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

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Lecture 18

Welcome to this course on manufacturing turbines. So, in Lesson 18 of this course, we will explore the investment casting route for the primary manufacturing of steam turbines. So, the outline of this lesson will be as follows: we will cover the investment casting process in detail. So, we will look at an overview of the investment casting process. We will see what the design for manufacturability, or DFM, consideration is. We will understand the various steps involved in the investment casting process; subsequently, we will look at how the investment casting process is used for steam turbines and conclude this lesson.

So, as we have seen in the previous lesson, steam turbines are one of the vital sources of generating energy from steam power. Steam power can be generated either by burning fossil fuels like coal or natural gas, or it can be generated by a nuclear reaction, primarily through nuclear fission. And as we have also understood that to improve the efficiency of the steam turbine, the operating temperature as well as the pressure has to increase, and as we are aiming towards ultra supercritical steam turbines, which have an operating efficiency of the order of. 60%.

It is essential to understand what materials go into making these turbines. As we discussed in the previous lesson, the various alloy steels that specifically contain chromium and nickel are widely used to manufacture steam turbines. And now we will see how the casting or manufacturing processes are done for manufacturing the steam turbine and for any manufacturing process to start with for any product. It is the primary manufacturing processes that come prior to the secondary processes, and in this, the casting process is one of the well-known primary manufacturing processes for components. So, casting, as we know it, is a process in which we allow the molten material to solidify in a cavity.

Inside a mold cavity, upon solidification, the material takes the shape of the mold cavity, and to create this cavity, we know that we utilize patterns, which are basically replicas of the product that has to be cast. Now, casting processes are available in a wide range, and again, as we have seen in the initial lessons of this course, the selection of the manufacturing process depends on several parameters. So, in this regard, the investment casting route, as we have seen earlier, is also a very popular method for the nickel-based superalloys that are used to cast the gas turbine blades. The investment casting process is also popular for steam turbines. So, in the investment casting route, as we have seen earlier, it primarily consists of a pattern made of wax.

So, here the pattern material is wax, and this process is also known as lost-wax. process. So, in this process, we have the die that is being constructed. So, inside the die, we inject the wax, and upon solidification, the wax takes the shape of the die. So, these solidified wax patterns are then assembled onto an assembly of this type of tree.

Subsequently, this assembly of various wax patterns is dipped in a slurry coating, followed by a stucco coating. So, the purpose of this slurry and stucco coating is to achieve the desired shell thickness. And once the desired shell thickness is achieved, we will take this assembly of the wax pattern inside the slurry and stucco coating to a furnace, where the heat from the furnace will harden the ceramic shell. And at the same time, the wax that is present inside will be melted out, and this wax can subsequently be recovered and reused to make new patterns. So whatever is left behind is the hollow ceramic shell, and subsequently, the molten material, or the material in this example, which is the nickel chromium alloy steel, is then melted and poured into these hollow ceramic shells and allowed to solidify.

Upon completion of the solidification process, the shell is removed by breaking away the ceramic shell, and individual pieces or components are cut from this assembly, as shown here. Subsequently, some minor finishing operations may be needed. After that, we can perform the inspection of the cast product using various non-destructive testing methods. For example, one of the methods shown here is the use of X-rays, which are a non-destructive testing method, and this can help detect defects inside the material. So why is investment casting so popular, even for steam turbines? So, as we know, investment casting is one of the preferred methods if we want to cast products with intricate geometry.

So, investment casting is very helpful for creating complex shapes with tight tolerances that are ideal for blade design. Superior surface finish is achieved because the pattern of wax leaves a very smooth surface on the interior walls of the cavity. which helps to produce the smooth surfaces which help to further improve aesthetics as well as minimize friction and improve the efficiency of the product. Specifically, with turbines, we are looking at the turbine blades, which have aerodynamic considerations, and smooth surfaces are essential for aerodynamic efficiency. Then the investment casting process as we know is very versatile it can allow casting for this high temperature melting nickel base super alloys as well as nickel chromium alloy steels.

And thirdly, because the investment casting process is based on this wax pattern, it is very easy to create patterns in complex shapes, regardless of the products being cast. From the investment casting process, it is used for the near-net shape. So near net shape means it reduces the need for extensive machining as well as it also saves time and material. So this is the overall methodology of the investment casting process, which starts with design and pattern creation. Then there is the wax injection process, the assembly, the ceramic shell building, de-waxing, metal melting and pouring, shakeout and cleaning, and lastly, the finishing and inspection.

So, now if we look at the design for manufacturability considerations in the investment casting of products such as steam turbine blades, So first we will understand what is DFM. So DFM is a philosophy that focuses on the ease of manufacturing, which improves product quality and the productivity of the process. So, for every process or product, there are certain points specific to that product at which the DFM philosophy can be applied. So the various points that are considered under DFM for such castings include the design of components for efficient wax pattern removal and mold filling. So whatever the design of the pattern is, it has to be done with the understanding that we are efficiently utilizing the wax for the mold filling.

Secondly, we also help minimize sharp corners and internal features to prevent cracking during casting. Because the presence of sharp corners and internal features generally makes them points of stress concentration. And upon solidification, there may be some residual stress that may result in internal or surficial cracking, which is not desired in the cast product. Thirdly, the consideration of draft angles should be made for the easy removal of the casting from the ceramic mold. Then we also need to strategically place the runners and the gates for optimal metal flow during pouring.

Because the presence of strategically placed gates and runners is essential for controlling the solidification of the molten material, as well as achieving the desired properties in the cast product. So, step one of the investment casting route for this is basically to utilize the wax pattern generated using the following methods. So we utilize a precisely machined metal die to create the wax patterns. To create the pattern itself, we will use a metallic die, and metallic dies are quite expensive to machine. They are generally made up of tool steels if they are machined properly and the die is developed in a proper way.

So one die can produce several thousand wax patterns. The molten wax is then injected into the die under pressure to ensure the accurate replication of various features. So what I mean by this is that, in case there are some internal features that need to be replicated on the wax pattern, if the wax is not injected at the proper pressure, it will not completely fill those cavities, and subsequently, those shapes will not be replicated in the pattern. The pressure at which the wax is injected should be sufficient for the accurate replication of the features to take place. So, the wax material should also have the desired properties for easy removal from the mold.

It should not be that the wax that is there reacts with the internal surface of the mold, thereby creating any residue on these metallic dye molds. In step 2, the wax pattern assembly is connected to this central sprue, which is also a wax bar. So, the wax pattern is replicated to form multiple parts. For example, in these steam turbine blades, there are several blades on a rotor disc, as we know them. So, it is very much desired that a number of blades, six to eight blades, be cast in one cycle, so that these individual back patterns of various blades are attached to the central sprue, forming a cluster.

So then, this sprue basically serves as a channel for the molten material. Enter the mold cavity while pouring. Strategically placed runners connect the sprue to each individual wax pattern, ensuring the complete filling of the molten material inside the wax pattern cavity that is left behind after de-waxing. So here we can see various patterned-filled waxes. There are some waxes for non-filled patterns.

Runner wax is available. Water-soluble waxes are present. Sticky wax is present. So here we can see different types of wax that are used in the investment casting process. Step number three is essentially the construction of the ceramic shell. Ceramic shells are highly desired in the investment casting process because ceramics, as we know, are stable at high temperatures.

The construction of the ceramic shell is accomplished using the following steps, in which the essential step is to dip the wax cluster, created by assembling various wax patterns, into a refractory ceramic slurry. So refractory means that the ceramic has a high temperature resistance and a high melting point. Each dip into the refractory ceramic slurry deposits a thin layer of ceramic material on the wax pattern, as shown here. So, inside this purple is basically the wax pattern, and this yellow color is essentially the coating of the ceramic that has developed around this wax pattern. So, this slurry is allowed to dry between the dips so that we can build a progressively thicker and stronger ceramic shell.

So, the thickness of this ceramic shell will depend on the weight of the casting and other factors. And multiple layers are applied to create a robust mold capable of supporting the weight of the molten material. Of course, there are considerations for handling the mold, etc. So, generally, a few millimeters of thickness are desired, which is achieved after several dips into the ceramic slurry. Once the ceramic slurry is coated around the wax pattern, we proceed to the de-waxing process, which is step four.

And in this process, the wax that is present inside the coated ceramic shell is removed. To remove this wax, steam autoclaving and chemical leaching are commonly used. In the steam autoclave, the wax cluster is exposed to high-pressure steam, which ensures that the wax is melted and drained. Chemical leaching is also utilized to remove the wax, in which the wax clusters are submerged in a chemical solution that helps dissolve the wax. But in this case, it is often reported that the reusability of the wax has been reduced.

So in the case of a steam autoclave, the molten wax can be recovered and reused to make the patterns once again. In step number five, we have the melting and pouring of the metal. So in this step, the molten material, now in this case, the molten material will consist of the nickel and chromium based alloy steels, which are the preferred choice of materials for steam turbine blades. So, the metal pouring is done in the following steps.

The chosen metal alloy is melted in a separate furnace and is brought above its liquidus temperature. The molten material is then carefully poured into the ceramic mold cavity which is created by the de-waxed shell. So gravity filling or vacuum assisted methods may be used for ensuring the complete filling of the mold. So in step number six is the solidification and cooling. After the molten material is poured into the ceramic pattern or the ceramic mold cavity, it is allowed to solidify in the ceramic mold.

The cooling rate is carefully controlled to influence the grain structure and properties of the casting. For example, in the gas turbines, we have seen the use of specialized furnaces along with the grain selector to create single crystal cast gas turbine blades. But that single crystal cast gas turbine blades were desirable for the operating conditions for the gas turbine. Nevertheless, for the steam turbine, the directionally solidified blades are also sufficient for getting the desired properties. And by controlling this cooling rate, we can do the directional solidification.

And in this case it is important to note that rate of cooling it also influences the grain size. And to get finer grains it is desired to cool at a faster rate because slower cooling results into coarser grains which are not desired for enhanced mechanical properties. Step number seven, this involves breakout and cleaning. So after the solidification of the molten material is complete, the ceramic mold is broken away to reveal the casting.

The process is known as shakeout. This process can also involve vibrations, mechanical hammering, or water jet cutting. So this vibration or hammering and cutting will remove the ceramic shell. from the outside and the casting is then cleaned to remove any residual ceramic material or the invested material. so if we see what are the specific advantages and limitations of the investment casting for the steam turbines so in case of advantages the investment casting is very suitable for the complex geometries with tighter tolerances it is also very helpful to get the desired surface finish it allows for wide range of high performance alloys like nickel chromium steels to be cast More importantly, it also helps to create near net shape parts, minimizing machining waste. But it also has certain limitations as the size of the turbine keeps on increasing.

The capability of the investment casting process is limited by the size of the product. Higher cost compared to other casting methods is there. Surface roughness to get very fine surface roughness some secondary processing or finishing may be needed. And very complex features may sometimes become difficult to cast. So specialized methods may be used to manage this.

So in conclusion we can say for manufacturing of the steam turbine blade investment casting process is a very versatile and reliable process for manufacturing complex high precision components. It enables creation of the intricate geometries with tight tolerances for essential and efficient operation of steam turbine. It also helps to cast various alloys nickel chromium alloy steels with necessary mechanical properties which also are able to withstand the demanding environment operating conditions and near net shape helps to further minimize material waste and production cost in the steam turbine plates. So with this we come to the end of this lesson.

Now we will summarize what things are covered. We have looked at the investment casting for steam turbine blades. We have looked at the process and methodology. of investment casting. We have looked design for manufacturability that is ease of manufacturability considerations. We have looked at all these steps in detail casting in detail and lastly we have concluded the various advantages and limitations of this process for the steam turbine.

So, in the next lesson we will see the deformation processes which are used for steam turbine.

Thank you.