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

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Lecture 40

Welcome to this course on manufacturing of turbines. In this lesson 40 of the course, we will summarize all the topics which are covered in this course on manufacturing of turbines. So, in this course we have dealt primarily with the connection between the service conditions of the various turbines as mentioned here. So, we have looked at the mapping between service conditions, how the service conditions affect the material selection, so what materials have been selected for making the respective components of the turbine, and then the material selection, how the material selection is influencing the selection of the manufacturing processes. So, in this regard we have looked at all the processes starting from the primary manufacturing process to the tertiary manufacturing process to realize the particular turbine. So, in this course, we have seen these details regarding the gas turbine, steam turbine, hydro turbine and wind turbine.

So, we will now summarize all these aspects now. So, if we see the summary of the various service conditions or the conditions in which the respective turbine is operating, so they are tabulated in this table. So, based on this the various parameters are mentioned on the left hand side which include energy source, operating temperature range, density of the energy source, size of the turbine and the important challenges in service. So, we start with the gas turbine.

So, we have seen that gas turbines, they basically utilize the combustion of natural gas and because of the combustion of the natural gas, once the gas is passing over the turbine blades, it is rotating the turbine blades, which is in turn connected to a generator because of which the electricity is produced. So, as in the gas turbine the combustion of the natural gas is taking place. So, there are lot of ambient hot gases as the energy source. So, the temperature of these hot gases is in the range of 1100 to 1300 degree Celsius. So, we have seen the density of the hot gases is approximately 0.

0 to 0.9 kilogram per meter cube and these type of turbines are generally medium sized turbines. Now, because of this high temperature in the operating conditions, there is very high tendency of oxidation. So, because of this tendency of oxidation, we have seen the selection of material for the gas turbine especially the blades is the nickel based super

alloys. We have seen that super alloys are basically the materials which can retain their strength, hardness and other mechanical properties even at elevated temperatures.

So, the reason of this property is the present of coherent precipitates in the nickel base superalloys which help to hold the microstructure of such alloys together and they also avoid the grain boundary sliding under elevated conditions. So, other than oxidation there is the challenge of creep, also there is challenge of fatigue in this type of turbines. So, we have seen that nickel-based super alloys, they offer very good mechanical properties even at elevated temperature. So, the material selection for this type of turbine blades are basically nickel-based super alloys. Moving on to the second turbine that we have discussed in this course is the steam turbine.

We have seen the steam turbines are based on the Rankine cycle and the current technology is basically using the superheated steam and the futuristic technology in steam turbine is basically based on ultra superheated steam. The operating temperature range because of this is in the range of 600 to 700 degree Celsius. The density of the energy source here is 0.1, 1.

2 to 1.3 kilogram per meter cube and these turbines are also large to medium size. So, in these turbines there is significant challenge of corrosion, cavitation and erosion. So, because of which martensitic or duplex type of stainless steels are widely used to manufacture the steam turbine. Next, we have looked at the hydro turbine. So, in the hydro turbine we have seen that water is basically the energy source because of which the flowing water causes the turbine blades to rotate and because of this rotation the energy or electricity is produced.

So, as water is flowing so the ambient condition is ambient temperature is between 15 degree Celsius to 25 degree Celsius. And we see that the density of water is almost 1000 times heavier than the air which is 1000 kilogram per meter cube. These turbines are exceptionally large in size and they also have certain challenges like cavitation, slurry erosion etc. Lastly, we have seen the wind turbine which are based on the polymer based composite materials because of their lightweight and high strength properties. So, ambient conditions of such turbine can be 20 degree to 40 degree Celsius or it can be sometimes lower in significant changes in weather can take place.

So, density of the air is approximated as 1 kilogram per meter cube. And these are extremely large sized wind turbines. So, these are very large we can say compared to the hydro turbine even. These are very large in size and they have significant effects from the environment such as from the rain or the sunlight. So, we will see all the summary of the materials and the various manufacturing processes.

So, if we look at the material selection for the gas turbine, we discussed the use of nickel based superalloys. For example, Inconel 718, Rene N5 etc. So, these type of materials they are known to have high temperature strength. They are able to retain their mechanical properties at temperatures up to 1200 degree Celsius. We have seen the creep resistance is also offered by such materials because of presence of the coherent gamma prime precipitates in this type of superalloys.

The materials also offer exceptional oxidation resistance because of presence of chromium and aluminum which help in providing protective oxide layers. The compressor blades of such turbines are known to be made with titanium-based alloys such as titanium-6-aluminium-4-vanadium because of certain properties. Titanium-based alloys are known to offer high specific strength which is high strength to weight ratio, corrosion resistance that is they are quite effective in resisting stress corrosion cracking and fatigue resistance as they can perform well under cyclic loading at temperatures of the order of 400 degree Celsius. So, here 400 degree Celsius is a relatively cooler temperature in the compression section as we can see here in this schematic but in the in this section we can say the temperature is of the order of say 400 degree Celsius because of the compression of the air but in the turbine section this temperature can go to as high as to 1300 degree Celsius. So, here we are it is proposed that nickel based titanium based alloys are used and here nickel based super alloys are used as the materials Because of this high class of materials which are having exceptional mechanical properties, different types of specific manufacturing processes are used which we will discuss.

Next, is the material selection for steam turbine. In the steam turbine, there are high pressure and intermediate pressure turbines which are made up of the material based out of chromium, molybdenum and vanadium steels. So, the properties of such material include creep resistance which is essential for maintaining performance at temperatures up to 600 degree Celsius, oxidation resistance which protects against high temperature oxidation, thermal fatigue resistance which ensures durability during thermal cycling. The low pressure turbine are generally made up of austenitic stainless steels that is 316L or 347 low alloy steels. The properties of such steels are basically corrosion resistance, which can resist intergranular corrosion in humid environments.

As there is steam or superheated steam present, but as the steam expands, so it can reach to the wet state. So, there are chances of generation of a humid environment. Secondly, there is toughness also offered by such materials which maintain the toughness even at these varying temperatures. Stress corrosion cracking is also important. So, stress corrosion cracking resistance is also offered by such materials used in manufacturing of the steam turbines.

Next, we have looked at the hydro turbines in which materials popularly as duplex stainless steels or martensitic stainless steels are widely used. So, stainless steels containing 13% chromium, 4% nickel or Ca6Nm based steels are widely used to manufacture components and blades of the hydro turbine. So, these steels are known to offer cavitation resistance that is protection against erosion caused by cavitation, corrosion resistance which is essential for operation in fresh and seawater environment, high strength which is required to withstand the hydraulic forces as we have seen that density of water is 1000 times higher the density of compared to the density of air. The guide vanes in case of hydro turbine are made up of stainless steel, chromium based stainless steels or sometimes bronze based alloys because of their good corrosion resistance which can prevent degradation under underwater environment. The wear resistance that is high resistance to erosion and wear under turbulent water flow is also offered by these materials.

Next, we have look at the wind turbine blade material selection. In case of wind turbines as they are extracting energy from the blowing wind. So, in this case composite material especially the polymer based composite materials are widely used. So, in the polymer based composite materials it is the epoxy based materials which are reinforced with synthetic fibers such as glass fiber and carbon fiber based composites are widely used to manufacture the wind turbines and the blades of the wind turbines. These materials are known to offer high specific strength with low weight and high mechanical strength.

They are also known to offer high fatigue resistance because of which the wind turbine blades can endure millions of cycles over the complete service lifespan of these turbines which is approximately between 20 to 30 years. Corrosion resistance is also possible in these type of materials because of the inherent resistance to environmental degradation crucial for offshore installation. The nacelle of such wind turbines is made up of composite material or aluminium alloys which are light in weight they are critical to reduce load on the tower corrosion resistance which protects against environmental exposure especially in marine settings structural integrity which provides sufficient stiffness and durability to protect internal components So, the tower we have seen, the tower of the wind turbine is made up of the high strength low alloy steel. These steels are known to offer high yield strength which supports the heavy nacelle and rotating rotor and can also withstand the dynamic load which is offered by the varying wind forces. The fatigue resistance is also important of the tower to withstand the cyclic load for decades of operation.

And lastly, the corrosion resistance on the towers is also important and these are offered by several coatings as provided on the tower by form of different materials or galvanization. So, now we look at the summary of various manufacturing processes used in each case of the turbines. So, we start with the gas turbine. So, in the gas turbine we have seen the manufacturing starts with the primary manufacturing process in which we have utilized the investment casting route to start with to develop the single crystal based alloys, nickel based super alloys to remove the grain boundaries. We have seen that as the presence of grain boundaries enhances the probability of creep failure because of grain boundary sliding, so it is always a good idea to have no grain boundaries because of which single crystal based nickel based super alloys are popular.

For doing this the investment casting route is chosen to start with development of basic mold cavity and using the wax based methods we can get a very good surface finish. After the investment casting, the mold development is complete. The complete casting process is executed in specialized furnaces such as bridgeman furnace, dipping and heaving process, liquid metal cooling process or gas cooling casting process which can yield single crystal based nickel base superalloys of such materials. So, next after the casting is done the process moves on to the hot isostatic pressing or HIP. So, as we have seen the HIP or hot isostatic pressing is known to remove the internal voids defects in the microstructure thereby refining the microstructure of the gas turbine blades.

The hot isostatic pressing is also widely used for repair and rejuvenating of the microstructure of the in-service gas turbine blades, thereby enhancing their service life. The various machining processes which are used in case of gas turbine blades are basically to develop the film cooling holes. And as the material of the gas turbine blade is the nickel based superalloys, therefore advanced machining processes such as electric discharge machining or laser beam machining has been used to develop these film cooling holes. Then we move on to the creep feed grinding process which is a surface finishing process which relies on high depth of cut and slow feed because of which the name is creep feed. And another characteristic of creep feed grinding process is to have the shape of the grinding wheels confirming to the shape of the product here which is the gas turbine blade.

So, these are widely used for surface finishing of the blades. And lastly in the gas turbine blades we have discussed the use of thermal barrier coating which is the use of refractory based materials to prevent the heat flow onto the gas turbine blade. So, we have seen the use of electron beam physical vapor deposition process as well as the atmospheric plasma spraying process to develop the thermal barrier coating on the blades. We have looked at the use of pyrocloths to improve the efficiency of the thermal barrier coating on gas turbine blades. So, in case of the steam turbines, we have looked at the investment casting route to develop the blades as the primary shaping or manufacturing process.

Next, we have looked at the deformation processes for refining the microstructure of the as cast steam turbine blades. Then, we have looked at the conventional machining processes where there is a physical contact between the tool and the workpiece. So, various machining processes like milling, cutting and grooving are widely used to manufacture the steam turbine blades. We have also looked at the use of laser metal direct fabrication and welding for steam turbine manufacturing using various processes for repair and maintenance in such type of steam turbine blades. In case of hydro turbines, as we have seen, they are extremely large in size and because of which there has been extensive use of sand casting processes.

Nevertheless, the investment casting route has also been used to develop some scaled down prototypes. The sand casting route is known to handle large size of objects. Then the use of forging where isothermal forging processes have been used to refine the microstructure of as cast hydro turbine components. After which the use of several fusion based welding processes like tungsten inert gas welding, metal inert gas welding, submerged arc welding, electron beam welding etc.

can be used to do the welding processes. Then, there is the use of CNC machining where, the use of the CNC control machine tools have been done to remove excess material from the workpiece surface. And lastly there has been use of extensive thermal spray based coatings to overcome the challenges of cavitation and erosion in case of the hydro turbine operation. So, here we have seen use of thermal spray based coatings based out of plasma spraying, high velocity oxy fuel playing, high velocity air fuel playing, air fuel spraying based methods. So, use of cermet based materials like tungsten carbide based and cobalt or chromium based materials in such coatings has been extensively discussed and how these presence of these materials can mitigate the effects of you say the erosion that is the sludge erosion caused by the increased sediment load or the cavitation can be managed in hydro turbines is discussed. Next, we have looked at the manufacturing of the wind turbine blades where, we have seen the use of polymer based composite materials in which the epoxy or the thermosetting based matrix being reinforced with fiber such as glass fiber and carbon fiber has been done.

So, use of hand layup and spray layup processes which are basically the category of open molding processes has also been discussed. The use of vacuum bag molding and resin transfer molding was also discussed where, the use of these methods have been widely used in industry for large scale wind turbine blades. We have also looked at the vacuum infusion processing which, is basically also used to make the wind turbine blades. And lastly, we have looked at various type of coatings which are applied on the wind turbine blades such as anti-corrosion coating, erosion resistant coating, anti-icing and de-icing coating, ultraviolet resistant coating, fouling resistant coating. thermal barrier coating and advanced nano coatings.

So, by use of such coatings on the wind turbine blade we can not only enhance this efficiency but also enhance the service life of the wind turbine blades which is operating in the varying conditions of weather ultraviolet radiation, offshore locations, marine environment, salty environment, rain etc. We have looked at several degradation mechanisms or the failure mechanisms in the wind turbine blade which are occurring and they can be mitigated by presence of such coatings on the wind turbine blade. We have also looked at various methods which can be used to coat the wind turbine blade such as the sprayer or maybe the brush and roller application, sole gel etc. With this, we summarize the whole of this course in which we have connected the service conditions of these specific four products, how the service condition influences the material selection. We have deliberated on in detail why the particular material is suitable for that particular service condition or in which the product will be operating.

Subsequently, by connecting the material selection to the manufacturing process, we have seen in series the philosophy on which the particular manufacturing process can be chosen. So, I hope this course has provided you the insight and philosophy of connecting the knowledge of material properties to the selection of the manufacturing processes and by looking at these four products similar philosophy can be applied to several other products in our daily life. Thank you.