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

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Lecture 10

Welcome to this course on manufacturing for turbines. In this lesson 10, we will continue our discussion on manufacturing of gas turbines by discussing the next processes in casting of gas turbine blades. So, this lesson will cover three casting methods that is the liquid metal cooling process, gas cooling casting process, dipping and heaving process. So, these processes are also used to cast the gas turbine blades. As discussed previously, after the investment casting, once the shell mould is developed, so subsequently these processes can be used to cast the blade in a single crystal format. So in the previous lecture, we have seen the details about the Bridgman furnace.

So Bridgman furnace utilizes hollow ceramic shells which are obtained from the investment casting route. But what happens in the Bridgman furnace, it creates a very high thermal gradient denoted by capital G. So, even though there is the utilization of grain selector, which is a narrow opening which allows only one grain to pass through, the grains they solidify or grow in a particular direction. But due to high G values and low constitutional supercooling, the resulting microstructure could be equiaxed, which is highly undesirable as it may have several grain boundaries.

So to overcome the limitations of the bridgeman furnace process, we have this process known as liquid metal casting process. So in the liquid metal casting or it is also known as liquid metal cooling process, it is an advanced modification technique of the conventional bridgeman process. designed to enhance the directional solidification of single crystal casting route. In the LMC process, this mold is withdrawn from the heating zone into the liquid metal bath which utilizes a dynamic floating baffle and there are two separate zones that is the heating and cooling zone which are separated thus improving the thermal gradient. So, utilizing of LMC is aimed to optimize convection over radiation for heat extraction and potentially this resolves the issues with the production of large industrial gas turbine components.

So the key features and benefits in the LMC process include improved thermal gradient. So these G values are achieved in the LMC are typically double than those which are achieved in conventional process which lead to faster cooling and finer microstructures.

Efficient cooling is second benefit in which liquid metals such as aluminum tin and other alloys are used as coolants to optimize the cooling efficiency. So, we will see the constructional details about the LMC process now. So, in the LMC process typically we have a liquid coolant which is stored in a tank.

So, this liquid coolant as stored in the tank is separated by a baffle from the hot zone of the furnace. So, here we can say we have the mold coming in which is separated by a chill plate which is basically a chill plate is placed at the bottom of the mold. Then we have a dynamic baffle which is separating the hot zone on top of this furnace. So hot zone of this furnace may be connected to an induction melting setup where the super alloy is getting melted and then we can have some heating in the hot zone. These are radiative heating, radiation heating.

This is basically the here is the induction melting part. where the super law is melted and then this is poured into this mold which is there so we have this ceramic mold here is the ceramic mold and this is the dynamic baffle. We can say that this part is the hot zone of this furnace and the bottom part is the cooling zone and sometimes basically what happens sometimes to enhance the cooling so we can also have a stator here. The stirrer is constantly stirring the liquid metal cooling here. So, all the liquid metal cooling is provided here.

This coolant, liquid metal coolant is here. and we can say our this thermal oil is surrounding this liquid metal coolant which is constantly recirculated (thermal oil) and this is the liquid metal coolant. This is the chill plate on which the solidification of the molten material will start. And suppose up to here we have the solidified solidified metal and on top of it because of the heat there may be the molten And then what can be there, this chill plate is sometimes connected to a platform which can be lowered. Using this arrangement of this platform movement, we can control the z-axis movement of the chill plate by dipping it further as the solidification continues.

So, as the complete blade solidifies in the respective thermal gradient which is maintained. So, this is basically a typical LMC (liquid metal cooling) process which is utilized to manufacture the gas turbine blades. So, what are the different challenges and limitations of the liquid metal cooling process? So the first is thermal impact on the moulds. So ceramic moulds sometimes we know they may crack due to significant thermal impact when immersed in liquid metal bath leading to potential contamination and degrading performance of the casting. Secondly, high cost and complexity, the equipment used like investment casting, procedural complexity are substantial and limiting widespread use of the LMC technique and sometimes there may be presence of non-axial temperature gradient.

So, the rapid heat extraction may result in non-axial temperature gradient which may result in curvature on the solidification front. Sometimes this may lead to lateral growth of the grains which is more pronounced in LMC even when compared to the conventional bridgeman furnace. Next we looked at another casting process used to manufacture the gas turbine blade which is the gas cooling casting process sometimes abbreviated as GCC. So, the gas cooling process, this is basically developed by ALSTOM Power Technology, which is manufacturer of a large scale single crystal gas turbine components. So, the GCC process it provides further improvements compared to conventional Bridgman process apart from radiation cooling.

Sometimes in this process an inert gas is injected directly below the furnace baffle to cool the casting, as it is withdrawn from the heating zone. So, upon withdrawing the casting from the heating zone this cooling inert gas helps to bring down the temperature quickly. So, by achieving the required thermal gradient at the solid-liquid interface, so in this case these thermal gradient are often observed to be twice than the conventional Bridgman furnace. However, there may be challenges due to opening between the heating and cooling chamber and the cooling gas in this case may inevitably blow upward into the heating chamber. So, this effect although is helpful in the cooling zone of the furnace, but this effect considerably it reduces the furnace temperature and the temperature gradient in the alloy melt, thus negatively affecting the directionally solidified or single crystal casting process of the components in the shell mould.

And due to this unavoidable problem, the GCC process is also having limitations in terms of industrial use. So, we will see and understand the GCC process from this schematic here. So, the basic philosophy is same that we have a furnace which is having two zones. So, the above zone here again is basically the hot zone. and then the bottom zone becomes the cooling zone and again we have here the chill plate here which is connected to the mold.

And in this case also we have a feeder in which the molten material is introduced and it enters the mold and under the effect of gravity it flows into the mold and as the mold part it enters the cooling zone so here we can see that there is a constant supply of inert gas from here on both the sides the inert cooling gas is provided which rapidly reduces the temperature and thereby basically it leads to you know directionally solidified blades and here we can understand the limitation as we have a partial baffle so in this case there is a partial baffle and due to these openings between the mould and the baffle the inert cooling gas it always enters because as the gas comes in contact with the heated molten material and the mold it also gets heated and hot gas always has the tendency to rise because of which it always enters the heating part or heating zone of the furnace which considerably reduces the temperature. So, other than this because of the forced gas cooling the high thermal gradients or temperature gradients are obtained in the GCC process which makes it favorable from the grain microstructure aspect. Next is the dipping and heaving process. Now what has happened up to now, we have looked at the bridgement process. We have also looked at the liquid metal cooling process, GCC process.

Now what is the inherent disadvantage with all these three methods is basically it is very difficult to have an or I can say there is an ineffective radiation heat exchange why because in this in these cases generally the thick ceramic molds are used so because of the thicker ceramic molds the radiation heat exchange is ineffective so sometimes because of this unclosed baffle which is separating the hot zone and the cold zone so unclosed baffle leads to you can say poor isolation between hot and cooling zones and thirdly high thermal resistance of thick ceramic molds leads to poor heat transfer. So, because of this poor heat transfer between the mold and the surrounding media. So there are challenges in the existing three processes that is the bridgman, liquid metal cooling and gas cooling process. Now these limitations of these three processes are somewhat overcome using this dipping and heaving process. So dipping and heaving process is also known by other names known as thin shell casting process.

It is also known by the name of downward directional solidification process. So, we can say by this process, we can overcome these challenges of the existing three processes. We will see how now. So, dipping and heaving is also known by these methods names as I just mentioned and it is primarily developed to address the limitation of maintaining high temperature gradient in the conventional bridgement process. So, these limitations what they do is they include ineffective radiative heat exchange, unclosed baffle isolation and so on as just we discussed.

So, all these limitations they are overcome using the dipping and heaving process. So, dipping and heaving process sometimes also abbreviated as D and H process. It consists of an initial setup where a super alloy melt is overheated in a crucible. which is then covered using hollow ceramic beads which act as a dynamic baffle. Now, here we do not have a separating heating and cooling zone rather we have a super alloy melt which is heated well above its melting temperature.

So, it is constantly kept at that temperature. So, that is why it is mentioned here overheated. So the mold preparation is similar that we prepare the mold using investment casting route. A ceramic mold is prepared which also has a grain selector or a single crystal seed connected to the chill at the top and then this is dipped into this alloy melt through the baffle. We will see how the process goes about.

So then after it is dipped, the molten bottom is sealed with a stopper made up of the same super alloy or the same alloy which is going to get cast, which allows the melt, melting alloy to flow into the mold and come in contact with the chill plate. So, this basically initiates nucleation and competitive growth of columnar grains. Once a stable thermal condition is achieved, so then what we do is we pull the mold up from the melt path at a specific rate, it is generally a few millimeters per minute to allow the single crystal growth through the grain selector. And additionally, sometimes cooling may be applied by inert gases to increase the heat extraction and have the higher withdrawal rates. So we can see the schematic of the dipping and heaving process where we have this chill plate.

Then we have this grain selector. Then here is basically the ceramic mould. and this is basically a stopper. So, this stopper is made up of the same material as this super alloy melt. So, here we can say we have the super alloy melt and the hollow ceramic beads are placed here as they are hollow of course they will be floating every time and they basically create a boundary or a barrier between atmosphere so that enables the temperature of the super-allowment to be maintained.

Once we want to start the process we just dip this hollow ceramic mold and again this hollow ceramic mold is obtained from the investment casting route as previously discussed so once the mold is dipped into the super alloy melt now as the stopper is made up of the same super alloy material so this will also melt and this will then allow the molten super alloy to go into this ceramic mold and upon coming in contact with the chill plate and through the grain selector, the grain growth or nucleation will start and once we reach a stable thermal condition, we will pull out or heave. So, heaving is basically pulling out this filled ceramic mold. So, this process is known as heaving. So, once we will pull out, so additionally some gas cooling may be used to maintain proper thermal gradient by utilizing additional secondary gas cooling. And then basically this initiates a downward solidification that is why the name of the process is also known as downward solidification process.

And this withdrawal is programmed at a very slow rate to enable development of single crystal cast gas turbine blades. So we can summarize the advantages of dipping and heaving technology. So this involves high thermal gradient, so it achieves almost 7 times higher thermal gradient compared to conventional bridgmen process leading to refined microstructure. with reduced primary dendrite spacing, deutectic pool size and micropores. So, thin shell moulds, so they also help to create a hydrostatic balance between the mould which allows wall thickness of the order of thin as 1 millimeter which is sufficient to maintain the casting shape and it also enhances the heat extraction efficiency.

So improved microstructure, finer and more homogeneous distribution of gamma prime precipitates, they reduce solution treatment times or enable full solution during heat treatment, particularly benefiting for high alloyed superalloys materials. Efficient heat extraction is the next advantage because of the thin shell molds and gas cooling which lead to more efficient heat extraction from the conventional or modified bridgement techniques. And here isolation of heating and cooling zone, so the dynamic waffle effectively isolates the heating and cooling zone increasing the thermal gradient at the solidification front. So, we can see the industrial application in future direction. So, it is that the D and H technology is used to produce single crystal alloy super alloy blades under protective argon gas.

So, some researchers have also shown that blades produced using dipping and heaving process exhibit refined dendrite structures and improved microstructural properties compared to the conventional methods. Future development could include construction of large vacuum furnaces for production of industrial gas turbine and aero turbine blades in clusters to enhance the productivity. And implementing molten slag such as floating baffle could further improve the melt bath isolation and facilitate cleaning similar to electro slag melting, remelting process. So, here we can see the microstructure of CMSX-4 blade produced using bridgman furnace and the dipping and heaving process. So, here we can see on the top we have the Bridgeman furnace in A, where we can see larger size of precipitates and inter eutectics, but in the dipping and heaving process we can see the finer gamma prime precipitates and small size of the eutectics which basically we can anticipate better mechanical properties of the components which are developed using the dipping and heaving process.

So, with this we have tried to complete the casting of the gas turbine, single crystal gas turbine blade and we can say one of the primary manufacturing process is complete and after this we have basically a single crystal cast gas turbine blade made up of nickel based super alloy. So, in the next lecture we will see the next process through which the gas turbine blade is subjected which is hot isostatic pressing we will see the various mechanisms advantages and application. And subsequently, we will see the requirement of machining processes on the gas turbine blades by looking at the different types of machining processes available and then specifically which processes are used. For example, EDM is one of the process which is used to machine the gas turbine blade to create the film cooling holes.

Thank you.