Manufacturing of Composites
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Lecture – 13
Vacuum Impregnation Methods

Lecture number 13 this is the last processing lecture of thermo set composites. Last class we studied little bit about resin transfer molding and then we also went quickly browse through vacuum assisted resin transfer molding. In this lecture we will prominently focus on vacuum impregnated methods. So, this is a very important process where in which you are looking for high strength very long size or very large size parts which are used for example, wind turbine blades are made out of vacuum impregnated methods the cover frame the closure for aeroplane, aeroplanes are made out of vacuum impregnation methods this is very important.

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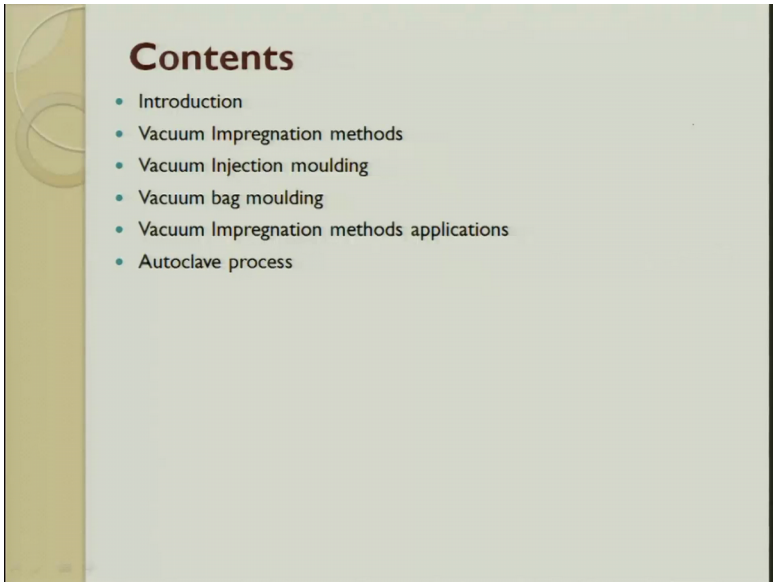

So, we will see this process. So, the content of this process you will have an introduction you will have vacuum impregnation methods, you will have vacuum injection methods, you will have vacuum bag molding, then vacuum impregnation method, applications then autoclave process. So, autoclave process is an industrial process where in which it is used for making complete closure for Toyota car almost all the race cars you design such that you have very minimum drag, and very light weight they make through autoclaves.

So, here what happens is as the name suggest there has to be a vacuum which is there then there it is a composite to be made you will have a fiber. So, this fiber is a reinforcing material. So, this reinforcing material either you add resin to it or you buy it with resin impregnated.

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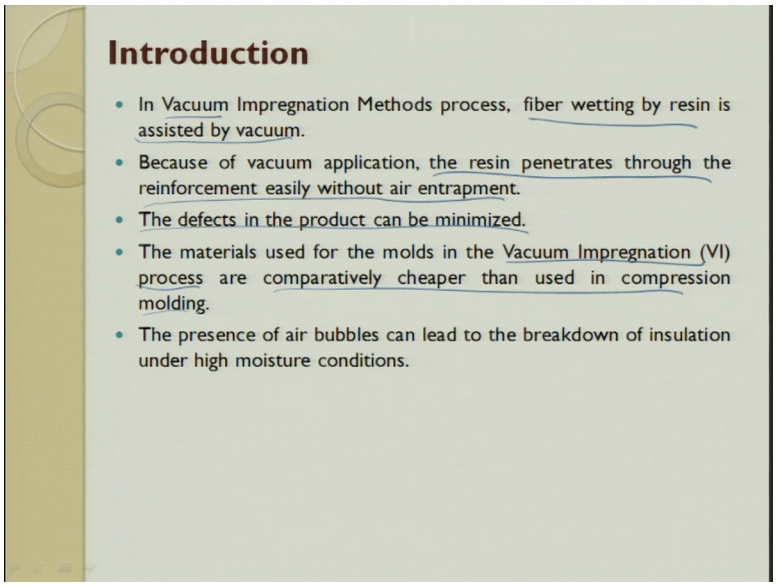

So, what it is this is the starting material and in the process you are going to apply vacuum. So, that is what is entire process. So, you have got the crux of the process. Vacuum impregnation method the fiber is wetted with resin and it is assisted by vacuum either you buy it from the market as resin infused or you try to buy the reinforcement from the market fiber mat and then you try to reinforce. Based on the vacuum application the resin penetrates through the reinforcement easily without any air trap one way is you pour and then you try to sweep it through when you try to sweep it through still there is a possibility of having small air bubbles and what are the problem with these air bubbles suppose if you have multi layer and this air bubble is stuck in between. Then you will never get a sound quality output.

In order to avoid this what we do is we try to put the fiber mat and then we try to suck air. When you suck air the possibility of air getting trapped is less. That is why we always go for vacuum assisted a while pouring the resin. So, the defects of the products are minimized and then the method used in this mold is vacuum impregnation process as comparatively cheaper than the compression molding processing, in compression

molding process what happens is you should have a capital intensive die you will have a machine energy source to be applied. So, that you get a flat surface or a curved surface whatever you want die is expensive and then die once you make a die the when you have a batch production then you can go for a die batch or a mass when you have only job shop requirements not many 5 parts 10 parts then going for compression molding is always expensive.

So, this vacuum impregnated process is an alternative for it and it gives you a sound product after fabrication.

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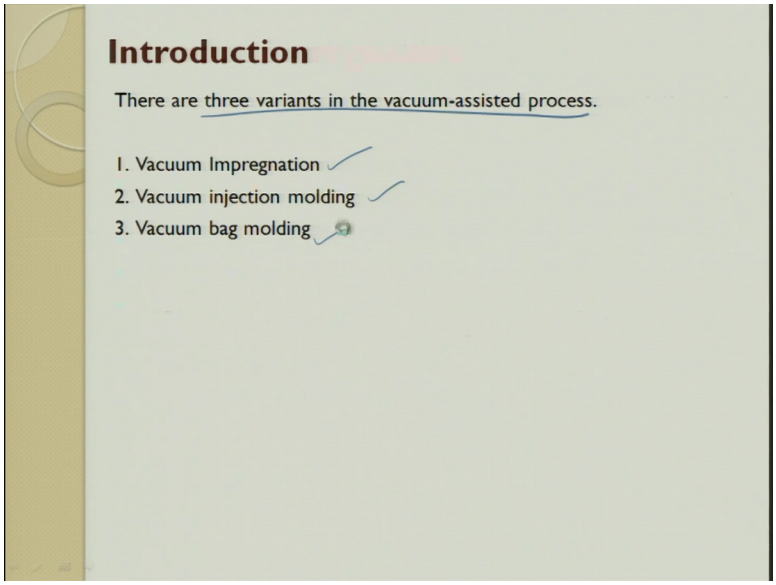

So, there are 3 variants of vacuum assistant process one is vacuum impregnation one is injection and the third one is vacuum bag molding impregnation I try to push that is impregnation and if I can try pushing through with the lot of force that is injection molding vacuum bag. We will see as and when it goes.

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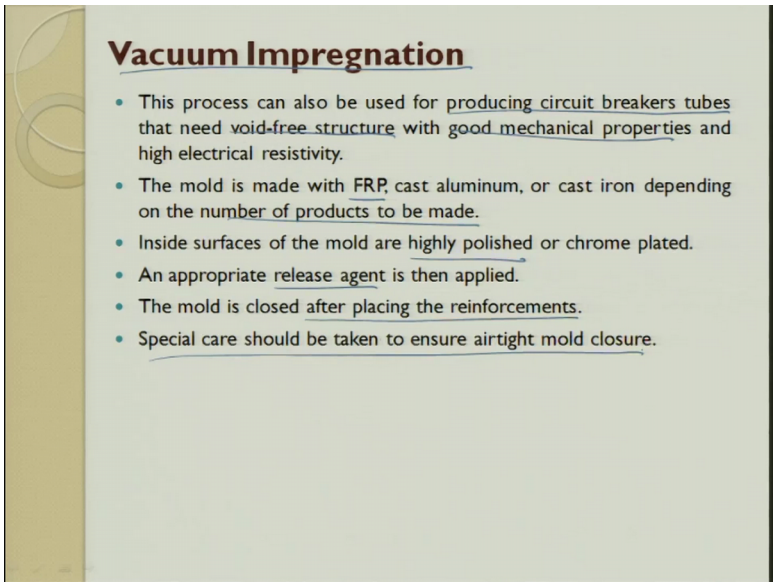

What is impregnation? The process which is used for these are examples I have given producing circuit breakers tubes that needs void free structures with good mechanical properties are always done by vacuum impregnation molding.

So, here the mold is made out of FRP or cast iron or cast aluminum depending upon the product you make, the inner surface of the mold are highly polished. So, they are polished for with the releasing agent and they are also polished to give a smooth surface and releasing agent is also applied you polish the surface releasing agent is applied the mold is closed after placing the reinforcement and the vacuum is applied then the resin is sucked inside.

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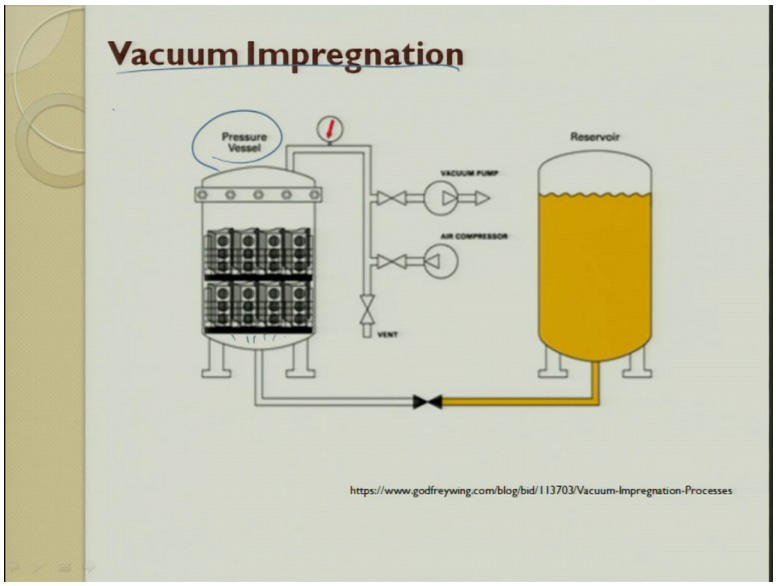

So, it is like this vacuum impregnation. Here you have this is for a mass scale we are talking about. This is a pressure vessel where in which you keep the product and then this is a resin here we are talking about a very large scale please do not think a tumbler of resin will be the reservoir no we are talking about meter long or we are talking about bulk production. Here what happens is. You have small components which are all arranged and then there is a reservoir which gets through it. There is reservoir where in which you have all the resin and you mix the ingredients whatever you want components are quoted with releasing agent or whatever you want. So, it is done.

So, then the reservoirs is allowed to move. You use air compressors. Then there is a vacuum which is there. So, this is used for sucking. From here it goes through the reservoir the epoxy or whatever is reinforce the matrix goes through this and the excess is collected and it is went out. This is a process where in which vacuum impregnation is done.

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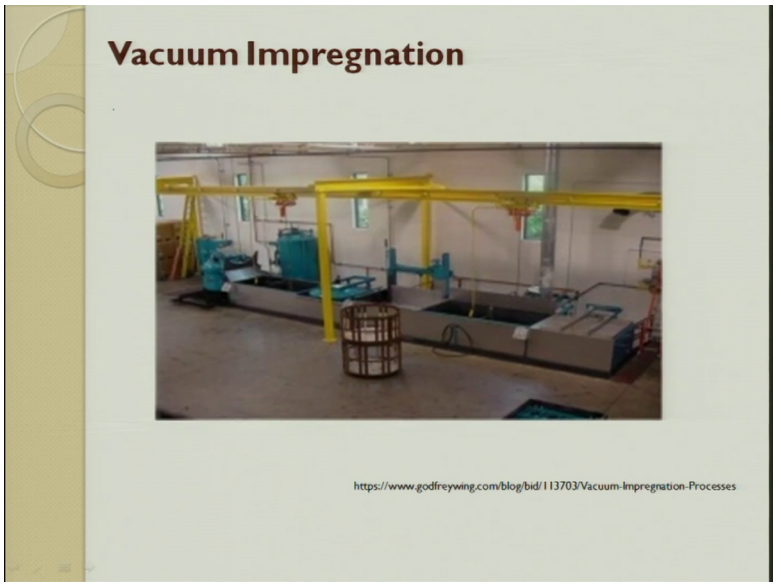

If you want to see that was a schematic diagram if you want to see a live product this is a live product which people use and then these are the place where the components are done this is a reservoir where in which the epoxy or any resin is placed.

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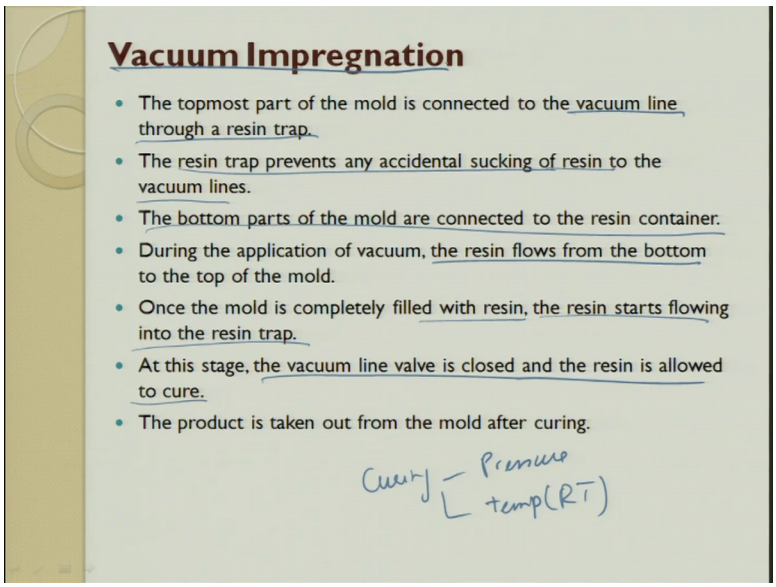

The top most part of the mold is connected to a vacuum line, through a resin trap the resin trap prevents any accidents sucking of the resin to the vacuum line the bottom part for the mold are connected to the reservoir container. If you see here bottom part is connected to the reservoir container the top part is the vacuum which we are looking at it

during application of vacuum the resin flows from the bottom resin can also flow from the top, if it flows from the top there is a possibility of air getting trapped or some other defects getting in to existence. We always suck from the bottom. So, the resin flows from the bottom to the top once the mold is completely filled with the resin, the resin starts flowing into the resin trap at this stage the vacuum line valve is close and the resin is allowed to cure. And here as you know very well I told you for curing to happen one is pressure the other one is temperature.

So, you maintain certain temperature you allow it to do it or you can also do it a room temperature if you want. So, room temperature slowly cures if you want to have accelerated curing you do it. So, this process is called as vacuum impregnation process where in which big by applying vacuum.

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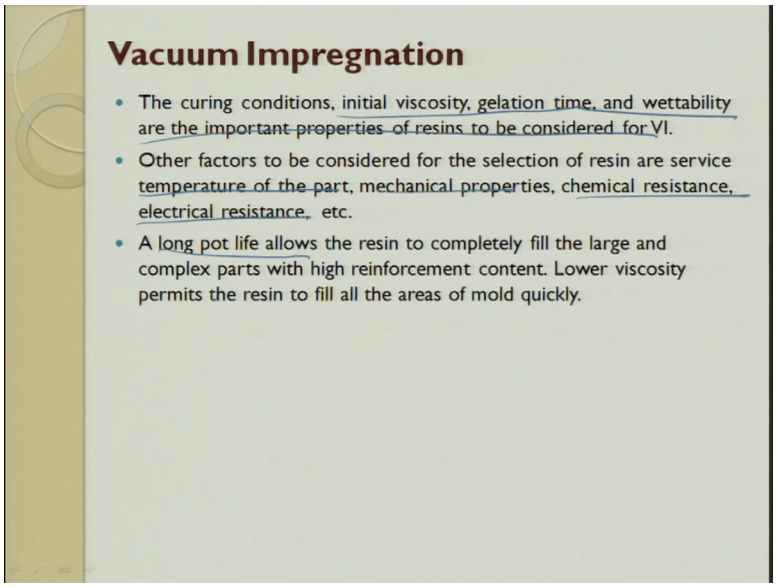

In this process the resin is impregnated into the pre form in the curing conditions initial viscosity gelation time wettability are the important parameters of the resin which helps in VI. We have already studied in the initial the resin viscosity plays the role gelation time is over a period of time when does it start curing and then wettability is the fiber and the polymer trying to attract each other join each other to form a strong bonding the matrix distributes the load the fiber takes the load. If the fiber has to distribute the load the wettability has to be very good.

Other factors to be considered for selection of resin are the service temperature of the part mechanical properties chemical resistance and electro resistance. These are all for choosing a proper resin. We have seen enough of resin properties so you choose a proper resin to meet out your application. The pot life the long pot life allows the resin to completely fill the large complex part what do you mean by large part life is the gelation, the gelling time does not start the resin does not cure the resin is still innation for a longer period of time such that it could completely wet the reinforcement. So, you get the best out of it. Naturally what do you want if some resin has to flow through the viscosity should be as low as possible, but provided you fix in all the other conditions like coloring agent as to be add a filler has to be added then all these things you have to make sure make a proper choice and then go for this process. So, this process is called as vacuum impregnated process.

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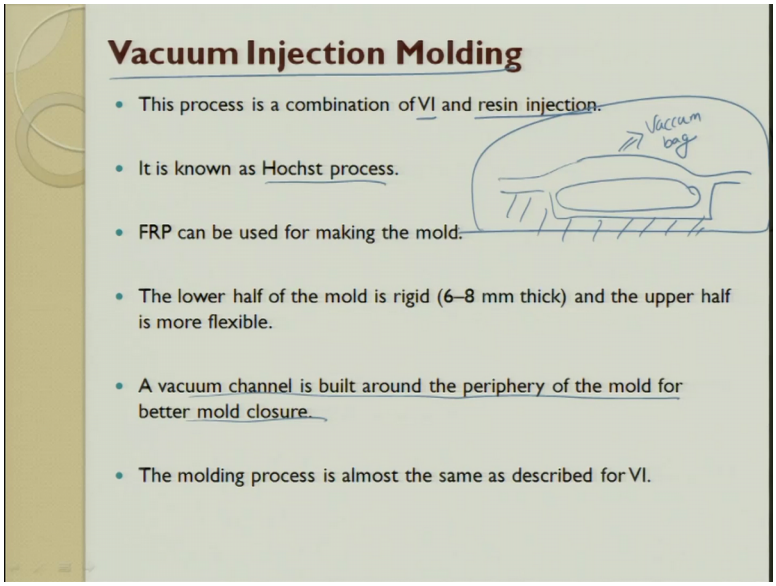

The next process is called as vacuum injection molding. This process is a combination of vacuum impregnation and resin injection process. This process is also known as hochst process the FRP is used for making the mold the lower half of the mold is rigid and the upper half is flexible. What does it mean? You have a die which is made out of any material then you put your component here whatever it is and then you cover the top fellow top fellow with the vacuum bag what is the advantage the top fellow die is removed completely, good advantage. Second thing is whatever was your shape of the

component you want to make which is guided through a die the vacuum bag takes that profile.

That helps you in getting the top surface also the smooth complete finished path the lower half of the mold is rigid as I said and the upper half is a flexible. It can be made out of rubber, it can be made out of a polymer, it can be a bag, whatever it is. The vacuum channel is built around the periphery of the mold for better mold closure, mold closure outside the molding process is almost the same as describe in VI. Here what we do is the vacuum channel is built around the periphery of the mold. So, all around you build a you build a periphery and then you try to maintain a vacuum there.

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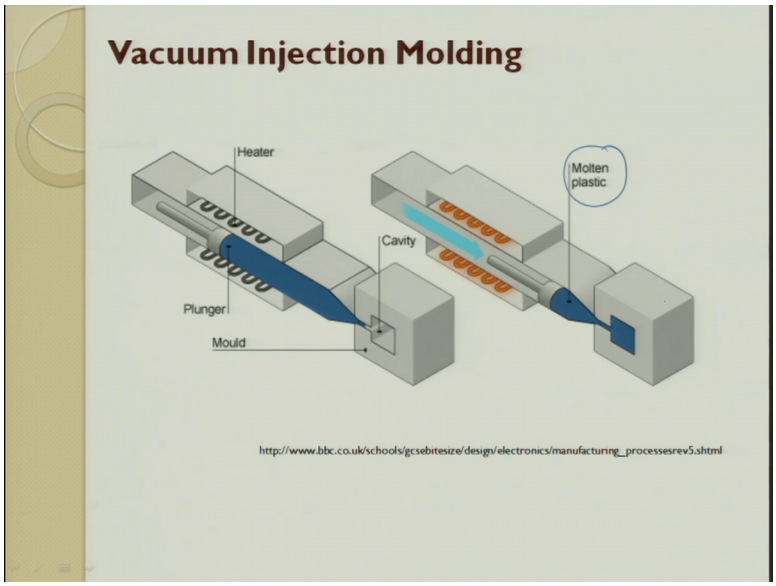

So, this is the heater vacuum injection molding this is a cavity you have a mold cavity you have a plunger through which the resin is heated in order to maintain the longer part life, What we do is we try to heat the resin and maintain it in the liquid state. So, viscosity is less. So hat it can be done. Here it is molten plastic is injected into the cavity. So, that you try to produce a part.

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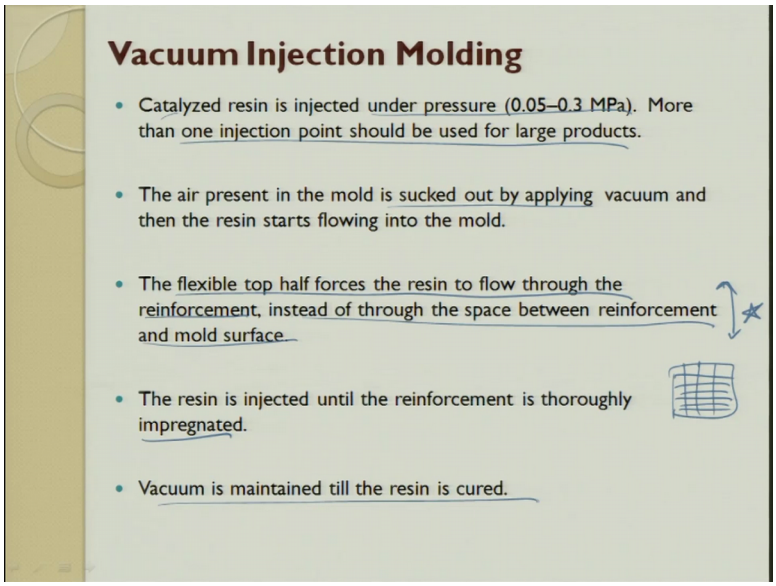

The catalyst resin is injected under a pressure of what is catalyst catalysis the catalyst is nothing, but to accelerate the reaction catalyst resin is injected at a pressure of 0.3 mega Pascals it is injected more than 1 injection point can also be used if you want to make a large component. You will have multi injection if you want to make a wind blade or if you want to make a closure for a complete car. You will have multiple injection points.

Location identifying location for this multiple injection points and the pressure needs lot of simulation studies and then we locate it. In fact, that is really hard the air trapped in the mold is sucked out by applying vacuum good. So, that is what we said and the flexible top half force of the resin to flow through the reinforcement instead of through the space between the reinforcement and the mold surface please understand this point this is very important.

The flexible top half forces the flexible top half forces the resin to flow through the reinforcement instead of flowing through the space between the reinforcement and the mold surface; that means, to say in between the pre forms it is pushing the resin to go rather than going around it. The flexible top half forces the resin to flow through the reinforcement instead of through the space between the reinforcement and the mold surface this is very important this makes the process different from other process the resin is injected through their and until the impregnation happens the vacuum is maintained till the resin is cured.

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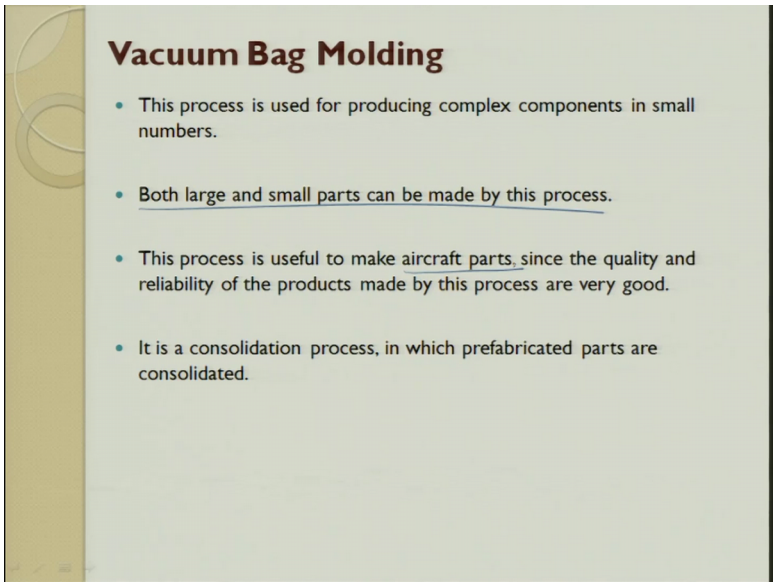

The vacuum bag holding this process is used for producing complex parts in smaller numbers both large and small parts can be made in this process for example, I told you aircraft parts windmill parts can be made and you get a you get a sound product the products that are fabricated by hand lay process can be consolidated by vacuum mold see what happens in hand lay process is?

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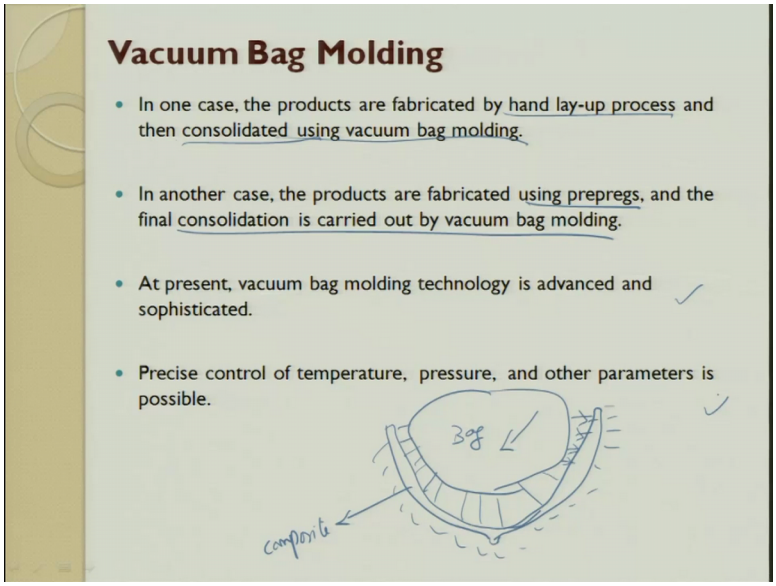

We always have a restriction in the reinforcement if you are really a very good efficient skilled man for making this hand lay process you can touch up to 60 65 percent volume fraction very easily normally we go around 30 percent.

If you want to make 60 or 65 or 70 percent hand lay process and then if you are not pretty sure about the quality it is better we do vacuum bagging and we enhance it. So, generally what we do is even in a boat hull we try to make a boat hull we try to place everything by hand lay process whatever it is we place everything by hand lay process and then what we do is we try to take a flexible tube and then we push air into it. So, that this fellow tries to press this fellow tries to press this bag. So, this is the bag. So, this bag is tried to press against the composite. So, this is a die this is a composite which is made out of hand lay process and then we apply a bag which is a flexible bag we apply it. So, that we this bag tries to apply lot of force on top of this work piece hand lay process. So, that you get a sound product. So, a proper consolidation of hand lay process can be one by this vacuum bag molding process.

So, that is what is the advantage vacuum bag is a flexible die process in another case the products are fabricated using prepregs what are prepregs where resin is already reinforced. So, you just have to place it properly and then you try to get it. So, hear it is all the more easy. So, the consolidation will be done by vacuum bag. So, at the present vacuum bag mold technique is very advanced and it is very sophisticated you can also maintain a quite, you can also control the temperature pressure to get the required output.

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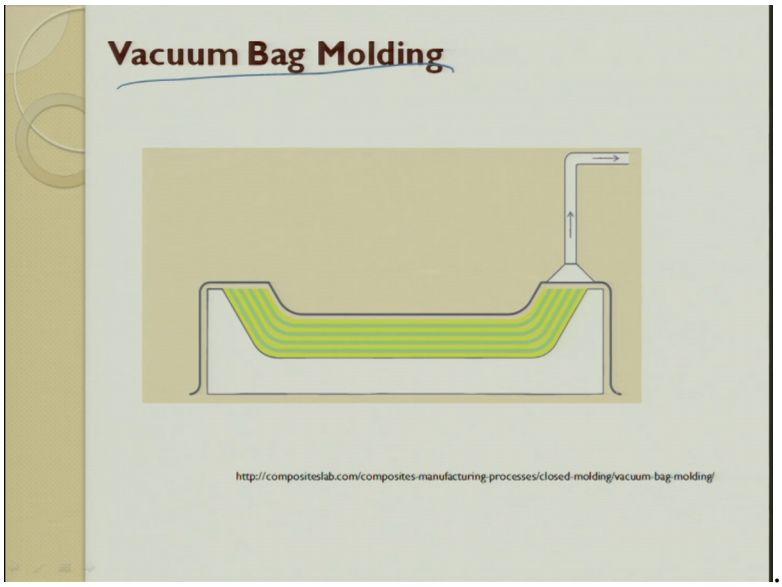

So, this is a schematic diagram of vacuum bag molding. So, we have several layers of reinforcement place and here is a vacuum which is there here is a bag which is there on the top.

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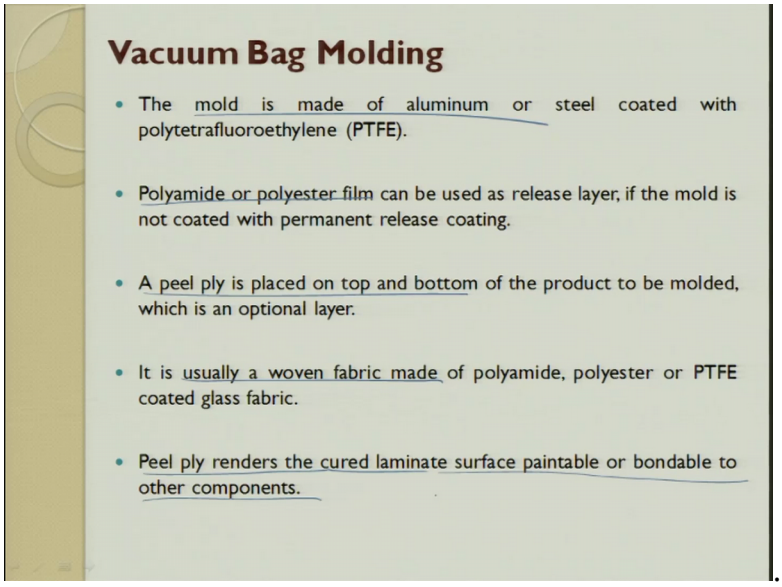

So, the mold is made out of the mode is a bottom surface which is made out of aluminum steel if it you want to have multiple process the polyester film can be used as a releasing agent the plies are placed on the top and the bottom of the product or the mold. So, the oven fabric of whatever it is you want to keep your placing it is quoted with glass fiber

and the peel ply renders the curing laminated surface paint ability or bondable with the components.

So, these are the steps which are involved. So, the last step is peel ply renders the cured laminates surface paintable means you are trying to give a color or bondable to other components can also be one by this vacuum bag molding process.

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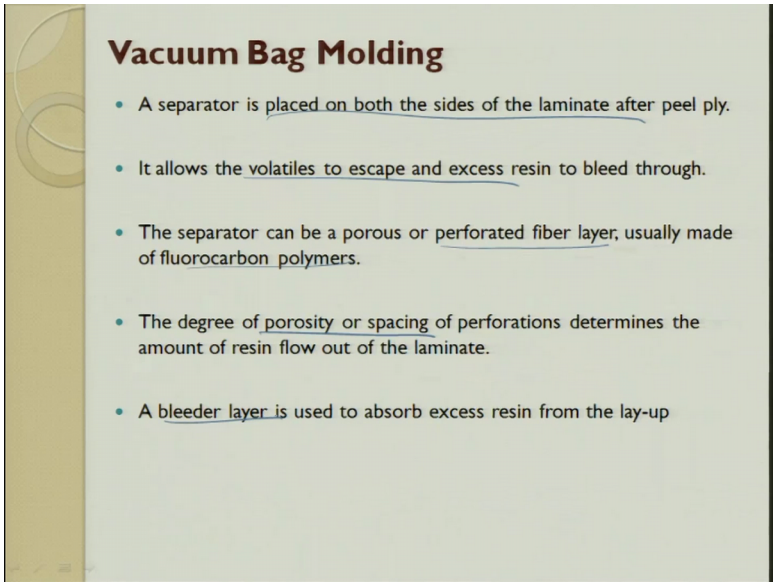

So, to go more the separation is based on both sides they it allows volatile material to escape the separation through the porous are perforated fiber layer usually is done by made out of fluro carbon polymers they have separators also applied the porosity can be reduce drastically there are bleeder layers where in which the excess resins are absorbed. So, it is like a cotton bleeder layer is like cotton where in which it observes the excess resins. So, that you get the sound product output.

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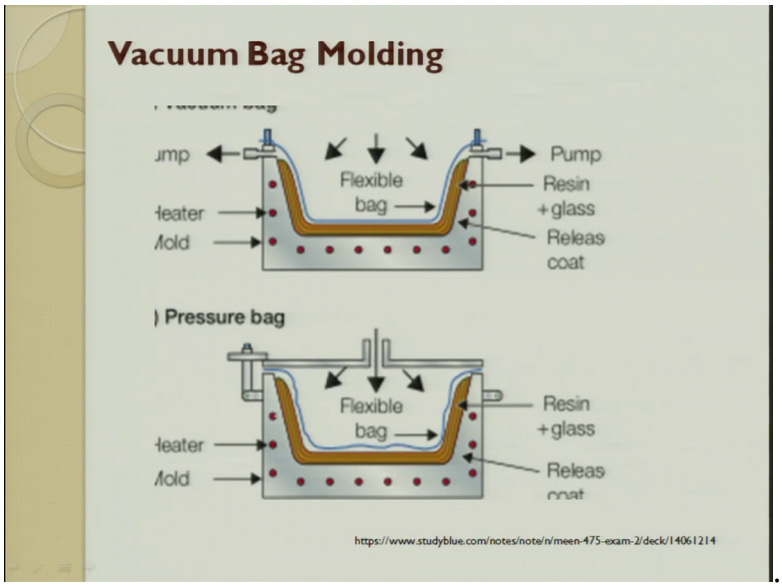

So, you can see here this is a flexible bag I gave you an example of a boat. So, this is a flexible bag if you want you can have it. So, here is the resin which is the prepreg is completely placed prepreg of the hand lay process is done glass fiber is done. So, below this you have a release agent coating will be there. So, you can apply heat for curing whatever it is and then here is a pump which is used for sucking and then creating vacuum here and then you apply flexible bag there also you apply pressure. So, that you get the good output. So, the pressure bags are also there. So, you put on top of the pressure bag you can also try to do it. So, these are the 2 ways where in which vacuum bags are used pressure bags are applied and then vacuum bag is applied.

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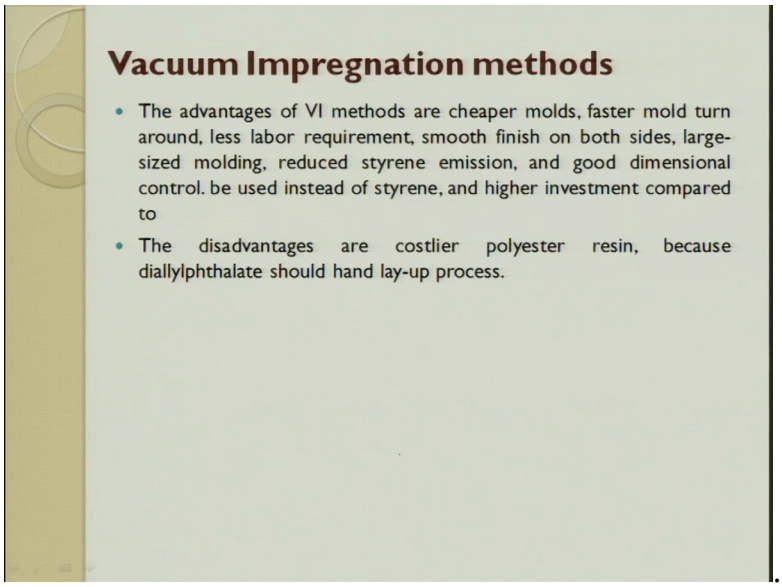

So, you suck and then try to get a good quality output bottom die is there top you do not have a die. So, you have a flexible bag to get the output the next process is vacuum impregnation methods the advantage of VI vacuum impregnation methods we have already seen. So, it is economical it is faster, it is less labor intensive it produces a smooth surface finish.

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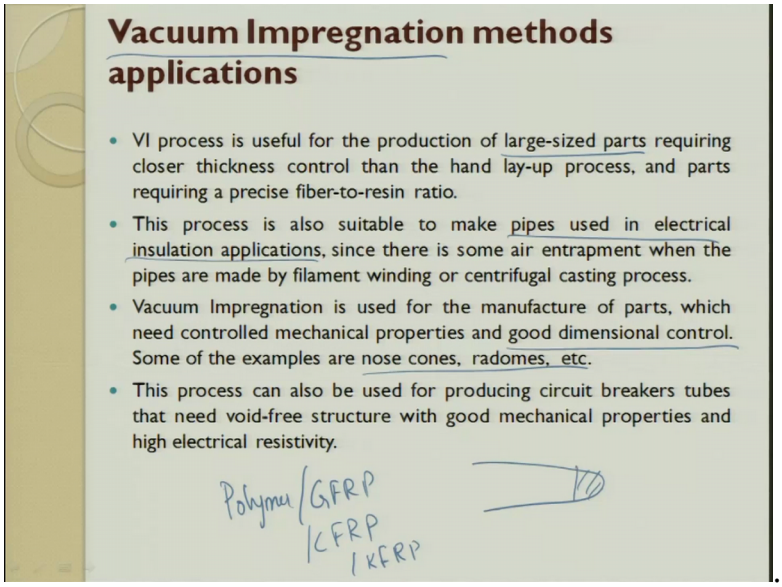

So, applications it has been used for large size component it can be used for pipes in electrical insulation applications can be made it can also be used wherever you want to

have a good dimensional tolerance you can mix such as a nose cone radome which is a what are the nose cone the aero plane the front portion this is called as the radomes front portion of the plane it is radomes nose cones also can be made. So, all these things are made out of vacuum impregnated moldings. So, you can make out of polymer based glass fiber reinforce GFRP, you can use CFRP if you want, you can also use KFRP. So, reinforcement so that you get the required output.

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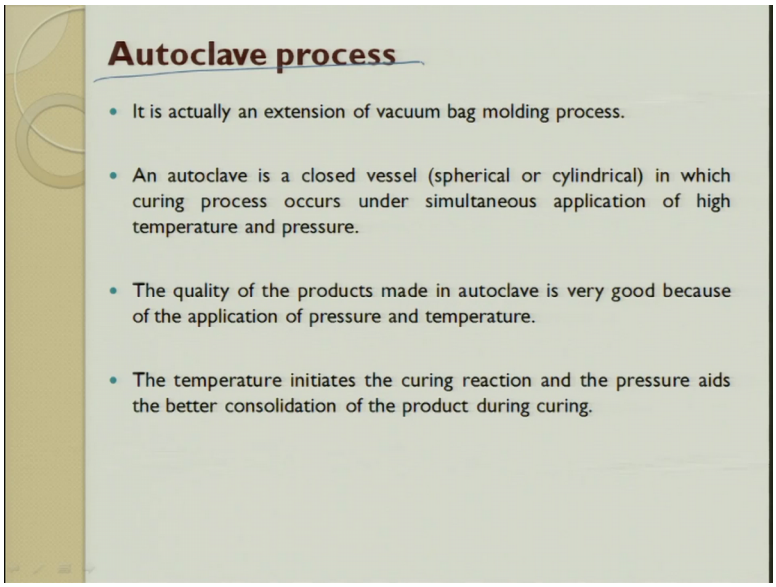

So, auto clave is another process which is used it is an extension of vacuum bag molding process.

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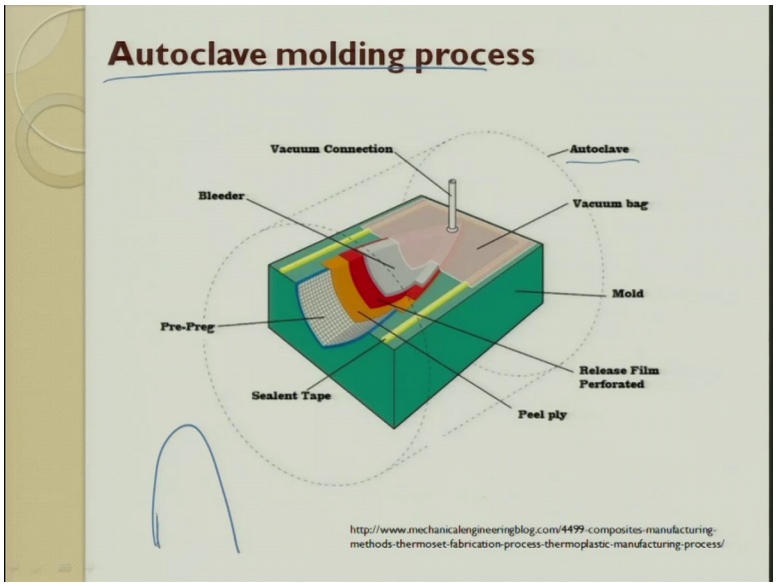

So, here I will show you the process first say if you see here. So, this is vacuum connection already applied this is vacuum connection already applied. So, you have put a bleeder whatever we studied in vacuum we have put a bleeder you have put a releasing film you have put a peel ply then you have put a prepreg then what you do is you this is a bottom die. So, you bottom die you put all as though you are making a normal composite or releasing agent then a bleeding agent then a bag everything then what do you do is completely all this the entire composite on top of this bleeder bag is put with the vacuum bag this vacuum bag is sealed by a double sealant. So, that you make sure there is no leak of air and then you try to make a vacuum connection.

So, after making this vacuum connection the die is completely placed inside a autoclave. So, what is there in an autoclave the autoclave will apply equal pressure and you can maintain a temperature. So, that you make sure the consolidation of the workpiece happens to produce a very good output. So, very large components are made out of it autoclave is nothing, but a furnace where in which pressure time temperature can be controlled so that you get the best out of it. So, you this is a negative you can also have positive mold positive mold in the sense if you want to have component which is made like a like a u inverted u. So, then your mold becomes something like this and then you repeat all the process through whatever you make here; that means, to say a prepreg is placed a bleeder is placed a pre peel is placed releasing agent is there a mold becomes a positive mold and you can put a vacuum. So, that you get the required output.

So, now let us go into the process and understand little bit of the process. It is an extension of vacuum bag process it is a closed vessel it depending upon the temperature and time see generally here for polymer matrix composite the temperatures and time the temperatures we always operate is somewhere closed around 150 to 100 maximum and depending upon a very rare combination of polymer we can go up to 300 400. The pressures are generally (Refer Time: 22:16) between one atmosphere to it can go up to 10 atmosphere or 20 atmosphere depending upon the consolidation depending upon your structural use of the polymer matrix composite.

Here it is predominantly thermoset. So, it is a thermoset process. So, you should also make sure that shrinkages strength all these things are done and here in the advantage of auto clip or all these vacuum bag is you are trying to avoid resin rich regions, if you avoid resin rich regions the weight goes down the quality enhances. The quality of the product made autoclave is very good as compare to all other process the temperature initiates the curing reaction and the pressure aids in consolation. So, I to you pressure time temperature place a very important role in autoclave.

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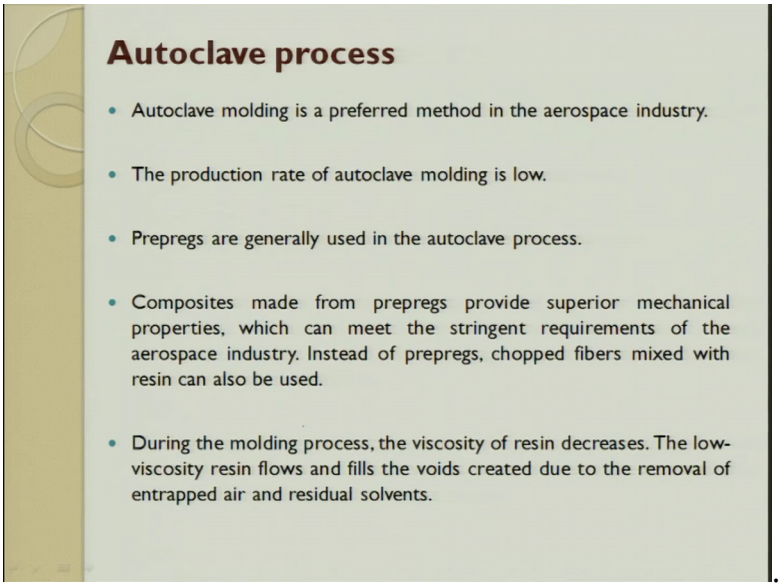

Autoclave mold is preferred for aerospace industries very low production the prepregs rather than like it is not like making out through hand layup and then going here we always use a prepreg. So, prepreg is glass for the fiber is reinforced and the matrix is wetted and it is consolidated and kept. So, we always try to maintain at a very lower

temperature. So, that it does not cure the composite made out of prepregs give a very good superior mechanical properties and it also stringent requirement for aerospace it is met very easily.

During the molding process the viscosity of their resin decreases. So, here it is almost like a readymade pizza or readymade item. So, it has all the ingredients there all you have to do is raise it to a certain temperature make sure the resin tries to change the viscosity it starts flowing in proper the low viscous resin fills and avoid the any defect.

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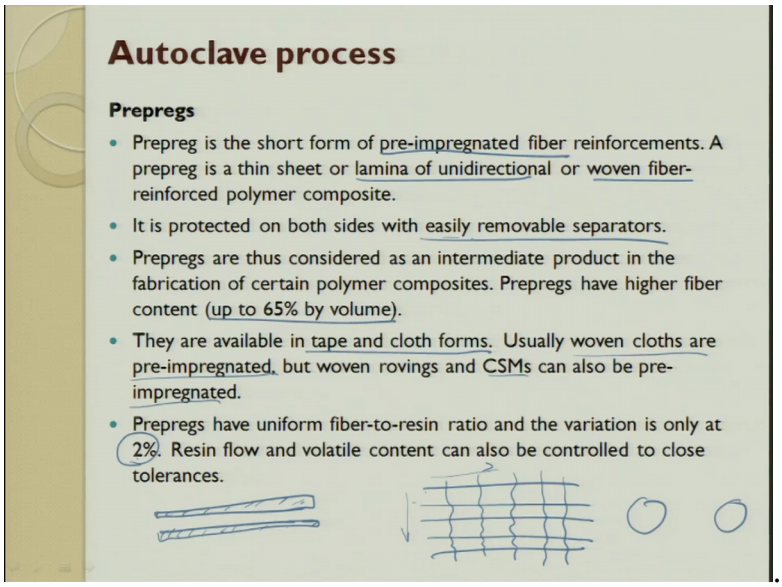

So, what is a prepreg? Prepreg is a short form of pre impregnated fiber. So, you can have unidirectional you can have woven roving. So, unidirection it is like you have all the fibers running in one direction, but this cannot independently have. So, you stitch this fellow with a small thread in the, this is warped direction. So, you try to do it that 90 degrees you try to stitch all these fellows. So, to only hold them. So, those fibers are called as unidirectional fibers if you want to have the same balance of fiber distribution in the 0 degree as well as in the 90 degree then it is called as woven roving. Depending upon your requirement you can choose unidirectional or woven roving and impregnated (Refer Time: 24:50). So, this is available in the market glass fiber, kevlar fiber, carbon fiber you can choose.

It is protected on both sides where removable separator. So, that if the curing does not happen it runs like a rim to rim reel to reel. So, in the reel to reel what happens you will

have a prepreg and then you will have a separator sheet on the top. So, this is a separator sheet on the top and the bottom. So, it is all bound in a in a reel so that you can as and when you want you cut it and then do it and then moment you cut it you can try to orient it any direction depending upon your requirements. So, 65 percent can be easily done with prepegs they are available in tapes and in cloth forms usually woven cloths are pre impregnated, but the woven rovings and CSMs are not can also be pre impregnated, but generally we do not do it.

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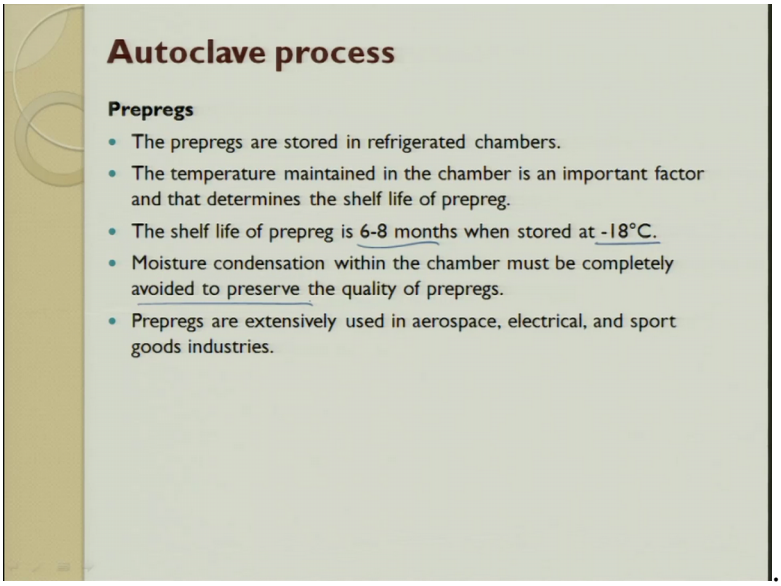

So, here the uniform fiber to resin ratio the variation will be as low as 2 percentage so; that means, to say you will get a very sound product. So, they are store in refrigerator because when you expose it to temperature it will cure. So, they are always maintaining at minus 18 degrees they have a shelf life of 6 to 8 months. The moisture consolidation within the chamber must be completely avoided to get a good quality output this is used for various applications.

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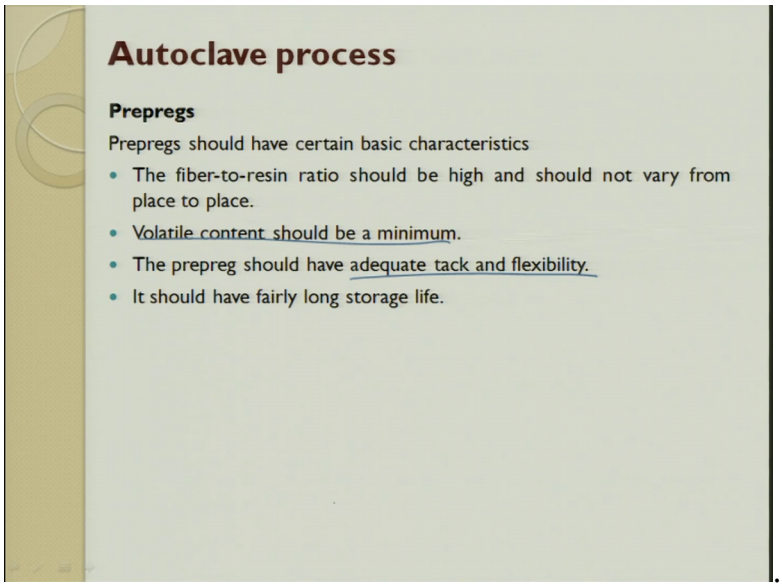

This I have already discussed the volatile content should be as minimum as possible. So, so that while vacuum or temperature application it should not create a void. So, adequate tacking and flexibility is required I will discuss you little later and it has a fairly long shelf life this is what it is. So, a molding process what happens this I will go to this figure which I have already dealt.

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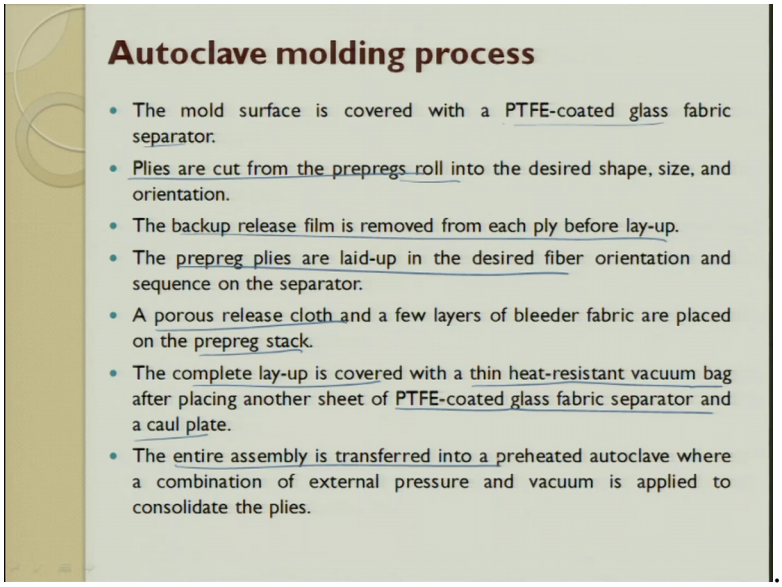

So, you put a you put the prepreg before the prepreg you try to put a small coating at the bottom releasing agent then what you put the prepreg then after that you put a peel ply

right you put a peel apply then you put a releasing film perforation then after this releasing film preformation you try to put a bleeder.

So, excess resin can travel up to here and get absorbed and on top of it you try to put a vacuum bag and this vacuum bag is sealed such that this portion is completely consolidated. So, this is what is dealt in the process. The mold surface is covered by a coating of glass fibers separator so that it can be removed. The p the plies are cut from the prepreg rolls the releasing film agent is remove. So, which is on the top and bottom is removed for the each ply and it is played. The prepreg plies are laid in the desired orientation which we have already discussed the porous release cloth of a few layers are placed on top are placed on the prepreg stack then a complete layup is covered with a thin heat resistance vacuum bag which is placed on sheet of PTFE coating which separates it from the caul plate. The entire assembly is transferred into a preheated autoclave to get the consolidation.

So, today there are companies which make the complete race car body through this they make a pattern and then they use all these procedures whatever it is they may get. So, this is as light as possible and it can be made with very high drag reduction.

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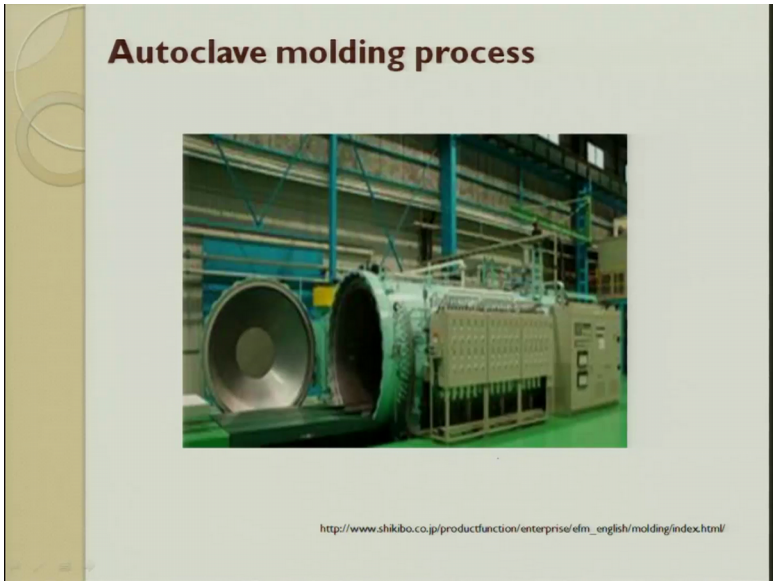

So, the efficiency goes very high and these are all made out of carbon fiber composites. So, you can see an autoclave this is real time autoclave you put the component here and

then it is moved inside the shell and then you lock it. So, that you get, you try to create a necessary pressure and temperature.

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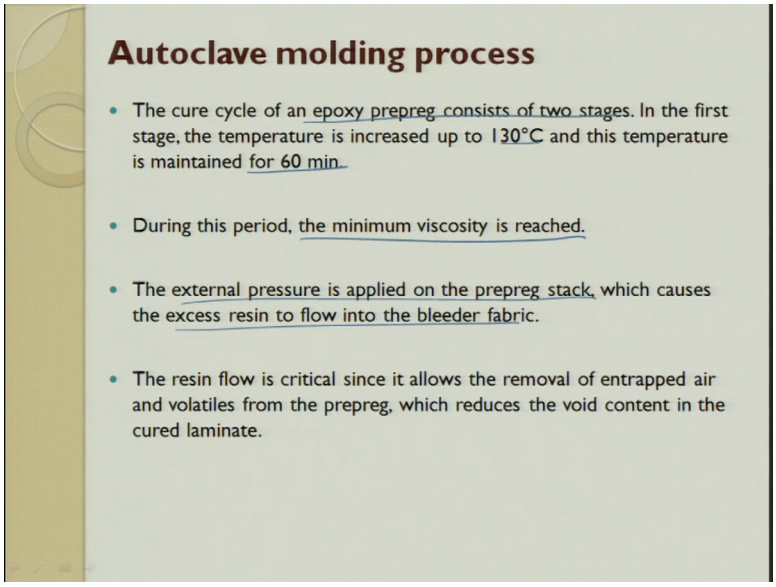

The curing cycle for epoxy is always done in 2 stages the first stage it is increased up to 130 degrees and the next and it is maintained for 60 minutes. As I to you the pressure temperature time is a very important thing in any furnace. So, here also it is for epoxy 130 we say if you add fillers to it this changes and the time also changes. During this period the minimum viscosity is reached the external pressure is applied on a prepreg stack so that the excess resin flows inside the bleeding fabric. So, what is a bleeding fabric? You see here the here is a bleeder. So, this is which tries to it is like a cotton which absorbs from the blood wound cotton is a same way it is used.

So, the resin flow is critical since it allows to remove the entrapped and the volatile material from the prepreg.

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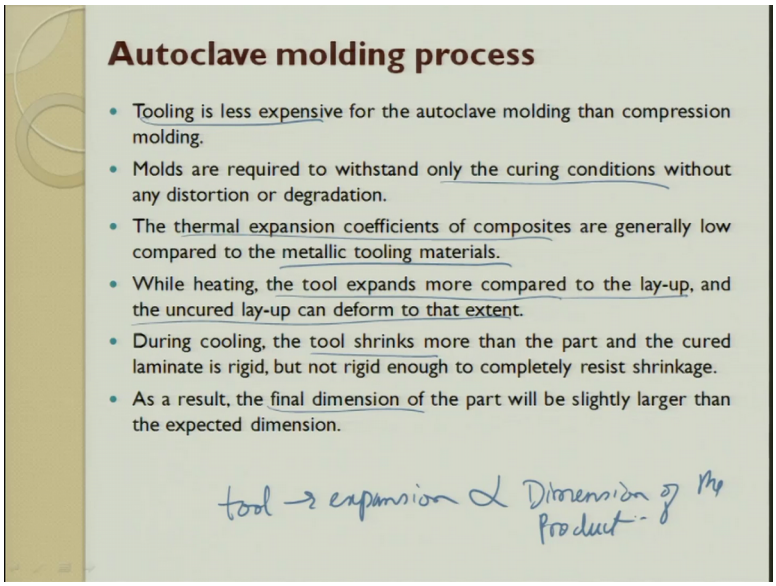

So, the tools here are very less in expensive. So, like a compare to a compression molding. So, here you make a small pattern or a mold or a. So, this can be made out of steel this can be made out of the pattern can be made out of steel, it can be made out of wood, it can be made out of a composite people have studied what is the influence of the basic pattern material over the output.

So, there are also research because even a small one percent change a deviation from the product requirement has a huge influencing in the aerospace industry. So, autoclave are used is (Refer Time: 30:18) the tooling is very less expensive the molds can withstand only the curing conditions. So, that is there the thermal coefficient of expansion of the composite are to be kept in mind. So, based on that we always go for metallic molds wooden molds anything is with you. So, we always while hitting the tool expands. So, that is what we make sure that it should not the tool expands as compare to that of layup uncured layup can be can deform to that extent of the process after cooling the tool shrinks. So, that it tries to give the output then final dimensions are reached. So, the tool expansion has a direct influence on the dimension of the product dimension of the product it is a direct influence. So, this you should make sure you do not this has to be properly chosen.

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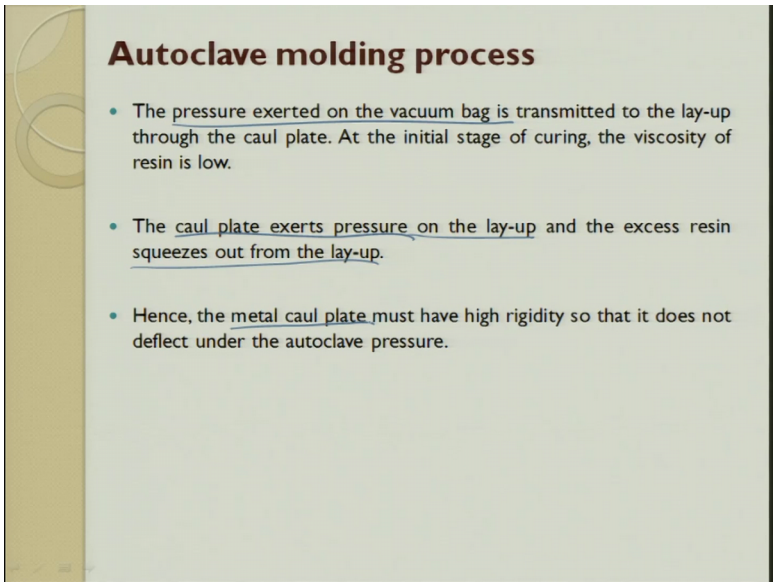

The pressure exerted by vacuum bag is transparent to the hand layer. So, that they can flow the caul plate exert pressure on the layup and the excess resin are squeeze out through the lay-up. So, hence we always use a metal caul plate must have very high rigidity to in the auto in the auto calve process. So, this is a typical cycle of an autoclave. So, you can see that the pressure which is maintained in bar the temperature is given this is the time in minutes.

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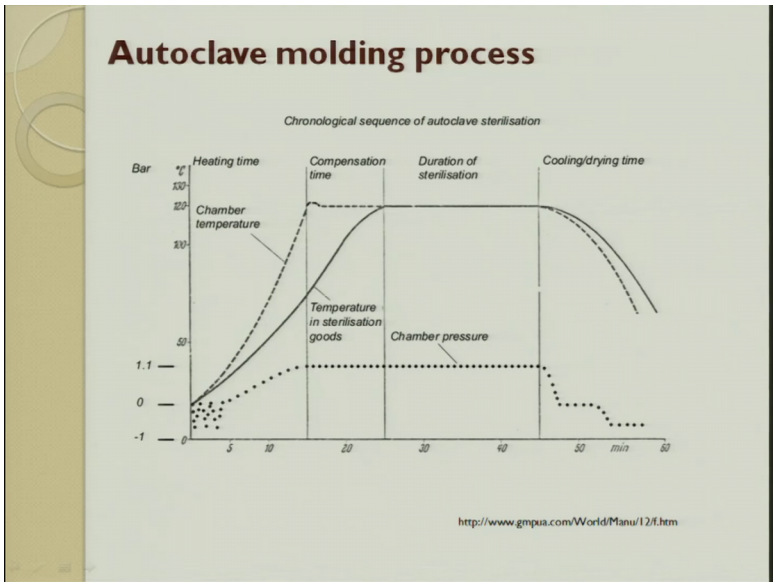

So, this is the chamber pressure. So, we always operate up to 1.1 and you can see the temperature going up. So, this is the chamber temperature which is preheat then you have a compensation time then you have a duration of sterilization and then you have a cooling period the temperature is a is the in the sterilization zone. So, this is what it is. So, the temperature initially goes high maintains it and then you try to get an output.

So, heating time compensation time you have duration for sterilization; that means, to say consolidation and then you will also try to have a cooling time to get the required output because of this autoclave the process becomes slightly expensive.

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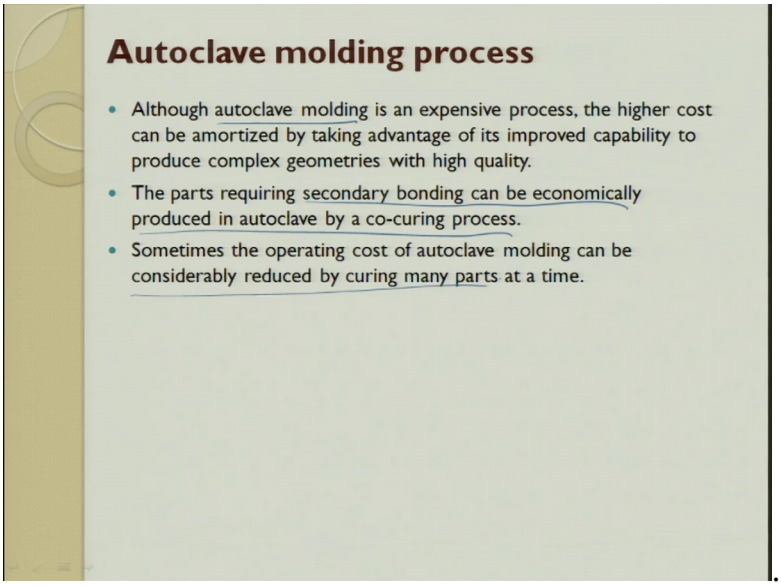

So, complex parts are only tried to get the output, the parts of the secondary bonding can be economically produced by autoclave by using co curing process. So, we will see what is co curing process little later sometimes the operating cost of the autoclave is also can be considerably reduced by curing many parts at a time; that means, to say one shot process you can do or try to have multiple parts in one autoclave process. So, by that we can try to compensate the produce.

So, with that we come to an end for of this lecture on vacuum impregnated process which is used for making thermoset polymer metal matrix composite for varying reinforcement like glass, Kevlar, carbon. And here the important process important instrument which we use is called as autoclave which helps in consolidating in producing

a good quality output. So, in autoclave we measure we try to maintain pressure temperature and time to get a better consolidation.

Thank you.