Processing of Polymers and Polymer Composites

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

Lecture – 22
Autoclave Molding

[FL] friends, welcome to the session 22 in our course on processing of polymers and polymer composites. Just to have a brief review of what we have covered in context of polymer composites, we have seen the basic fundamentals of composite materials that why the composites are made, why the 2 constituents are combined together to make a third material which we are calling as a composite material. Then we have seen the classification of composite materials that how the composite materials can be classified based on the matrix as well as based on the reinforcement.

Then we have identified that based on the matrix we are going to focus our attention on polymers only at the reinforcement will be in the form of fibers, and the fibers can also be directionally oriented they can be randomly oriented, they can be continuous fibers, they can be random fibers, they can be in the form of particulate or they can be in the form of a powder.

So, that understanding we have developed and then we have seen that how to combine these 2 things together, that is the matrix as well as the reinforcement. So, that is what we have to understand that how to combine 2 physically and chemically different constituents together so that they develop into a new material which is much more efficient much more strong much more stiffer much more resilient as compared to the individual constituents. So, that is the purpose of understanding this particular course that is the processing of polymer composites I think I have not address this point earlier that in processing of polymer composites.

Our focus is majorly on the manufacturing or fabrication aspects of composite whereas, the composites is a very large family there is another domain that is mechanics of composite materials in which we discuss about the strength how to calculate the strength of a composite material how to calculate the stiffness how to calculate the deflections or the strains developed in the composite material.

So, that mechanics part we are not focusing in the current course, here our focus is primarily to understand that how the composites are fabricated, how the composite products are fabricated and in that series. If you remember we have already discussed four sessions and the first one was on hand layup process, the second one was on spray layup process the third one was on compression molding and the last one the previous session that we had was on injection molding.

Now, if you remember in injection molding also we have seen 2 different variants, that was the injection molding that is conventional injection molding and then we have seen the reaction injection molding which could further be classified as reinforcement reaction injection molding as well as the structural reaction injection molding. So, there are lot of processes which are used for processing of polymer composites, depending upon the specific requirement of the final product.

And in that series we are going to cover another topic today that is the autoclave molding. Autoclave molding as I have already highlighted we have to see that how the fibers and polymers have to be combined together. So, this we can say is kind of a cooking oven that way use in our houses, if you see we have microwave oven and in microwave oven we put the food which has to be heated and finally, we get our hot food out after specific period of time.

So, there what we can control in a microwave oven, we control that duration of the time for which the food item will be exposed to the electromagnetic radiation. So, basically it is the autoclave process is also like a microwave oven only, but the source of heat will not be the electromagnetic radiation, but the source of heat will be some other source it can be induction heating, as one of the sources of supplying heat to the composite material. So, here we have a cavity or we have a oven in which we put our raw material and the curing happens because of the pressure and the heat, that is supplied through the equipment.

So, basically this is a we can say process in which we have 2 major operating variables that is the heat and pressure. How the heat and pressure will be applied that we have to understand and the 2 ingredients have to be combined together now what are these 2 ingredients? One is the matrix another one is a reinforcement and the matrix here is a polymeric matrix and the reinforcement is the fibrous reinforcement. So, that is a

understanding that we have to develop today, that what is the autoclave process and how it is done and we are going to understand the autoclave in conjunction with or in combination with the vacuum bagging process also, because vacuum bagging is another process which is used for processing of polymer composites.

So, autoclave plus vacuum bagging we are going to combine together, because the time slots are limited we have to cover all aspects of composite material in this domain of 20 hours and already we have as you are as it is clear on your screen today we are in session 22 and we have 18 sessions more to go of half an hour each and there are so many other things that we need to discuss in context of the composite materials, but if the time permits we may also go for specific session on vacuum bagging, but currently we have to understand the process of vacuum bagging in today's session only. So, let us start the discussion on autoclave molding, in addition to that we are also applying a vacuum bagging approach here to remove the air entrapment or the air bubbles that may be formed inside the composite part.

So, let us quickly try to understand the process and there is a very good video from a commercial company which has put it in the open source and that we are trying to see today that how the process happen and if you are attentive will see that video careful you will be able to appreciate the beauty of the process, you will be able to understand the mechanism of the process and you will never forget it throughout your life. So, let us first try to understand the process of autoclaving. So, autoclave method is also open mold process.

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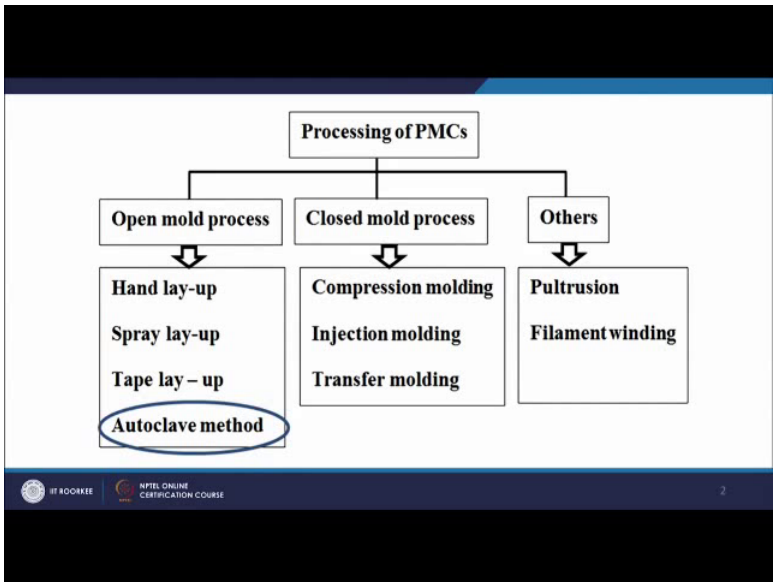

Now, I think first the learners must understand that what is the difference between open mold process and add a closed mold process. In closed mold process usually we have 2 mold halves and examples you can see on your screen, it is compression molding and injection molding. In compression molding the diagram that we have seen there is a bottom half of the mold which has a cut out and there is a top half of the mold and when the 2 mold halves close in between we get the mold cavity, which is exact replica of our final product.

In case of compression molding we have seen there are the vertical mold halves one is a fixed another one is movable. So, they combine together a clamping force is applied and in between we get the mold cavity and the melt mixture which has fibers also, if we are talking of only the processing of polymers it can be a need polymer need thermoplastic which is injected through the nozzle into the mold cavity or in case of composite of melt mixture, which has fibers also is injected under pressure into the mold cavity which is closed.

So, the mold halves are closed. So, therefore, the compression molding process the injection molding process, we usually called it as the closed mold processes is where as in open mold you have seen in hand layup process we have seen to flat plate mold, but they were open from the side. So, therefore, we call them as the open mold process similarly is spray molding process there was a chopper or a spray gun which was used to

spray the mixture of polymer and fibers on to the mold surface and that was also open mold process only and today we are going to cover auto clay which is also an open mold type of process.

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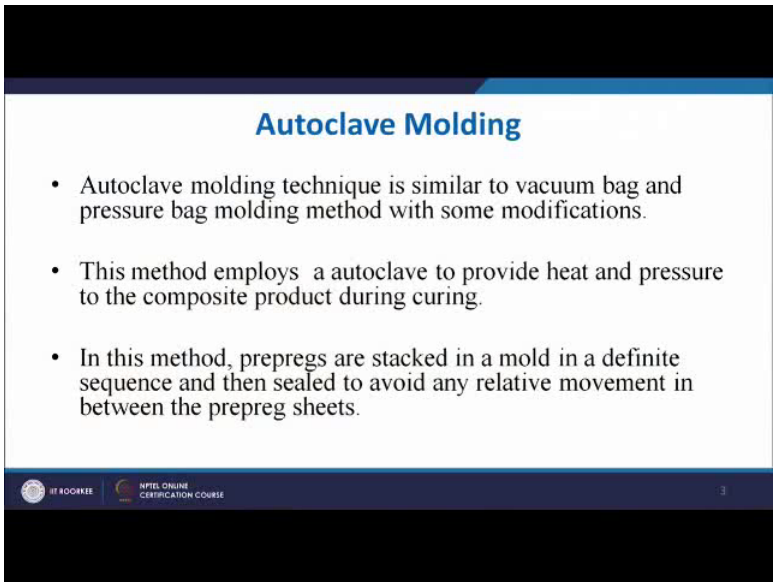

Now let us try to understand the autoclave molding process; autoclave molding technique is similar to vacuum bag as I have told you here also we will try to understand the process of vacuum bagging also, and pressure bag molding method with some modifications. So, maybe autoclaving vacuum bag molding pressure bag molding. So, all these process are maybe the basic principle remains the same. This method employees autoclave to provide heat and pressure to the composite product during curing which I have already explained. So, the 2 major operating variables in case of autoclave molding process are heat and pressure.

Now, how heat and pressure is applied that we need to understand with the help of a diagram as well as with the help of an animation. In this method prepregs; now the new term has come in our discussion today, prepregs we will have a complete session on prepregs and what are the prepregs and how they are useful that we are going to cover, but currently we can just remember that prepregs are the half cooked we can say raw material which is used for making the composite products. Usually in a composite we have a matrix as well as we have reinforcement. So, we have fibers and a polymer. So, prepreg is a combination of the fiber and the polymer, but the polymer is in the semi

cured state, it is not in the fully cured state, it is semi cured state only. So, that is the beauty of this raw material that it has both it has both the polymer as well as the fibers.

Now, it can be taken an example of a band aid, usually what happens whenever there is a cut or a bruise on our body or the skin what you have do? You take out band aid we open it and we apply it on the part which has been injured and then after some days we get cured or we get hale and hearty. So, this prefix also were simi in similar nature only we will see in the animation that there also packed inside the films thin films which protect them from the atmospheric we can say environment or from exposure to the environment and then when we remove these the 2 films we get a prepreg and it is semi cured state of polymer plus the fibers.

So, fibers and polymers together they are called the prepreg and we will see in the animation that how prepregs are useful. Usually what happens in hand layup process if bring the fibers separately if you remember the animation that we have seen for hand layup process what we do? We bring the fiber separately we mix the polymer separately we had hardener into it, and then we put on the bottom half of the mold we put our fiber and then we apply the resin with the help of a brush.

So, there 2 things are coming and we are combining them manually, in case of prepreg the things are pre cured only pre blended is another word we can use the fibers and polymers are pre blended it is a sheet which has got both fiber as well as the polymer and they can be directly used as the raw material. So, that is the term prepreg, I think it should be it must have been clear to all of you we will have a complete session on prepreging and there we will try to highlight the other aspects of prepreging. So, in this method the prepregs are stacked in the mold. So, there will be a open type of mold and that in that mold we will stack this prepregs as per the thickness requirement.

Now, how much how many prepregs we have to apply that will depend upon the thickness that we want to produce. So, in this method prepregs are stacked in the mold in a definite sequence and then sealed to avoid any relative movement in between the prepreg sheets. So, we have to seal this lime layer by layer addition of the prepreg so that the there is no relative movement between the prepregs that we have applied on the mold surface but prior to that we have to apply a release gel on to the mold surface in order to avoid sticking of the polymer to the mold.

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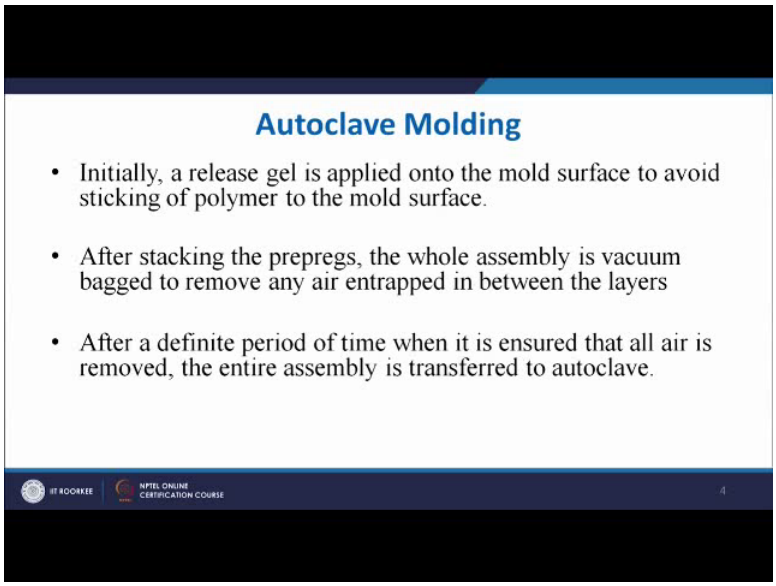

So, that is common as we have seen I think I have not highlighted this point in compression molding and injection molding, in these 2 processes also before the mold closes there is a spray of a release gel on to the mold surface why so that the polymer do do not stick to the mold surface.

So, similarly we have seen we are specifically highlighted that point in case of hand layup process and spray layup process. In hand layup also we apply a release gel before doing the laying up, and in spray layup process also we apply a release gel on to the mold surface. Sometimes we use thin plastic sheets also on to the mold surface before doing the layup so that the laminate do not stick to the mold surface on curing. In this case also in autoclave molding we have to ensure that are released gel is applied on to the mold surface in order to avoid sticking of the polymer to the mold.

After stacking the prepregs the whole assembly is vacuum bagged to remove any air entrapped in between the layer. So, vacuum bagging is applied here we will see how vacuum bagging is applied with the help of a animation, and that vacuum bagging what is the purpose of that? Ihe purpose is that it will help us to remove what it will remove it will help us to remove the entrapped air in between the layers of the prepregs. After a definite period of time when it is ensured that all air is removed the entire assembly is transferred to the autoclave, now autoclave as I have already given an example is a

cavity or is kind of a oven in which we can supply heat and pressure to the composite for the curing process.

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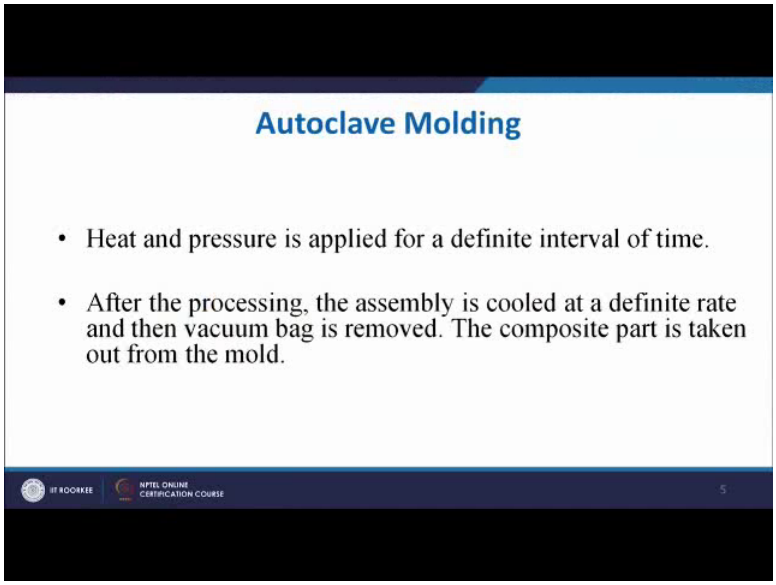

Heat and pressure is applied for a definite interval of time, after the processing the assembly is cooled at a definite rate and then vacuum bag is removed the composite part is taken out from the mold. So, these are the steps that have to be followed for making a composite product using the autoclave molding technique. Now just to summarize what we have to do in 2 or three sentences the raw material is in the form of prepregs, the prepregs are cut as per the shape of the mold and then they are means put in on the mold or they are deposited on the mold layer by layer the number of prepregs will depend upon the thickness of the desired product. One this once this has been done a vacuum bag is applied on top of the prepregs and a vacuum is applied.

So, that all the air and trapped or any bubbles present in between the prepregs are removed and once this vacuum has been applied and air has been removed or air entrapment has been remove, the whole assembly is put inside the autoclave there we control our heat and pressure, and this heat and pressure will help in the curing of the polymer and once the cooling once the this curing is complete we will allow the composite part that has been formed to cool down for some time, and after the cooling the vacuum bag is removed and the product is taken out and it is the final product that we want to produce.

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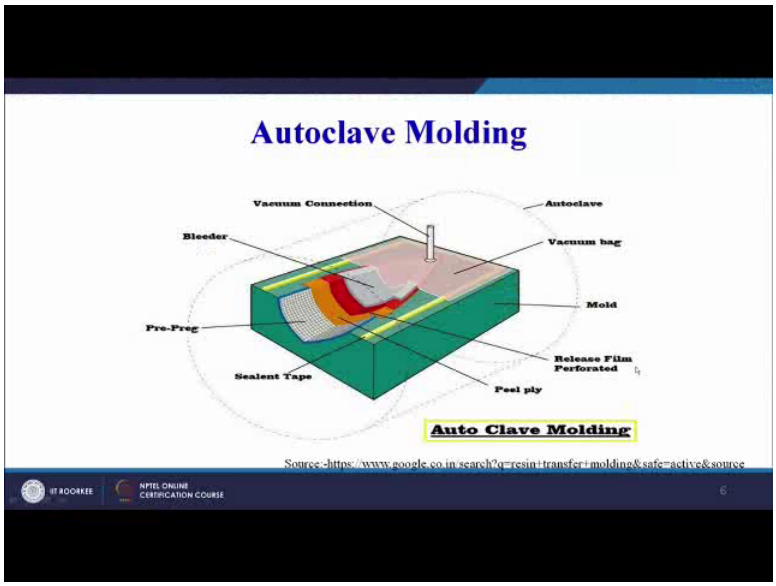

Whatever has been explained now we can see this is one diagram, it has been taken from Google images and this is autoclave molding process we can see here this is a prepreg fibers are running in both the direction, then there is a peel ply release film red color, bleeder which we usually used in case of autoclaving process and this a vacuum bag which we apply on top of the prepregs and then the vacuum connection, it will remove all the air and trapped inside the prepreg and all these layers will finally, be removed and we will get our final product, which will only be the staged up prepregs.

So, this is we can see the and on the bottom side also we will have the release gel. So, that the prepregs or the composite part which has been formed from the prepregs do not stick to the other half of the mold; this side we have ensured it with the help of feel ply as well as the release film which is perforated, but on the other side also we have to ensure sometimes we may have a spraying arrangement of the release gel and before we do the stacking up of the prepreg, it is ensured that this spray is uniform all across the mold surface so that later on our laminator or the cured composite product do not stick to the base mold or the outer surface of the mold.

Now, let us try to understand the whole process with the help of a diagram; diagram we have already seen let us see the animation.

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Now, you can see the; this is the autoclave the blue color outer assembly.

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This is the mold that has come out and this is the prepregs coming from the tape there is a on the top side it is a green film.

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The 2 films are coming out these are prepregs now prepregs are going into the mold cavity, there we will see this is the mold cavity or the final product that we want to make this is a prepregs coming inside and settling down on the mold surface.

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So, these prepregs are covered with thin film. So, that they are not exposed to the environment and the automatic curing may not take place, there for their storage requirements are very very stringent.

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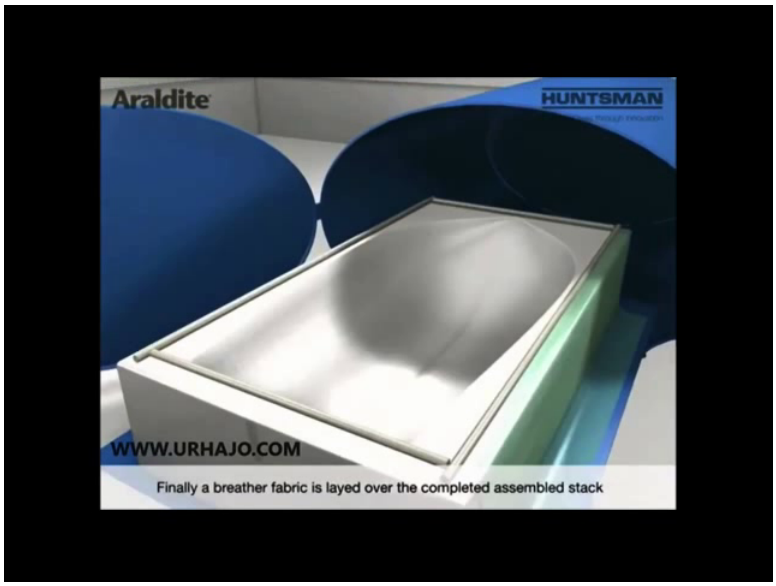

So, this is a prepregs have now been applied on the mold surface, now we are closing it, this is a breather fabrication is applied vacuum bagging film is secured by the sealant tape.

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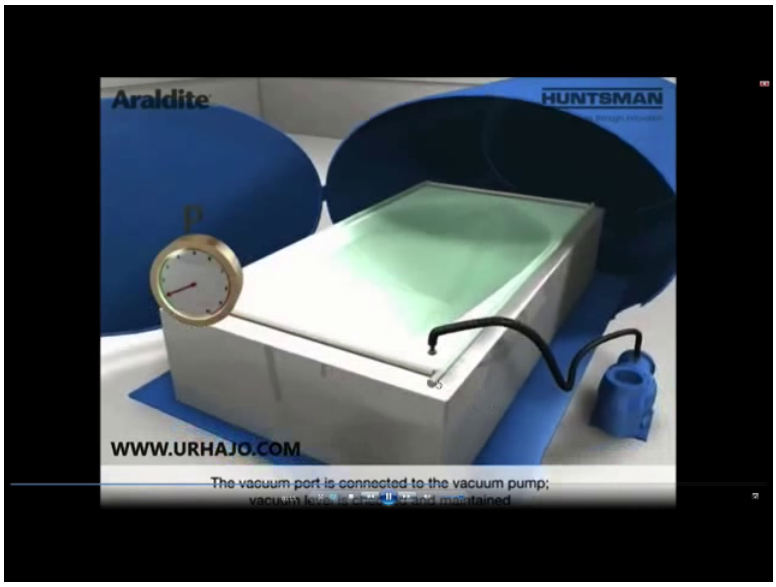

We will again go through this video once so that even I did this is a vacuum pump. Cacuum is applied you can see; what is happening here the vacuum bag is applying pressure on the and this is autoclave the whole assembly as input in the autoclave we can control the temperature and pressure, and polymerization takes place inside the autoclave

for a required amount of time or a defined interval of time this will be inside and then the finally, the mold comes out. We have to remove the vacuum film this is cooling off the composite taking place and d molding.

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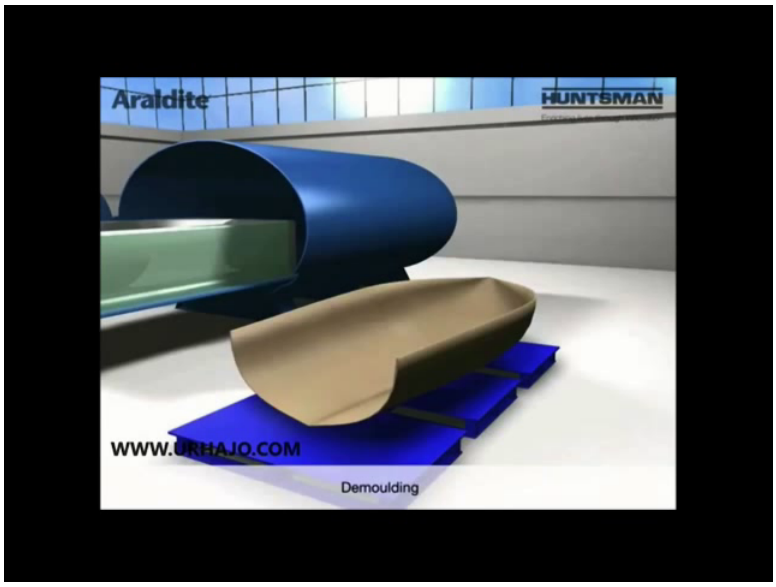

We have to do this is a product which has come out now and this is our final composite product that we want to produce.

Let us have again we can see the process once again, this is a mold that is coming out and the other side prepregs are being cut as per the defined size and you can see the 2 films are being removed from air, blue film and green film will be removed this is a prepreg now finally, in the usable form the 2 films were used in order to avoid the exposure of the prepregs to the environment, of those have been removed. Now the prepregs are being deposited on the mold surface or being fixed at the required position a stack of prepregs is than laid in the mold this is sealant tape is applied all around the edge of the mold breather fabric is applied, the vacuum film is secured by the sealant bag the vacuum port is created, the vacuum port is connected to the vacuum pump vacuum level is checked and maintained.

A complete assembly is placed in the autoclave temperature and pressure is controlled in the autoclave and polymerization takes place, then this is the cooling phase, the mold has come out cooling phase is still continuing vacuum film is removed, this is d molding the

sealant tapes are removed breather fabric is removed and finally, we get our product this is a final product composite product.

Now, some of you may definitely be wondering that from where the fiber and the polymer has come in this and why we are calling it as a composite product. As I have told you the prepregs that were coming and this green and blue films were being removed from the prepregs. So, this prepreg already has free blended fibers and the polymer. So, this is simple process it is kind of a tape which we are using and laying get inside the mold layer by layer depending upon the thickness required for the final product and finally, we are applying heat and pressure so that the polymerization takes place quickly and we get our composite product at a high highly productive rate. So, that is the basic concepts.

So, there was one term which has come here that is a breather fabric that we are not going to discuss in much detail, today because today we have to finish our discussion on autoclave molding, but definitely when we go to prepreging we will and try to understand that what is the role of the breather fabric in the whole process. But today our process is autoclaving in which there is a autoclave oven which in which we can control the heat and pressure and we can make a composite product from the prepregs.

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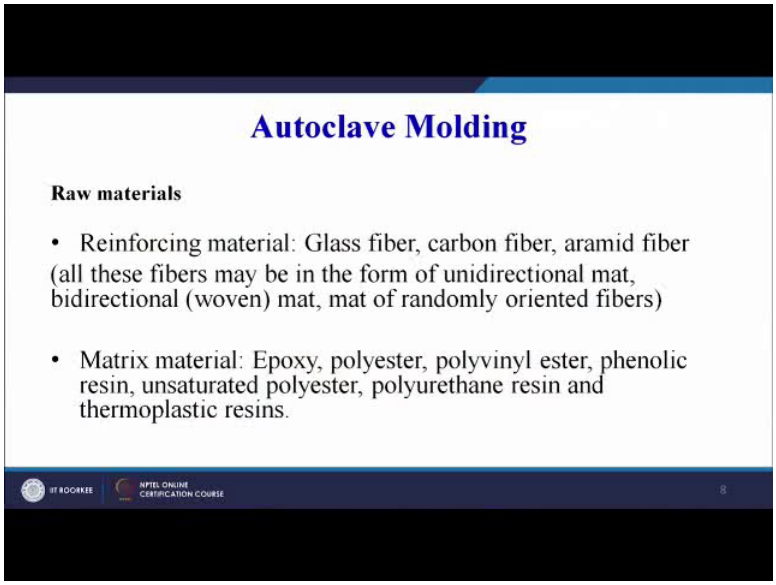

Now what are the raw materials used in autoclave molding? Glass fiber carbon fiber aramid fiber all these fibers may be in the form of unidirectional mat bidirectional mat

mat of randomly oriented fiber. So, that a that is one thing that the fibers must be in the continuous form, they can be small fibers also shot fibers also, but they should also be available in the form of a randomly oriented mat. So, mat form is the requirement for the fiber matrix material can be epoxy polyester polyvinyl ester unsaturated polyester. So, there are different types of polymers which can be used for making products from auto cliff molding.

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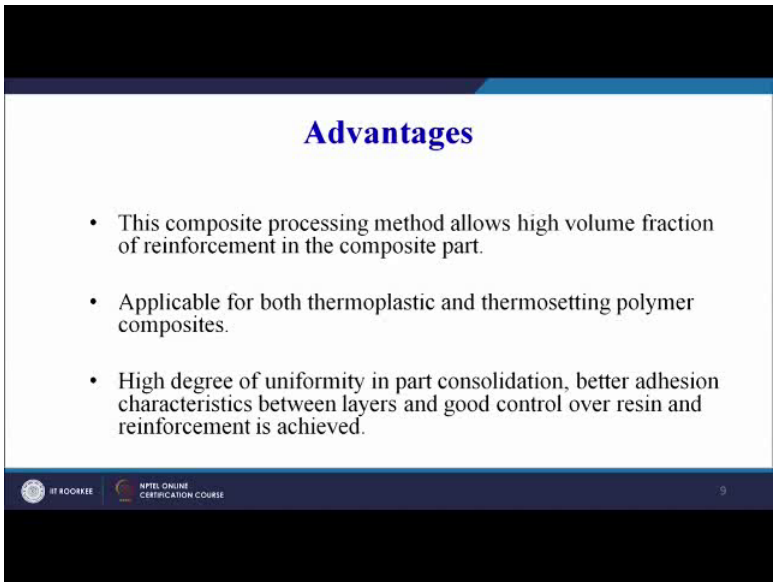

Now, what are the advantages of the whole process? This composite processing method allows high volume fraction of reinforcement in the composite part now this is important because if you remember in case of hand layup process we were removing the axis polymer with the help of a roller arrangement whereas, here we have pre branded prepregs that we are using as well as we are replying the vacuum bagging also. So, whatever accessorizing even if it is there will be removed and therefore, we will be able to achieve high volume fraction of fibers, that is high volume fraction of the reinforcement in the composite product, that is desirable from the mechanical engineering point of view because the fibers are the main load bearing members in the composite and if we have more fibers in the composite, the strength stiffness of the composite will be more.

So, this is applicable for both thermoplastic and thermosetting polymer composites which is another advantage. High degree of uniformity in part consolidation better

adhesion characteristics between the layers and good control over resin and reinforcement is achieved and if we use prepregs as the raw material I think all these characteristics are bound to happen, what can be the disadvantages of auto clawing?

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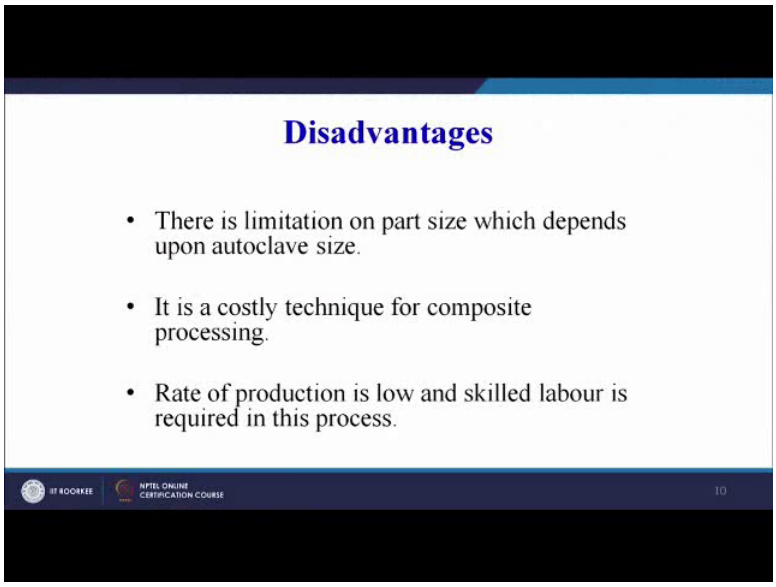

There is limitation on part size which depends upon the autoclave size. So, we cannot have a very large size product, composite product being made by the autoclave molding process as in the case of hand layup or spray layup.

So, if a very large size product has to be made we have to go for either the hand layup process or the spray layup process. It is a costly technique for composite processing relatively costly as compared to the other techniques, rate of production is low and skilled labor is required in this process because we have to control the number of parameters, if we are using the vacuum bagging technique also alongside the autoclave we have to control the pressure, the vacuum that we have need to understand and judiciously select then once we have put our assembly into the autoclave we have to see how to how much temperature for how long the temperature has to be maintained for how long we have to cool the product, similarly we have to see that how much pressure has to be applied. So, maybe labor intensive or maybe worker intensive process.

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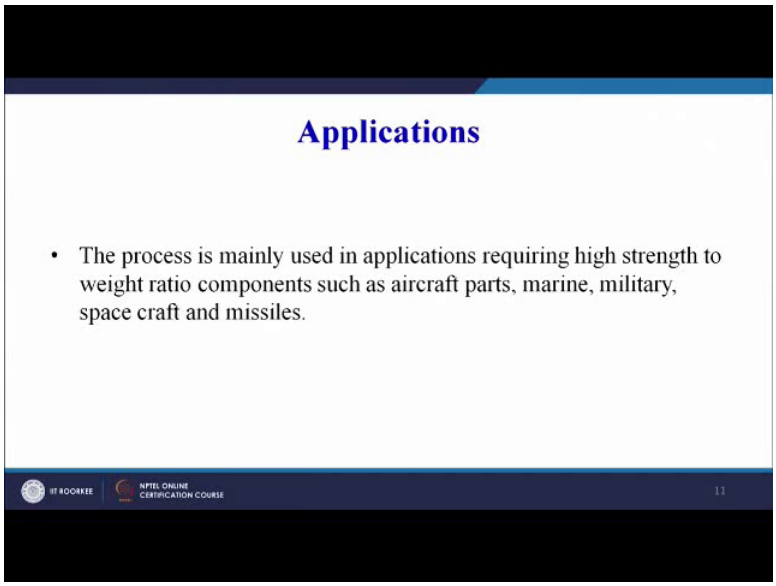

What can be the applications? This process is mainly used application requiring high strength to weight ratio. So, high strength to weight ratio definitely we will achieve if we have high volume fraction of fibers because the density of fibers is less as compared to most of the polymer.

So, if we have more fibers, more reinforcement in our composite product better will be the strength to weight ratio or stiffness to weight ratio and then this process is commonly used for aircraft parts marine military space crafts and missiles. So, with this we come to the end of today's session that is an autoclave molding, I think we have been able understand the basic concept of autoclave molding and we have also added another dimension of vacuum bagging alongside the autoclave molding process, which has added another dimension to the understanding of this process as applied to the composite materials.

If time permits we may go for the vacuum bagging as a separate session or we will see that how we can cover the concept of vacuum bagging in any of the other alongside any of the other processes, but one important thing that we have understood today is a pre pragging and prepregs. So, we will definitely like to have one session on pre price and try to understand that how prepregs are helpful for engineers for making the composite products.

Thank you.