherent, third adherent and in between we have the black color 2 layers of adhesive and therefore, we have a double lap joint here, we have 2 adherents joined in, but on top we have a single cover lap layer of the adhesive and therefore, we call this as a single cover lap joint. This is the black color adhesive and this is double cover lap joint even maybe more stronger as compared to single cover lap and then, we can have a scarf type of lap joint maybe if you can see the length of the joint is increased if you adopt the scarf configuration.

So, we can have different, these are not the only joint configurations that can be used for joining of polymers or polymer composite. There can be number of other joint configurations that are possible, but just to highlight that joint configuration also plays a very important role in the joining of polymers as well as polymer composite, this slide has been included in our discussion. Now, this is from a research article that is an updated review of adhesively bonded joints in composite materials by S. Budhe.

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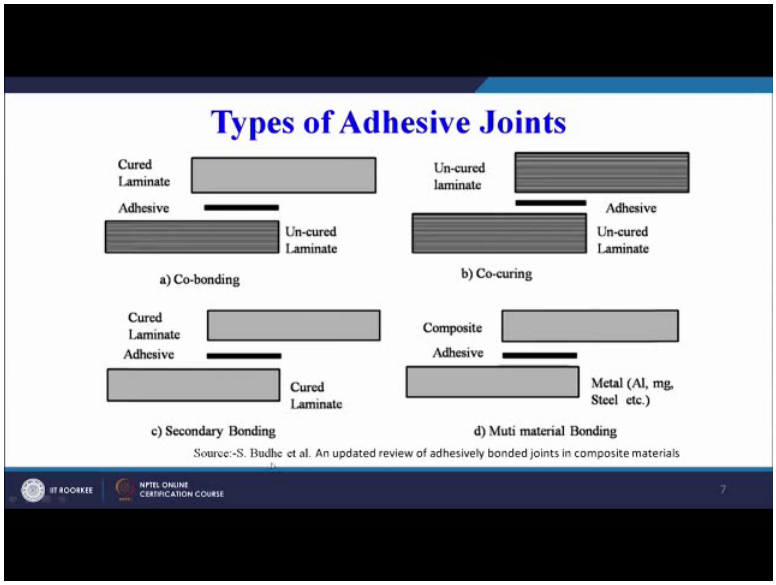

So, we can see the types of adhesive joints. Here this is a cured laminate. Now, I think by now you understand the difference between a cured and a uncured laminate. So, cured is which has completely undergone the process of polymerization and strong and stiff physically and the complete polymerization has taken place, that is the product is ready

for use. So, that is the cured laminate; uncured means that the polymer is not enough fully cured state and still it requires heat or pressure to fully cure the material.

So, we can have this black portion is the adhesive again. So, we can make a joint in which one laminate is cured and another composite material or laminate is uncured and we can make a joint which we call as the co-bonding type of joint. Then, both the laminates are uncured. The top adherent or laminate is also uncured, the bottom adherent or laminate is also uncured. So, this is also uncured, this is also uncured in between of the adhesive may make this joint laps, single lap joint configuration, put it in a furnace or in a heating oven and we can go for co-curing. Co-curing means both the adherents are getting cured.

Third type is secondary bonding. In most of the cases, in case of composites, we will have both the laminates which are in cured state. This is also final product of a process. Both the adherents have been cured successfully and completely and finally, we put a adhesive between the 2 and we joined the 2 or we join the 2 adherents together or 2 composite laminates together to form a composite joint. So, between we put the adhesive, then the last configuration is multi-material bonding and this is called secondary bonding and we are calling it as a secondary joining technique for polymer composites.

Last one is the multi-material bonding. The top adherent, this is a top adherent, this is a composite material. The bottom adherent is a metal. It can be aluminium, magnesium, steel, any other metal and then, we are joining them together with the help of an adhesive. So, this is multi-material bonding. So, these are different types of joints. There can be other combinations of materials also. That is possible maybe in some cases we may have to join a composite laminate with glass which is a non metallic material. Sometimes the composite laminate may be required to be joined with a ceramic type of substrate that is different type of joining and we have to see what are the conditions and requirements required or necessary for making that joint possible and making that joint a good joint.

So, therefore these are not the only, these are just depictive of the different types of joints which are possible with the composites. So, basically just to revise this slide, we can have a look that we can have a co-bonding where one laminate is cured and other

laminate is uncured. In between we put the adhesive we can have co-bonding or co-curing, co-bonding one laminate, cured another laminate uncured in between adhesive.

Co-curing both the laminates are uncured in between adhesive, then you go for the complete curing of the complete assembly. In between there is a adhesive top and bottom laminate, both are uncured. So, you get your complete product out of the oven, then you have secondary bonding in which both the laminates are cured. In between you have the adhesive and finally, the multi material bonding in which one is a composite material and another one is a non-composite material. It can be a metal or a nonmetal. In between you have an adhesive and then, you make the joint.

So, friends in our previous slide, we have seen that; what are the types of adhesive joints. Now, let us try to understand failure mechanisms in the adhesive joints. So, we can have a adhesive failure. These are the 2 adherents; the blue color, this is a adherent 1.

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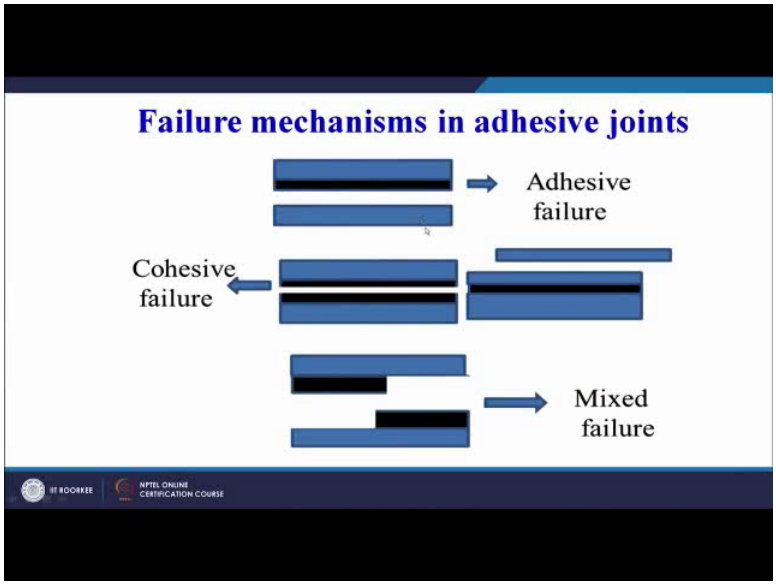

This is adherent 2. In between the black layer depicts our adhesive. Now, we can have an adhesive failure in which the adhesive has failed or we can see the bulk failure of the adhesive has taken place. So, that is the adhesive failure.

So, second is the cohesive failure in which either the adhesive has failed or the adherent has also failed. So, adherent failure means that the layers have got delaminated, the joint is intact, but the adherent has failed on the application of load or the adhesive has failed.

So, we can see the adhesive failure or the adherent failure, we can call it as the cohesive failure. Then, we can have a mixed type of failure in which the adherent can fail, the adhesive can fail, the adherent and the adhesive both have failed plus there is a de-bonding between the adhesive and the adherent.

So, different modes of failure are coming into picture and therefore, we call it as a mixed failure. So, basically to revise just in the previous session also I have told that in case of a adhesive joint, 3 types of failures may happen which was explained earlier also that adherent may fail, joint is intact, that is the laminate that we are using as a raw material for joining the laminate has failed in between 2 layers have got de-laminated. So, that is the failure of the adherent. Then, there can be failure of the adhesive that we have applied a thin layer of the adhesive between the 2 adherent. The adhesive was failed form in between of the bulk failure of the adhesive has taken place.

The third type of failure can be the de-bonding between the adherent and the adhesive, but there is fourth that is a mixed mode. The adherent has also failed. The adherent has got de-bonded from the adhesive as well as the adhesive also had a bulk failure. So, all 3 things have failed. The adherent has failed, the joint has failed as well as the adhesive has failed, but from another point of view we can have an adhesive failure or a cohesive failure.

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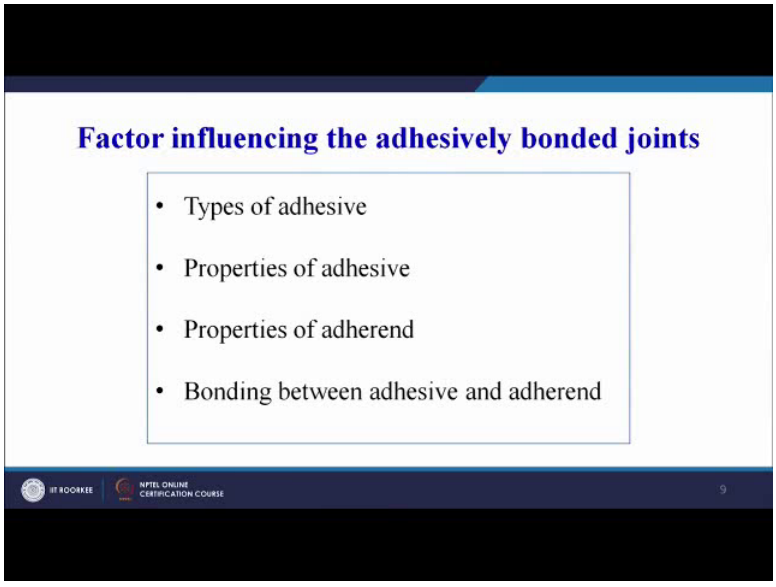

Now, what are the factors influencing the adhesively bonded joints? Just we will have a long list. First one is the types of adhesives used. Different types of adhesives are used for joining the composite materials or the polymers, properties of the adhesive properties of the adherent, the 2 pieces or 2 composite parts that we want to join together bonding between the adhesive and the adherent. Now, again the factors influencing the adhesively bonded joints you can see again the same things what can fail an adherent, can fail adhesive, can fail or the bond can fail.

So, the bonding will depend upon the type of the adherent, the type of the adhesive, the type of the joint, the type of the interface that we are developing between the adhesive and the adherent. Again same points are being listed here, type of adhesive property of adherent bonding between the adhesive and the adherent.

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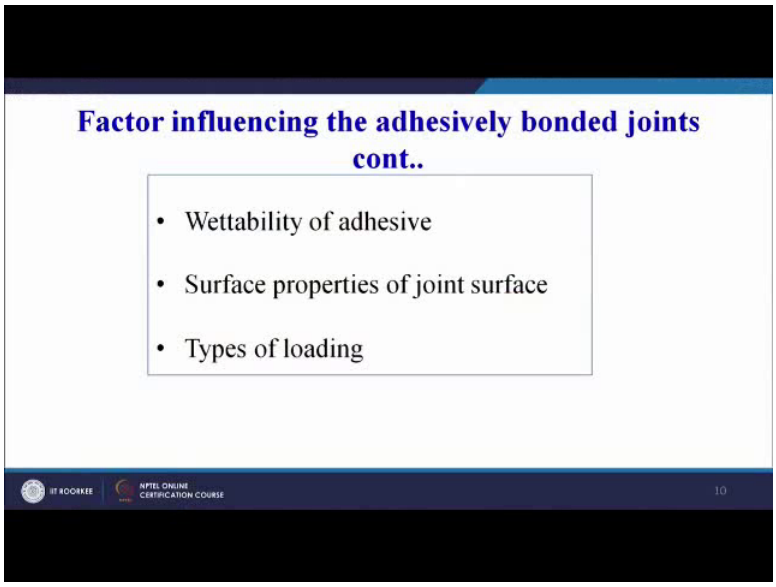

Wettability of the adhesive is also very important. Now, we need to have very good wettability that if you remember in our first session, we have seen a video in which the 2 plates were being, 2 glass plates were being joined together in between a thin drop of adhesive. It was dropped from the tube and another adherent or substrate was placed on this plate having the adhesive. When it was placed on top of it, the adhesive spread all across and the joint was formed.

So, wettability of the adhesive is very important. If the adhesive will not wet the surface properly, the joint strength would be very poor and may not lead to a good quality joint.

So, the wettability of the adhesive is important, then the surface properties of the joint interface are very important and today, we have seen that in order to develop a joint either by mechanical interlocking or by chemical bonding between the adherent and the adhesive, we require or we need or it is necessary to do the edge preparation or the surface preparation for mechanical type of interlocking. We need to develop pores, crevices, peaks and valleys on the surface or in nutshell we need to make our surface rough for joining purposes from chemical bonding point of view. We can very easily say that we need to go for plasma treatment, ion treatment or corona discharge treatment in order to improve the surface energy, so that we can bond between the adhesive and the adherent.

So, surface properties of the joint surface need to be manipulated, need to be maneuvered in order to get a good joint and then, the factors that influence the adhesively bonded joint are the type of loading also that how the joint is going to be loaded. Either it is going to be loaded under tensile load or it is going to be loaded under compressive load or under flexural load that we have to see and accordingly, this will influence the selection of the joining method, the type of joint configuration. It will also help us to decide on the type of adhesive that we are going to use. It will also help us to decide the joint overlap area.

So, the type of loading will also be an important design parameter which will help us to join the member successfully or I should say that it will also help us to design our joint properly that what type of loading the joint is going to bear in its service life. Now, finally we come to the advantages of adhesive joints.

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So, we will see quickly that what are the advantages. They are fast and cheap. Joining technique, the adherents are not affected by heat because we are only applying the adhesive and then, we are joining them together.

Now, some of you may be wondering from where heat is coming into picture. Please refer to our last session in which we have seen microwave joining, we have seen resistance joining, we have seen induction base joining broadly falling under the fusion joining method or fusion joining technique. There lot of heat has to be supplied whereas, in case of adhesive joining, not much heat is required. If the adhesive and the adherent join by chemical bonding, there may be some exothermic reaction take place, some amount of heat may be generated, but the bulk of the adherent will not be influenced by that heat.

So, the adherents are not subjected to heat in case of adhesive joining whereas, they are subjected to lot of heat in case of induction joining or resistance joining or microwave joining and we have to do the adequate masking in order to avoid the effect of heat. Then, we get uniform stress distribution which is a challenge in case of mechanically fastened joint. In case of mechanical fastening, we require a hole which will induce a stress concentration point in the joint whereas, in case of adhesive joining, no stress concentration will take place or the stress distribution will be uniform all across the joint overlap area.

Possibility to join large structures, yes it is a possibility with adhesive joining, their ability to join different types of materials, good advantage of adhesive joining, possibility to joint very thin adherents. They can make gas proof and liquid tight joints. An adhesive joining has that capability. No crevice, corrosion, no contact corrosion, good damping properties. Now, lot of advantages are there because whenever we talk of mechanical fastening and mechanical or metallic fasteners, there are chances of corrosion whereas, in case of adhesive joining, such type of corrosive effects can very easily be avoided.

So, therefore adhesive joining has got lot of applications, lot of advantages as compared to the other methods of joining, but it has got its grey areas also.

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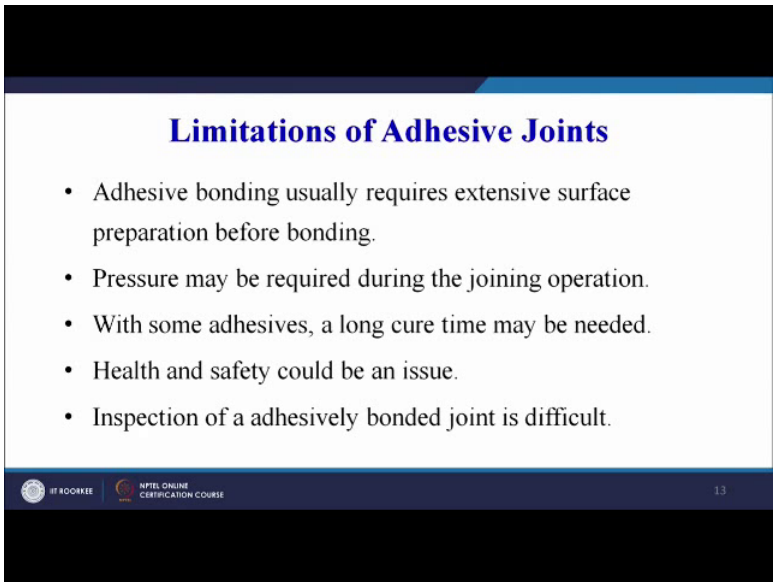

Let us try to understand; what are the limitations of the adhesively bonded joints. First is the adhesively bonded joints usually requires extensive surface preparation before bonding. I think it has become absolutely clear to develop mechanical type of interlocking or to develop chemical bonding between the adhesive and the adherent surface preparation is mandatory. So, the adhesive joining requires exhaustive surface preparation in order to develop a good joint pressure, may be required during the joining operation. Usually you will see when we join some household items by applying the adhesives, we keep some load or some weight on that joint, so that a joint may be strong and steady. That is our household remedy of applying the pressure, but when we are doing the adhesive joining on a industrial scale, many times we may need to apply

uniform pressure across the joint interface in order to get a good quality joint. With some adhesives a long cure time maybe needed. Again coming to our household, if we join a particular toy using an adhesive, we will keep it may be 6 to 8 hours for complete curing of the adhesive to take place, so that it can form a good joint.

So, sometimes the cure cycles may be very long specially in case of industrial scale joining or using adhesives and therefore, may not be that productive technique. Sometimes health and safety can be one issue with the adhesives because they are chemical in nature and then, inspection of adhesively bonded joint is difficult because we have already seen that it is a permanent joint and the permanent joints cannot be disengaged. The joint only has to be broken in order to get the 2 adherents separate. So, therefore, this is one disadvantage of the permanent joints that maintenance and scheduled maintenance and other problems related to inspection are difficult.

So, with this we conclude today's session on adhesive joining of polymers and polymer based composites. I think in next session, we will discuss the joining intricacies in case of polymer and polymer composites and subsequent sessions will be focused on the secondary processing or secondary processing in terms of joining and machining of polymers and polymer based composites.

Thank you.