

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

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Lecture 35

Welcome to this course on manufacturing of turbines. So, in this lesson 35 of the course we will see the details about resin transfer molding process which is used to make the wind turbine blades. The outline of this lesson will be starting with discussion on introducing the resin transfer molding process. We will understand the basic of resin infusion technology before we jump into the details of resin transfer molding. We will look at advantages and disadvantages of resin infusion process. We will understand different types of resin infusion technology.

We will look at introduction to resin transfer molding, the basic raw materials which are used in this process, the process methodology, key technical features, advantages and limitations and we will conclude the lesson by looking at some other application and industry use cases of this process. So, resin infusion technology, it is basically a cornerstone of composite manufacturing and is well known for its efficiency and quality in producing composite parts. So, while the resin transfer molding is often used as the blanket term for resin infusion process, this presentation will use RTM in its narrow sense with resin infusion. Serving as a more general term, occasionally these processes are also referred to as liquid molding processes.

So, these processes are popular when we are using resin or thermosets as the matrix. Especially these type of matrix are very well compatible with the high performance fibers like the glass fibers and carbon fibers. And because of this uniqueness, the combination of these materials, that is the epoxy based resins, Glass and carbon fibers are popular in making the wind turbine blades which need to be light in weight despite their large size. The key features of resin infusion process include a closed mold. So, resin infusion processes come in the category of closed mold manufacturing process which means the mold is consisting of two halves and both of the halves are closed before the molding starts.

So, the key features also include preform placement. So, this process begins with placing the dry fiber preform into the mold. So, the preform is basically the stacked arrangement of the various fibers as per the orientation desired in the final product as per the loading

conditions. Next step is the mold closure. Once the preform is positioned in the mold cavity, the mold is closed, ensuring accurate shaping and finishing.

The third step of this process includes resin injection. So, resin is injected into the closed mold which is present with the preform and this injection basically ensures the complete wetting of the fiber preform. Next step is basically the curing step in which the resin is cured and as we have seen in the previous lessons, curing is basically an irreversible chemical reaction which generates cross links in the resin therefore leading to a solidified product into the final composite material. After the curing is complete, the final step of the resin infusion process involves part extraction. This is after the curing the mold is opened and the complete part is removed.

So, we understand the basic philosophy of the resin infusion process. So, the resin infusion process, it essentially consists of two tanks having component A and B. So, here component A and B refer to say the resin. So, say component A is the resin or the epoxy resin and component B may be containing the hardener. So, as we know that to initiate the crosslink, the resin and hardener they have to be mixed in a proper ratio and this mixing in the proper ratio is conducted in the mixing head.

So, mixing head is basically connected to the tanks of component A and B and the quantity of component A or B or the resin or matrix resin or hardener is supplied using this metering device. So, metering device ensures that only appropriate or the required quantity of resin and hardener is pumped into the mixing head. So, inside the mixing head the both the resin and hardener they are mixed properly and the reaction of cross-linking can be initiated. Immediately from the mixing head, the mixture of resin and hardener is pumped into the mold cavity. Here, we can see it is being pumped and inside the mould the pre-form, the fibre pre-form is already pre-placed.

So, at an elevated pressure, once the mixture of resin and hardener is injected into the mould cavity with the pre-formed fibre, so this elevated pressure ensures complete wetting of the fibre pre-form by the resin hardener mixture. So, there are several advantages with the resin infusion process. These advantages are primarily including the quality control. Because of the higher injection pressure, the process ensures high tolerance control and repeatability. Surface finish is the another advantage of resin infusion process in which these processes are capable to produce class A surface finishes directly from the mold.

The efficiency of the process is also higher as there is low labor requirement and reduced need of auxiliary equipment like autoclaves. Design flexibility also includes to support wide range of part sizes and complexities with options of in-moulding inserts and fittings. Environmental benefits of this process include reduced emissions. As we have seen, this process is a closed mould manufacturing process. Furthermore, the cycle time of the

process can range from few minutes for small parts to up to 2 to 8 hours for large parts like railroad cars or yachts.

The unique advantage of resin infusion also lies in two points that is the continuous fiber placement. So, this is very important once we are using the continuous fibers for structural parts such as, wind turbine blades because continuous fibers can be spread across the complete part which are crucial for advanced composite performance. The material and cost efficiency also support the use of low cost materials while maintaining high mechanical performance. The resin infusion technology also has certain limitations which can be addressed. So, these limitations include tooling cost.

These are especially high because the mould which is used may need to be quite robust and having good surface finish. So, expensive materials like tool steels etc. can be used to develop such type of tooling and to develop such type of tooling the cost may be higher for intricate or complex designs. Next is the mould design which needs to be carefully done to ensure complete resin saturation with challenges in complex mould filling and air entrapment. The material restrictions may also be in place because of the resin viscosity.

Because higher viscosity in the resin can restrict the resin choices as the injection pressure may not be sufficient to overcome the viscosity of the resin and this may lead to resin starved regions in the mold thereby leading to defects in the composite part. Production limitation may also be present and typically such type of process is limited to up to 100 to 5000 parts. Nevertheless, for the wind turbine blades this type of production run quantity is sufficient. There are several challenges also in the resin infusion technology which involves the mold design. So, proper design is essential to achieve efficient resin flow and complete fiber wet out.

Software limitations are also currently in place because the current mold filling software are mostly effective for simple designs and they rely on simple permeability database. So, under the umbrella of resin infusion technologies, there are several names of the process which come in this category. So, these processes, they include the resin transfer molding, which is one of the very popular resin infusion technology process in which the pressure injected resin infusion is done so that there is a complete wet out between the resin and fiber. This is suitable for high quality and complex parts. The second process is the vacuum infusion processing or VIP.

So, this process involves injecting resin or infusing resin under vacuum pressure. So, rather than using positive pressure, it is vacuum pressure which is utilized here. This process is quite cost effective and ideal for medium complexity parts. The third technology is resin film infusion. So, resin is applied in form of a film and is infused with heat and pressure.

This is ideal for complex geometries and precise fiber placement. The fourth technology under this umbrella is expansion resin transfer molding or ERTM. So, this process utilizes expanding cores or inserts for uniform pressure during infusion. This also enhances fiber wet out in complex shapes. The fifth process is the Siemens composite resin infusion molding process or SCRIMP.

This is a trademark process, which is specialized for flow media for faster infusion and this process can be optimized for large and thick sections. So, among all these five processes, it is the resin transfer molding process which is specifically used for manufacturing the wind turbine blades. So, in next few slides, we will be focusing our attention on the resin transfer molding process specifically to look at the technical details, the setup details of this process. Other processes are not being covered as the focus of this module is manufacturing of the wind turbine blades. So, resin transfer molding or RTM is basically a liquid composite molding process where, the fiber preform is placed in a closed mold.

So, the thermoset resin is then injected into the mold at an elevated pressure. This pressure or this resin injected at a higher pressure permeates the preform and the composite is cured into the mold to create a high performance part. The pressure of the high pressure of the resin here does two types of job. First is to ensure complete wet out between the fiber and the matrix and the resin. The second job the high pressure does is to ensure the permeability or permeating the resin through the porous structure of the fiber preform.

In terms of historical context, Resin transfer molding has evolved from earlier processes like transfer molding, reaction injection molding or RIM, where primarily these processes have been used for thermosetting polymers. The RTM process distinguishes itself by specifically targeting advanced composites with high fiber content. So, fiber content of the order of 60 to 65% by weight can be managed using resin transfer molding. If you look at the principle of this process, so this process involves low pressure closed molding process for moderate volume production quantities. Dry continuous strand mats and woven reinforcements are laid up in the bottom half of the mold.

The mold is closed and clamped and a low viscosity catalyzed resin is pumped, displacing the air through strategically located air vents. The injection pressure of the resin is in the range of 70 to 700 kilopascals. So, if we focus our attention on the basic raw materials here, so the reinforcements in the resin transfer molding, so the reinforcements in various forms like unidirectional or woven reinforcements can be used in the resin transfer molding. So, fiber preforms or in terms of fabrics can also be used. The different types of preforms which can be used, they include thermo-formable mat, conformal mats and braided preforms.

Resin systems include the use of polyester, vinylester, epoxy, phenolic and methyl-methylacrylate. Commonly used resins in resin transfer molding include unsaturated polyester and epoxies. Epoxy with carbon fiber is prevalent especially in the aerospace industry. The equipment considerations of resin transfer molding include high viscosity resin like epoxy that require equipment adjustments for metering and conditioning before injection. So, if we understand the process of resin transfer molding, so this involves mold preparation.

So, in the mold preparation, the preform placement is the first step where a dry fiber preform, typically this fiber preform can be of glass fiber, carbon fiber or aramid fiber is carefully pre-placed into a matched metal mold. So, this metal mold is made up of either aluminum, steel or for high production runs this can be made up of tool steels to achieve the precise fiber architecture and alignment. The tooling considerations involve the mold design is expected to accommodate a resin flow. To account in factors such as fiber volume fraction, preform compaction and potential resin pathways. Resin injection involves resin system which is basically a high performance thermoset resin such as, unsaturated polyester, epoxy or vinyl ester are used.

The resin is injected into the mold at moderate pressure, typically ranging from 207 kPa to 690 kPa. The injection process involves is basically capable of delivering resin uniformly overcoming the inherent resistance posed by the dense fiber preform. The pressure ensures that resin penetrates the complex geometries and achieves full wet out of the fibers. The third step in the resin transfer molding involves curing cycle. So, curing cycle, in the curing cycle it is the temperature control where the mold is maintained at a controlled temperature to facilitate the exothermic curing reaction of the thermoset resin.

The cure cycle parameters which involve temperature ramp, dwell times and cooling rates are critical for optimizing mechanical properties of the final part. The cure kinetics also play a very important role in the resin transfer molding process. Cure kinetics involve the gel time, peak exotherm must be carefully managed to prevent defects such as voids, resin rich areas or incomplete curing. The fourth step in the resin transfer molding is basically the part demolding. So, this involves ejection mechanism after curing the part is ejected using knockout pins or similar mechanisms.

The mold surface finish and release agent selection is critical to avoid surface defects and ensure easy demolding of the completely cured composite part. We will now see the schematic of the resin transfer molding process. The resin transfer molding process basically starts with a presence of a mold. This is basically the lower half of the mold. In the lower half of the mold, there can be certain heating coils which can be present.

So, we can say these are the heating arrangement. So, these are generally electrically controlled and this is basically the lower mold. So, then we can have the fiber preform,

and on top of the fiber preform we can have the upper half of the mold. So, this is the fiber preform and this is the upper half, the upper mold. The upper mold is having a feature to have the resin injector connected.

So, in the upper half of the mold, we have this resin injector pipe which is connected here and this pipe is then connected to the mixing head. This is basically the resin mixing head and this is the resin injector. So, this upper mold can move up or down for closing the mold and then the fiber preform is already pre-placed. Now in the mixing head, there are two supply lines or one supply line is basically for the catalyst or the hardener. So, this is the catalyst or sometimes it is also known as the hardener.

So, for epoxy based resin, commonly the amine based hardeners are there, are used. And we then separately we can have the resin here. So, generally these are not pre-mixed because if they are stored in the pre-mixed condition, so because of the pre-mixed condition, the cross-linking can initiate which can render the resin mixture hardener to be useless. Because if they are mixed and already cross-linking is initiated, so then there is no point in pumping it into the resin transfer molding equipment. So, via a pump, the resin is separately pumped and brought into the mixing head and the catalyst which is or the hardener is separately brought and mixed into the mixing head.

So, the pump arrangement is there. So, this is through the pump, through the pump both of these components are pumped here, and in the mixing head basically the proper mixing of the resin and hardener is done before it is injected into the mold where the fiber preform is already placed. The heating arrangement here can facilitate faster curing and this can also improve the part quality, reduce several defects and so on. So, this is basically the complete arrangement of the resin transfer molding equipment. So, next we will see the key technical features of resin transfer molding. So, key technical features of resin transfer molding include surface quality where resin transfer molding allows for precise control over the surface finish producing a class A surface suitable for visible high performance applications.

This is achieved due to pressurized resin injection which forces the resin into intimate contact with the mold surfaces. Fiber volume fraction, so resin transfer molding can achieve fiber volume fraction up to 65% and in some cases it can go as high as 70%. High fiber volume translates into superior mechanical properties such as tensile strength, stiffness and impact resistance. The third important technical feature of the resin transfer molding process includes void content where low void content of approximately less than 1% is achievable, which is critical to maintain integrity of the composite, especially for load bearing applications. We can now summarize the various advantages of resin transfer molding.

So, this involves high performance components. RTM enables production of parts with high mechanical properties critical for aerospace, wind turbine blades, automotive applications. Complex geometries, the process is capable to produce parts with intricate geometries with uniform fiber distribution and consistent resin content. Integrated features so resin transfer molding can incorporate inserts, cores and other features directly into the mold reducing for post processing and assembly. This also enables co-curing of various parts. The limitations of resin transfer molding also include the tooling cost and complexity where high quality and robust mold are needed to withstand injection pressure, tooling cost and complexity.

Potential for fiber wash, so the resin injection pressure can cause displacement of fiber within the mold, potentially leading to non-uniform mechanical properties or surface defects. Cycle time includes cure time for thermoset resins in RTM is longer compared to other processes. This may impact production efficiency in some cases. So, if you look at some applications and industry use cases, so for wind energy, the turbine blades, for turbine blade manufacturing, resin transfer molding is employed because large scale wind turbine blades are manufactured using this process where combination of high strength, low weight and excellent fatigue resistance is essential. For aerospace components, the structural parts are made using resin transfer molding such as wing spars, fuselage panels, bulkheads, where high strength to weight ratio are critical.

Complex shapes with the process also supports the complex shapes lightweight structures with integrated stiffness and features reducing need for assembly and additional fasteners. For automotive crash structures, the process is capable to produce high energy absorption parts characteristics making RTM suitable for safety critical components like crash structures or reinforcement beams. So, with this, we will look at the summary of this lesson. In this lesson, we have looked primarily at the resin infusion technologies. In the resin infusion technologies, we have looked at various technologies.

Then we have in detail looked at the resin transfer molding process. So, in the resin transfer molding process, we have looked at the equipment which is used the setup outline. We have looked at what materials are used in the resin transfer molding. We have looked at various advantages and limitations of this process. In the next lesson, we will look at another process for manufacturing of the wind turbine blades which is also based on resin infusion and this process is vacuum infusion processing or VIP. Thank you.