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

**Dr. Sunny Zafar**

**School of Mechanical and Materials Engineering**

**Indian Institute of Technology Mandi**

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**Lecture 20**

Welcome to this course on manufacturing of turbines. So in this lesson 20 of this course we will see laser metal direct fabrication and welding processes for steam turbines. So the lesson outline for this laser metal direct fabrication or the LMD fabrication process as well as the welding processes for steam turbine manufacturing will be covering topics on introduction to additive manufacturing, laser metal direct fabrication, how the laser metal direct fabrication is utilized for repair, coating, and free form manufacture of steam turbines. Subsequently, we will look at a case study where repairing of steam turbine is done using laser metal fabrication. So, in the welding part, we will look different types of weld repairs. We will focus on some of the welding techniques used for steam turbine components, which include shielded metal arc welding, submerged arc welding, gas tungsten arc welding.

Then we will see preheating and post weld treatment applications. And subsequently we will see a case study where submerged arc welding process is utilized for repairing the rotor of the steam turbine. So first we start with laser metal deposition for manufacturing of steam turbine. So LMD process is one of the additive manufacturing technologies and as we know additive manufacturing technologies rely on a fact that the development or manufacturing of the product is done in a layer by layer fashion.

So in the additive manufacturing umbrella there are several techniques which include Vat photopolymerization, metal extrusion, material jetting, binder jetting, powder bed fusion, direct energy deposition and sheet lamination. So these technologies, they are based on several principles. For example, the Vat photopolymerization is based on stereo lithography. Metal extrusion, it is based on fused deposition modeling. Material jetting is based on polyjet or inkjet printing.

Binder jetting, it is based on indirect inkjet printing or we call it as binder 3D printing. Powder bed fusion, it is based on selective laser sintering, direct metal laser sintering, selective laser melting, electron beam melting. Direct energy deposition, it utilizes laser engineer net shaping or LENS, electronic beam welding and sheet lamination utilizes laminated object manufacturing. All these techniques we have seen are basically applicable to all the different types of engineering materials which are available. For example, the Vat photopolymerization technique is applicable to photo polymers and some ceramics.

Similarly, the material extrusion process it is utilized for thermoplastics, ceramic slurries, metal pastes. Material jetting, it is utilized for photopolymer, wax. Binder jetting is utilized for polymer, metal or ceramic powder. Similarly, powder bed fusion is also applicable to polymer, metal and ceramics. Direct energy deposition is utilized for metal powder or wire.

And sheet lamination is applicable for plastic film, metallic sheet, or ceramic tape so laser metal deposition process as we have seen it is one of the additive manufacturing process used for repairing of the steam turbines so in this process a laser which we know is light amplification by stimulated emission of radiation and we have looked at in detail how the laser is produced in the topic of laser beam machining which we covered during manufacturing of gas turbines. So laser here is utilized to melt metal powder or wire which is deposited in a layer by layer fashion to build the damaged part. So the basic principle on which the laser metal deposition process works on that laser it generates a melt pool on the substrate. The metal powder or wire is fed into the melt pool. The material solidifies to form a new layer.

So if you see on the right hand side the schematic of LMD process. So here we can see there is a base material. On top of the base material, we have the molten pool which is created as the material absorbs the laser energy. The powder is coaxially fed into the molten pool and this coaxially fed powder is then subsequently melted once it interacts with the laser beam. So there may be application of several shielding gases like argon etc to prevent any contamination because of the oxide formation and as this setup it moves we can see the deposited material getting solidified so to connect the solidified material with the base material so metallurgical bonding between both takes place that is why a fusion zone is also observed wherever the deposited material is in contact with the base material so if we compare the LMD process with other additive manufacturing technology so it is particularly advantageous for repairing and adding material to existing components So with this technology in the existing component, we just we can add the material and repair whatever defects or cracks have been generated.

So now we see how the use of LMD through a process known as laser cladding is done for repairing. So laser in LMD it offers several advantages beyond some of the thermal spraying processes like high velocity oxygen fuel flame or HVF process or the submerged arc welding process. In particularly the laser based processes are very popular in manufacturing domain because of their obvious reduced heat input which minimizes distortion. It also reduces heat affected zone and almost it eliminates any post weld procedures. At the same time, the metallurgical bond which is generated in the laser metal deposition or LMD process, it assures excellent consistency in material density and perfect adhesion with the parent material of the component.

So we can see a flow chart of an on-site repairing process schematic with laser cladding. So here we can see that we start the process with non-destructive testing. So any of the non-destructive testing technique can tell us the location or the extent of defects in the various components. We may need to do some prior machining in order to reach the defective area or to expose it. So, first again we can carry out the non-destructive testing whether or not the machining process has removed some material appropriately to reach the defect area.

After which we can preheat the component. for effectively being processed with laser cladding. After preheating laser cladding which is a variant of laser metal deposition is carried out. So in this process again we have a coaxial nozzle through which the laser and the powder are fed along with the shielding gas powder material comes in contact with the laser it melts and then solidifies in the region to heal up the Defect or for example the crack is there.

After which we may need to have several passes of the laser cladding So after one pass there is interlayer grinding done to remove some of the basic oxide layer on top of the deposited material and and by performing the laser cladding in several steps we can build up the layer to prepare the complete component after which the final laser cladding is done and subsequently to create the correct shapes and final machining operation may be done  Subsequent to this, to improve the properties of the deposited material or to remove any residual stresses that may have come into the component, a post weld heat treatment cycle may be used. After which again non-destructive testing may be carried out and if the product satisfies the requirement, we reach to the end of the repairing process using this laser cladding system. So laser cladding are also used to deposit several coatings for hot corrosion etc. which enhance the durability of the steam turbine components. Coatings in general they improve the thermal and mechanical properties of various components of the steam turbine and they also enhance its performance.

Coatings they act as a protective layer by protecting the components from the harsh environments  And to deposit coating using laser cladding, three essential steps are carried out. So this involved surface preparation, then laser cladding or the LMD coating process, and third is the inspection. So here we can see how the LMD is used to coat the turbine shaft with the wear resistant material or the material  which can help to enhance the performance in the service conditions of the laser or the steam turbine which is operating. So the manufacturing methodology here utilizes these three steps which involve pre-processing. In the pre-processing step, we generate a CAD model of the blade.

We perform simulation for optimum parameters. and according to that material preparation is conducted. After which we come to the deposition process in which layer by layer building of the component is done. During this process real time monitoring and adjustments are also done for the process parameters so that the deposited material is placed properly without any defects therein. Then comes the post processing step.

In the post processing step, heat treatment operations are carried out for stress relief. Machining is also carried out to give the final dimensional accuracy to the deposited layer. And surface finish may also be utilized to improve aerodynamics on the deposited layer. So now we can summarize the various advantages and limitations of laser metal deposition for manufacturing of steam turbine blades. So in this regard, the advantages of this process include precision and accuracy.

This gives high level of control over material deposition. Reduced material waste, because the process efficiently uses material compared to other subtractive methods. Repair and refurbishment, this is the ability to add material to existing parts thereby extending their lifespan. The process also offers flexibility in design, which is ability to produce complex and customized geometries. The process has certain limitations.

Lasers as we know are having high initial investment because of the costs associated with equipment and setup. The process has a complex process control and requires precise control of multiple parameters. Limited build size also restricts the size of the parts which can be produced. and post processing requirements often requires additional machining and finishing operations. So now we look how the LMD process is utilized for repairing a steam turbine blade.

A burnout blade here is repaired in the following way. A practical example of LMD is demonstrated for in-situ repair of the bone steam turbine. In-situ means the steam turbine blade is not removed from the turbine assembly. rather the repair process is carried out while the blade is attached onto the turbine assembly so this reduces the downtime also reduces the overall cost of repairing because if we remove the blade so then there will be cost associated by for reassembly of the blade and so on the process involves cleaning the damaged blade depositing the new material by selecting appropriate process parameters of the laser metal deposition process And after the deposition is done, the finishing operations are carried out. This results in the restored blade functionality and extend the service life cost saving compared to an entirely new blade production.

So this we can say that the laser metal deposition process has given a second life to this blade and also reduce the overall cost by repairing the existing blade in situ. Also it has resulted in reduced cost of repairing as in situ repairing  minimizes downtime and reassembly costs. Next we look at some of the welding processes which are utilized for manufacturing as well as repair of steam turbines. Welding processes as we know they are used to join two or more materials and in case of steam turbines the welding processes have been specifically used for repair of steam turbine rotors. So this classification of weld repairs they include repair of low stress areas such as stumps.

So these are simple weld repairs with minimal impact on the overall rotor performance. The second category of repairs they come as rotating elements example vanes and lugs. In this regard high precision welding is required and also balancing may be needed after the welding is conducted because in rotating elements if there is an unbalanced mass so this may lead to eccentric loading and vibration as the rotating components will rotate at high speed. Sometimes the blades and grooves on the rotor disc, they may also need some repairs because they have complex geometries. So in that regard, high quality welds are needed to enhance the structural integrity of the component.

Then fourth category comes the full or partial disc replacement the rotor discs also require significant welding and machining effort and this requires precise alignment and residual stress management after the welding the deep grooves on the shaft of the steam turbine may also need some repair so advanced welding techniques are utilized to ensure the proper depth coverage is there Post weld heat treatment is again needed for relieving residual stresses. Axial segment replacement, so large scale weld repairs may be carried out and these are critical to maintain the rotor alignment. Circumferential section repairs, so full circumference welding, uniform heat distribution and cooling may be required in this regard. So we will see these details of the shielded metal arc welding process which is utilized for repairing of the steam turbines. So the shielded metal arc welding it is one of the consumable electrode type of welding where we have an electrode here.

And which is having a coating on top of it for generation of slag and adding several alloying elements into the weld pool. And this is connected to a power source and the other terminal of the power source is connected to the workpiece through the work lead. And here an arc is generated between the electrode and the workpiece and this arc subsequently consumes this electrode by providing the liquid metal which will fill in the gap or the filling provide a layer of this liquid metal on top of the workpiece. The electrode in this process gets consumed. So, that is why it is also known as one of the consumable electrode type of welding process.

The electrode coating around this coil wire or the electrode wire, it provides the generation of several shielding gases thereby preventing any oxidation in the weld zone. And the impurities in the weld are basically collected in form of this slag which is deposited on top of the weld metal. And if we were interested to have multi-pass welds or the weld is the final layer, so in that regard the slag has to be removed from the weld surface. So in the context of the steam turbines, shielded metal arc welding process is used where a manual welding is carried out using flux coated electrode. So these are applied in steam turbines with respect to low stress area repairs, ideal for minor repairs on turbine stumps and non-critical components.

Material compatibility is effective for carbon steels as well as low alloy steels. Technical parameters such as electrode type of E7018 for low hydrogen applications is used. Direct current is generally utilized for better control over the welding arc and the process is having several advantages such as it is quite versatile, portable for on-site repairs. It is simple and cost effective. But because of the manual operation, the process may lead to several inconsistencies and the additional step of removing the post weld slag also incurs significant amount of time and cost.

So next process which comes for a repairing and welding in steam turbine is the submerged arc welding. This process is somewhat automatic or semi-automatic where we have the filler material in form of a wire reel. which is provided into the welding arc and subsequently the arc is submerged into granular flux. So, the granular flux is provided from a flux hopper which continuously moves as the wire traverses on the base material. Upon solidification, we generate the solidified weld metal  On top of it, the molten slag is also available in form of solidified slag and since the arc is submerged in the slag, so very less chances of any oxide inclusion are there.

Submerged arc welding is known for high metal deposition rates with consistent quality of the deposited material. So in case of steam turbines, the submerged arc welding process is used for automated welding with continuously fed consumable electrode under a blanket of granular flux. Rotor disc manufacturing with high deposition rate and deep penetration make it ideal for heavy duty components. Casing repairs especially for thick wall section require robust welds which are done using submerged arc welding. So the process can have deposition rates of the order of 45 kilograms per hour with a current range of 600 to 1500 amperes and voltage range of 28 to 40 volts.

Process of submerged arc welding yields high productivity, consistent weld quality, effective for thick materials and extensive welds. Challenges with respect to submerged arc welding include limited to flat or horizontal positions because it is very difficult to contain the granular flux in the weld zone in other welding positions. The process may also require significant initial setup and flux handling as the granular flux needs to be properly handled and placed while the welding is conducted over the workpiece. So the next process which is used for repairing and manufacturing of steam turbines is the gas tungsten arc welding or GTAW process. So GTAW process is one of the non-consumable electrode welding process which utilizes a non-consumable tungsten electrode along with a shielding gas.

So, in this case we have a power supply which provides the required voltage and current to the electrodes and we have a torch on which the tungsten electrode is fixed. So, the torch also has the capability to supply shielding gas which is supplied using a pressurized cylinder on which the flow meter and regulator adjust the flow rate and pressure at which the shielding gas is supplied in the weld zone. GTAW with respect to steam turbines is used for welding with precise control and generating high quality welds. It is critical for component welding for thin sheets and complex geometries. Electrode types with 2% thoriated tungsten and current of alternating current may be used for thin sheets or aluminum or direct current may be used with ferrous based materials.

Shielding gas of argon or helium may be used with rate of 15 to 20 CFH. The advantages include precise heat control and clean welds as there is no utilization of flux. So no slag is also produced in this process. But the process requires highly skilled operators and is also having a slow or a very low deposition rate. So this means several passes may be need to build up the required amount of materials.

So after the welding process is conducted so it is generally subjected to several preheating that is of course before welding and some post welding treatments. So preheating is generally done to reduce thermal gradients, minimize residual stresses. Typically preheating is conducted at temperatures of 100 to 300 degree Celsius depending on the type of material and it is crucial for high carbon and alloy steels to prevent cracking. And post weld treatments are carried out because they restore ductility and impact properties essential for rotor and blade integrity. Stress relief annealing, this reduces residual stresses at 600 to 650 degree Celsius, crucial for maintaining dimensional stability.

Non-destructive testing, it ensures the weld quality integrity is maintained which is very mandatory for high stress components. So here we see a case study how the rotor is repaired using submerged arc welding. So here we can see the submerged arc welding setup being utilized to repair the rotor of the steam turbine made up of nickel chromium based steel of the steam turbine. The objective of this repair work was to restore the structural integrity and performance of the steam turbine rotor. so submerged arc welding was utilized for its high deposition and high depth of penetration post weld heat treatment was carried out for stress relief annealing to ensure the dimensional stability and reduced the residual stresses so the process resulted in hardness and strength with desired mechanical properties on the deposited material and it also offered resilience and FATT50 factor which needs further optimization under controlled heat treatment.

So with this we come to the end of this lesson. We will now summarize what all topics are covered. So essentially in this lesson we have covered the laser metal deposition process which is one of the additive manufacturing process for depositing coatings or repair then we have looked at various welding processes which can be utilized for manufacturing as well as repair so in the welding processes we have looked at shielded metal arc welding process we have looked at submerged arc welding process and we have looked at capabilities of gas tungsten arc welding process for the repair, both the processes have been used for manufacturing and the repair of steam turbine components. In the next lecture, we will see the manufacturing of hydro turbines where we will start with material selection and challenges in case of hydro turbine.

Thank you.