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

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Week - 08

Lecture 37

Welcome to this course on manufacturing of turbines. In this lesson 37 of this course, we will look at the coatings which are being applied on wind turbine components to enhance their durability under the service conditions. So, this will be a two lesson topic in this wind turbine blade manufacturing. So, here the first lesson that is today on this topic of coatings for wind turbine. We will go through the introduction to coatings. What is the importance of these coatings in wind turbines? What are the challenges that wind turbines they basically encounter? Because of which these coatings are needed on various parts of the wind turbine.

We will look at different types of coatings. We will also look at what are the methods or processes to apply these coatings on wind turbine blade or other components and we will wind up this lesson by looking at a specific case study where coatings have been applied on the wind turbine components. So, as we know wind turbines are basically the energy harvesting or energy conversion devices that utilize the blowing wind and convert the blowing kinetic energy of the blowing wind and then subsequently this energy is converted into electricity by the rotating blades. Wind turbines as we have seen the size of these wind turbines has been continuously increasing and these wind turbines have been installed in offshore locations so as to extract the maximum wind energy.

So, the critical infrastructure of this wind turbine which is necessary to extract renewable energy is there but as we have seen they operate in quite complex and challenging environment which can lead to wear and tear over a long period of time. So, we can see here the images of the leading edge erosion on the wind turbine blade across the various years of service. So, in the beginning we can see that the wind turbine blade after one year of service there are some pitting regions. Then the size of these pitting regions after 2 years it grows and after 10 years of service we can see that the leading edge that is the edge which encounters or is the front edge is completely getting damaged and as after 10 years the leading edge has completely damaged. So, it is the elements or the weathering elements such as rain, ice, sea water, ultraviolet radiation, lightning, all these factors basically they enhance the degradation of wind turbines and especially this degradation

for the blade is detrimental because this enhancement or detrimental, you know, effects on the blade.

They compromise with the aerodynamic shape of the blade. They reduce the wind turbine efficiency. They also call for repair and maintenance because of which there are huge economic losses. So, we can see the importance of certain coating materials which are applied on wind turbine components. So, these coatings basically help to enhance the lifespan.

They protect against corrosion and erosion, particularly in offshore and high wear areas, thereby maintaining structural integrity of the wind turbine components. The coatings are also known to enhance the performance of the wind turbine by maintaining the aerodynamic efficiency, prevent ice formation and optimize energy generation. The coatings they also are important to reduce costs because they help to bring down the repair efficiency, maintenance cost as well as they enhance safety and reliability of the wind turbines. So, we can see that in different situations, different need of coating is there. First, there is erosion of the wind turbine blade, especially on the leading edge.

So, the leading edge protection is needed. So, the leading edge of the turbine blades, these are subjected to continuous impact from airborne particles such as sand and dust particles, also the hail. They also are damaged because of the rain leading to material loss and generation of surface roughness. Because of which there is a chance of reduced aerodynamic efficiency, high operational cost and increased risk of blade failure. The second phenomenon is corrosion due to environmental exposure.

Wind turbines especially those which are installed in offshore environments are exposed to harsh elements of nature such as salty water, humidity, varying temperature, leading to significant corrosion of metallic components and also this may lead to degradation of the polymer composites because of the hygrothermal effects. So, these lead to structural damage and increased maintenance cost. The third challenge is basically the ice formation and ultraviolet or UV degradation. Cold climates and long UV exposure causes degradation of materials leading to imbalances and reduced energy efficiency. This leads to reduced power output, surface cracking, fading and reduced coating effectiveness.

So, because of which so all these challenges there are different types of coatings which are applied on various components of the wind turbine. Out of these coatings, there are seven most popular type of coatings. So, these are anti-corrosion coatings, erosion resistant coatings, anti-icing and de-icing coatings, ultraviolet resistance coating, fouling resistant coatings, thermal barrier coating and advanced nano coatings. So, out of these seven coatings, the three coatings will be covered in today's lesson that is the anti-corrosion, erosion resistance, anti-icing and de-icing. The rest four that is ultraviolet

resistance coating, fouling resistant coating, thermal barrier coating and the advanced nano coating, we will cover it in the next presentation or the lesson.

We begin with the anti-corrosion coating. Anti-corrosion coating are basically needed in the wind turbine to protect it from rust and degradation, especially in harsh environments which are encountered in offshore installations. These coatings are applied on the monopile or the tower of the wind turbine which is basically in direct contact with the seawater and the sediment below the seabed. So, challenges like high salinity, humidity and exposure to increased water leads to high risk of corrosion. So, towers, nacelles and blades sometimes become very susceptible to corrosion.

So, these coatings are applied on specially the nacelle and the tower part. So, what are the materials which are used in the anti corrosion coating? So, these materials basically are corrosion resistant materials and popularly three materials are used which include zinc rich primers. So, the composition of the primers contains high concentration of zinc dust. So, the function of this primer is to provide a sacrificial protection by corroding in place of the underlying material. So, this application is typically applied as the base layer on steel structures.

Second type of material is the epoxy coatings. So, the epoxy coatings are basically thermosetting polymers which offer excellent adhesion and durability. The function of this epoxy coating is to create a protective barrier resistant to water and chemicals. And these are commonly applied on towers and other structural components of the wind turbine. Next is the polyurethane top coats.

So, polyurethane top coat consists of a high performance finish for excellent weatherability. So, their function is primarily to provide ultraviolet resistance that maintains color and gloss over time. So, the application includes the top layer of various epoxy primers and polyurethane based primers. Next are what are the methods to apply the anti-corrosion coating. So, popularly three methods are popular.

So, these are include the spray application in which an airless spray and electrostatic spray are commonly used. The advantages of these methods include application of even coating, fast application and efficient use of materials. Various challenges include use of skilled operator and proper ventilation. Second method is the brush and roller application. This is sort of a manual application of the coating material using brush and roller.

Advantages include ideal for small areas and touch up work. So, the process is slow and there is risk of uneven application and these topics become the challenges in the brush and roller application. The third method is cathodic protection where the combination of coating with sacrificial anode is used for enhanced protection. This leads to enhanced lifespan of the coating particularly in marine environment, and the method has challenges such as high cost and complexity. Next, are the erosion resistant coating.

So, erosion resistant coating are specially applied on the leading edge of the wind turbine blade. So, these coatings protect the wind turbine blade from the high speed winds, rain and particulate matter. So, the challenges include the erosion if it takes place on the leading edge of the wind turbine, it reduces aerodynamic efficiency and leads to increased maintenance. Key components where the erosion resistant coatings are applied. So, these include the leading edges of the blade and leading edge protection coating is widely used for corrosion protection of the wind turbine blade.

So, here in the image we can see the various layers of the laminate filler etc. are being used and then the primer and leading edge protective coating is being applied which is generally 1 to 2 layers and the thickness of this coating is between 500 to 1000 μm. So, the various materials which are used in the erosion resistant coating they include polyurethane coating fluoropolymer coating and elastomeric coating. So, polyurethane coating these consist of cellulose microparticle and tough polymers. So, these coatings are known to absorb impacts and they resist wear.

So, these are applied on the leading edges of the blade of the wind turbine. The fluoropolymer coating they are known to consist of fluorine atoms which are known to create a low friction surface. So, this reduces the impact of the incoming particles or airborne particles thus improving longevity of the wind turbine blades. So, these are used especially in environments where there is high concentration of particulate matter or airborne particles. The third type of coating is the elastomeric coating.

Elastomeric coating generally consists of a rubber like material that provides flexibility and toughness. The function of this coating is to absorb shock and reduce the risk of cracking. So, these are suitable for blades which are operating in extreme conditions. So, here we can see in the schematic the polyurethane coating on a wind turbine blade and this coating consists of a putty layer which is applied on the glass fiber reinforced polymer on top of which the top coat is applied. The thickness of the top coat is 120 micron whereas the thickness of the putty layer is around 350 microns.

Now we will see the various methods of application of the erosion resistant coating. So, the first method is the spray application. So, this method includes the high velocity air spray or airless spray. The advantages of this method include uniform coverage and high adhesion. The challenges in this method include require careful control to avoid over spray.

Second is automated coating systems. So, these are robotic systems which are used to apply coatings with precision. The advantages include consistent application and reduced human error. The challenges include high initial investment cost in the equipment. Second, third method is the tape and film application.

In this method, erosion resistant tapes or films are applied to the blade surface. These methods have quick installation and are easy to replace. However, the challenges in this method include limited lifespan and potential for edge lifting. Next type of coatings are the anti-icing and de-icing coatings. The purpose of anti-icing and de-icing coatings is to prevent ice accumulation on the turbine blades and also to facilitate ice shedding during cold weather with high humidification regions.

Ice formation as we know can reduce the energy production and can also lead to safety risks. The blade surfaces in cold climates are known to generate ice and these are the primary focus of the anti-icing and de-icing coating. So, here we can see the basic composition of the anti-icing coating where, certain nanoparticles are added in ethyl alcohol and these are then sonicated with the epoxy and are applied on the blades. So, these certain nanoparticles, they create a superhydrophobic surface which resists the formation of ice as these surfaces, they repel the water droplets, thereby the ice formation is prevented. So, next are what are the materials which are used in anti-icing and de-icing coatings.

So, these materials, they include hydrophobic coating, phase change materials and thermal sprays. So, hydrophobic coatings particularly these include certain nanoparticles consist of epoxy which are hydrophobic combinations. So, these prevent initial formation of ice by reducing water adhesion. So, these are used on the blade surfaces which are prone to freezing.

Next are the phase change material. So, in this the composition includes inorganic and organic compounds or eutectics of these compounds. The function of this phase change material is to absorb heat when ice is formed, therefore preventing the buildup of the icing layer. So, applications of this phase change material are generally integrated into the coating for blade for extremely cold regions. Next are the thermal spray in which metal or ceramic particles may be sprayed on the surface. So, these provide a heated surface that melts the ice on contact and they are often used in conjunction with active heating systems.

So, these are the various methods of applying the anti-icing and de-icing coatings. So, these include spray coating. These are the traditional spray techniques which have advantages of broad coverage and quick application. However, the challenges of this method include reapplication in some cases. Next, are the electrothermal systems in which heating elements may be embedded on the coating or the surface.

So, these heating elements, they prevent the buildup of ice. The challenges of this method include energy consumption as such electrothermal systems, they need a power source to generate heat. Then, are the self-generating coatings which are coatings which can heal small cracks and maintain the anti-icing properties. These coatings are known to have

longer service life and reduced maintenance. However, the coatings are also currently in experimental stage and are of high cost.

Here, on the right hand side we can see the antifreeze test being conducted on an uncoated wind turbine blade as well as the anti-ice coated wind turbine blade. So, we can see the effect of the anti-ice coating wind turbine blade that there is no ice accumulation even after 240 minutes of exposure in the icing conditions. So, different coating methods that are discussed include the spray type, brush roller type, tape and film type and the thermal spray method. So, spray application is the most widely used method on coating on the wind turbine. Even the spray coating is utilized with the help of a spray gun.

So, these are airless spray and electrostatic spray. In airless spray, a high pressure coating is delivered without use of air, which is ideal for large surfaces. Electrostatic spray includes electric charge to enhance the adhesion and reduce the chance of overspray. The advantage of spray application includes uniform coverage, fast application suitable for large and complex surfaces. The challenges include skilled operator and safety precautions due to aerosol materials.

So, here we can see how spray application is used for coating where a spray gun is used to spray the material onto the substrate which is prepared for the coatings. Next, are the brush and roller. These are the manual methods in which rollers and brush are used to apply the coating materials for the wind turbine parts. These are ideal for small regions or repairs for touch-ups or detailed work for effective for intricate components where spray might miss the area. So, these are known to have precise application, low cost and minimal equipment requirement.

The challenges in this process include time consuming, risk of uneven layers and is not suitable for large surfaces. Next is the tape and film application. So, this technique involves applying preformed adhesive tapes or films to the turbine surfaces. These surfaces then act as protective barrier against the environmental factors such as erosion and ultraviolet radiation. These are especially used for leading edge part of the wind turbine blade.

Application of tape and film method include use for erosion and ultraviolet protection on the blade edges. The process is known to have easy application and replacement with a minimal downtime. The challenges of this method include limited lifespan and potential for edge lifting. Next are the thermal spray methods. So, thermal spray methods are widely used on the towers of the wind turbine where, coated material are heated and sprayed onto the wind turbine surfaces.

So, these include the high velocity oxy fuel flame and the air plasma spraying. So, we have seen the details of these two methods in our hydro turbine and the thermal barrier coating section of this course. So, high velocity oxy fuel is known to create dense coating

which are strongly adhered to the substrate. Whereas, air plasma spraying is also known to have several ceramic coatings. So, these are ideal for erosion and corrosion resistant on the towers of the wind turbine blade, which generate durable coating with excellent adhesion.

However, these methods may require high cost and precise control. Here in the schematic, the photograph we can see thermal spray method being done on the tower of the wind turbine blade. Next, is the case study where the objective is to develop a thermal insulation coating for wind turbine blade using silicon oxide aerogel with nanopore structure to enhance anti-icing performance. The key features of silicon dioxide aerogel include low thermal conductivity, of the order of 0.014

to 0.032 watt per meter Kelvin due to its nanoporous structure. These coatings are light in weight and highly porous with more than 93% of the volume occupied by air. These are suitable for applications with ultralight and highly effective thermal insulation. So, this aerogel is applied using atomized spraying which is a preferred method for uniform and defect-free coatings.

Spraying involves spraying of silicon dioxide slurry with 0.95 MPa pressure maintaining a standoff distance of 20 cm. The brush coating is the other method which is easy to apply but results in rough surface and structural defects, less effective in maintaining mechanical stability of the coating. The performance and benefits of silicon dioxide aerogel coating include wear resistance where atomized coating exhibited a low wear rate after 20 cycles under a load of 1734 Newton per meter square. So, this adhesion achieved highest adhesion grade of class 0 according to ISO 2409 standard ensuring strong bond. Thermal insulation performance after 5 spraying cycle achieving a significant temperature differential between coated and uncoated surfaces.

A uniform layer fault structure was formed by atomized surface for effectively blocking the heat transfer enhancing the insulation. Viscosity considerations included the ideal viscosity range of the slurry in 31.3

and 36.9 mPa.s. This ensures uniform coating application on the inclined surfaces critical for wind turbine blades. So, in the summary of today's lesson, we have seen the need of coatings on wind turbine blades. We have seen different types of coatings. So, in the various types of coatings we have looked at various methods of coating, materials used in these coatings and lastly, we have looked at the case study where, silicon dioxide aerogel has been used to enhance the thermal insulation of the wind turbine blades. So, in the next lesson we will look at the other types of coatings used in the wind turbine blades like ultraviolet resistance, fouling resistance, thermal barrier and the advanced nano coating. Thank you.