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

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Lecture 23

Welcome to this course on manufacturing of turbines. So in this lesson 23 of this course, we will see the use of forging and welding processes for hydro turbines. So the outline of this lesson will be as follows. So this lesson will broadly cover two topics involving the forging process for hydro turbine as well as the welding process. In the forging process, we will see the details of forging process, the materials used, severe plastic deformation using equi-channel angular extrusion, isothermal forging process, how the use of simulation methods and finite element methods is done in forging process, heat treatment, damage and stress analysis and microstructural evolution and subsequently we will see applications in hydro turbine manufacturing. In case of welding processes for hydro turbine, we will see the various welding processes, the materials used, We will look at how welding process is used to weld the runner, guide vanes, casing, draft tube, pre and post welding treatment and inspection, challenges and solution in hydro turbine welding.

So, we start with forging in hydro turbine manufacturing. Forging, in hydro turbine manufacturing involves shaping the metallic components using localized compressive forces. The importance of this process includes essential for production of robust durable components which can withstand the harsh operational environments. Key components which are subjected to forging in hydro turbine they include hydro turbine blade, shaft, disc and other critical parts.

The forging process involves heating. So, in the first step the metallic blocks known as ingots are heated to a near molten stage where the metal remains solid but malleable. So we also know this is also known as the hot working range of the materials where the materials are processed above their recrystallization temperature. The purpose of heating is so that the metallic components can be easily shaped under the influence of compressive forces. The second step of forging in hydro turbine manufacturing involves pre-forming.

So, in this process, the heated ingot, it undergoes edging to increase the working cross-section area and blocking to refine its shape. So, these steps involve pressing or hammering the metal. Purpose is to form a piece that can be pressed between closed dies. Step number three is finish forging. So, in the finish forging, the preformed metal is forced into impression between two dies.

The metal takes the general shape of the end product, sometimes requiring multiple strokes or different dies for complex items. The purpose of this finish forging is to achieve the final shape and dimensions of the product. Step number four in forging involves cooling. So in cooling, coordinated cooling is done to enhance the strength of the forged product by optimizing grain flow within the metal. Sometimes in this the flash which is the excess metal is produced and this flows outside the dies cooling and hardening rapidly to fill the die cavities completely.

The purpose is to strengthen the final product and ensure the dimensional accuracy in the product. Then step number five involves finishing. In finishing, the trimming of the flash is done. Surface treatments are applied to enhance corrosion resistance and improve appearance. The purpose is to improve dimensional accuracy and surface quality of the final product.

Here we can see the three methods of forging in the first method we can see the use of closed die forging process where the hot metal billet is in contact with the moving die and as the die moves in the downward direction by thereby applying the compressive forces we can see the hot metal billet, it shapes up into the cavity of the die and as the more compressive force is applied the metal completely fills the die cavity. In the other process that is the open die process we can see that the hammer is continuously being blown onto the workpiece, which is held using a tong and the area of the workpiece coming in contact where the hammer is being applied. We can see the transformation of the coarse grain structure into the finer grain structure which results in enhanced mechanical properties. And subsequently we can see the use of upsetting where a heading tool is advanced to upset the end of a bar and this can be done at various stages thereby increasing the contact area of the product. So, here we can see how the use of the AA6063 aluminum alloy is done with respect to forging.

So, properties of aluminum alloy AA6063 involve high corrosion resistance, good mechanical properties such as, strength and ductility, excellent workability and weldability and this is also suitable for high performance application in harsh environments. So, pre-processing involves the grain refinement for improved forgeability and mechanical properties. So, on the right hand side we can see the table highlighting the chemical composition of the AA6063 alloy. Where, the aluminium is present in significant proportion almost 99% and we can see the list of other alloying elements and their respective weight percentages in the alloy. So, next process in the forging processes which are used in hydro turbine manufacturing involves severe plastic deformation processes.

Although there are several severe plastic deformation processes but equal channel angular extrusion or ECAE process is popularly used. In this process of equal channel angular extrusion, the material is pressed through the die with the channel bent at an angle, causing intense shear deformation without changing the cross-sectional area. The route C involves rotating the billet by 180 degrees between passes, enhancing uniformity of deformation. The benefits of the ECAE process involve ultra-fine grains, significant enhancement in strength and fatigue resistance. It also prepares the metal for subsequent forging processes by improving its mechanical properties.

So, here we can see how the preform is being used in the extreme or the severe plastic deformation in the die. Here, the workpiece is placed and this is the die. and on the right hand side then we can see after the severe plastic deformation is conducted the workpiece, It takes the shape of the die and is subsequently removed and because of which we can get this type of complex shaped products using severe plastic deformation processes Next process in the forging processes which are popularly used in hydro turbine manufacturing involves isothermal forging process. So, isothermal as the name is indicating in this process the die and the workpiece they are maintained at same temperature throughout the forging process. The advantages of this process involve ensuring uniform microstructure and mechanical properties, reduced thermal gradients, and it also helps to minimize the risk of defects.

Process parameters involve specific to an alloy being forged. For example, the AA6063 aluminium alloy is being forged at 520 degrees Celsius. The strain rate, it needs to be carefully controlled to optimize material flow and final properties. And flow stress law, so this is developed through isothermal upsetting tests which is crucial for predicting material behavior during forging. So, in this basically flow stress law is basically involving the how much stress is induced upon applying the required compressive load, and is that stress sufficient enough for the material to flow into the die cavities and take the shape of the die cavity.

So, here we can see the schematic of isothermal forging process. where, we can see the raw material is placed inside the cavity. So, both the raw material and the forging equipment are at same temperature, thereby giving the name as isothermal forging process. the other aspects of the process they remain same that is application of compressive forces. So, that which enable the generation of flow stresses on the workpiece material and this enables the workpiece to flow and fill the die cavities and shapes and in the end the forged product it takes the shape of the die.

Next, is the very relevant and modern use of simulation and finite element modeling in forging process. Role of FEM in forging process involves simulation to predict forging outcomes, optimizing process parameters to reduce trial and error. It also helps to simulate material flow which analyzes how material deforms during the forging process thereby ensuring uniform distribution of material in the die cavity. Finite element modeling can also be used to predict temperature distribution so as to ensure there is even heating and cooling, which is critical to maintain the required microstructure in the forged components. Example results involve deformation patterns which is a visual representation of material flow during forging process.

Temperature fields, this shows the temperature distribution during the process. Stress distributions to highlights the area of high stress important for die design because it is the die which is used multiple times. So, die has to be designed to withstand the stress distribution over a cycle of manufacturing several components. So, we can see some aspects of finite element modeling being used where we can see the meshing being conducted on the right hand side. to generate the mesh subsequently on which the finite element modelling will be conducted.

Then after the forging, there is the role of heat treatment processes. So, heat treatment processes in general are applied to refine the microstructure, relieve any residual stresses in the forged components. So, in the heat treatment processes, processes such as quenching, aging etc. are being utilized to improve the performance of the forged component. The quenching process involves rapid cooling of the forged part in water or oil to lock the refined microstructure.

This impacts undesirable or it prevents the undesirable phase transformations retaining the fine grain structure. The other process in heat treatment is ageing which involves heat treatment at a relatively lower temperature to precipitate the strengthening phases. So, what happens once the strengthening phases are precipitated, they hold the microstructure in one place and they increase the mechanical properties such as hardness, strength and other properties such as fatigue. Comparative analysis may be there by having different processing room, quenching may be followed by forging and this extreme or equi angular extrusion process may be followed. Then micro hardness measurements may also be conducted after heat treatment to analyze the significance and impact of the heat treatment process on the final component properties.

Next comes the damage and stress analysis as well as the microstructural evolution. In the damage analysis, the accumulated damage during the forging process is very critical to understand the material limits. So, here use of Cockcroft and Lantham damage model to predict the failure points. So, Von Mises stress is used in the dies during the different process stages and importance of stress analysis is also critical for the die design and longevity. In terms of microstructure evolution, the grain refinement during the forging process as well as the heat treatment process is conducted.

Impact of this refined grain on the mechanical properties is correlated to increase strength and toughness. Then the microstructural control by achieving the submicrometric grain for the enhanced mechanical properties through ECAE and controlled forging process is achieved. So, in terms of the hydro turbine such processes manufacturing processes under forging as we have just discussed, are widely used for different components such as turbine blades which impart high strength fatigue resistance and precise shape. Shaft and discs of the turbines which are critical in transmitting mechanical power, they also may require high toughness as well as a resistance to deformation. So, all these components are subjected to forging related manufacturing processes.

Next, we see the use of welding processes in hydro turbine manufacturing. Welding as we know is a critical process in fabrication of hydro turbines which also ensures structural integrity and performance efficiency. So, importance of high quality welds is essential to withstand the extreme operational conditions in the hydro turbines such as high pressure and flow velocities of water. So, application of welding is widely there in assembling the various parts of the turbine such as runner, guide vanes, casing and draft tube. So, we can see different types of hydro turbines and the welding requirements there.

As we know, hydro turbines are classified on the two types of actions. One is the impulse action and the reaction action of the flowing water. So, in case of impulse turbines, this example is Pelton wheel. The materials which are used in this turbine involve stainless steel and carbon steel. The welding techniques, which are used in this turbine assembly include tungsten inert gas welding, metal inert gas welding, submerged arc welding.

Reaction turbines involve Francis and Kaplan which are, widely made of austenitic stainless steel or duplex stainless steel. So, techniques such as tungsten inert gas welding, metal inert gas welding, submerged arc welding as well as the electron beam welding process is widely used to weld the components of these type of hydro turbines. So, as we know in case of welding of the runner, the material is typically made up of austenitic stainless steel or duplex stainless steel given the high corrosion resistance of these materials. So, the welding processes such as tungsten inert gas welding is used for precise welding of the runner blade to the hub as well as metal inert gas welding is employed for welding thicker sections of the runner. because, we know in case of metal inert gas welding there is a consumable electrode which is melted and the weld material is provided in the weld section.

So, therefore thicker sections can be easily welded using MIG process. There are several challenges with this such as to ensure dimensional accuracy, avoiding distortion and achieving high quality surface finishes. Solutions involve use of precise fixtures, controlled welding parameters and subjecting the components to post weld heat treatment. So, right hand side we can see the schematic of the tungsten inert gas welding where we have inert gas supplied from the gas supply. The welding is accomplished using an electric arc stuck between the workpiece and the non-consumable tungsten electrode.

The filler material is provided using a separate filler material rod and the interaction of this rod in the welding arc, leads to formation of the weld pool and subsequently the weld material is deposited into the weld joint. Then we can also see the use of metal inert gas welding for materials such as stainless steel or carbon steel. So, as TIG welding is applied for high precision joints, so metal inert gas welding is used for welding of larger vane section, especially the thicker section. But there are challenges to maintain a smooth surface finish as well as controlling the heat input to avoid wrapping. Solutions such as preheating, controlling the welding sequence such as if there are several passes and conducting post weld inspection are some of the solution to overcome the challenges in metal inert gas welding.

And as discussed previously, metal inert gas welding consists of a consumable electrode which is supplied using this machine fed wire rod and the arc is stuck between this consumable electrode and the base material or the workpiece and because of the intense heat of the arc, the filler material, it melts into the weld zone, thereby providing the material in the weld joint. So, we can also look at the use of submerged arc welding process, which is typically again used for carbon and stainless steel. This is especially useful for thick section due to high penetration and high deposition rates. It is even better than metal inert gas welding which is used for medium sections requiring efficient weld. there are challenges in submerged arc welding such as to ensure full penetration of weld and minimizing the residual stresses solutions such as, implementing preheating using stress relief techniques and preforming through inspections is very much essential, and as we know in the submerged arc welding so the arc is always submerged in a granular flux.

And as the arc melts the weld metal, the flux it converts into slag and the slag prevents further oxidation of the weld zone from the surrounding gases. welding of the draft tube which is often made up of the carbon steel or stainless steel is done using submerged arc welding or metal inner gas welding. And using these processes we need to also ensure structural integrity and managing the complex geometries. Solutions involve again use of precise welding fixtures performing staged welding in case of multi-pass welding and post weld heat treatment. Sometimes to achieve good quality welds, some pre-welding preparations need to be also conducted.

This involves the proper selection of material, not only the base metal but also the filler material to ensure compatibility and meet the design specifications. Surface preparation involves cleaning, degreasing and ensuring a proper fit up. Weld joint design where, selection of appropriate joint configuration may be done such as lap joint, butt joint, corner, edge or T joint. Pre-heating may also be conducted for materials which are prone to cracking or reduce thermal gradients and residual stresses. Filler material selection is there for matching the base material properties considering mechanical and corrosion resistance.

Post weld heat treatment may also be done and certain inspection may also be conducted. Heat treatment primarily after welding involved towards relieving the residual stresses improving microstructure. Stress relieving using post weld heat treatment non-destructive testing which involves use of ultrasonic testing radiographic testing magnetic particle testing dye penetrant test with the purpose to detect internal as well as surface defects and ensure weld quality. Dimensional inspection of the welded components may be conducted using coordinate measuring machine or the CMM or the laser scanning to verify the adherence of design specification and proper fitment. Surface finishing may also be needed or surface treatment using grinding, polishing and coating to enhance the surface finish and provide corrosion protection.

Some challenges and solution in hydro turbine welding involve the thermal distortion which occurs due to wrapping and distortion due to uneven heating and cooling. Use of fixtures and controlled weld sequence may be useful in preheating and as well as use of preheating can be done. Residual stresses can be also a significant challenge leading to cracking or reduced fatigue life. Post weld heat treatment stress relief techniques can be employed. Material properties for specially welding dissimilar materials can be looked at by maintaining the mechanical properties.

Use of compatible filler materials controlled welding parameters can be done. And of course, sometimes welding may be need to conduct in underwater conditions or harsh environment. So, specialized welding techniques and protective measure need to be used. So, in summary of today's lesson, we can see use of forging processes as well as use of the welding processes for manufacturing of the hydro turbine components. We have also looked at the challenges and certain remedies to overcome the challenges in the forging and welding processes, how we can overcome the challenges.

In the next lesson, we will see the machining and coating processes for the hydro turbine. Thank you.