Processing of Non- Metals

Prof. Dr. Inderdeep Singh
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Module - 5
Polymer Matrix Composites: Processing
Lecture - 4
Hand Lay-up and Spray Lay-up

A very warm welcome to all of you, in this fourth lecture on hand layup and spray layup, we have been having a series of lectures on polymer matrix composites and the processing of polymer matrix composites. Till now, we have taken three lectures on polymer matrix composites and the challenges in the processing of polymer matrix composites. In the first three lectures our major summary or major focus was on the materials aspect, that is what are polymer matrix composites? What are the various constituents that go in to the polymer matrix composites and what are the challenges in the polymer matrix composites processing.

Today, we are going to start the major processing techniques for polymer matrix composites. Although there are large variety of processes, which have been used for processing, but we are going to focus on some specific and widely used processes for fabrication or processing of polymer matrix composites. In today's lecture, we will see how these processes has been broadly classified into various categories. We will see, what are the constituents that go into the fabrication that are, what are the basic ingredients or the constituents that are combined together to make a composite material. Finally, we will see the basic process, the procedure, advantages, limitations, and the applications of the two processes in picture today. The two processes in question today are the hand layup and the spray layup process.

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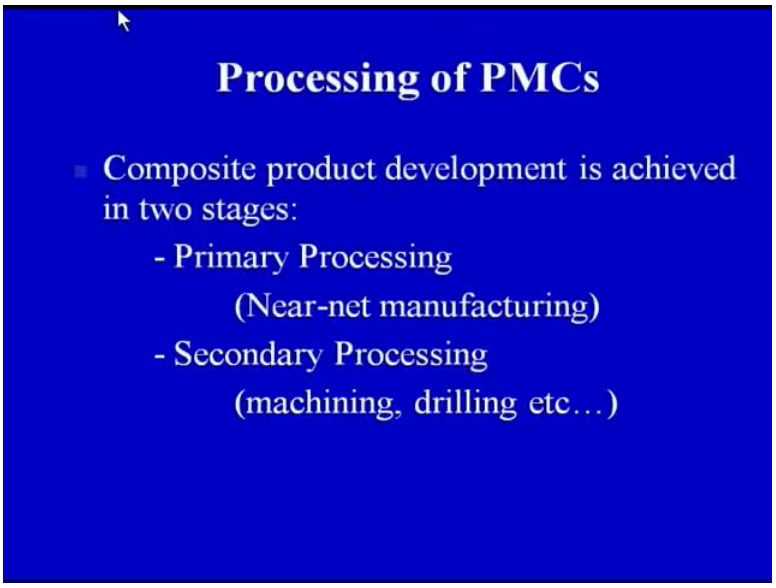

Let us now start our discussion on the classification of the processes or the classification of the primary processing processes for polymer matrix composites. Now, processing of polymer matrix composites can be broadly classified into two categories; primary processing and secondary processing. On your screen you can have an idea, we have a primary processing, a techniques in which we used near net manufacturing.

I am just going to explain, what is near net manufacturing? We have secondary processing in which we will do the machining and drilling. So, the composite product development is achieved in two stages. Now, let me take an example of this mouse, this mouse is a plastic material, it is not a composite, but this plastic has been made or it has been given or it has been molded into this particular shape.

So, the process is the primary processing, it is the primary processing method of molding this particular mouse to give it a particular shape, but now suppose, I have to put certain additional things in this, some cutting has to be done some slots have to be cut. So, that cutting of slots in this particular molded shape is called the secondary processing, that is machining and drilling of holes in a particular product is secondary processing.

Now similarly, this is an example of a plastic material, which has been molded to the near net manufacturing. Later on, it has been machined in order to fit some additional things or additional components in to the product. So, giving the shape is near net manufacturing, subsequent machining and drilling of hole is secondary processing.

Similarly, in processing of polymer matrix composites also, we have primary processing in which, we mold or we give desired shape to the composite material. In case of secondary processing, this particular molded product or molded component is drilled or hole is made by the drilling processes or some (( )) is done or some finishing is done all those processes fall under the secondary processing.

So, in this series of lecture, our focus is primarily on the primary processing aspects of polymer matrix composites. So, we will see, what are the different primary processing method for polymer matrix composites and how they are classified into different categories, then our focus would be as the title of the lecture goes, hand layup process and spray layup process, then we would be focussing on these two aspects of, or these two processes of, fabricating or processing polymer matrix composites. So, I think just to summarize again this particular slide, the total composite product is made in two stages; the primary stage and the secondary stage.

Though, the primary processing incorporates near net manufacturing, whatever shape we want to produce, that is molded using any of the processes or the primary forming processes. When the shape is got near net manufacturing has been done for a particular shape, if we gone to fix some extra thing, or we want to assemble this particular job or this particular part, with another part to get the complete composite products. Then we need to make certain holes, or do some (( )), to facilitate the assembly operations, and for that we go for the secondary processing. So, secondary processing is in terms of machining and drill. So, first near net manufacturing and then secondary processing in terms of machining and drilling.

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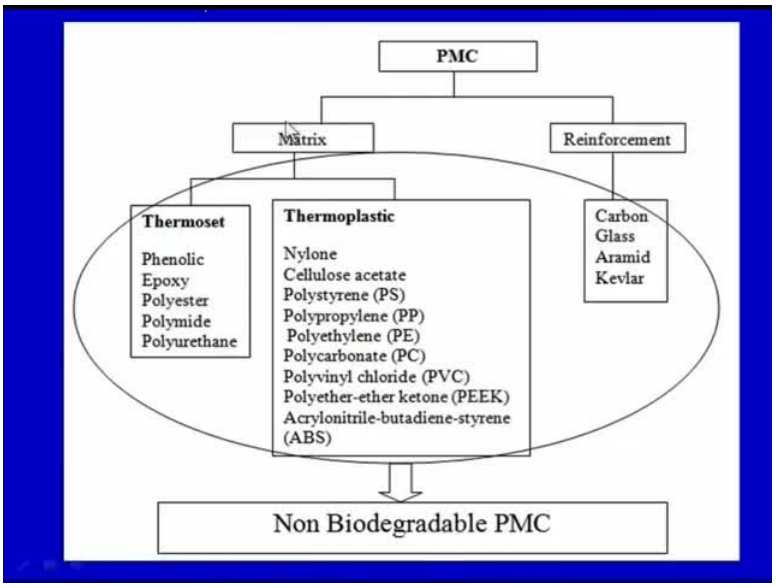

Now, basic polymer matrix composite has two basic constituents, that is matrix and the reinforcement. So, the matrix can be thermoset matrix, or it can be a thermoplastic matrix so why this classification is given here? Because the processes that we are going to discuss would depend, or their applicability would depend, upon the type of the material, they are going to process. So, if a thermo set is being used there would be some processes, which would give very good results, for thermoplastic there would be another set of process, which would give better results, as compared to the processes which are most suited for thermo sets.

Similarly the reinforcement can be in different types. So, reinforcement can be in the form of carbon fibre, in the form of glass fibre, in the form of aramid fibre, in the form of Kevlar . Kevlar and aramid are one and the same thing, the technical name sometimes is Kevlar , so aramid and Kevlar is the one and the same thing, we can have carbon, glass and aramid fibres.

So, we have a matrix, we have reinforcement, these two things have to be clubbed together in order to make a composite material. So, the matrix material can be thermo set or thermo plastic, within thermo set and thermo plastic, on your screen you can see. There are number of further types of thermo sets for example, thermo sets, phenolic epoxy, polyester. On the contrary thermoplastics we have nylone, we have cellulose acetate, we can have polypropylene, we can have polylactic acid, we can have polyether

ketone. There are different types of polymers, which fall under the category of thermo plastic. So, In matrix we have thermo sets and thermo plastic, on the contrary we have reinforcement, which has to be clubbed together, with matrix in order to make a composite material.

The broad differentiation between the thermo set and thermo plastic, we have already seen in the module on plastics, in which we have seen, what are the important properties and characteristics of thermo sets, what are the important properties and characteristics of thermo plastic, what is the basic structure of thermo set, and the basic structure of thermo plastic, which has been already been seen, in the lecture on thermo plastics and thermo sets, which has been covered in the module on plastics.

So, here we have us plastic, we have a polymer, we have a fibre, which we are combining together, to make a composite material. These are on the in the end, on your screen you can see, these are non bio degradable polymer matrix composites, the non bio degradable means, the matrices that, we are using here matrix materials, that we are using here is non bio degradable. The reinforcement, that we are using that is the synthetic reinforcement in terms of carbon fibre or glass fibre or aramid fibres. So, synthetic reinforcement, synthetic polymers, so we get a non bio degradable polymer matrix composites. So, these are the, you can say materials that will go, into the hand layup process or spraylio process or for that matter or any other process, which would used for fabricating the polymer matrix composites.

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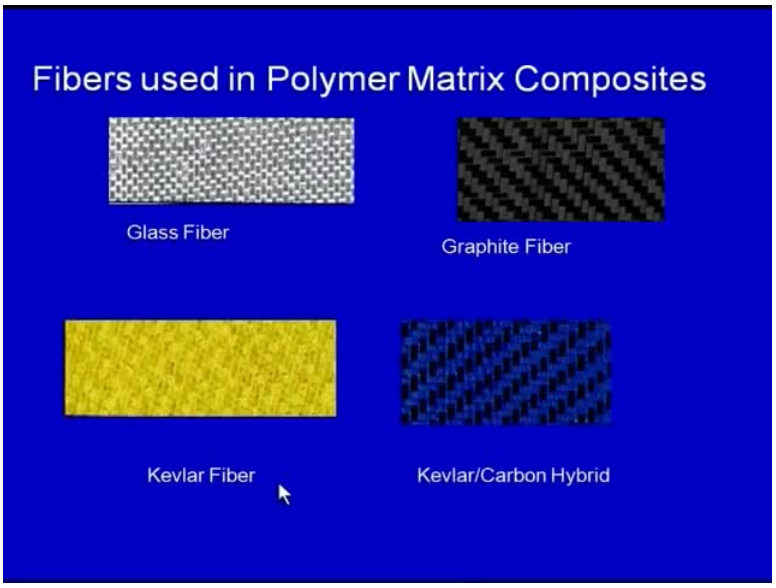

Now, this is just you can see representation, how the fibres unusually looks like in industries, this is the glass fibre you can see the fiber, there are fibres in x directions suppose call this direction as x directions, as this direction as y direction. So, we have fibres in x directions, we are fibres in y directions. Similarly this is the Kevlar fibre, this is the graphite fibre black in colour, carbon fibre wood also looks like same, this is the Kevlar carbon hybrid. We have in one particular direction carbon fibres, all these black fibres are carbon fibres, and in the other directions perpendicular directions we have the Kevlar fibre. So, this is how, the fibre mats would looks like, that oven fibre mats wood look like, these days there is a trend towards bio degradable composites, so the fibres not only can be synthetic, in nature there is can be natural fibre.

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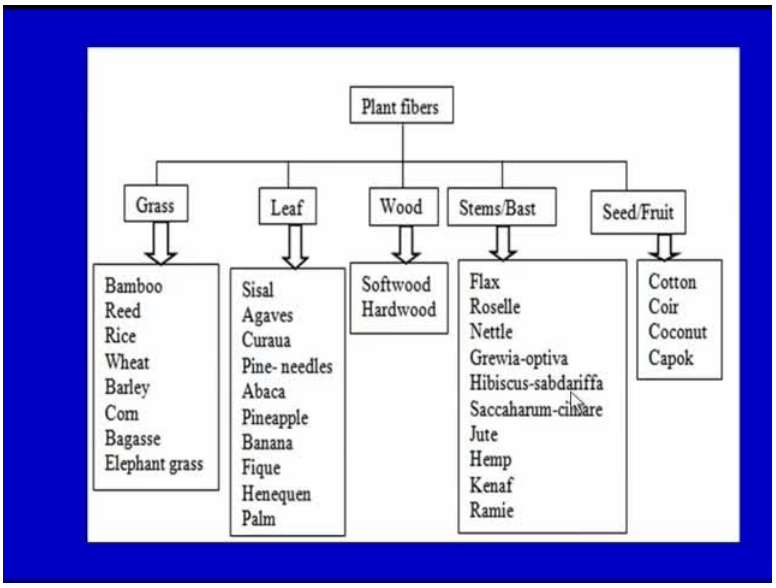

So, there are different types of fibres, which are available from the plants also. so this particular diagram or this particular classification gives us an idea, that fibres not only can be got synthetically, they are natural fibres are available, which can be used and which are being used very widely in today's in order to develop fully bio degradable polymer composites.

So, the plants fibres can comes from glass, they can come from the leaf, the plant fibres can be got from the wood, those plants fibres comes from stems, seed and the fruit, further from glass we have different type of list of fibres on your screen, you can have bamboo fibres, you can have corn fibre, you can have elephant grass fibre, from the leaf different type of fibres can come like, sisal fibres, banana fibres, palm fibres, from wood also different type of fibres can comes, like from softwood, hardwood fibres, from the stem or the bast, we can have flex fibres, we can have grewia-optiva fibre, we can have hemp fibre, kenaf fibres, from the seed or the fruit also cotton fibres, can be got coconut fibres can be got.

So, there is a huge variety of fibres, which can be used for making polymer matrix composites. So, In the previous slide, we have seen that there is a family of the polymers, which is broadly categorised into thermo set and thermo plastic, within thermo set and thermo plastic, there was a huge number of different types of thermo sets and thermo plastics, which can be used as the matrix material.

When we talk about the reinforcement, there is a category or there is a big family of the fibres, which can be use, we can have synthetic fibre, which are carbon fibre, glass fibre, Kevlar fibre or we can have natural fibres which is clear on your screen, different types of fibres can be used like, fibres can come from grass, they come from leaf, they can come from stem, they can come from seeds. So, within these are different types or categories of fibres, so we can have different types say coconut fibres, bamboo fibres, grewia-optiva fibre, sisal fibre, nettle fibres. So, there are large types of fibrous types, which can go into the polymer matrix, to make a polymer matrix composite.

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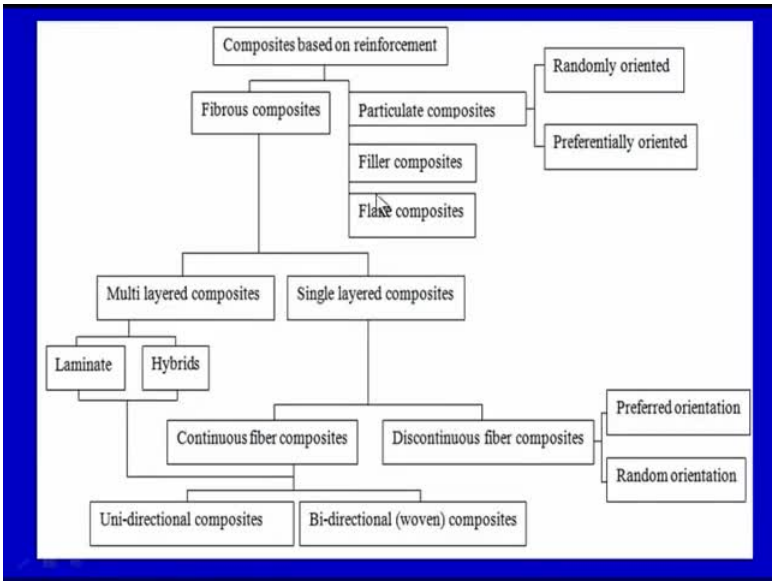

On the basis of the shape, of the reinforcement's also we have different types of composites, so composites based on reinforcement can broadly be classify into fibres composites or particulate composites. So, as we have seen in previous lecture, that the reinforcement can be further classified on the basis of its shape, so the fibres can go into the matrix in a continuous form, so we can have continuous fibres reinforcement, we can have randomly oriented fibres or short fibres, we can have viscous, we can have particulate.

So, the fibres can be in different shapes or different types, continuous, discontinuous viscous, particulates. So, on the basis of reinforcement, we can have fibres composites in which the reinforcement in terms of fibre, we can have particulates composites in which the reinforcement is in terms of the particles. Now the particles can be either randomly

oriented or the particles can be preferentially oriented, so when we have the particles preferentially oriented, the properties would be different in the direction of the reinforcement. Then the properties in the transverse direction to the direction of reinforcement, suppose we have all the particles oriented in one particular direction, the properties would be different as compared to the transverse direction.

So, particulate composites it can be randomly oriented, they can be preferentially oriented, then in within particle composites, we can have filler composites, we can have flake composites. So, flakes can also be used as the reinforcement type, within fibrous composites, we can have multi layered composites, we can have single layered composites. In multi layered composites, we can have laminates, we can have hybrids, laminates and hybrids can further we classified as unidirectional, In which all the fibres are in one particular direction or they can be bi directional, in which the fibres are in both the directions.

So, the fibres or woven mats we have seen in the previous slide, in which four different types of fibrous mats are shown, the glass fibre, the Kevlar fibre, the graphite fibre and hybrid between the graphite and the Kevlar fibre. So, when fibres are in both the directions, we can call them as the woven composites, because the fibrous reinforcement is in both the directions x and the y directions, we can have all the fibres in one particular direction those are called unidirectional composites. Now, hybrid composites basically, we have different types of reinforcement in the single composites, that reinforcement can be graphite fibre and the carbon fibre, graphite fibre and Kevlar fibre. So, when we have different types of reinforcement, we will be calling them as the hybrid laminates or the hybrid reinforcement composites.

Within single layered, we can have continuous fibre, we can have discontinuous fibres reinforcement, within discontinuous fibres reinforcement, we can have preferred orientation or we can have random orientation. So, we can see on the basis of the type of reinforcement that we put into the polymeric matrix, so you can get different types of composites. So, we can have continuous fibres, we can have discontinuous fibres, we can have particulate fibres, we can have viscous, we can have small fibres, we can have all the reinforcement in one direction, we can have randomly oriented reinforcement. So, all these types of composites will have different properties, all the fibres in one direction suppose the tensile strength in that particular direction would be very high, whereas the

tensile strength transfers to the direction of fibres would be comparatively low. Because the fibres are the main load bearing members, which we have already seen in our previous lectures

So, when we are loading a particular composites, which is having all the fibres in one particular direction, we are using long continuous fibres as the reinforcement in a polymer matrix, the load when applied in the direction of the fibre, would be the failure load would be very high, suppose we the same composites, which is having same composites which is having long fibres in one particular direction, we are applying a tensile load, in opposite to the direction of fibres, or perpendicular to the direction of fibre or in transverse direction to the direction of fibres. The load bearing capacity of the composites would be considerably less, why? Because the fibres now would not be taking much of the load, the load the failure would be induced by the failure of the matrix.

When the fibres are in x direction, and I am applying the load in y direction, and the tensile load is applied in y direction. So, we can see depending upon the type of reinforcement, whether it is continues or it is discontinues, it is in form of fibres, or it is in the form of particles, or it is the form of viscous. It is prefer in one direction or it is randomly oriented, so the type or the way we are putting the reinforcement in the polymer matrix is going to affect the mechanical properties of the composites, which we are going to develop, which is very clearly seen in this particular slide, where the composites have been classified, on the basis of the reinforcement, or the shape or you can say the type of the reinforcement that we are putting.

So, we can once again summarize we can have fibrous composites or we can have particulate composites within fibrous, we can have multi layered or single layer, within single layer, we can have continues or discontinues, in multi layered we can have laminates or hybrids in hybrids, we can have one layered of glass fibre, then carbon, then glass, one Kevlar , graphite fibre graphite fibre graphite. So, we can have different combinations, or you can say different setting sequence lamination sequence in hybrid composites. So, on your screen you can very easily see the reinforcement can be put, into the polymer matrix in number of ways.

Now, till now we have seen, that matrix has to be reinforced with the fibres, the fibres

can be of different materials for example, the carbon fibres, glass fibres, aramid fibres. We can have natural fibres also for example, grawia obtiva, sisal, nettle, bamboo or coconut fibre. So, there can be different material, which can be used for making the fibres, then on the basis of shape or size the fibres can further we classified, we can have long fibres, we can have small fibres, we can have fibres in one direction, we can have fibres in all the direction, the fibres can be randomly oriented, the fibres can be aligned in one particular direction and we have a polymer matrix. So, now these fibrous reinforcement, has to be clubbed with the polymer matrix to make a composite materials, now the processing of polymer matrix composites there are different methods, which are used to process the polymer matrix composites. These methods we can further, we classified into different categories.

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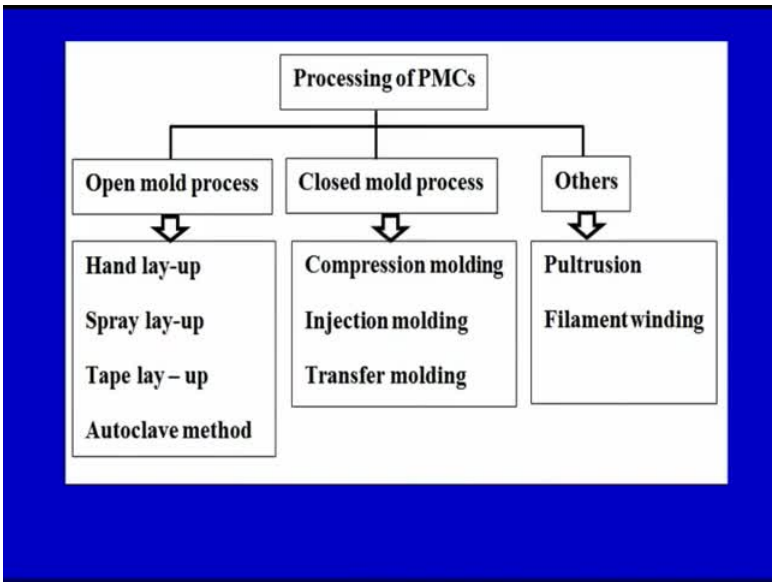

Now, we can have open mold processes, on your screen you can have an idea, you can see very clear cut distinction between the various types of processing techniques used for processing of polymer matrix composites. So, processing of polymer matrix composites can be achieved by open mold process, it can be achieved by closed mold process and it can achieved by other processes. Within open mold process we have hand layup techniques, we have spray layup techniques, tape layup and autoclave method.

In this particular classification this particular processes, the mold that will be used for making the polymer matrix composites would be a open mold. Open mold means it can

have you can say interaction, with the atmosphere there would be a open mold whereas, in certain circumstances, we will go for closed mold process, in closed mold process we have different processes such as compression molding, injection molding and transfer molding. So, the mold is closed it has two parts two parts will closed together to form a cavity of the product, which has to be produced inside and the material would be injected or it would be placed inside the closed mold, in order to convert the raw material. What is the raw material in a polymer matrix composites? The raw material is the fibrous reinforcement and the polymer matrix.

So, we have a polymer matrix, we have a fibrous reinforcement these are the raw materials, these raw materials have to be converted into a composite product, in open mold process the mold would be open, type which can have interaction with the atmosphere, in closed mold two parts will be used and clubbed together, male part and the female part they will be joined together, in between we will have a cavity and in that cavity the raw materials would be converted into, the final product and the final product would be a composite product and more specifically a polymer matrix composite product. There are few other processes, which are used for fabricating or processing the polymer matrix composites, these are the processes, such as pultrusion and filament winding.

This particular diagram gives a classification of the techniques, which are used for processing of polymer matrix composites. These are the not only processes, which are used there is a wide variety of processes, which have been developed over a period of time, for processing of polymer matrix composites. So, during these series of particular modules five, we will see that which are the most important processes, which are used for fabricating composite products, which types of composites we are talking about? We are talking about the polymer matrix composites.

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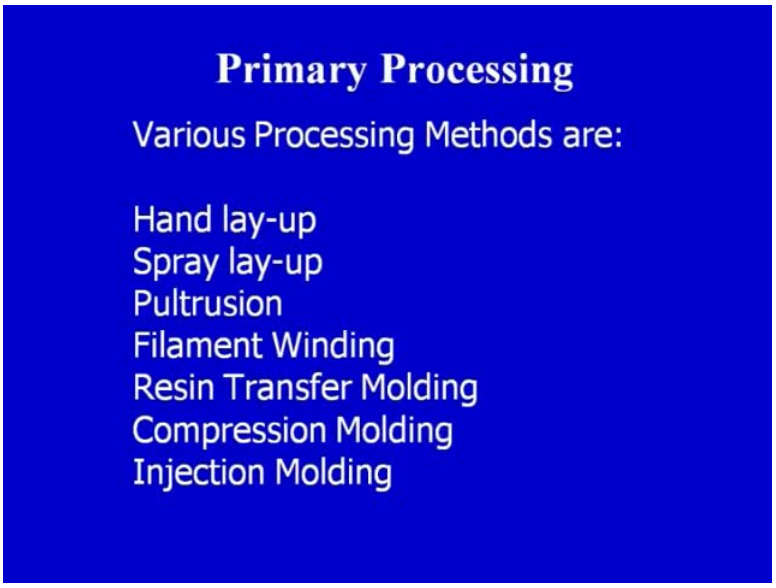

So, further we can have the types of processes, which are used for processing of polymer matrix composites. These are the processes, hand layup, spray layup, pultrusion, filament, resin transfer molding, compression molding, injection molding. So, these are few important processes, which are used for processing of polymer matrix composites, we would be seeing each one of these process, with the process diagram the process procedures the control variables, the advantages, the limitations and the applications areas of this particular processes. So, the focus would primarily be on the processes, which are widely used for processing of polymer matrix composites.

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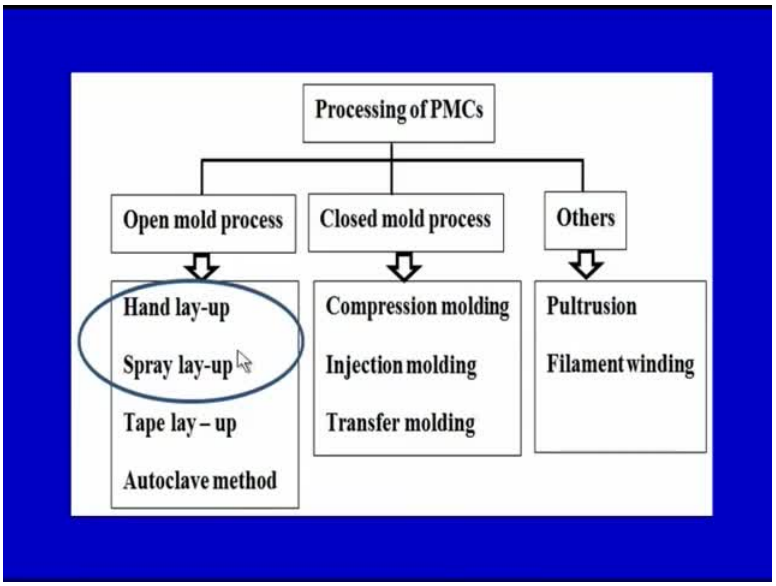

So, in today's lecture our focus would be on, hand layup and spray layup. As on your screen you can see, the processing of PMCs, can be broadly classified to open mold process, closed mold process and the other processes. So, hand layup process and spray layup process falls in the category of the open mold process, so these two processes are open mold process, now what all the process details what are all the constituents, that will go into the processes that we are going to see in the subsequent slides.

Now, the first and the foremost process most common process, that is used for processing of polymer matrix composites is the hand layup process. So, hand layup method or the hand layup technique, is the simplest method of composite processing, it is a most simple method, and it can be very the needs and the requirements are not stringent, even a very simple mold can be used for processing of using the hand layup techniques.

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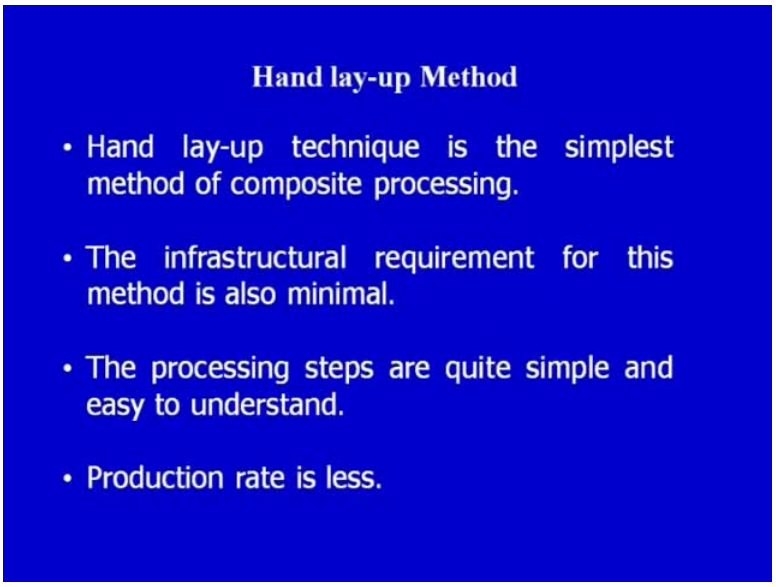

The infrastructural requirements for this method, is also minimal. So, we need to have a mold, we need to have a constituents that is the fibre and the polymer, and we can use the mold to give a shape to the particular raw material. So, the raw materials as I have already discussed two three times, the raw material is the fibre and the polymer, we have to somehow combine these raw materials to get the final product. So, the infrastructure requirements is only in terms of the mold, so the mold can be a metallic mold or can be other materials, even wood can be used as a mold material in order to give shape, to the

polymer matrix composites. So, the infrastructural requirements are there are no big machines required for hand layup process, it is manual process it is labour intensive process and the quality of the product would depend upon the skill, of the molder as well as on the quality of the mold used for fabricating the polymer matrix composites.

So, on your screen you can see the hand layup is the most simplest method of processing of composites, the infrastructural requirements are not too much or the infrastructural requirements are very minimal, the processing steps are quite simple and easy to understand. I can emphasise here that most of the research work what is being done, In the field of the polymer matrix composites, the researcher most of the researchers are using the simplest method of fabricating the composite materials, hand layup is one of the processes which is widely used for making the composite materials, and more specifically the polymer matrix composites materials.

The production rate is less it can be less to media, and this particular process is quite suitable, when the production volume required is minimum or to a medium level, for very high production rate hand layup process is not suitable. So, hand layup process is suitable for low to medium production volume, so just to summarize the broad, you can say introduction of the hand layup process, it is a simplest method we do not require very complicated and sophisticated machines for the hand layup process, it is a labour intensive, manual process, the processing is very simple, the steps are very easy to understand. The production volume for which the hand layup process is suitable is low to medium, for low to medium production volume; we can justify the use of a hand layup process.

Now, as we have seen in the hand layup process, it is a simplest method it is widely used infrastructure requirements are minimal, and the processing steps are quite easy to understand. Now what are the raw materials used in the hand layup process? We can see, there is a matrix and the reinforcement which are clubbed together, to make a composites. Today I have think I have referred this number of times, so what are the matrix materials, which are used or most widely used for hand layup process.

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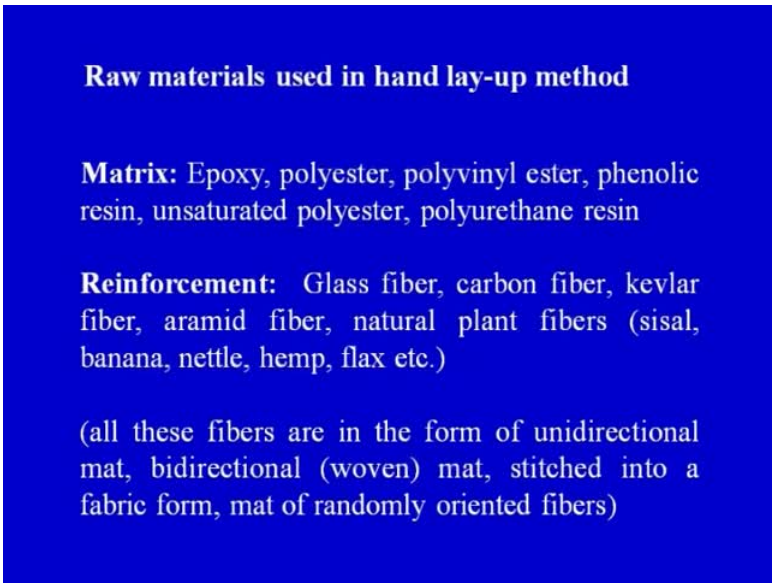

These can be Epoxy, polyester, polyvinyl eater, phenolic resin, polyurethane. So, there are different types of matrix materials, which can be used as the raw material, in case of hand layup process. Also what are all the reinforcements that are used? Reinforcement can be in terms of glass fibre, it can be a carbon fibre, Kevlar fibre, aramid, natural plant fibre. Natural plant fibres again, we have already seen one particular slide, in which we have seen a wide variety of plant fibres used today, in the fabrication of polymer matrix composites products. Now, what are these? These are, these can be plants fibres can be in terms of sisal fibres, banana fibres, nettle, hemp, flax.

These are some of the categories of the plant fibres, or the natural fibres, which are being used as reinforcements, as to the polymer matrices. So, we have a plastic material as a matrix and all these types of fibres can be used as a reinforcement materials. So, the raw material for the hand layup process are the plastic, or the polymer in terms of epoxy polyester or polyurethane resin, as the reinforcements in terms of fibres, fibre can be a synthetic in nature, or they can be natural in nature. So, natural fibres are flex, hemp, as on your screen you can see, sisal fibres or synthetic fibres can be carbon graphite and Kevlar.

All these fibres are in the form of unidirectional mat, can be available in the form of unidirectional mat they can bio directional or woven mats or you can say these would be in the form of cloth, which would be used as a layer of reinforce mat. Then we can have

mat of randomly oriented fibres also, so depending upon the requirement we will choose the type of the reinforce mat, either we are going to use it in the form of cloth form or we are using it randomly distributed form or we are going to use it as differentially oriented mat, or randomly oriented fibre mat.

So, we can see, we have different type of fibrous reinforcement, we have different types f matrices, which can be clubbed together in the hand layup process, to make a composite product. Now, hand layup procedure it is very simple, we will try to understand with the help of a diagram also, so just I will read it for you. We have a mold it can be a flat plate mold, as you can see on your screen. So, in order to make a polymer matrix composite product using a hand layup process, the first and the foremost requirement is a mold. So, the mold can be a flat plate mold, we have a diagram in our presentation that we will see, that how a flat plate mold would look like?

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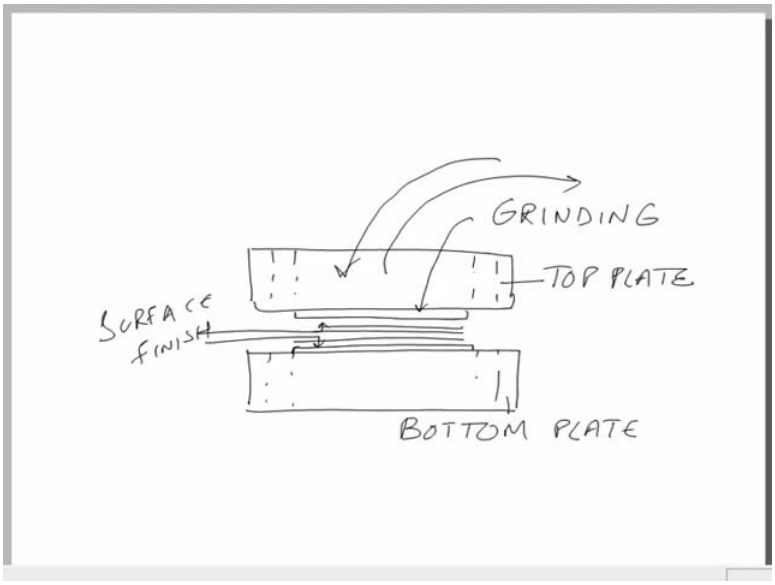

So, on your screen you can see, that we have a flat plate mold like this, this is the bottom plate and we can have a top plate, and the layup would be done in between the two plates. Now, this is the top plate of the flat plate mold, and this is the bottom plate mold of the flat plate mold. So, we have a bottom plate and we have top plate, now how these two would be joined together? These two would be joined together, with the help of nuts and bolts. So, the layup would be done between this two plates, in order to have a very good surface finish, we can have slightly embossed portion on the two. This particular

portion can be growned or grinding operation can be done on these two plates, in order to have a very good surface finish.

So, the surface finish of these two surfaces should be very, very high, so the surface finish has to be high. Why the surface finish has to be high? Because this surface finish would be duplicated on to the composite product, that we are going to make, and here on these two plates the layup would be done. Alternate layers of the fibrous reinforcement, and the and polymer would be put on this particular plate. So, this plate would not be in use initially, only we will do on the bottom plate, and then the finally once the layup is ready, we will bring the top plate and we will place the top plate, on the top of the bottom plate in order to get a composite.

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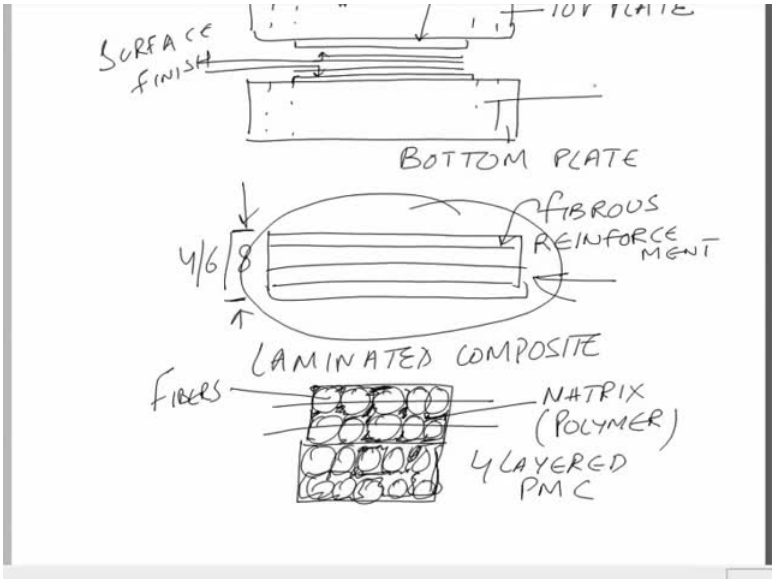

So, what is would be the construction or the structure of the composites, that we will be getting here? The structure of the composites would be a layered structure. So, this line represents the fibrous reinforcement, so these layers are the fibrous reinforcement and we have alternate layers. Now, depending upon the types of layers, we will have a different layered composites, we can have four layers, we can have six layers, we can have eight layers, so different layers and we will this is called this total is called laminated composites. So, what are the main constituents of these? The main constituents of these are the fibrous reinforcement and the polymer matrix.

Now how this is done? This is a simple flat plate mold, which is used for making a

composite material, and we are making a laminated composite the different layer. If I have side view of this particular composite, it should look something like this, in which I have all these are the hands of the of the fibres, and in between the portion that I am highlighting, or the darkened portion is the matrix material. So, how many layers are there in these particular composites? There are two layers, this is layer number one, and this is layer number two.

So, we have a layer one of the fibres, layer two of the fibres, and in between this particular portion is the matrix, which is a polymer, any type of polymer examples, we have already seen and these are the fibres, which are the bundle of fibres. So, this is one representation of a composite material, so we have different layers we can add other layers also, this particular view I am showing we can add other layers. So, this particular composite, now become a four layered polymer matrix component, so we have a four layered composite, in which this darkened portion represents again, the matrix or the bulk of the material, and the circular portion represents the edges of the fibres, at the edge of the laminates.

So, this is the simple way of making a composite material, I have shown that there are different plates top plates and the bottom plates, this is a flat plate mold, now the shape of the composites that will, we will get will depend upon the shape of the mold, now this is a flat plate mold, we will get a composite laminate, if you use this process of hand layer. If you have a particular shape, we will get a different shapes, of the composites depending upon the shape of the mold. So, on your screen now you can see the hand layer procedure, now you have a mold as I have already explained a flat plate mold suppose, now a release gel on the surface, so that the polymer does not stick to the mold surface, or plastic do not stick to the mold surface and easily the final product can be extracted out, or removed or demoled from the mold.

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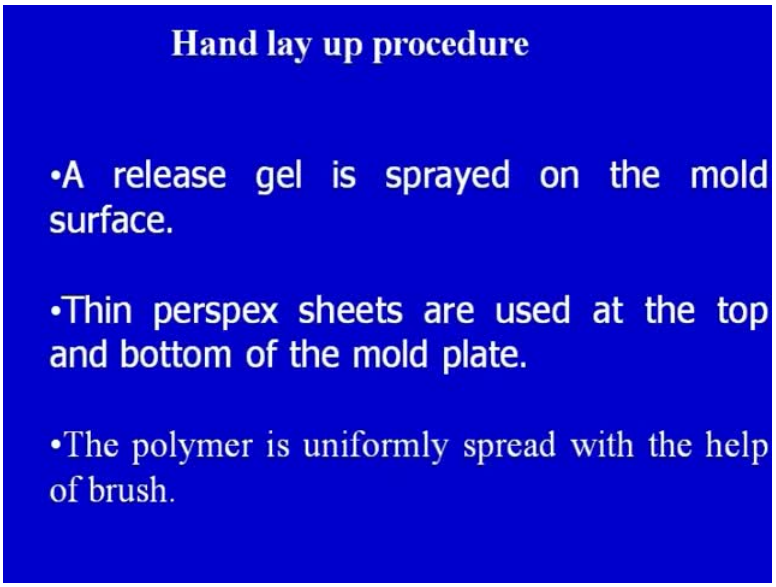

So, release gel is sprayed on the mold surface, thin plastic sheets are also sometimes used on the top and bottom plate of the mold, so that the final product is easily removed. The polymer is used uniformly spread with the help of the brush, the polymer or the plastic is available in different forms. So, the main important point is the viscosity, that is one of the important parameter, it should be viscous enough to be spread on the mold, and it should have a optimal viscosity, it should note flow and it should be controllable, and it should not be too, you can say high viscosity, that we are not able to manure it on top of the mold, so we should have a optimal viscosity of the polymer.

Now the polymer has to be applied on the mold with the help of a brush, but before applying there is a other important step hardener, or catalyst has to be added to the polymer, in order to accelerate the rate of polymerization or curing. In very simplistic terms the process can be described as the hardening process, in which because I have already told the polymer will have some viscosity, it means it is in a semi solid state or in a liquid state, and from the semisolid or liquid state, it would be converted into a fully solid state, that means it is polymerized or it will cures. An in order to aid that process of conversion from a particular state to another state, that would be accelerated, if we add a particular catalyst or a particular hardener, with a resin or a polymer.

So, this polymer would be added with another, you can say hardener or catalyst in order to accelerate, the rate of polymerization or curing. So, we have a flat plate mold or any

given shape of the mold, we will apply a released gel, we can place optionally, we can place thin plastic sheet, and then we will prepare the resin and the catalyst together, we will steer them properly and we have the fibres reinforcement, suppose in the form of woven mat.

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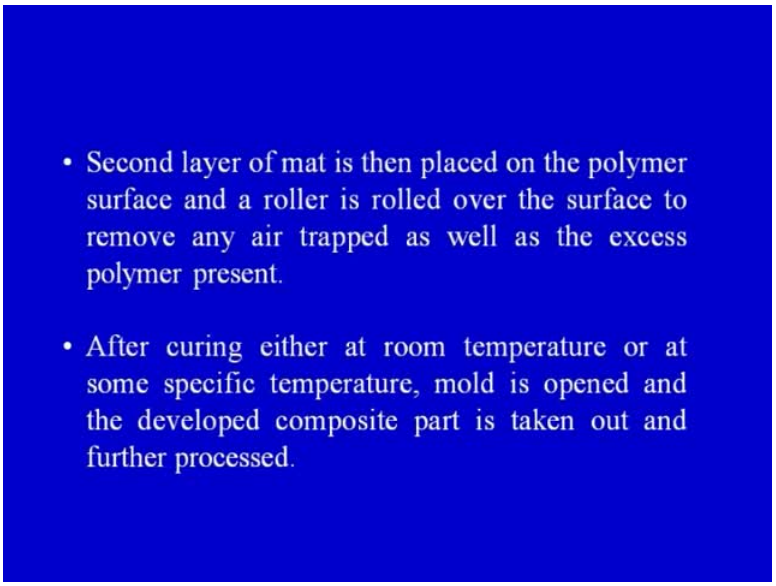

So, we have the ingredients ready and we have the mold ready, now we will do the layup process. The first layer of the mat is placed on the top of the fiber, on the top of the resin that, we have already spread with the help of the brush, second layer of mat is then placed on the polymer surface, and the roller is rolled over the surface to remove any air trapped as well as the excess polymer present. So, we applied the polymer, we have put the fibrous mat on top of the polymer next to this, after curing either at room temperature or at the some specific temperature, mold is opened and the developed composite part is taken out and further processed.

So, the thickness of the composite product or the polymer matrix composite, that try to develop using the hand layup process, would depend upon the number of layers that we are putting in the polymer. So, it is a alternate process as I have explained with the help of the diagram, suppose you are using a flat plate mold, first of all release gel is separate, a thin plastic sheet is kept, and then with the help of the brush, we are applying the polymer. We are putting the mat of the fibre, on top of the polymer, again we are applying the polymer with the help of the brush, again we are putting another mat, of the

fibrous reinforcement, again we are applying with the help of brush the polymer and again we are applying the fibrous mat.

So, we may have four layers of fibrous mat, we may have eight layers of fibrous mat, we may have sixteen layers of mat or the woven mat or the cloth and the fibre and then finally the top part or mold is placed on the bottom part of the mold. It is tightened pressure is applied even we can apply a pressure, with the help of hydrolic press a pressure is applied the excess resin is removed.

Finally it is left for curing, the curing can also be done at an elevated temperature, but mostly in hand layer process curing is done at the room temperature. Finally, the top part is removed the top part of the mold is removed and we get the composite material, if it is a flat plate mold we will get a composite laminate, which would be, in the form of we can say sheet. In case of different shape of the mold we will get a different type of a composite material.

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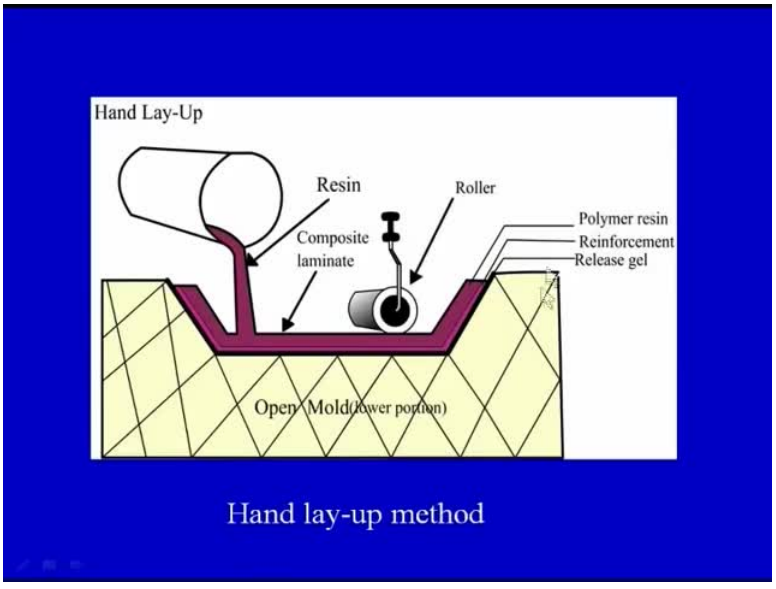

On your screen you can see, a very simple representation of the hand layup process this is the open mold, yellow colour, then there is a release gel, next to the mold, which is applied in order to facilitate the easy removal of the composite material. Then there is a layer of reinforcement, which has been put on top of the release gel, then the polymer resin is spread this is the, you can say container of the resin, the resin you can say spread on top of the fibrous reinforcement, and we get a composite laminates. The roller is used

as a consolidation process to apply a pressure, in order to remove the excess resin from the composite product. Finally we will get the composite in this particular shape that is the shape of the mold.

In the example, I have taken in the prior slide, I have already told, with the help of a diagram we can use of flat plate mold also. So, the three or four important steps are incorporation or the putting up of the release gel, the putting up of the thin plastic sheet, in order to facilitate the easy removal of the composite product, and then we can even apply certain gel coats also if possible. If required depending upon the surface space required and then we will put the alternate layers of resin, and reinforcement, finally we will get the composites product.

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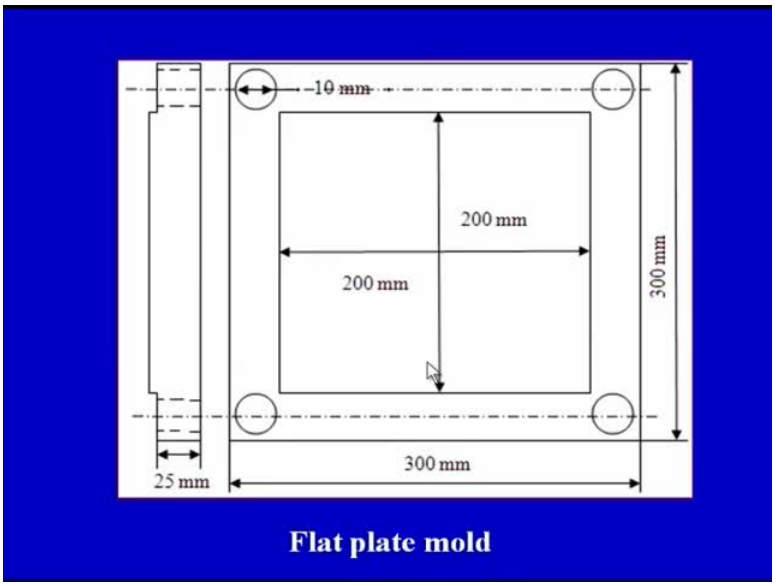

Now, this is one diagram of a simple flat plate mold, this you can see this is the, you can say holes for fixing of two parts, and we have this raised portion, which can be given a very good surface finish, with the grinding process. The layup or the hand layup process would be carried out, on this particular surface, and very good surface finish can be got. So, this is that raised portion here, 200 millimetre by 200 millimetre layup would be done here, in the form of alternate layers of resin and the reinforcement. The reinforcement, as we have taken example in today's class, the reinforcement is in the mat form or cloth form, in which it is a continuous reinforcement fibres are both in x direction and the y direction.

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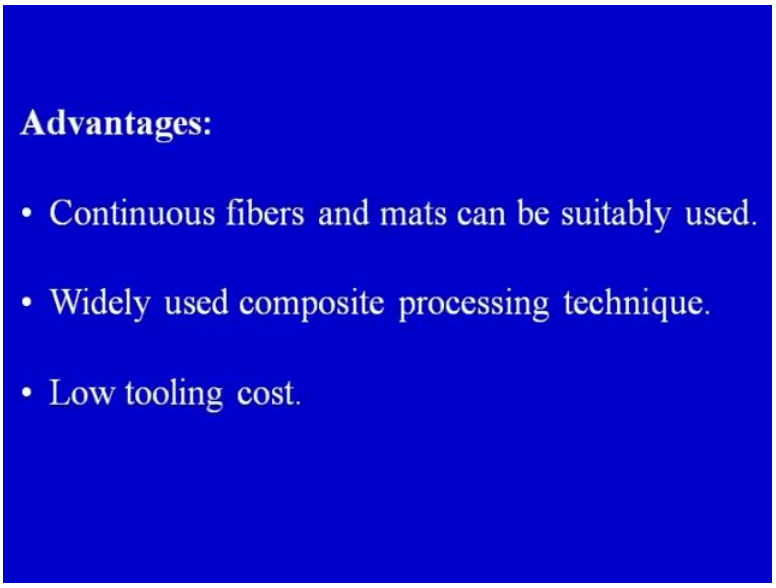

Now, what are the advantageous of the hand layer process, continuous fibres and mats can be suitably used, widely used composite processing technique and the tooling costs are very low. The steps are comparatively easy, and easy to understand, and the control can be exercised properly, in case of hand layup process, excess resin anyway we are removing with the help of the consolidation roller.

So, in hand layup process there are basically four steps only, we have a mold, on that mold we are suppressing the release gel, after the release gel has been spread, optionally we can put a thin plastic sheet and on top of that, we will with the help of a brush, we will apply this resin, after the resin has been applied we will put the fibrous sheets. On top of the sheet again we will apply the resin and depending upon the thickness of the laminates required, we will put alternate layers of the fibre mats, after applying the resin. Finally, the pressure would be applied with the help of the top plate of the mold, and after room temperature curing, we will get a composite laminates.

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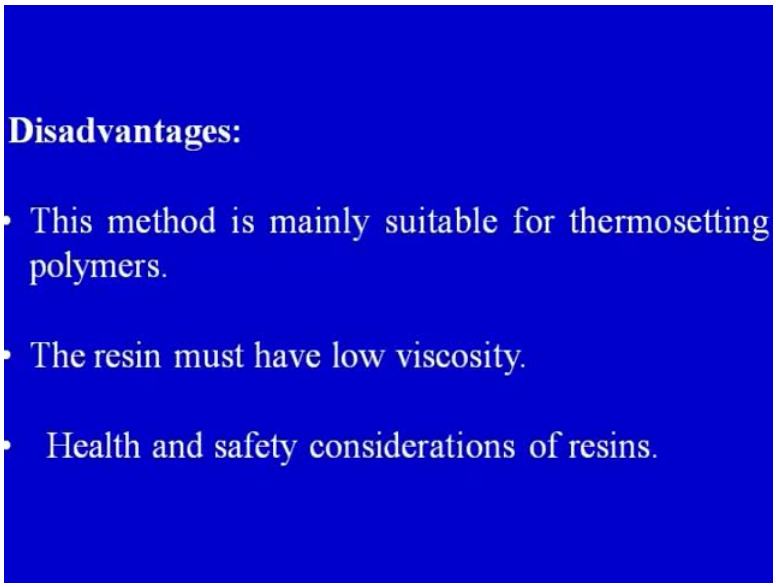

So, the process is fairly simple, the disadvantages are the method is mainly suitable for thermosetting polymers, not very suitable for thermo plastic resin must have low viscosity, and there are health and safety considerations also involved. Because we are doing the things manually, we are touching the fibre with our own hand suppose, we are using glass fibre, it is a aggressive in nature, it may have some health hazards, glass fibre also sometimes carcinogenic in nature, again there are few issues involved there.

So, the resin and the catalyst when they are reacting there may be few gases, which may be generated, which may not be too good for our health. So, there are some health and some safety considerations, so these are some of the disadvantages and also another disadvantage can be in terms of limitations, on the thickness. If we are using a flat plate mold, suppose we want to make a very thick laminates the pressure, that we applied would be very high, on the top and the bottom layer, but in between the pressure may not be uniform. So, there can be some disadvantageous associated with the hand layup process but otherwise it is a very simple, and very easy process of making a polymer matrix composites.

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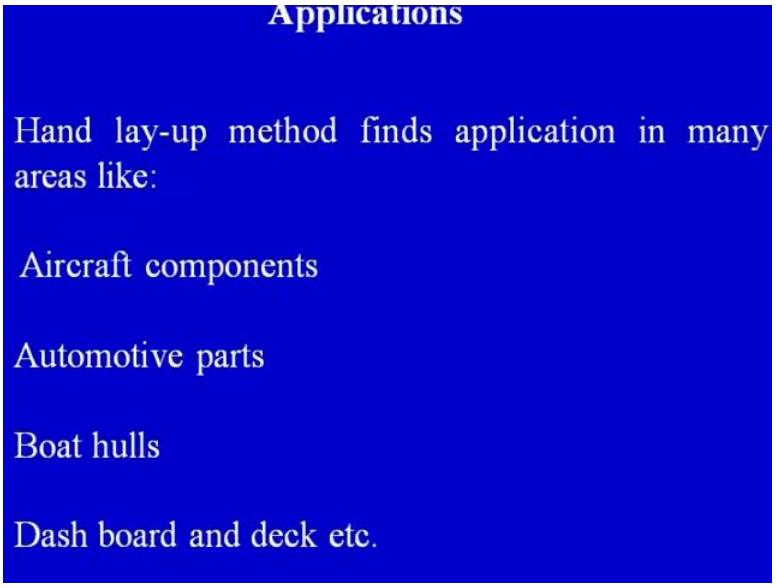

Now, the applications of hand layer process are aircraft, in some aircraft components it can be used for automotive parts can be made by the hand layup process, boat hulls is one of the most historical applications, of the hand layer process dash boards and discs can also be used by the hand layup process. So, this is one of the most easily and widely used of making the composite parts.

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Now, coming on to the spray layup process, which is fairly similar to the hand layer process, but there are few distinct differences between the hand layup process, and the

spray layup process. Here again we have to combine the fibre and the matrix, or the fibre, and the polymer together in order to make a composite product.

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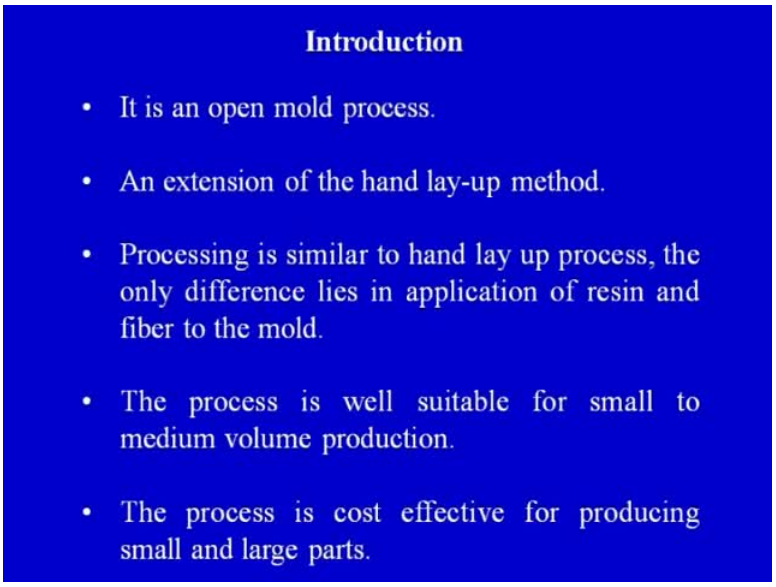

So, spray layup process, it is again as we have already seen open mold process, it is further extension of the hand layup method, processing is similar to hand layup process, the only difference lies in the application of resin and the fibre to the mold. So, in case of hand layup process, we are putting alternate layers of resign and fibre on the mold, in this particular case of spray layup, we would be using a different method of putting the fibres and the resign on to the mold surface. The process is well suitable for from small to medium volume production, and the process is cost effective for producing small and large parts.

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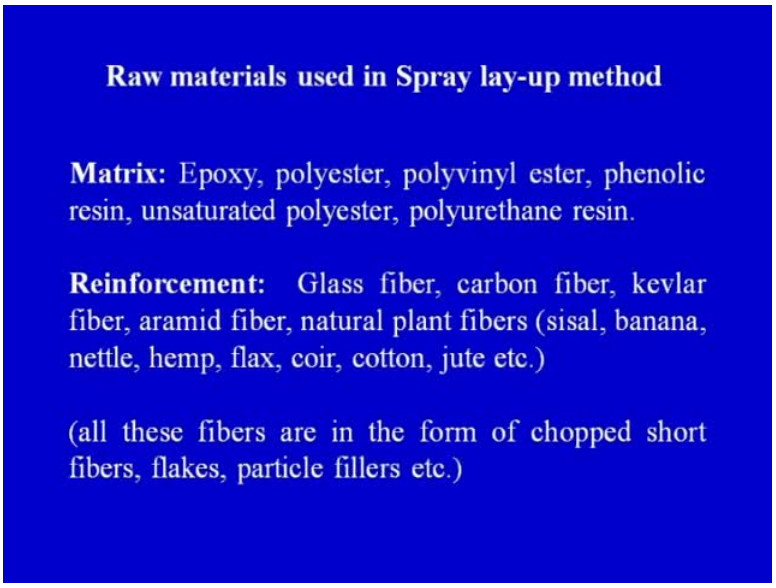

The raw materials used in spray layup method, are again same epoxy, polyester, polyurethane resin, the reinforcement can be again glass fibre, carbon fibre, Kevlar fibre, aramid fibre, in terms of hem, flax, coir, cotton etc, all these fibre are in the form of chopped short flax or particles or fillers.

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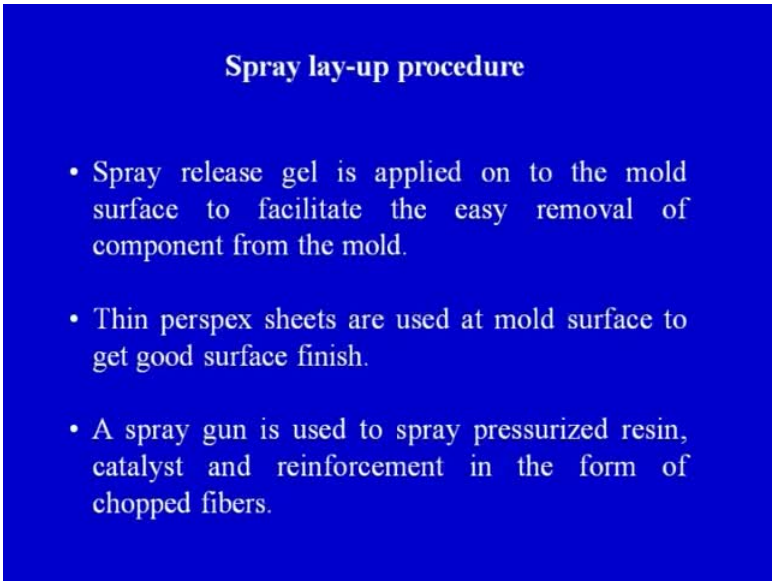

The spray layup process, how it is done? The spray release gel is applied, on to the mold surface, to facilitate the easy removal of component from the mold, it is same as in case of hand layup process, thin plastic sheets are used at mold surface to get good surface

finish. A spray gun is used to spray pressurized resin catalyst and reinforcement in the form of chopped fibre. So, this is the difference between the hand layup process, and the spray layup process, in this particular process, we are spring the catalyst, the resigns and the chopped fibres, on to the mold surface, a chopper gun or spray gun is used in this particular case.

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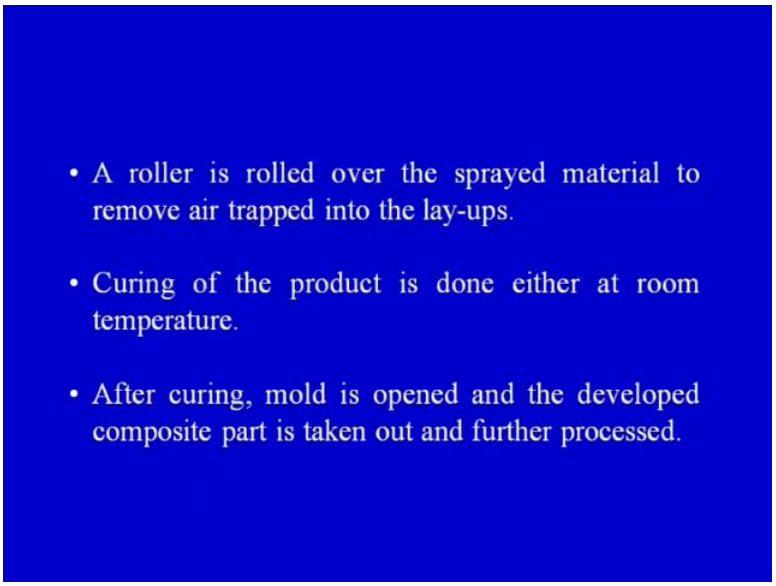

A roller is used, or rolled over the spread material, to remove the trabbed, air, bubble or trabbed you can say excess resin, curing of the product is done either at the room temperature or it can be done at the elevated temperatures also, after curing the mold is opened and the developed composite part is taken out and further processed, may be for secondary processing, we may be required to make holes in that product, so that we would be further processed.

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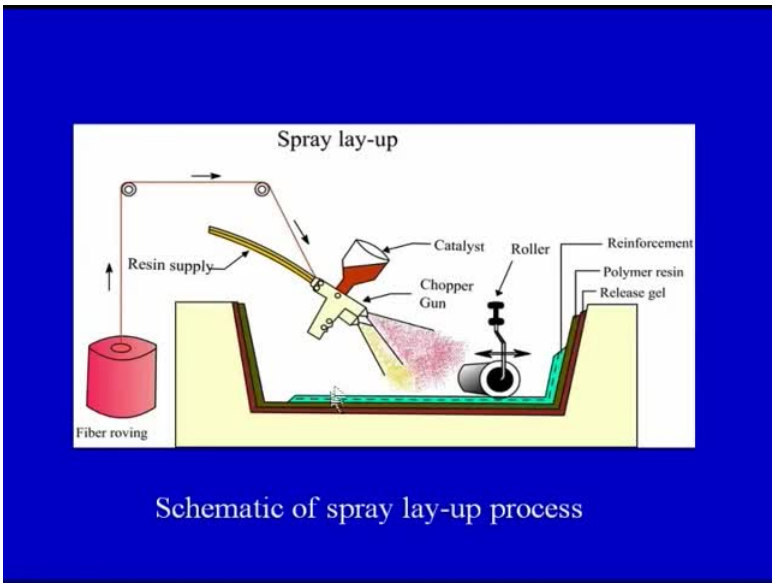

Now, this is the simple diagram of the spray layup process, on your screen you can see, the same type of mold, as we have used, for the hand layup process, we are using again, we are applying the release gel to facilitate the easy removal a polymer resin, and reinforcement this is the green portion represents the spread material. And this is the most important part of the spray layup process, which is called the spray gun or the chopper gun. We have the fibre roaming the fibre is coming from here, in this direction it is getting chopped in this spray gun, and this is the supply of the resin in between we can have a different tubes for the catalysts also, so we have a resin and the catalyst coming from the tube, where fibre coming from the roaming, and the fibre and the resin getting mixed, sorry the catalyst can come from this hopper also.

So, we have a catalyst, we can have another tube in this only, in order to bring about the catalyst, in the chopper gun. So, we have a chopper gun catalyst is coming, a resin is coming, the fibre is coming all these three ingredients are getting mixed in the chopper gun, then finally we are supplying the chopped fibre on to the surface of the mold, the thickness will depend upon the number of times we spray this particular mixture on the mold. So, it is

sometimes difficult to control the thickness of the composite parts, being made by the spray layup process, which may be one of the limitations, but it is a very good process, when we want to make a composite material, in which the fibre are randomly oriented.

So, we further need to study the advantages, limitations and applications of the spray layup process, which we will take in the subsequent lectures. So, in order to summarize what we have covered today, we have basically seen, three important parts in today's lecture, the first important part focussed on the constituents, that go into the fabrication of the polymer matrix composites, the matrix and the reinforcement different types of polymers and different type of fibres, which are used for fabricating the polymer matrix composite material.

We have seen the hand layup process and we have seen the basics of the s spray layup process, in today's lecture, we have also seen in the classification of the polymer matrix composite processing techniques, which can be classified into a open mold process, a closed mold process and the other processes, in terms of pultrusion and filament winding. So, in the next lecture, we would focus our attention, on the advantages, limitations application area of the spray layup process, and we will carry forward the discussion on the pultrusion process, which is one of the automated processes for making the polymer matrix composites.

Thank you.