Processing of Polymers and Polymer Composites

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Lecture – 17
Hand Lay-up

[FL] friends, welcome to session 17 or lesson 17, in our course on processing of polymers and polymer composites, just to have a brief overview of what we have covered till now until thirteenth session, we were focusing our attention only on polymers, if you remember we have seen, what are the different types of polymers what are the specific properties of the polymers also. We have seen the processing techniques that are used for processing of various types of polymers that is thermosets and thermoplastics.

If you remember, we have seen the casting process, the extrusion process, the thermoforming process, the transfer molding process, compression molding, injection molding, rotational molding processes for processing of polymers. Now, we can make a polymer parts using any of these processes, but currently there is a trend of increasing or improving or enhancing the properties of the polymers for structural applications and in that scenario, we are making use of the polymer based composites. The basic matrix or the basic bulk is the polymer and it is reinforced with different types of reinforcements. So, once after session 13, our discussion was over on processing of polymers.

We shifted our attention towards processing of polymer based composites and if you remember and if we have seen, the previous sessions, we have then focused our attention on the classification of composite materials prior to that, we have seen what is the basic concept of composite materials, then we have seen that what are the challenges in the processing of polymer based composites. We have also seen that composites are broadly processed in 2 major categories, that is, first is the near net shape manufacturing, that usually we call as the primary manufacturing, in which we give a shape to a composite.

And then we go to the secondary manufacturing, in which you join the 2 different parts together, either by adhesive joining or by making a hole and doing nut bolt type of fastening or using microwave energy. We try to join the 2 parts together. So, joining the machining, the heat treatment or all these processes that try to bring these composite

parts into actual application, are falling under the secondary manufacturing category. So, broadly processing of polymer composites can be classified into two, the primary manufacturing and the secondary manufacturing.

And currently our focus is on the primary manufacturing of composite materials and we are going to start our discussion and as is the feedback from the students, in other course, which is also available on YouTube, that is processing of non metals. There was a request by a large number of students that, there should be videos, also showing the process and we have tried, if you see the previous sessions that we have taken very simple, 1-2 minute videos of the process. We have try to incorporate in our discussion. So, that it becomes more, we can say understandable for the students.

So, today we are going to start with hand layup technique, which is the most common primitive and simplest form of processing of polymer based composites and this is used for continuous fiber type of reinforcement. So, the reinforcement is in the form of continuous fibers. So, we can have a cloth type of a reinforcement in the, that is the fibers. We will see in the video also. We will try to see it in our diagrams also that the reinforcement is continuous fiber, like our cloth, the shirt, I am wearing. You can cut it as per the requirement and then that we can use as a reinforcement and the polymer, generally used for hand layup process, is a theromset and epoxy and polyester are examples of polymers which are used in case of hand layup process.

So, we will try to see that, what are the basic fundamental steps of a hand layup process which is a most commonly used simplest method of processing of polymer based composites and for those of you, who are planning to conduct a research also. In the area of a composites, if the most simplest form of setup, that you can develop in your lab, is the hand layup setup and we are going to see that, what are the basic requirements for the hand layup setup and how you can make a composite material using a hand layup process.

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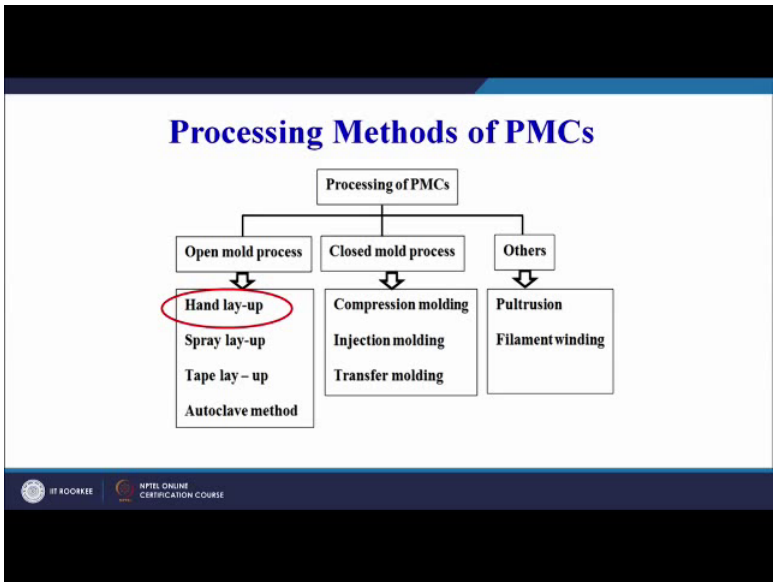

Let us start our discussion. Now, before going to the hand layup process, let us quickly see the broad classification of the processing techniques, on your screen, we have tried to summarize or we have tried to classify the processing of PMCs, you can see a open mold processes, closed mold processes and the miscellaneous and other processes, which usually do not fall in the open mold or the closed mold processes. Now, open mold processes are hand layup, spray layup, tape layup, autoclave method and closed mold, are compression molding, injection molding, transfer molding and in others category, we have pultrusion and filament winding. So, we are currently at lesson number 17, in our course on processing of polymers and polymer composite.

So, we are left with 13 more sessions, in this course and we will try to see, sorry not 13, 23 more sessions in our course, because we have a 20 hour discussion in which, we have completed seventeen half hour courses. So, which means we have today is a 17. So, we are 8 and a half hours of discussion, we have done and remaining, a 11 and a half hours discussion. We have to still complete and I have must address here, that our subsequent part will be focused on polymer based composites only, and we will try to cover as much processes as possible, as is are shown on your screen.

So, we have a total of around 9 processes on your screen. So, we will try to cover each one of them with respect to the composite materials and specifically, the polymer based composite materials. So, by lesson 17 out of 40, we are starting our discussion on

polymer composites and the remaining 23 will be focused on these processes only. So, the why I am emphasizing, it is second time, because we have to cover all these processes, one by one and also we have to cover the secondary processing, which is not mentioned on this screen.

So, we have to cover the machining aspects of polymer based composites, we have to cover the joining aspects of polymer based composites. So, all that information has to be completed within a domain of 20 hour, within a span of 20 hours. So, we are, we have to maybe slightly more cautious, as well as more brief. So, that we are able to cover all these aspects. So, today, our focus will be on the very first process in the open mold processing category, that is the hand layup process. This is what; we are going to cover today, as has been highlighted on your screen.

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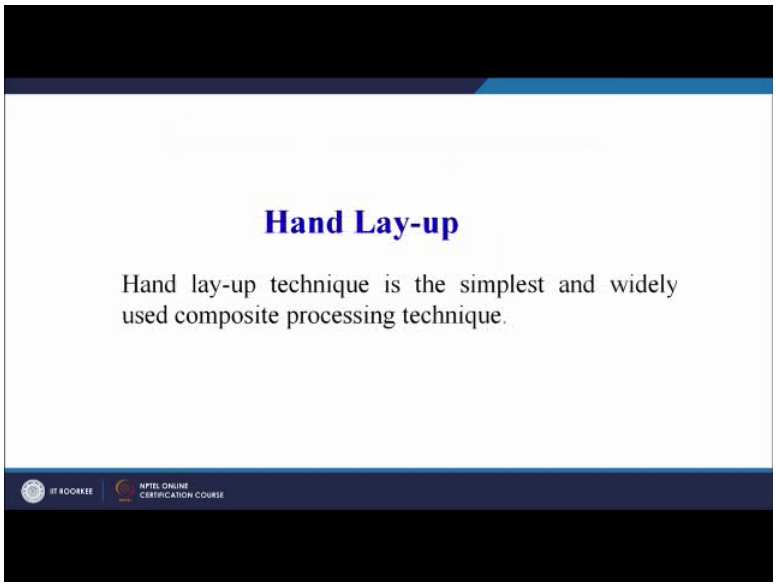

Now, hand layup as the name suggest, I usually emphasize it in case of polymers also I have emphasize, that we should focus on the name and we will always remember the process, throughout our life, we need not cram the things. We need to understand the things. Now, here you see hand layup. So, layup maybe a combined word; so, hand layup. So, what we are going to do; layup laying like laying of bricks, what we do in laying of bricks? We first make one layer of bricks, then we put on top of that second layer of bricks, then third layer of bricks is laid up, then forth layer of bricks is laid up.

So, laying up means stacking and hand means manually. So, what we are going to do in case of a hand layup process, that manually we are going to stack up the different layers. So, that we have to see and try to understand that what will, what are the layers, how the polymer will come into picture, how the 2 will be blended together, how we will consolidate them, how we will get a composite material based on the fiber and the polymer, all that we have to understand if you remember in our previous session. We have seen that composite materials are tailor made materials, which is the biggest advantage, but that is a most flexing challenge also, because how to combine, 2 different materials, one is substantially different chemically and physically.

Another constituent is entirely different may be reinforcement is different, matrix is different and we have to combine. These 2 distinct materials together in order to make a third material and a third material should have better properties as compared to the individual constituents, then only the purpose of combining these 2 constituents is achieved. So, we have to see that how we consolidate this material. So, that we get the desirable properties. So, hand layup process is the simplest and widely used composite processing technique. Here, the size of the job size of the work size of the product does not matter, it can be as big as a boat or a marine boat, it can be as big as a tank over head water tank.

It can be made by filament winding process also, but just to explain that the size does not matter, in case of a hand layup process. We need to have a mold and based on that mold. We can make a very big composite product, using the hand layup process. This is a simplest and most widely practiced process, for making of polymer based composites.

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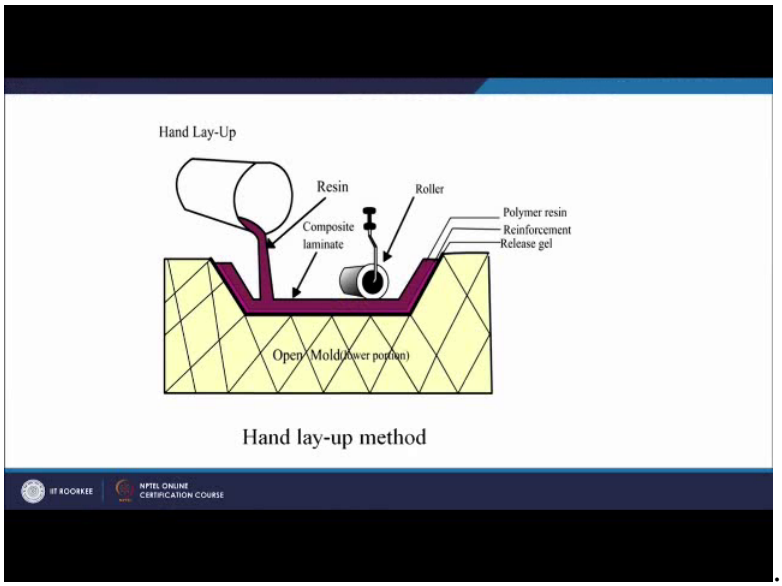

On your screen, you can see the most simplest diagram, which can explain the basic working principle of the hand layup process, just first I will read, what is there on the screen.

First of all, we have a open mold as this process was falling under the open mold processing technique, you can see, we have a open mold, this is a mold, then we have a release gel, this there, here we have a release gel, why release gel is used we will see, then we have the reinforcement that is a fibrous reinforcement in the form of continuous fibers. Then we have the polymer resin here you see the polymer resin coming from this container the polymer resin and then once this stacking up, laying up has been done. There is a consolidating roller; they will see this roller in the animation or the video also.

So, it will apply a pressure manually on the different layers that we have stacked up together in between, we have applied the polymer and we are applying pressure, manual pressure with the help of a roller. Now, how the process is done, let us try to understand that first question, that will come to your mind is how to decide the shape of the mold, you see a specific shape of the mold, we can say, it is a bucket type of a mold. Now, how we have decided that shape. So, the shape of the mold will depend upon the type of or the shape of the product that we want to make.

So, you can see, we have this bucket type of mold and in this mold, we have to do the layup of the composite. Now, the shape of first answer is the shape of the mold will

depend upon the shape of the final product that we want to fabricate. Second, why are we using the release gel? This is a very logical question, now, there is a tendency of the resin or the polymer to stick to the mold, we have to avoid that sticking action between the polymer and the mold and therefore, we have to apply or release agent or a release gel, the release gel is usually in the form of a deodorant that we apply on our body to the spray type of release gel and we can spray that gel on the surface of the mold, before starting our process.

So, that is one thing, that we can do the release gel, the purpose of release gel is to avoid the sticking of the polymer with the mold or the sticking up of the laminate with the mold, then one by one, layer by layer, depending upon the thickness of our final product. We will put the fiber layers on the surface of the mold and we will keep on applying the polymer. If you remember in one of our slides, we have seen the polymer is usually available in the thick gel form, thermosets are usually available in the thick viscous liquid form, a gel form.

So, we can take that gel with the help of a brush, we can apply it on the fiber and then we can place another layer or fiber and apply the gel form of thermoset polymer, then the third layer again, the process and forth layer and finally, once our laminate is ready, now the terminology of laminate should be clear to you. Laminate is the stacked layers of fibers, would polymer resin. So, laminate will have maybe four layered GFRP laminate what does that mean four layered GFRP laminate, it means that there are four layers of glass fiber, which has been used to reinforce the plastic and we can also name it as four layered glass fiber epoxy laminate.

So, what we have, four layers of glass fiber have been used to reinforce epoxy and the laminate that we are getting has four layers of glass fiber. Similarly, we can have four layered glass fiber polyester composite in which the matrix is polyester and the reinforcement is glass fiber. So, these type of laminates, we can make using the hand layup process and therefore, the word composite laminate is also written here. Finally, once we have laid up all the layers, suppose, it is these are four layers only, we will then use a consolidating roller to apply the pressure.

Now, why we are applying the pressure that also we need to understand, there is a tendency of the formation of voids or air bubbles in the resin. So, we have to avoid those

air bubbles. Now, this air bubbles can easily be avoided, if we apply a pressure with the help of a roller, another point from the mechanics point of view, we need to understand that the fibers are tough. They are stiff and they give strength to the composite. Whereas, the thermosetting resins are mostly brittle in nature especially epoxy.

Now, we want that in order to make a structural member, what should be more, I am putting this question to you whether we should have more fibers or more polymer we can think over it, but as I believe that more fibers will add more strength to our structural member, therefore, we wish that more fiber should be there in our composite laminate, maybe the ratio can be 60-40. We have 60 percent fibers, we have only 40 percent polymer and this combination will give us good strength to the composite material, now how to ensure that.

When we have applied the polymer, the ratio of polymer maybe much more than the fiber; sow, how to avoid that in order to avoid that, this process of rolling will help us. So, when it is rolled the excess resin will be pushed out of the laminate only. A required amount of resin will be present in the laminate which is sufficient to impregnate the fibers; the role of the polymer is to provide the bulk to the material. Secondly, it has to act as a continuous phase; thirdly, it has to act as a medium of stress and load transfer between the fibers.

So, we do not want any excess resin in our laminate and therefore, this consolidation with the help of a roller will help us to remove the air bubbles to remove the excess polymer or plastic, that is present in the gel form, inside the laminate and that is going to help us in order to achieve, our desirable mechanical properties and therefore, the process of rolling is very important in case of the hand layup process. Now, what all we can control here, we can control the thickness of the laminate by the number of layers that we are using during the layup process. We can control the amount of polymer by pushing the excess polymer out of the laminate also; we can control the direction of the fibers, because during the layup, we can be have unidirectional fibers. We can lay them in different directions and we can control the fiber orientation.

So, number of parameters, we can control and therefore, this process is a very widely practiced process, in case of composite materials. So, we will try to know whatever I

have tried to explain in the most simple terms. Let us read it and try to assimilate much more information that is available in the form of these sentences. Now, a release gel.

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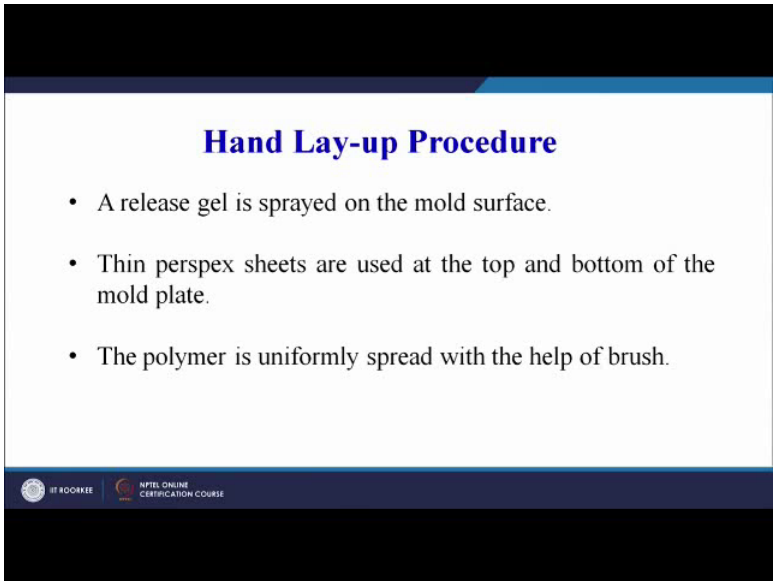

Now, let us see the process step by step. We have a mold, which is the exact replica of our final product; in that mold can be a metallic mold, many times people use wooden molds also in case of polymer composite.

So, maybe, whatever may be the material of the mold? First step is a release gel, is spread on the mold surface and that is usually available in the silica based gels, are there or the deodorant type of arrangement, where you can spray this all over the mold surface. The purpose of this release gel is to avoid the sticking between the laminate and the mold thin Perspex sheets are used at the top and bottom of the mold plate. So, that thin polythene sheets as we use a cover of our notebooks for the children, those type of thin plastic sheets can also be used on the surface of the mold, both if we were using a top and the bottom half of the mold. These thin plastic sheets can be put at the top as well as at the bottom in between, we can do our layup.

The polymer is uniformly spread with the help of a brush, which I have already explained .

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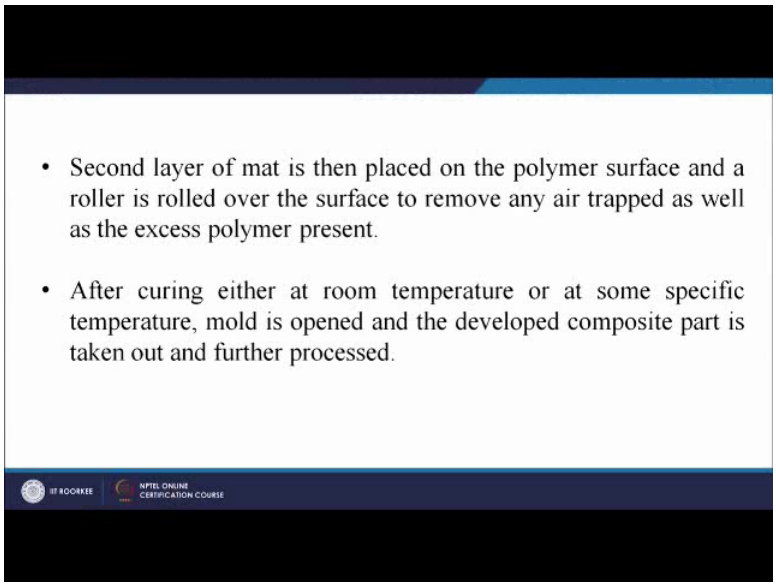

Second layer of mat is then placed on the polymer surface and a roller is rolled over the surface to remove, any air trapped as well as the excess polymer present. I have already explain this in, I think much more detailed, detail as it is given on the slide, we have to roll out the excess resin. We have to avoid the formation of air bubbles or voids, because of the air bubble that consolidation process or the rolling process will help us in achieving both these objectives.

So, the and a roller is rolled over the surface to first objective is remove any air trapped, second objective is to remove the excess polymer present after curing, either at room temperature or at some specific temperature, this is important many a times for example, epoxy may have a curing cycle of 24 hours. So, what we do, we do the layup and we keep the mold in ambient conditions, only a room temperature conditions and after 24 hours, we get our composite, solid rigid composite. Many times we do not want to give 24 hours for curing.

So, what we do, we do the curing at an elevated temperature and then the process of curing accelerates and we are able to save some time. So, after curing at room temperature or at some specific temperature that we have to decide mold is opened and the developed composite part is taken out and further processed. Now, further processing means that sometimes, we may have some polymer, which has moved out, we have to cut that polymer which are solidified along with the composite and we will get our

composite plate or sheet or product that depending upon the shape of the mold as I have already explained that shape of the mold will decide the shape of the composite product.

Now, let us try to understand this with the help of a video, please see the video attentively and we will be able to understand it. So, the fiber is being cut with the help of a scissor.

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You can see this is glass fiber, white color usually is glass fiber, and this is a mixing up of the resin, which is available in the gel form.

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Now, the layer has been placed on the mold and the polymer is being applied, as the plastic is being applied, and you can see the fiber is getting impregnated, more polymer in the form of gel has been put. You can see this is a consolidation by the roller as well as showing the; and this is a second layer of the fiber; that is glass fiber being put, and then again this is a woven fiber. As it is clear from the video the fibers are running in both the direction warp and the weft, and again the fiber is being wet by the polymer or the plastic.

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And consolidated with, and this is a third layer being applied. So, this is the basic process for making a composite. So, I think the basic fundamental process has been explained that layer by layer, we have to build up. Three layers were shown here, but usually symmetric laminates are made. So, maybe the process would have been completed by the scientist or the engineer, the source is also given, the source for this video is department of material science and engineering, the University of Sheffield, and the videos available on YouTube.

So, you can watch further videos, or showing the hand layup process. There are number of good videos available we have taken one, because this is showing the process what we are trying to explain here. Now this is what we have developed here at a very sutured. So, we are using a mold, which is a flat plate mold, this is upper half of the mold.

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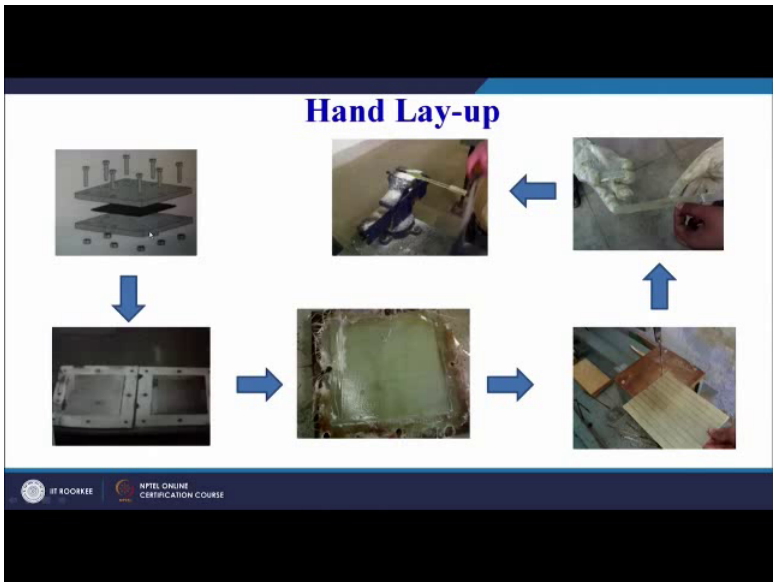

This is lower half of the mold, and in between we have a composite that we want to make the black color carbon fiber reinforced plastic composite. So, this is what we want to produce, we have to, in order to apply the pressure, we are not using the consolidatic roller here, but the 2 mold halves; the top and the bottom half are being fastened with the help of a nut and a bold type of assembly.

So, here we can see in the second slide, 2 halves of the mold are shown. Now some of you may wondering what is this central raised portion. So, central raised portion is a portion, where grinding operation has been done in order to have a very smooth surface finish, because this surface finish will be duplicated on our composite product. So, what type of product we will get, here we will get a flat composite sheet using this hand layup process, where the mold is a flat plate mold.

So, we have 2 flat plates metallic plates. These can be mild steel plates, and then this is a ground portion, where grinding has been done, and we do our layup on these ground portion. So, we will cut as I have told you first of all, we will use a release gel, the release gel will be spread over these 2 plates, then we will use thin plastic sheets. We will put the first layer of the glass fiber, then we will apply the polymer as was shown in the video, that the second layer of glass fiber, again we will apply the polymer third layer again polymer fourth layer, again polymer maybe. If we are making four layers only then we, when the polymer has been applied, we will use a roller to push out the excess

polymer from the laminate, and then we will put another plastic, thin plastic sheet on top of it, and then put the second part of the mold, and fasten it using a nut and bolt assembly.

And finally, we will get a sheet like this glass fiber reinforced plastic GFRP sheet. We can see excess resin has flown out on all the four corners, and this can be cut. You can see this can be cut, this is a final sheet additional resin or polymer or plastic has been cut out, and we get a final sheet like this, and then we can make specimen, which are cut like this. We can apply the tabs on the specimen, and then use them; you can use them for testing. So, these 2 points are not that important, but these points are, these four points are important, that we have a mold 2 flat plate mold, then we do our layup. Once it has solidified after curing, we take out the laminate and then we can cut it as per the required shape.

So, this is the most simplest manual type of process in; therefore, it is called the hand layup process. Now what are the raw materials used. I think I have already explained the matrix in these cases, a thermosetting matrix in most of the cases. So, we can use epoxy polyester polyvinyl ester phenolic resin, unsaturated polyester polyurethane resin.

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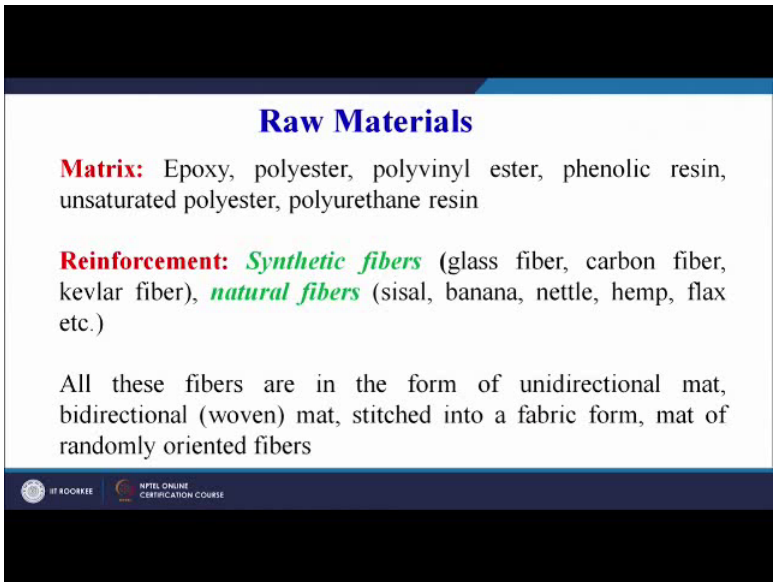

So, these are the matrix materials, which can be used in case of hand layup process, then what can be the reinforcement. As we have seen the classification of composite

materials. If you remember, we can have natural fiber reinforcement; we can have synthetic fiber reinforcement.

So, the synthetic fibers can be glass fiber, carbon fiber, Kevlar fiber and the natural fibers can be sisal banana nettle hemp flax, but mostly in hand layup process, our focus is using the woven mat type of reinforcement, cloth type of reinforcement to be explained to a layman. It will be a mat or a cloth type of reinforcement. So, the fibers have to run in both direction; x direction also and y direction also. Sometimes we may use unidirectional fiber also for some specific application, in which we have fibers running in only one direction, but maybe at a particular distance, we have a small a maybe a low strength fiber running across, just to keep these fibers in a particular direction.

So, the fibers maybe unidirectional, they can be bidirectional or woven form. So, we can use both synthetic type of fibers. We can use natural type of fibers also, and whatever I have said, is fortunately also given on the screen. All these fibers are in the form of unidirectional mat. So, all fibers running in one direction, bidirectional are woven mat stitched into a fabric form, or a cloth form, or a mat of randomly oriented fibers. So, we can even use randomly oriented fiber, but that has to in the form of a mat.

So, that is the type of reinforcements, that we can use, based on the type of the reinforcement, not much relevant slide, but just shows a drawing of a mold, how the mold should look; like four holes for fastening purpose.

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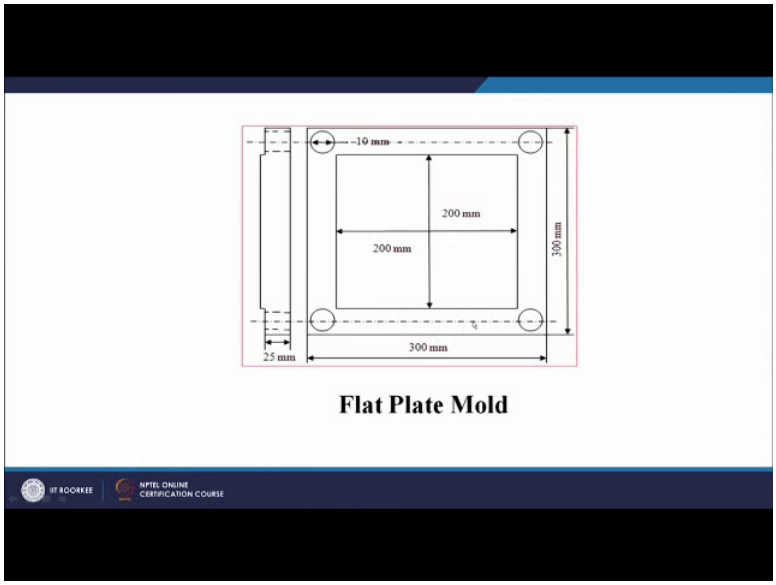

This is the embossed portion or raised portion, which is shown here. So, this portion basically, is going to be ground properly. The grinding has to be done in order to ensure a very smooth surface, because this surface will be duplicated on our composite part that we are producing.

So, as fine as good quality, as good surface finish, we can get on our mold, similar type of surface finish, we can get on our composite part. And therefore, I am emphasizing again and again that we should have a grinding operation done on our mold metallic mold. So, that we get a very good surface finish of our composite part.

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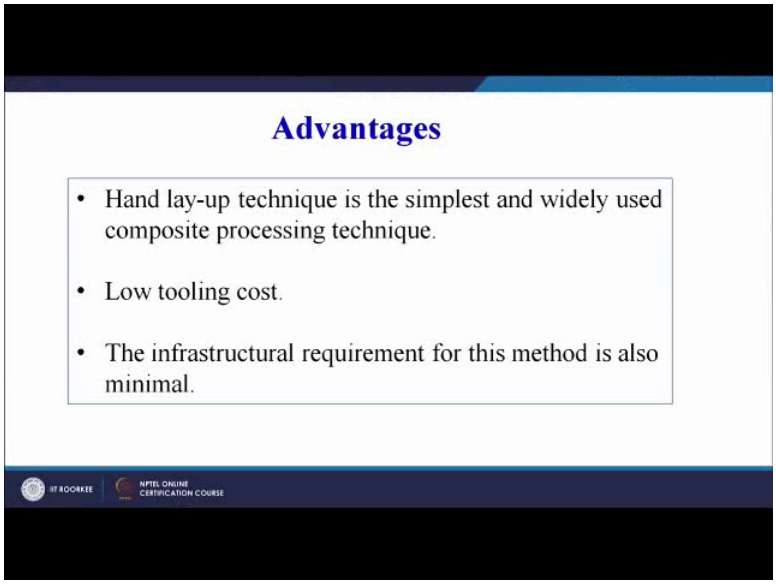

What can be the advantages of this process hand layup process, simplest, easy to operate. Hand layup technique is simplest and widely used composite processing technique. Tooling cost is low, because you can see no actuators or sensors or control mechanisms are required. Only 2 flat plate mold is, or flat plate, if you want to make a composite plate.

If you want to give any other shape, you need to have a mold of that particular shape. So, tooling cost is not very high, and the infrastructural requirements for this method is also minimal.

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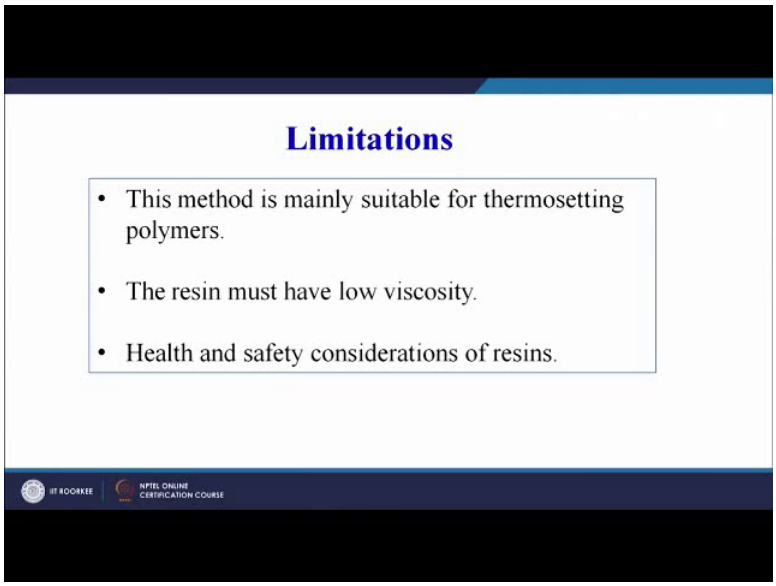

So, we do not require very elaborate arrangement for hand layup process. What are the limitations this method, is mainly suitable for thermosetting polymers, which I have already highlighted epoxy polyester. These are the major thermosetting polymers, which can be used in hand layup process. The resin must have low viscosity; that is another requirement, because the resin has to impregnate, it has to wet the fibers completely. So, that we can get a good composite material, if the resin or the plastic or the polymer is not able to wet our fibers properly. The load transfer between the 2 constituents; that is the matrix and the reinforcement will not be uniform, and therefore, their composite that we have developing, may not be able to achieve the desired properties, specifically the mechanical properties for which the composite is being designed and developed. Therefore, it is important that the resin should be able to wet, it should be able to impregnate the fibers properly.

Health and safety consideration of resin; that is also important we have to mix the hardener, and the resin together. We have to make our matrix in this case. Making the matrix means that we have to add the hardener and the resin; the hardener acts as a catalyzing agent, and we when combined together, it starts the chain of polymerization or the process of polymerization, and the solidification of the polymer takes place on the addition of hardener. So, this reaction that takes place between the hardener and the polymer, or the epoxy has to be controlled, and there make, there can be sometimes some safety issues involved or some. We can say a fumes or other kind of gases maybe

developed, because of this reaction that we have to take care. We have to ensure that we are using a right combination of the hardener, and the resin or the hardener and the polymer.

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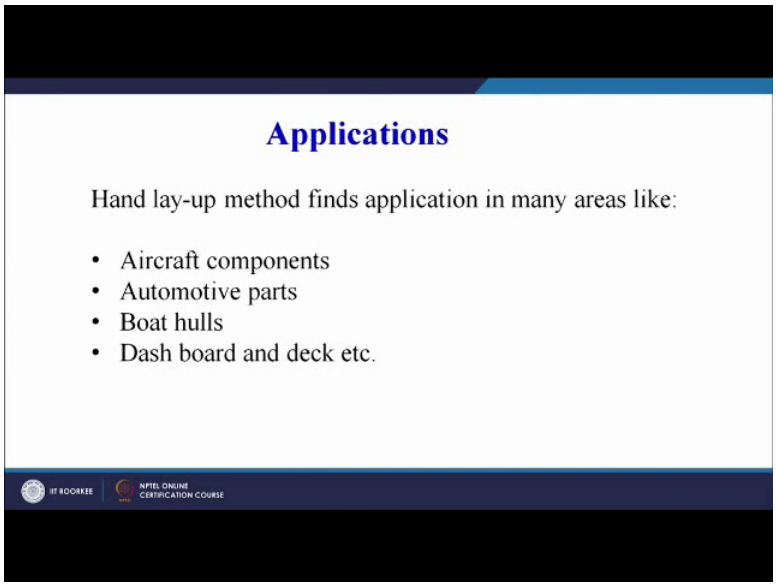

Now, what can be the application areas for the hand layup process? We can see hand layup method finds the application in areas; like aircraft components, maybe some a non structural. Simple aircraft components can be made by hand layup process, automotive parts can be made by hand layup process, boat hulls, dash boards and decks can be made by the hand layup process. So, this is a most widely used. I will advise you, I will request all of you to look at all other videos on hand layup process that are available freely over the internet, and try to understand the process, and try to see specific application areas, where hand layup process has been used to develop various engineering components.

So, with this we come to an end of our first session, exactly on the processing of polymer composites. We have had 2 or 3 sessions earlier, but those were majorly on the introductory part, regarding the processing of polymer composites. Today actually we have started our discussion, and we have seen the very first process, which is the most widely used process for processing of polymer composites in our subsequent sessions as I have already highlighted. We will be covering many other processes; like we will be covering compression molding, injection molding, resin transfer molding, filament winding, pultrusion. We will try to understand the process mechanisms of all these

processes, and for what type of applications these processes are being developed and used, that we will try to understand. Also we will focus our attention on the secondary manufacturing in terms of machining and joining of polymer based composites.

Thank you.