Manufacturing of turbines (gas, steam, hydro and wind)

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Week - 08

Lecture 36

Welcome to this course on manufacturing of turbines. So, in this lesson 36 of the course we will see the vacuum infusion processing which is one of the manufacturing processes for manufacturing the wind turbine blades. So, the outline of this lesson will follow the vacuum infusion processing we will start with introduction of vacuum infusion processing We will do a comparison of vacuum infusion processing with other open molding process like the hand lay up process and vacuum bagging process. We will see the benefits of vacuum infusion. We will understand resin saturation and flow dynamics. We will look at the VIP or vacuum infusion processing setup and the equipment which is used.

We will also look at step-by-step process which is followed in vacuum infusion processing. And lastly, we will look at the various challenges which are there in this process of vacuum infusion processing. So, as we know, we are dealing with manufacturing of wind turbine blades which consist of the composite materials essentially made up of epoxy as the matrix and reinforcement in form of glass fibers and carbon fibers. So, in this regard, the use of vacuum infusion processing as a composite manufacturing technique, this involves infusion of resin into the fiber preform within the mold under vacuum pressure.

The process utilizes atmospheric pressure to drive the resin through the fibers, ensuring complete wet out and strong composite parts. The significance of VIP in the composite manufacturing is there from the aspect of producing lightweight, high strength composite parts wherever required. The method is particularly valued for its ability to produce large, complex parts with consistent quality and reducing material wastage and tooling costs. So, if we do a comparison of the vacuum infusion processing with hand layup and vacuum bagging. So, in hand layup, this process involves manually applying the resin to the reinforcement using brushes or rollers.

While the method is straightforward, it often leads to excess resin which can lead to a weakened composite structure. For the vacuum bagging process, an improvement exists over hand layer process as vacuum bagging involves placing of a vacuum bag over the wet laminate, which helps in removing excess resin. However, this process still starts with an over saturated laminate and the amount of resin removed depends on several

variables leading to inconsistencies in the part quality. On the other hand, the vacuum infusion processing or VIP differs by applying vacuum while the laminate is still dry. This means the fiber preform which is placed is in the dry condition.

The resin is then infused in the fiber preform, minimizing excess and achieving a near perfect fiber to resin ratio. The process ensures that only necessary amount of resin is introduced leading to a stronger, lighter and more consistent composite parts. Because of these attributes of vacuum infusion processing, there are several benefits of vacuum infusion. Some of the namely benefits include superior fiber to resin ratio. The VIP process achieves a more optimized fiber to resin ratio compared to traditional methods.

Excess resin which can lead to brittleness and reduced strength is minimized resulting in composites with enhanced mechanical properties. Consistent resin usage is the second advantage in which the controlled nature of vacuum infusion processing ensures predictable resin usage reducing material wastage and improving cost efficiency. This consistency is particularly beneficial in large-scale manufacturing where uniformity is critical. The third benefit of vacuum infusion processing is extended setup time. The vacuum infusion processing method allows for an unlimited setup time since the vacuum is applied before resin infusion.

This eliminates the rush associated with the resin pot life and reduces the risk of errors in therefore improving pot quality in the final product. Lastly, the vacuum infusion processing is a much cleaner and safer process. The absence of manual resin application in vacuum infusion processing reduces the mess and exposure to harmful fumes. The process is contained leading to a safer working environment with less need for personal protective equipment. So, now we will focus our attention on a resin saturation and flow dynamics.

So, this is particularly with respect to the flow of the resin in the dry fiber pre form under the influence of vacuum pressure. In vacuum infusion processing, resin flow is carefully controlled to avoid over saturation. The process starts with dry reinforcement and the excess resin is infused under vacuum pressure. The method ensures that resin completely wets out the reinforcement filling all the voids without leaving excess resin. The flow dynamics are managed by strategically placed resin feed lines and use of flow media ensuring even distribution across the laminate.

Vacuum infusion processing setup and equipment includes some of the key components. So, these key components include vacuum pumps, vacuum tubing, resin traps and spiral tubing. So, we will see in little detail each of this component and what role does each of the component play in vacuum infusion processing method. The vacuum pumps are basically the essential component to create the necessary vacuum pressure to drive the

resin into the laminate. The choice of pump depends on the size and complexity of the project or the product.

The vacuum tubing is basically a strong vinyl tubing that can resist collapse under vacuum pressure ensuring a reliable vacuum seal throughout the process. Resin traps include the third component which protect the vacuum pump by catching excess resin that could otherwise damage the pumps. Multiple traps are recommended for larger products. Spiral tubing is basically used for both vacuum line extenders as well as resin feed lines. The spiral design allows for a more even distribution of the resin across the laminate.

So, here we can see the schematic of vacuum infusion processing setup. So, vacuum infusion processing setup is also a open molding process. So, as we have seen some of the processes previously, those were the closed molding processes, but it is an open molding process. So, this means the mold is open, it is not closed here. So, here in this mold, the fiber preform is pre-placed in dry condition.

So, here we can pre-place the fiber preform in dry condition. Subsequently, this mold is connected to a resin inlet pipe on the left-hand side, which is connected to a resin tank. On the right hand side there is a vacuum outlet pipe and this is connected to the resin trap. So, as we have just seen the role of resin trap is to capture the excess resin coming out from here and thereby preventing this resin from going into the vacuum pump. The vacuum pump is basically the driving creates the driving vacuum which generates vacuum inside the mold thereby pulling in the resin from here.

The atmospheric pressure acts on all the parts, all the sides, all the faces of this mold thereby creating the consolidation pressure in the laminates. So, this setup is widely used for manufacturing the wind turbine blades. So, now we will see step by step the processes which are followed in vacuum infusion processing for manufacturing the wind turbine blade. So, the first step involves mold preparation and reinforcement selection. Mold quality is a very essential parameter here to ensure the mold is rigid and it possesses a high gloss finish for effective resin flow and easy part release.

A minimum flange of width of approximately 6 inches is recommended to facilitate proper placement of sealant tape and spiral tubing. So, this sealant tape and spiral tubing are basically auxiliary components used in vacuum infusion processing so as to proper generation of the vacuum inside the mold as well as that spiral tubing ensures uniform distribution of the resin. The reinforcement is used in form of fabrics or the woven fabrics which can be the fiberglass or glass fiber and carbon fiber. So, fiberglass is known to have high permeability which is quite advantageous for the viscous resin flow making a fiberglass or glass fiber as a preferred reinforcement material in vacuum infusion

processing. On the other hand, the carbon fiber due to its lower permeability, so additional flow media is sometimes required for uniform resin distribution.

So, this is basically the first step where we are preparing the mold and pre-placing the reinforcement in form of woven fabrics. So, in the second step, the resin and vacuum lines are set up. So, resin feed is typically done from a standing source such as a bucket, ensuring a consistent supply of resin during the infusion process. The resin line should be installed before the vacuum bag is sealed, ensuring a smooth transition during the infusion process. The vacuum line basically are used as a vacuum tubing which can be used for both vacuum application and resin infusion.

Specialized material unique to vacuum infusion processing can be employed to optimize resin flow through the laminate ensuring uniform distribution. So, here we can see that resin feed lines etc. are placed inside the mold along the reinforcement and the vacuum feed lines are also placed. Next is the EnkaFusion filter jacket in vacuum infusion processing. The role of this component is the EnkaFusion filter jacket is a standard material used in nearly all vacuum infusion processing projects.

It is placed on top of the laminate and is removed when the part is demolded. The material also serves as an anchor for T fittings which connect the resin and vacuum lines. The design and functionality of the filter jacket include a 4 inch wide resin flow channel typically laid along the length of the laminate. Similar to the nylon matting but narrower and it is contained within a fabric sock. The sock design holds the resin until the entire length is filled with the resin, ensuring consistent resin flow across long spans.

Once the sock is fully saturated, the resin begins to flow outward into the laminate, maintaining a steady flow rate. The application as surface media include using the filter jacket as surface media which is crucial to place beneath the peel ply. The failure to use the peel ply will result in filter jacket being permanently adhered to the laminate and this will lead to several defects in the cured laminate. Next important component in the vacuum infusion processing is the spiral tubing. Spiral tubing sometimes also known as the spiral wrap is a plastic ribbon that is coiled into the shape of a tube.

Due to its construction, air or resin can enter or leave the walls of the tube throughout its entire length. This property makes the spiral tubing ideal for in-bag vacuum lines or resin feed lines. When used as a feed line, resin will quickly travel through the tube but simultaneously seep along the way. This allows quick wet out of long stretch within the laminate, and it needs to be sure to wrap the spiral tubing in the peel ply for easy removal. So, here we can see that the T fittings and the filter jacket being placed inside the mold.

Subsequently, we can also see the placement of the T fittings of the spiral tubing along the periphery of the mold along with the presence of the sealant tape which ensures that

no leakage occurs in the vacuum infusion processing setup. Step number three is basically the step in which the vacuum bag is constructed. This step also ensures that vacuum bag is tightly sealed and it provides ample space for all materials and tubing. We need to also avoid excessive or insufficient bag material to prevent resin pooling or improper infusion. The tubing attachment needs to be carefully done for the resin and vacuum lines.

Caution needs to be exercised while cutting holes through the bag for tubes as these connections are prone to leaks. Pre pump setting is done before activating the vacuum pump and clamping of the resin line. The resin line must be sealed and the vacuum is drawn before introducing the resin to prevent it by acting as a temporary leak. Use of a flow regulator to clamp the resin line is creased at the tube. The vacuum pump setup is the next step in vacuum infusion processing.

Attaching the vacuum pump is the first step where all the components are securely placed and attached to the vacuum pump system. All connections need to be air-tight to maintain optimal vacuum pressure. Here there is a very strong importance of the strong vacuum pump. Because it is the vacuum pump which is driving the resin into the pre-placed pre-formed fibers. The vacuum pump is crucial for resin infusion as it drives the process through using the vacuum pressure.

A stronger pump is generally more effective and helps to expedite the infusion process ensuring uniform resin distribution. Selecting a pump with sufficient capacity and strength can enhance the overall efficiency and quality of vacuum infusion processing process. Step number five is basically preparation for infusion. Here the resin choice is a key aspect in vacuum infusion processing. As we are dealing with manufacturing of the wind turbine blade, so epoxy based resins are more popular.

There is a common misconception that the special infusion resin is required. While this may not be the case, the general guidelines to consider are to be considered while making the choice of the appropriate resin. Resin viscosity is another important parameter because lower viscosity resin aids in infusion as it allows for easy permeation of the reinforcement. Highly viscous resins may require more careful planning and additional resin lines and flow media to ensure that even the viscous of the viscous resin completely wets out the reinforcement and there are no resin starved regions in the mold. Next step is basically the preparation of infusion where the resin bucket is set up, so no use of brushes or rollers is done in this case and certain steps are necessary to keep the resin line from the bucket.

So, bucket resin line holder, zip strips and spring clamps are used. The resin line holder is the length of the rigid material attached to the resin tubing via zip strips. This setup keeps the resin tubing straight, preventing it from twisting and curling. Cutting the tubing end at

an angle to avoid vacuum sealing to the base of the bucket is also done to ensure consistent flow of resin. Next step is to clamp the resin line to the bucket to always ensure that it stays in its place during the infusion process.

So, here we can see in the schematic the angle cut of the resin line, the use of zip strips to hold the resin line in its place to ensure that nothing moves and there is a complete resin infusion during the vacuum infusion processing for wind turbine plates. Next is the resin infusion step. So, this also involves certain sub steps in which the first sub step is to catalyze the resin and prepare for infusion. Here, the catalyzation of the resin is basically mixing of the resin with the hardener. The resin is mixed thoroughly, ensuring the resin bucket assembly is securely in place to prevent leaks.

Also remove flow regulator from the resin inlet to begin infusion. The second step is infusion process. The resin will be drawn through the tube into the laminate. We need to watch for resin feed line to fill the resin and the resin should expand outward into the reinforcement. And this process of resin infusion shall continue until the laminate is fully saturated.

The third step, sub step involves clamp offing the resin line. After the laminate is saturated with the resin, we need to clamp off the resin line to prevent the presence of air bubbles. Use of the same method is done as before to crease the tube and attach the flow regulator. We need to perform this task carefully in order to avoid creation of new leak points. Lastly, the maintenance of vacuum pressure is done to maintain a constant pressure and this is continued until the resin has gelled which means the crosslinking has started in the resin to prevent premature air introduction.

So, here we can see the complete detail of the vacuum infusion processing setup where all the components have been assembled starting with the mold. In the mold, we have replaced the reinforcement. On the reinforcement, the filter jacket is applied through which the resin inlet pipe is connected. The spiral tubing is placed all around the mold to ensure the complete filling and uniform filling of the mold. The sealant tape is also applied on the periphery of the mold to avoid any air leaks and subsequently at the T fitting the vacuum outlet line is also connected as we have seen it is further connected to the vacuum pump, and then the peel ply is also applied to in order to remove safely remove the filter jacket and to also ensure that the filter jacket is not adhered to the cured part.

So, here we can see the use of vacuum infusion processing in manufacturing of the wind turbine blades where, the lower half of the blade is placed in the mold and we can see all these vacuum lines and resin infusion lines passing through it. We can also see the connection of the various resin inlets on the vacuum bagging and subsequently the complete setup is being infused with the resin here in the schematic in the photograph as

shown here. This is one of the popular process to manufacture the wind turbine blades. So, next is the curing. So, curing as we know is an irreversible chemical reaction which occurs at a molecular level and this reaction leads to development of the cross links between the polymer molecules.

The polymer which is used in this case is resin based out of epoxy which is thermoset. On a macro scale, during curing, heating is done and debulking is done. As we have also seen earlier, the debulking is important to reduce void content and always it is targeted to have a reasonable goal of void content less than 0.5%. After vacuum infusion processing is done, sometimes the autoclave curing can be proceeded.

Autoclaves as we know are pressure vessels which allow for simultaneous imposition of pressure by vacuum and heat. Vacuum is directly applied on the part. However, autoclaves can have high capital cost. Sometimes the autoclaves may also be filled with inert gases to avoid any tendency of oxidation. Use of autoclave may also be beneficial for assemblies which need to be bonded while they are cured.

So, this process of use of pressure to ensure intimate contact of the bonding and curing to occur together is known as co-curing. Now we will look at some of the challenges and pitfalls of the vacuum infusion processing. As we have seen the vacuum infusion processing involves a setup of a complex equipment. The setup of vacuum infusion processing as we have seen is quite intricate and complex compared to other processing methods.

This requires careful planning and execution. Mistakes in placement of fiber in place of vacuum and resin lines can lead to parts with defects. The second challenge is trial and error where vacuum infusion process often requires multiple attempts before we achieve the perfect combination of the process parameters. The beginners of this process should expect a learning curve and initial failures in this process can serve as valuable lessons, than risk of ruined parts as infusion begins there is little room for error. Even the minor issues such as small vacuum leak can lead to resin pooling or under saturation potentially ruining the part. So, with this we have seen several details the mechanisms and the equipment of vacuum infusion processing.

We will now summarize what all is covered. So, in this lesson we have seen the details of vacuum infusion processing. This process is also abbreviated as VIP. So, we have seen the details of various equipment, which are used in VIP. We have seen the stepwise procedure which is followed in vacuum infusion processing. We have also looked at how VIP has been used for manufacturing the wind turbine blades.

And lastly, we have looked at some of the challenges and pitfalls in vacuum infusion processing. So, in the next lesson, we will move to discuss the coatings which are used on the wind turbines. Thank you.