

Processing of Polymers and Polymer Composites
Dr. Inderdeep Singh
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture - 31
Mechanical Joining

[FL] friends. Welcome to session 31, in our course on processing of polymers and polymer composites. Just to have a review what we have covered we have covered the course in three broad phases, in phase one we have covered details related to polymers, in phase two we have covered details related to primary processing or primary manufacturing of polymer composites in which we have seen the basic fundamentals of polymer composites that why what are composite, what are polymer composites, why they are required, where they are used, what are the advantages, how they can be classified and then we are focused our attention towards the various processing techniques that are used for processing of polymer based composites. So, phase two was focused on primary information or basic information related to composites as well as the processing techniques that are used for making definite shape or near net shape of the polymer composites.

Now, we are towards the third phase of our course that is a secondary processing of polymer based composites. In secondary processing our focus is on techniques that are used for machining joining of polymer composites, so that we get a tangible product. We have seen that during primary processing of composites may let us take few examples of the techniques that are used for primary manufacturing such as hand layup, spray layup, then compression molding, injection molding, resin transfer molding all these techniques have few limitations - limitations in terms of types of product we can make, limitation in terms of the shapes that we can make limitations in terms of the size of the component that we can make using these processes.

Now, in order to have a complex intricate product we need to join two or three different parts components processed by any of these primary manufacturing techniques and these primary manufacturing techniques have lot of versatility, but still they are not able to make a product which is fully functional. They may be able to make, but there will be some products which are highly complex cannot be processed directly. Let us take a very

very good example of aircraft. Now, aircraft is a big in size product very large size product cannot be directly made using any one process, so you make the parts separately using different processes and then you combine them together. And this background I have already given in our previous sessions also. So, our third phase is now focused on assembly operations joining operations and then we will see that how we can machine the parts in order to make them ready for assembly.

So, third phase is focusing on the secondary processing techniques or secondary processing methods which are used for polymer composites and similar methods are used for polymers also. So, plastic products also can be assembled using these techniques and the polymer based or plastic based composite materials can also be assembled using these techniques. And in this light if you remember we started with the need of secondary manufacturing in which we have try to understand what I have just summarised in last 8 or 10 sentences. Then we have focused our attention on the classification of the secondary manufacturing techniques in which we have seen that we can secondary manufacturing can be done using different techniques.

For joining purposes also we have seen we can use adhesive joining we can use mechanical joining or mechanical fastening, we can use microwave joining, we can use induction joining we can use resistance welding for polymer composites and we are try to understand with very basic schematic of each one of these processes. And now, we are focusing our attention on each one of these techniques. So, we have already understood that what is adhesive joining how it is done what are the limitations, what are the advantages, what are the characteristics of the process in our previous session.

So, today our focus would be on mechanical joining which we can further classify into mechanical fastening as well as there is another name that is given in which we have a integral joint which can be which is mostly used for making wooden types of joint

So, today our focus is on mechanical joining, but if some of you may be wondering that when the material is same, the composite is same and we a want to join them why, there are so many different techniques let us say 5 different techniques we have already highlighted in our session or in our discussions.

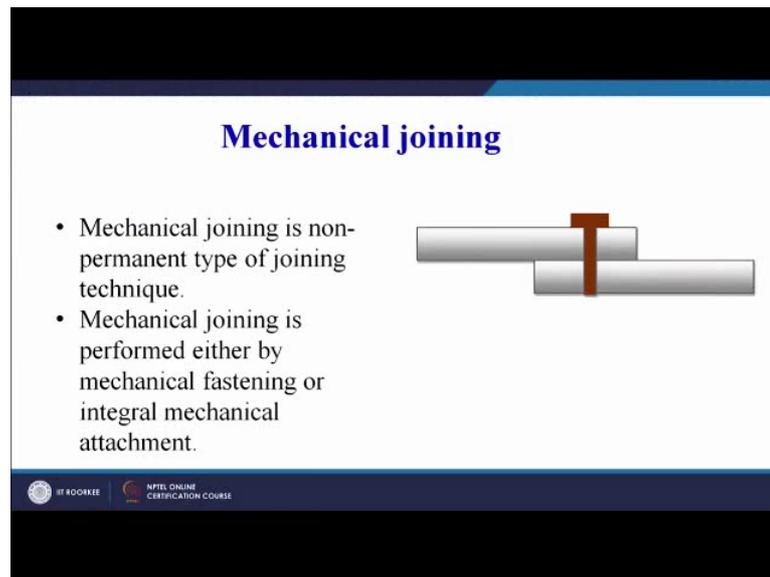
The first one being adhesive joining, mechanical fastening, microwave joining, induction joining and finally, the resistance based welding techniques. So, when the material is

same why do we need to join them using different techniques. Now, there has to be some salient advantages of each one of these techniques for specific applications. For example, where weight is a very very important criteria we would like to use adhesive joining why because in mechanical fastening the nut and bolts if they are metallic we will add weight to our structure. So, where weight is the prime requirement or in situations where we do not want any surface a non uniformity maybe head of the bolt or may come up. So, during that situation we may like to avoid using the mechanical fastening. So, we will use adhesive joining because we do not want to add weight to our structure.

So, depending upon the specific requirement we will use different types of processes or joining processes. So, in the last session we focused our attention on adhesive joining today we will focus our attention on mechanical joining. So, one important application I have told that weight saving as why I have taken this example because majorly composites are developed, conceptualized and they are applied to situations where weight saving is the prime criteria. And mechanical fastening will definitely add some weight to the structure therefore, adhesive joining is preferred, but there will be number of other situations where we have to do a trade off between the adhesive joining and mechanical fastening, between the mechanical fastening and microwave joining, between the microwave joining and the adhesive joining. So, we need to understand that what is the basic requirement for which the joining operation is to be carried out and what are the relative advantages and disadvantages of the joining technique that we are proposing we service or as compared to the other joining techniques.

So, today we will try to understand the fundamentals of mechanical joining and what are the challenges in making a mechanical joint. So, let us start our presentation and try to understand the basic fundamentals of mechanical joining. So, the first point that you see on the screen is that mechanical joining is a non permanent type of joining technique.

(Refer Slide Time: 07:40)



Mechanical joining

- Mechanical joining is non-permanent type of joining technique.
- Mechanical joining is performed either by mechanical fastening or integral mechanical attachment.

The diagram shows two grey rectangular bars joined by a brown T-shaped fastener. One bar is positioned above the other, and the T-shaped fastener passes through a hole in the top bar and fits into a corresponding hole in the bottom bar, illustrating a mechanical fastening technique.

IT ROORKEE NPTEL ONLINE CERTIFICATION COURSE

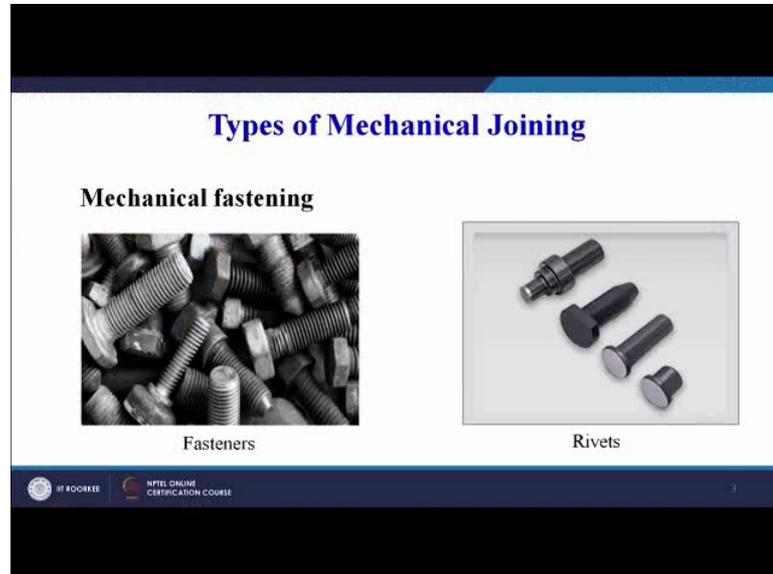
One of the disadvantages of adhesive joining if you remember in the previous session was that it is a permanent joining method.

So, if you apply the adhesive and then you try to disassemble it or you want to do the servicing of a particular part which has been joined using adhesive joining you need to break the joint then only you can access the areas where repair and maintenance is required. So, there we feel that the joint should be semi permanent type so that we can open up the structure and do our repair and maintenance, but in case of adhesive joining that was the limitation and mechanical joining overcomes that limitation of adhesive joining by providing us a joint which is non permanent in nature we so that we can easily disassemble the structure which has been joined using a mechanical type of joint. So, mechanical joining is performed either by mechanical fastening or integral mechanical attachment.

So, in case of mechanical fastening we will use fasteners, in terms of nuts and bolts or rivets whereas, in integral mechanical arrangement we may try to join make a mechanical type of joints, few examples we will try to understand with the help of the figures. So, basically one advantage of the mechanical joint that comes out of this slide is that they are semi permanent in nature we can very easily disassemble a mechanical joint and which will facilitate the easy repair and maintenance of the structure. So, that is one salient advantage of mechanical joints over the adhesive joint. Now, different types of

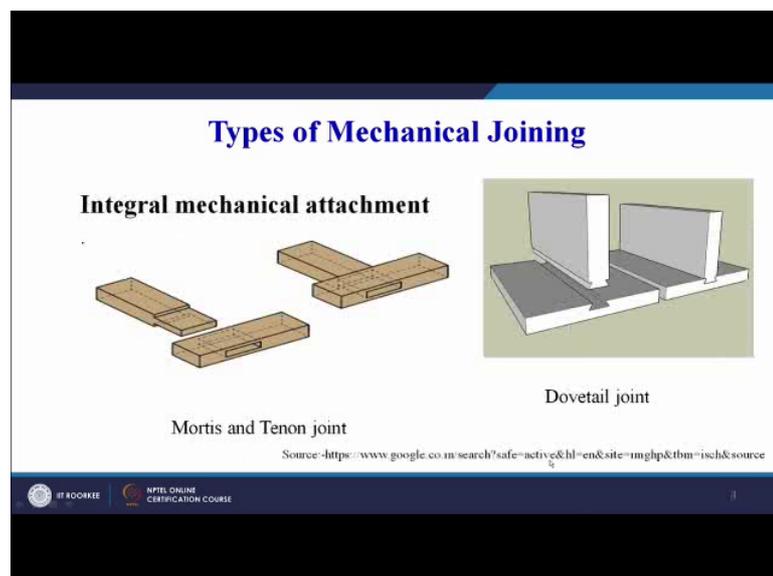
mechanical joining methods are there in which we can use mechanical fastening in terms of fasteners or rivets.

(Refer Slide Time: 09:32)



So, you can see on your screen we can use nuts and bolt type of assembly in mechanical fastening, we can use rivets for mechanical fastening.

(Refer Slide Time: 09:44)



And then there is a integral mechanical arrangement as I suggested this is one joint mortis and tenon joint and those of you who are from mechanical engineering background or production engineering background and might have gone to the workshop

during your first year or the second year, might have been told to make this mortis and tenon type of joint especially in woodworking laboratory or you can say in carpentry shop. So, in carpentry shop or woodworking laboratory you may have developed this mortis and tenon joint where we plane the wood at we make a integral joint that is mortis and tenon joint.

There are other similar types of joints which also used which we can classify into integral mechanical attachments. Similarly a dovetail joint here you can see a very common type of joint we see in our day to day life when we have a sliding type of arrangement we usually have a dovetail joint there. So, this is an integral mechanical arrangement. So, depending upon the requirement we will see that in composites which type of joint can be used.

Now, out of the two that is integral mechanical arrangement and the mechanical fastening. Let us first see the mechanical fastening, in mechanical fastening when we have to use nut and bolts and there are two adherents or two composite parts that have to be joined together, so we will have a lap type of arrangement and then we require a hole through which we can do our nut and bolt fastenings and therefore, it requires making up of holes to here the point mentioned is need drilling of holes rather I must mention that is it that point should be need holes in the composites why because drilling is only one process which is used for making holes.

(Refer Slide Time: 11:30)



Mechanical Fastening

- Need drilling of composites
- Drilling requires selection of tool geometry, tool material and process parameters



IF ROORKEE NPTEL ONLINE CERTIFICATION COURSE 5

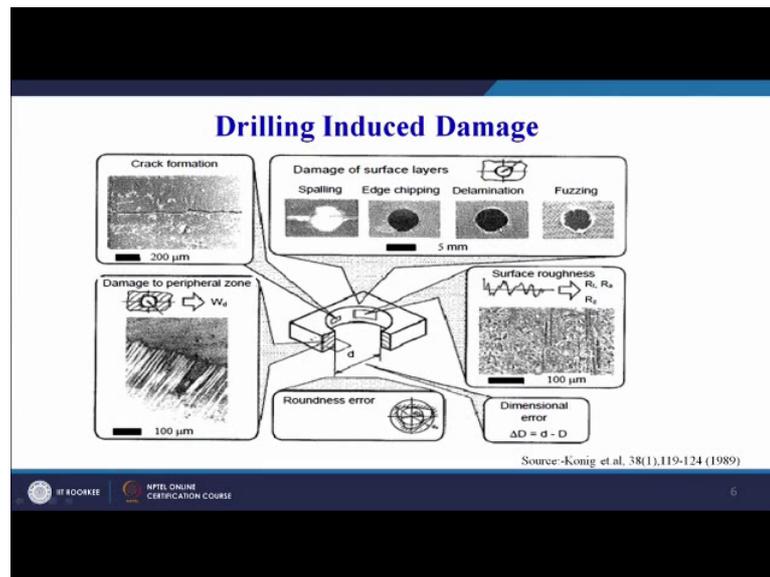
There can be number of other processes which can be used for making holes in the plastics or the composites and those processes what are those challenges, what are those processes process mechanisms we will try to understand in one or two sessions towards the end of our course because making of holes in composites is also very challenging task and what are the problems involved there off we will try to understand today also with the help of one slide.

So, mechanical fastening if you say has advantage that it provides us is with the joint which is semi permanent in nature, but also has limitations that it requires holes in the composite parts or components and the hole making is a challenging task. And therefore, need of drilling becomes imperative and it is necessary in order to ascertain the structural integrity of our composite product. Drilling requires selection of tool geometry. Why it is challenging? I just mentioned that making holes is very easy you if you take a metallic part you take it to a drill drilling machine and make a hole there it is easy, but in case of composites there are challenges, what are those challenges?

We require selection of the tool geometry usually in case of metals we use a twist drill geometry which is already shown in all on your screen this is twist drill geometry can be easily used for making holes in metallic components or parts, but same drill point geometry cannot be used for making holes in polymer or polymer based composites. So, first thing that is required is selection of the tool geometry also the tool material has to be selected this we will see when we will focus our attention on making of holes in composite products.

Today, we are just trying to introduce the concept of mechanical joining but there it requires hole therefore, we are trying to just outline the basic problems associated with mechanical joining. Then the process parameters we need to select in case of drilling usually there are two or three process parameters only the most important being the feed rate and the cutting speed. So, we need to choose and appropriate an optimal cutting speed and optimal feed rate in order to get a hole which is good in quality otherwise what is going to happen you can see on your screen a very important research article published by Konig in the year 1989, you can see this figure has been taken from there and you can see this is the hole which has been made in the composite.

(Refer Slide Time: 14:17)



And this surface is been highlighted here you can see the surface roughness. So, we are not getting a very smooth surface finish in case of drilling of composites. Then we can see crack formation here this section very small section here it is showing the crack formation here. So, you can see the type of defects we are not getting a very good surface finish, surface roughness values are high we get cracks also then at the peripheral zone we can see here we are not getting a very good surface finish. So, the fuzzing is one thing, fibers are coming out then delamination also takes place. So, there are different types I will not going to the detail of each one of these, but you can just keep few important damage forms in your brain or in your mind which you can relate to when you are making holes in composite parts or products.

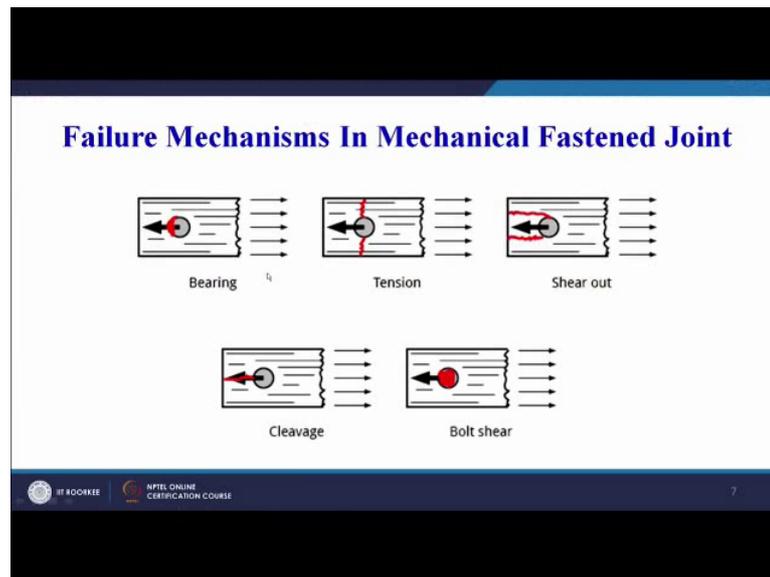
Now, what are these? This is spalling is one type of damage, edge chipping is another type of damage, delamination the most important type of damage in composite laminates specifically in laminates and then fuzzing you can see four different types of damage forms. Then surface roughness is poor we should the surface finish is not good cracks are formed and damage to the peripheral zone and then there are roundness errors also dimensional errors also. So, this slide in a way summarises the problems that mechanical fastening entails; that means, that if you go for mechanical type of joining of composite parts you require holes for making of holes you require some process.

Let us take example of drilling as a process for making holes in composite parts if you drill a hole you will get different types of damage in the composite part what are those damage forms I will just read them out – spalling, edge chipping, delamination, fuzzing, poor surface finish, damage to the peripherals zone, crack formation, roundness error, dimensional error. So, these are all the damages or damaged forms that are associated with the drilling of holes in the composite or specifically polymer based composite parts and components and this we need to avoid. How we can avoid this? We will have two sessions specifically the related to making of holes in composite products.

Now, suppose we are able to make a very good hole in a composite part and then we use nut and bolt a rivet type of fastening method for joining the two composite parts together when we apply the load we can apply a tensile load, we can apply a compressive load it can be a flexural load it can be a impact type of loading environment. Now, depending upon the type of load why the load will act on the joint because the structure that we have developed is going to perform its intended function. It has been developed for a particular application and in application the component or the product has to bare some kind of load and when the load will act on the product what is going to happen to our joint that is a cause of concern or need of concern for all engineers.

And engineers have tried to figure out scientists or researchers have try to figure out that what kind of damage can happen to our mechanically fastened joints and these are the failure mechanisms in the mechanical fastening or mechanical fastened joints.

(Refer Slide Time: 18:15)



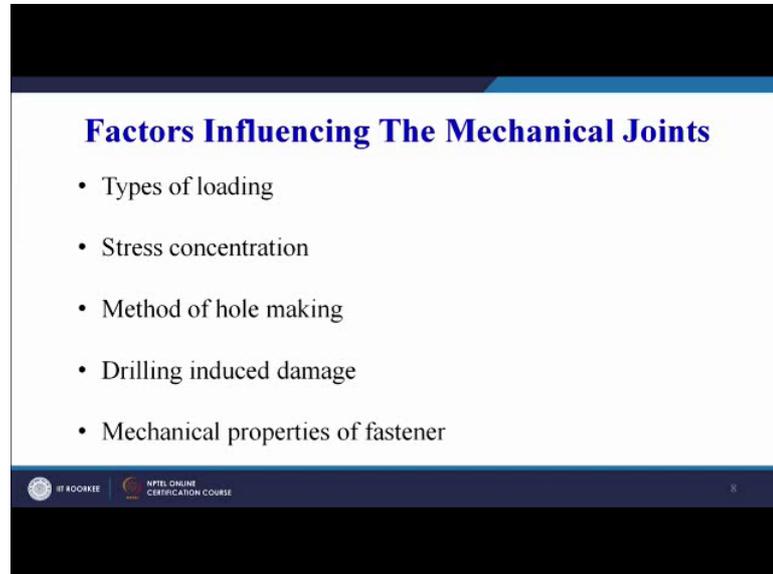
So, we can have a bearing type of failure under tension we can have this tensile type of failure if the red portion is dictating that how or where our composite part is going to fail on application of load. So, when we apply a bearing type of load this is the area that can fail. Tension under tension it can fail like this it can shear out like this then cleavage type of mechanism can also be there and then the bolt shearing where the bolt will shear. So, different types of failure mechanisms can happen when you have used a bolted joint or you have used a mechanically fastened joint what are these bearing failure tension, tension based failure shear out can be one reason cleavage can be the other type of failure and bolt shear is a last type where the bolt may even get sheared.

Now, the bolt will get sheared if the strength of the composite that we are joining is more than that of the bolt or there are some crack initiation points or the bolt has got some inherent defects which have led to the shear of the bolt. So, we can have failure of the mechanically fastened joint under different types of failure modes and failure modes are mentioned on your screen bearing tensile shear out bolt failure or bolt shear or cleavage type of failure may take place.

Now, what are the factors that influence the mechanical joints? There are number of factors which will dictate the performance of a mechanical type of joint. Now, what are these factors? In the previous slide we have seen that there are different failure

mechanisms for the failure of mechanically fastened joint and here you can see the type of loading is one important parameter which we need to control.

(Refer Slide Time: 20:16)



Now, we can have a tensile type of loading on the two members we can ever compressive loading it can be a flexural loading out of plane loading then we can have impact loading we can have fatigue type of loading. So, different types of loads can act on the composite joint and the made using a mechanical fastening technique. So, we have two adherents we have joined them using a mechanically fastened joint and different types of loading environments may act and these loading environments will definitely affect the performance of our mechanically fastened joint. So, that is one important parameters that is type of loading on the joint.

Second is a stress concentration, when you have cut outs when you have holes in composite parts it will lead to stress concentration in that geometrical area or in that area and this stress concentration we will definitely affect the performance of the joint. So, first thing is type of loading, second is stress concentration, third is the method of hole making.

As I have told you never today's session only that it was written it need is drilling of holes. So, I told drilling of holes is one important point, but we should try to understand the need of hole making in composite parts. Because mechanically fastening joint will definitely requires holes and the method of hole making will also influence the

performance of the joint. If you remember in our sessions I think two sessions prior to this session we have try to understand the different secondary processing techniques in which we have seen ultrasonic method of hole making. So, it is not only drilling as a method of hole making in composite parts we can have other methods of hole making also, different types of geometries like trepanning tool can be used for making holes in composite parts, similarly ultrasonic drilling of holes can be done in case of composite parts. So, the method of hole making is also important and why it is important because different method will induce different type of damage in the composite part.

For example, when the tool is not coming in direct contact with the work piece we may not get delamination as our damage type or damage form whereas, when the tool is in direct contact with the work piece delamination is one of the most significant damage forms that is no that is noticed or that is observed in the composite parts. So, therefore, the method of hole making we can use conventional drilling method, we can use ultrasonic drilling method, we can use the woodpecker cycle for making a hole, we can use step drilling method. So, there are we can use vibration assisted drilling method. So, there are different type of drilling methods which are used in each one of them will have its own characteristics, own advantages, own limitations.

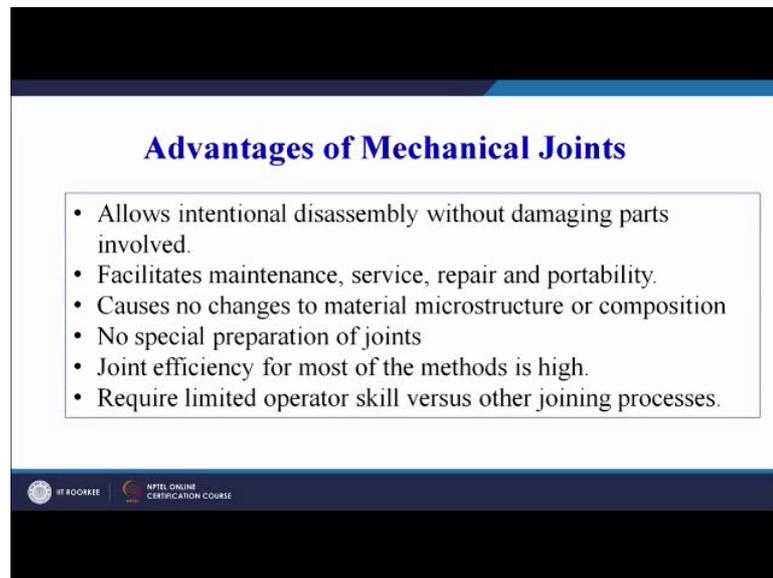
So, therefore, when we are going to use a mechanically fastened joint and we require a hole in the composite part, we need to choose the method of hole making very very judiciously. So, that it does not have much damage or the damage in the composite part is minimal on account of the hole making technique. And therefore, we will get a good joint which will give us better performance. In comparison to a joint or a composite part which has lot of damage around the hole then we are using nut and bolts for fastening on loading the product of the structure may fail. So, therefore, the method of hole making is also very very important and we will try to understand it in our subsequent sessions. Similarly drilling induced damage I have already related that two that if the method is not proper you get more damage your performance is poor.

If you chose the best method your damage is less and you get a good performance from the joint. So, therefore, method of hole making is directly proportional to the drilling induced damage. Then the mechanical properties of fastener is also very very important as I have told you the bolt shear may happen on loading why because the fastener is not designed properly the diameter is not accurate it may have some inherent defects which

may lead to the failure of the fastener. So, the mechanical properties of fastener are also very very important. Suppose we choose a material which is brittle and when we apply the load instead of the adherent or the composite failing our fastener has failed. So, there is no point in using that fastener which fails before the adherent.

Now, let us conclude our session today with the advantages as well as limitations of the mechanically fastened joints.

(Refer Slide Time: 25:15)



Advantages of Mechanical Joints

- Allows intentional disassembly without damaging parts involved.
- Facilitates maintenance, service, repair and portability.
- Causes no changes to material microstructure or composition
- No special preparation of joints
- Joint efficiency for most of the methods is high.
- Require limited operator skill versus other joining processes.

IT ROOIKEE NITEL ONLINE CERTIFICATION COURSE

Now, major advantage is that it allows intentional disassembly without damaging the parts involved. So, this point has been adequately addressed in our first slide only that mechanically fastened joints are semi permanent types of joint and they facilitate disassembly of the composite parts for ease of repair and maintenance. It facilitates maintenance service repair and portability. Now, composite structure may be developed in parts in the factory and from there it can be transported to the site where the products or the structure has to be used and mechanical fastening can be done to raise the structure or to assemble the structure there.

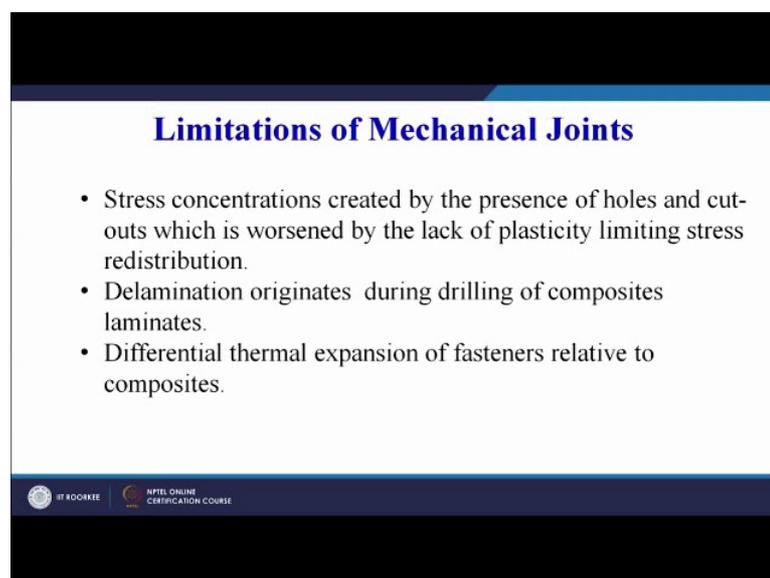
Therefore the mechanical fastening ensures maintenance, service, repair and portability to our structure. Causes no changes to the material microstructure or composition because mechanically we are making the holes so we are using nut and bolt type of fastening techniques, so there is no change in the material microstructure involved. Physical damage may happen because of the drilling action, but no changes in the

microstructure happens because of the mechanical fastening approach. No special preparation of joints one of the disadvantage in case of adhesive joining that we have seen in our previous session was that it requires extensive surface preparation in order to facilitate a joint between the two mating parts, but that kind of surface preparation is not required in case of mechanically fastened joints.

Joint efficiency for most of the methods is good; it requires limited operator skills versus the other joining method. So, it is easier method for joining of two composite parts only thing is research is required related to the hole making approach which is integral part of the mechanical fastening technique. So, we have to understand that how the hole should be made in the composite part so that we can facilitate our joint using the mechanical fastening. So, operator skill required is less joint efficiency is good no special preparation is required for making the mechanically fastened joints.

Now, let us see the limitations because I have told you there are 4 or 5 different methods of joining adhesive joining, mechanical fastening, microwave joining, induction joining resistance welding. So, each one of them have got their advantages and limitation none of the process has got no limitation every process has got some limitation similarly mechanically fastened joints also have got limitation so stress concentration. As I have already explain it is created by the presence of holes and cut outs which is versant by the lack of plasticity limiting stress redistribution.

(Refer Slide Time: 27:58)



Limitations of Mechanical Joints

- Stress concentrations created by the presence of holes and cut-outs which is worsened by the lack of plasticity limiting stress redistribution.
- Delamination originates during drilling of composites laminates.
- Differential thermal expansion of fasteners relative to composites.

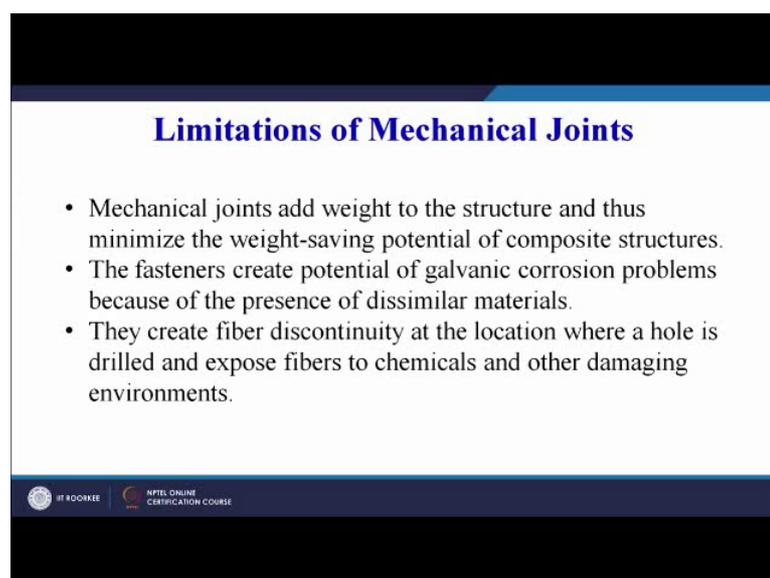
IT ROORKEE NPTEL ONLINE CERTIFICATION COURSE

So, usually stress distribution does not happen that easily in case of holes and cut outs in the products or the parts that is composite parts or plastic parts or polymer based components. So, the stress redistribution is relatively difficult sorry and therefore, there is an issue in relation to or in context of the stress concentration.

Delamination originates during drilling of composites on this damage forms how to make a good quality hole in a composite product we will try to understand it with a special session dedicated to this topic. Differential thermal expansion of fasteners relative to composite that also poses problems because most of the fasteners will be made up of metals and our composites we have in the bulk a polymer or a plastic and the fibers. So, we have a combination of materials or a multi material metal concept in our joint a metal a polymer and a fiber and therefore, a coefficient of thermal expansion becomes important. So, therefore, they this is one limitation when we have some of you may be wondering.

That why not to use a fastener also of the same material. So, that is also important suggestion maybe from your side, but in order to make the fasteners of composite material it itself require a very specialized method. Therefore, the standard fasteners which are available are mostly used for fastening the composite parts I have already explained the first point that is on your screen.

(Refer Slide Time: 29:49)



Limitations of Mechanical Joints

- Mechanical joints add weight to the structure and thus minimize the weight-saving potential of composite structures.
- The fasteners create potential of galvanic corrosion problems because of the presence of dissimilar materials.
- They create fiber discontinuity at the location where a hole is drilled and expose fibers to chemicals and other damaging environments.

IT ROORKEE NPTEL ONLINE CERTIFICATION COURSE

Mechanical joints add weight to the structure and thus minimise the weight saving potential of the composite structures. Now, composites are usually developed for weight saving purposes and if we are using mechanical fasteners made up of metals and then subsequently, then the mechanical fasteners will add weight to the structure and our major purpose of saving weight is lost.

The fasteners create potential of galvanic corrosion problems because of the presence of dissimilar materials. So, the multi material concept which I have already explained in context of the differential thermal expansion also plays a role in the galvanic corrosion also because we have a metallic fastener, we have a polymer based, we have a polymer based material. So, different materials there are chances of galvanic corrosion and if sometime another maybe a liquid or oil is added in between the fastener and the bulk material there are chances that chemical reactions may happen and the material may start degrading. So, the chances of galvanic corrosion also high when we use multi materials for fastening the joints.

They create fiber discontinuity at the location where a hole is drilled and exposed fibers to chemicals and other damaging environment. So, this is also one of the limitation as we can see that when we are using the structure oils or chemicals may seep in at a location where we have a fastener and our composite product in contact. So, the composite part if a hole has been made using the drilling action there are going to be certain cracks as was shown in one of the slides today that crack formation is also one of the damage forms. So, now, we have a crack we have a mechanical fastener and we have oil or a chemical seeping into the crack. So, you can yourself imagine that galvanic corrosion plus the degradation of the material will definitely affect the performance of joint which is the severe limitation of the mechanically fastened joints.

So, with this you come to the end of our session on mechanical joining. In today's session we have tried to understand that what is mechanical joining how mechanical joining is done using the nut and bolt type of fasteners, then we have try to understand the problem areas associated with mechanical joining and we have tried to understand the advantages of the mechanically fastened joints. We have also tried to very briefly understand that how the failure of a mechanically fastened joint may happen. In the next session our focus would be on another technique which is different from adhesive joining

and mechanical fastening and which is also used for developing or making joints in the composite parts specifically polymer based composite parts.

Thank you.