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

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Lecture 34

Welcome to this course on manufacturing of turbines. In this lesson 34 of the course, we will see the vacuum bagging molding process for the wind turbine blades. So, the outline of this lesson will be as follows, where first we will discuss the introduction to vacuum bag molding process. We will see what materials are used in this process. We will look at the key points in vacuum bagging. We will also understand the vacuum bagging system assembly and see how curing takes place in the vacuum bagging arrangement.

We will look at the importance of curing, how the process control parameters influence the curing process, the challenges, benefits and applications of this process of vacuum bagging. And, in the end we will see certain case studies of this process to other manufacturing techniques. So, vacuum bagging molding is an open molding process to manufacture the wind turbine blade. So, we have seen other open molding processes which were the hand layup and spray layup process.

So, the vacuum bag molding process or vacuum bagging process, sometimes it is also known as the vacuum bagging process, is a process in which the resin, so now here we are talking of specifically resin means thermosets, especially epoxy, in which the resin to fiber wetting is assisted using vacuum. So, the main purpose of vacuum process is it removes the air which is trapped inside the laminate thus reducing the defect and improving the strength of the laminate. So, various advantages of vacuum bag molding method include improvement in strength of the laminates by reducing defects because by using the vacuum, so there is a very good consolidation of various plies in the laminate. The vacuum bagging process is also of low cost compared to other methods such as compression molded laminates. The density of the laminate in this case is much better compared to the compression molded laminates.

The various materials which are used in vacuum bagging for manufacturing of the wind turbine blade include various fibers like carbon fiber and glass fiber, resins, epoxy, polyester and some auxiliary materials are also used in the process of vacuum bagging which include release agents, peel ply and bleeder cloth. So, we will see some of the key points in vacuum bagging process. So, key points in vacuum bagging process involve first is the debulking process. So, debulking process is used like if a composite part has few plies say up to four debulking can occur as vacuum is applied during the curing. For more number of plies debulking occurs after every four to six layers.

So, this repeated vacuuming helps to eliminate trapped air and volatiles, reducing void content and improving parts structural integrity. So, second point is vacuum application during cure. Applying vacuum during curing not only consolidates the layers but also removes volatiles like residual solvents or absorbed gases. This ensures a lower void content which is crucial because even a small percentage of voids can significantly weaken the composite. Third point is the resin movement.

So, the vacuum which is applied in the vacuum bagging arrangement, it encourages the flow of resin or movement of resin between the layers and into absorbent materials, improving fiber resin ratio and reducing the risk of delamination is there. So, this controlled resin loss results in lighter and yet robust composites which are manufactured using this technique. So, we will now understand what is the steps which are followed in vacuum bagging process. In vacuum bagging process essentially there are four steps which include first step is the preparation of materials. So, preparation of material means layup of the fiber reinforcement layer and resin application.

So, as we have seen in structural composites which are used in wind turbine blades, the composite may be consisting of several layers of the fibers which are stacked up together. So, this stacking up of the layers in the various configurations is known as layup. In the second step of the vacuum bagging setup, this includes placement of peel ply, release film, breather and then the vacuum bag over the composite layup. The third step in the vacuum bagging process includes sealing and applying vacuum. Seal and the vacuum bag is connected to a vacuum pump to remove air.

Fourth step is curing. The composite is cured under pressure to achieve the desired mechanical properties. So, here the pressure is basically applied by the atmosphere as the vacuum is developed inside the vacuum bag. So, the atmospheric pressure then helps to consolidate and keep the plies together and removes any entrapped air from the system. Next, we will see what are the various other auxiliary components used in the vacuum bagging system.

So, vacuum bagging system basically involves use of multiple layers and materials. So, this involves first is the mold preparation. As vacuum bagging is an open molding process, it is very important to prepare the mold before applying the vacuum bagging system. So, in this regard, the mold is coated with the release spray for easy removal of the part upon successful completion of curing. Second step includes the layering.

So, here the part which has to be built so, various reinforcement layers are stacked up together in the desired pattern. Third is application of release film or peel ply. So, in this layer often perforated Teflon aids in removing the vacuum bagging system after curing.

Fourth is the use of bleeder material. So, bleeder material is applied in vacuum bagging system to absorb excess resin.

Common materials which are used as bleeder material include polyester, felt and fiberglass mat. Fifth is the breather material. So, breather material basically helps to distribute vacuum, prevents formation of wrinkles and this must remain porous under pressure. Sixth is basically the vacuum valve and sealant. So, this use of vacuum valve and sealant ensures air tightness and even vacuum distribution.

Vacuum bagging application is basically a bag which is externally covering the whole layer. This bag usually consists of nylon or high temperature Kapton film which is sealed and vacuum activated. We will now see the arrangement of the vacuum bagging molding setup. So, this arrangement basically consists of many layers as just we have seen. We will see how these layers are stacked up.

Basically, it consists of the mold which is placed at the bottom. So, this is basically the you can say the mold or sometimes it is also known as the tooling or the tool on which the part which has to be cured is placed. Next, we place the various reinforcement or the layers of the reinforcements are there are placed on top of this mold or the tool. So, on top of the layer we apply the release film. So, then we can say that a release film is applied.

So, this is basically the fibers. Then, we have the release film. On top of the release film, we apply the peel ply. So, this is basically the peel ply. This is followed by applying a bleeder film.

This is a thick layer which can absorb excess resin. Then we have the breather. So, this is the bleeder layer. And then we have here the breather. And on top of it is the vacuum bag.

So, we can extend this mold which if the mold is slightly oversized on this. And at the ends here where the vacuum bag is touching the mold there is application of a sealant. And in the vacuum bag basically there is a vacuum line going in. So, we can have a vacuum line here. This vacuum line is then subsequently connected to the vacuum pump and sometimes the part which is to be applied which has the resin is already applied here and then with the help of this vacuum line we create the vacuum inside this vacuum bagging arrangement.

And after the curing is complete, we remove all these layers and subsequently the part which is there, the composite part which is there with the resin is cured here. And this is removed and the mold, this is generally metallic molds, they can be reused to make new parts thereon. So, these various layers of materials such as bleeder, peel ply, release film, breather etc. are basically one-time use sort of materials and for every composite part which is made using the vacuum bagging molding, a fresh set of all these materials has to be used and these are generally disposed after every manufacturing cycle of composites used using this process. And as we can see the mold here is a open mold.

So, this vacuum bag molding is categorized in the category of open molding process. So, this is what which is an open molding manufacturing process for the composite parts. And specially this mold, this mold can be made into the shape of the wind turbine blade and this mold can run several meters of length to accommodate the full blade, and by making the blade into halves later on the blade can be assembled together to have the full wind turbine blade. So, next we see the use of a pressure intensifier and a pleated vacuum bag and many situations what may happen that in this mold there may be certain tight corners wherein the resin may not flow very easily, and because of which there may be some wrinkling on the vacuum bag. So, to avoid this type of a situation because this type of situation may lead to development of some entrapped air which may manifest itself in form of some porosity or micropores in the cured part.

So, use of a pressure intensifier is done here. So, this pressure intensifier helps to uniformly distribute the pressure in the tight corner therefore, avoid the any situation of unfilled regions in the composite part. And the pleated vacuum bag basically helps to smoothen out any types of wrinkles as the split can open up and therefore a smooth surface on the cured part is observed. So, next is basically the curing process in the vacuum bagging molding. So, curing in vacuum bagging molding refers to the chemical reaction because we are dealing with thermosets, especially epoxy.

So, this chemical reaction is the curing reaction in which the resin matrix undergoes polymerization or cross-linking, therefore transitioning itself from a liquid gel into a solid state. So, the crosslinking helps to lock the reinforcing fibers in place, solidifying the composite and defining its final mechanical properties. Temperature control is a very important parameter in curing. Curing schedule indicates the time temperature profiles which are precisely controlled depending on type of the resin which is used. So, this will vary what type of resin is being used like if it is a polyester or it is an epoxy.

Second is the controlled thermal gradients. The temperature is increased in controlled steps so, as to increase the possibility of uniform cross-linking to initiate and sustain the exothermic reaction. Avoiding thermal spikes is crucial to prevent micro cracking or uneven curing. Second is the role of vacuum pressure. The role of vacuum pressure is to maintain continuous pressure during curing removing entrapped air or volatile gases by therefore minimizing voids and ensuring optimal fiber to resin ratio.

Pressure regulation is done for proper pressure usually it is below 1 atmospheric pressure to ensure laminate consolidation leading to high density and defect free composites. The various heat sources can also be used with the vacuum bagging arrangement to accelerate the crosslinking. So, oven curing is popular where parts are cured in an oven with circulating air to ensure uniform distribution of heat. Or autoclave may also be used for high performance composites as autoclaves are able to apply heat and pressure of the order of 85 to 120 psi to achieve superior fiber compaction and void reduction. Post curing some secondary heat treatment may be carried out.

So, this post curing phase raises the temperature to complete polymerization process. So, this leads to enhanced properties. Post curing improves thermal stability, chemical resistance and mechanical strength of the composite. The next phase involves cooling. So, in this cooling, the cooling is done at a controlled rate.

Gradual cooling is essential to avoid internal stresses which can cause wrapping or distortion. Stress relief is also important in the cooling phase because slow cooling prevents residual stresses, ensuring structural integrity and dimensional stability of the part. Next is importance of curing. So, importance of curing lies in the final mechanical properties in the composite part. So, proper curing is critical to achieve specified tensile strength, modulus and fatigue resistance and these properties become much important for the wind turbine blades.

Dimensional accuracy ensures the part confirms closely to the mold geometry, meeting the need for reduced post-processing and machining. Surface quality ensures maintenance of smooth surface finish essential for aerodynamic and aesthetic requirements. Defect minimization involves elimination of potential voids, delamination, incomplete resin wet-out leading to a more reliable high-performance composite. So, other than the arrangement of vacuum bagging as shown in the schematic previously, there are vacuum pumps which are used to create the vacuum inside the vacuum bag molding setup. So, these pumps may be diaphragm or rotary vane pumps.

Vacuum bags as we have discussed are typically made up of nylon or polyethylene. Vacuum bag may also be consisting of certain pressure sensors and gauges to continuously monitor the in-situ pressure during the curing process. So, typical process control parameters in vacuum bagging involve typical pressure range of 0.8 to 1 bar. This effects on the resin flow and fiber compaction.

Curing temperature can be different type of temperature profile be used for different type of resins. And there is also a trade-off between what temperature is being used with oven or autoclave as both the systems are acting in a different way. Vacuum time is basically the time for which the vacuum is applied and this is ensuring optimal air removal and resin distribution. The various challenges are also there in the vacuum bagging arrangement as discussed now. So, there are possibilities of leaks and breakage because sealant failure and bag damage may also result and often due to this thermal instability which may be caused because of thermal instability and improper handling and this can ruin the part quality.

Bridging is another challenge where bagging material may fail to conform to the part surface leading to insufficient pressure in some areas. Resin flow control, this preventing resin starvation and ensuring proper resin movement perpendicular to the fiber is crucial. Complex setup, careful preparation and handling of the material is required. As we can see there are several layers which are used in the vacuum bagging.

So, this proper layer setup has to be done. So, cost due to higher initial cost due to specialized equipment and materials is incurred in vacuum bag molding, and often a skilled labour is required to achieve optimal results as the labour has to be trained in handling the vacuum bagging arrangement as well as the pumps which are used in the vacuum bagging system. However, there are many benefits of the vacuum bagging molding. So, the various benefits involve improved fiber volume fraction because of which higher strength in the composite can be achieved. Reduced void content because of use of vacuum, the void content can be drastically reduced. Consistent laminate thickness can lead to precision manufacturing.

Superior surface finish can also be generated which reduces any need for post processing. The vacuum bagging arrangement is also used in other industries which also include the components of wind turbine blades, aerospace industry which where aircraft wings, fuselage panels are made, marine application where hulls, deck of boats are made using this process. For automotive component lightweight body panels and chassis components are made using vacuum bag molding, and sports equipment may also be done using this process include tennis rackets or bicycles. So, in the case study for aerospace component we can see the vacuum bagging being used with carbon fiber wing section where the vacuum bagging is done using an autoclave which has resulted in weight reduction, increased strength and aerodynamic efficiency. When compared to other composite manufacturing technique like hand layup, so it is basically more providing hand layup is providing more simplicity but inferior quality control.

Resin transfer molding is having higher automation versus higher tooling cost and prepreg processing in autoclave where advanced quality and higher operational cost is there. So, with this we come to the end of this lesson where we will now summarize what all is covered. So, essentially we have covered the fundamentals of vacuum bagging arrangement, bagging system. We have looked at the various components in vacuum bagging molding system or molding process. We have looked at various advantages and limitations of the vacuum bagging molding process.

In the next lesson, we will see the resin infusion technologies, wherein we will focus on resin transfer molding process which is widely used to manufacture the wind turbine blades. Thank you.