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

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Lecture 38

Welcome to this course on manufacturing of turbines. So, in this lesson 38 of this course we will look at the second part on our discussion on coatings on wind turbine components. So, the outline of this lesson will be as follows, where first we will discuss the ultraviolet resistant coatings, fouling resistant coatings, thermal barrier coatings, advanced nano coatings, And lastly, we will see details about rain erosion and protective coatings for wind turbine and we will also understand how the rain droplets they cause rain erosion and, the phenomena of solid particle erosion on which the wind turbine blades are greatly exposed during their service conditions. So, the first type of coating in today's lesson is the ultraviolet resistant coating. As we have seen the materials which are used to manufacture the wind turbine blades are epoxy based polymer composites in which fiber glass or carbon fiber acts as the reinforcement. So, these materials, the polymer materials are greatly sensitive to ultraviolet radiation from the sunlight.

So, the purpose of applying ultraviolet resistant coatings is to protect the wind turbine components from ultraviolet radiation which can degrade materials over time. The key challenge is that during the prolonged exposure of ultraviolet radiation, this leads to fading, brittleness and loss of structural integrity. The key components which are exposed to ultraviolet radiation, they include blades of the wind turbine, nacelle and tower. The coatings of ultraviolet resistant materials are also beneficial for erosion protection of wind turbine blades.

So, here we can see the schematic of the ultraviolet resistant coating which consists of several layers in which we have the epoxy zinc primer, then we have the epoxy intermediate coat and then we have a polyurethane top coat. So, all these materials basically help in resisting not only the ultraviolet radiation which is resisted by the top polyurethane coat. The water and salt which is another weathering element to which the wind turbines are exposed especially in the offshore locations are resisted by the epoxy intermediate layer. So, now we see what are the different type of materials which are used in ultraviolet resistant coatings. So, these include acrylic coatings.

So, these are basically water based or solvent based polymers. The function is to provide a clear protection with excellent ultraviolet stability. The application is done in form of a clear top coat on painted surfaces. The second type of materials which are used in such coatings are the polyurethane coatings. So, these are often contained with ultraviolet stabilizer which prevent the degradation of the coating material.

So, these coatings they offer long term protection and also maintain gloss and color over a prolonged duration of time. Such coatings are applicable for high exposure areas of wind turbine especially the blades. The third type of coating materials include ultraviolet blocking additives. So, the composition of such materials are ultraviolet absorbers that hinder amine light stabilizer or HALS. The function of these materials involves absorption of harmful ultraviolet radiation and dissipate them in form of heat.

So, these are incorporated in both primers as well as the top coats. The various methods of applying the ultraviolet resistant coatings include spray application, dip coating, brush and roller application. So, in the spray application, the method includes electrostatic or airless spray systems. Advantages of spray application include even coverage, especially on complex shapes. Challenges of spray application include protective measures for workers who are applying these coatings due to presence of aerosol particles.

The dip coating method includes submerging of the components in the coating solution. The advantages of this method include complete coverage, ideal for small to complex parts. The challenges of dip coating are excess coating must be managed and for very large parts the dip coating method sometimes becomes unsuitable. The brush and roller application is basically the manual method to apply the coating material on small areas and this is popularly used for touch up applications. The advantage of brush and roller include precision application and easy control.

The challenges of brush and roller application are time consuming and also this type of method as is dependent on manual effort, so there may be generation of uneven layers. Next type of coatings are fouling resistant coatings. So, as the wind turbine blades are installed in offshore location or these wind turbines, the towers of the wind turbine are submerged in water especially in the seabed. So, the purpose of fouling resistant coating is to prevent accumulation of marine organisms, algae or other debris on the wind turbine components particularly in offshore environments. The challenges of fouling resistant coating involve fouling increase drag, it reduces the efficiency and requires frequent maintenance.

The key components on which the fouling resistant coatings are applied include the submerged parts including the foundation and tower base. So, here we can see the phenomena of the marine fouling in offshore wind turbine. Where, the several marine life like planktons or the algae are basically developed or are basically growing on the surface of the tower which leads to degradation of the material as the algae grows or the microorganisms gather on these regions. The anti-fouling coating on the offshore wind turbines have some of the key considerations. So, these key considerations include fouling assemblages.

So, unique substrates of the offshore wind turbine, they create a non-natural surface that differ from natural substrates affecting the fouling species. Common organisms which come in this category of fouling include blue mussels, brankles, leading to high biomass but low species diversity. The other factor in this regard includes the hydrodynamic and structural factors. So, these include the monopile effects where vertical monopiles enhance filter feeder growth due to increased water flow and reduced sedimentation. The other consideration involves coating influence where glass flake reinforced polyester coatings offer specific advantages on fouling pattern.

So, here we can see the different zones which keep on developing as the depth increases. However, at very deep regions because of the seabed mobility there are less number of or less regions where the fouling occurs. So, mostly this region range between 1 meter to 6 meter of depth and where lot of fouling occurs because of the soft coral, mussels, tube worms etc. So, now we will see the different type of materials which are used in fouling resistant coatings. So, these include silicone based coatings where the composition of this coating is elastomeric silicone materials.

The function of these coatings creates a smooth low friction surface that organisms cannot easily adhere to. The application of such coatings is in the submerged areas and the waterline regions. Next, are the fluoropolymer coatings. These coatings contain fluorine atoms that are helpful in creating a non-sticky surface. This reduces adhesion of biofouling organisms and are used in marine and offshore wind turbine foundations.

The third type of coating are the biocidal coatings. These coatings incorporates biocides that deter the growth of marine organisms. The function of such coating is actively to prevent the biofouling due to release of biocidal agents. These coatings are also applied on the foundation and other submerged structures of the wind turbine blade. So, next we will see the various methods of applying the fouling resistant coating.

So, this method also include the spray coating, brush and roller application. So, these are similar to what we have discussed earlier with the only advantage is basically here high pressure systems are used in the spray system and there also needs to be a careful environmental management to prevent the contamination of the surrounding region. In terms of brush and roller application, so it offers precise control for complex shapes but is quite time intensive and may lead to uneven application of the fouling resistant coating material. The third method is the in-situ application where, the coatings are directly applied on site using specialized equipment. The advantages of in-situ application eliminate the need of transporting the coated parts.

The challenges of fouling resistant coating involve environmental factors such as temperature and humidity that must be controlled. Next, are the thermal barrier coatings. So, thermal barrier coatings in terms of wind turbine are primarily geared towards protecting the wind turbine components from extreme temperature variation and thermal cycling. So, this is from the environmental thermal cycling because rapid changes in temperature can cause thermal fatigue and may lead to material failure. So, the key components where the thermal barrier coatings are applied include the nacelle housing, electrical components and other parts which may be exposed to temperature variations.

As we have seen in the construction of the wind turbine, the mechanical parts where we have the gearbox which is connected to the shaft, and the shaft is ultimately connected to the electric generator. So, all these components are also quite sensitive to temperature variations that may occur over seasons or during the variation in weather. So, the presence of thermal barrier coatings avoids the variation in temperature therefore maintaining a reliable operation of the wind turbine even in varying temperature conditions. So, the various materials which are used here include the ceramic based coatings. So, these are typically consisting of zirconia and other refractory ceramics.

So, the function of such coatings is basically to insulate the components from high temperature and reduced thermal stress. Such coatings are applied on nasal and other heat sensitive areas of the wind turbine. Sometimes metallic layers of nickel and cobalt may also be added in the thermal barrier coatings that provide a protective and heat resistant surface. So, these are often used in combination with ceramic layers for enhanced protection. Next, are the insulating paints where the composition contains microspheres of several insulating materials.

The function includes reduced heat transfer and it protects the underlying materials. The application is generally done on external surfaces exposed to direct sunlight and other heat sources. Next type of coatings used in the wind turbine are the advanced nano coatings. So, the purpose of such coatings is to provide multifunctional protection using ultra thin layers of nano materials. Such coatings they balance performance with cost and scalability, and the key components on which such advanced nano coatings are applied are the turbine blades, towers and nacelle.

So, here we can see the use of nano carbon coatings on wind turbine where, such coatings when applied they develop the formation of anti-icing capabilities hydrophobic surfaces from which, the water droplets may drop off and therefore enhancing the service life and reliability of the wind turbine blades. The various type of materials which are used in advanced nano coatings they include the nano silica coatings, nano titanium dioxide and carbon nanotubes. So, the nano silica or the silica nano particles coating include these particles are embedded in the polymer matrix which provide hardness and abrasion resistance with self-cleaning properties. These are applied on the blades of the wind turbine and other high wear areas. The nano titanium dioxide coating consists of the photocatalytic properties which also offer ultraviolet protection as well as the self-cleaning capabilities.

These coatings are applied on surfaces which are exposed to sunlight. The carbon nanotube coating basically consists of tubular carbon structures with exceptional strength and electrical conductivity. This material not only enhance the mechanical properties but also provide conductive pathways for anti-static applications which may be generated because of lightning strikes. So, such coatings are applied for all the electrical components of the wind turbine as well as the blades of the wind turbine which are most prone to the lightning strikes in bad weather. So, the various application methods of advanced coating include spin coating, spray coating and electrostatic application.

So, in the spin coating method, a thin layer of nano coating material is spun on the surface. The advantages of such coatings, it produces a uniform and ultra thin coating with challenges limited to small and flat surfaces. The spray coating includes the application of nanomaterials being sprayed onto the surface using advanced spray systems. The advantages of spray coating is that it can be applied to large and complex surfaces. The challenges include precise control of particle dispersion.

The third method that is the electrostatic application. In this method, the nanoparticles are applied using an electrostatic charge to enhance adhesion. The advantages of electrostatic application include even coverage and reduced material wastage. The challenges of electrostatic application are high initial cost which require specialized equipment. Next are the rain erosion and protective coatings for wind turbine blades.

So, environmental erosion factors such as high speed impacts leading at edge erosion are basically the some of the environmental erosion which occurs on the wind turbine blade. In terms of high speed impact wind turbine blades, especially the leading edge of the wind turbine blade, it is subjected to high speed impacts from the rain droplets and airborne particles. The leading edge erosion is basically a progressive damage of the blade material, primarily affecting the blades aerodynamic profile and ultimately the overall efficiency of the wind turbine blade. The consequences of such environmental erosion occurs in terms of energy production in which the erosion can reduce the annual energy production by 25%. The structural integrity of the blades may also be compromised because of long-term erosion which can lead to critical material failures.

Next, we will see the mechanism of rain droplet erosion. So, rain droplets when they form or when they basically come in contact with the wind turbine blade, so they generate shock wave. So, shock wave dynamics which include the formation of compression wave which are the fastest and they transmit about 7 percent of the impact energy cause minimal material deformation. The next shock wave dynamic mechanism includes the shear wave which are, relatively slower but are more destructive and they transmit about one-fourth of the impact energy penetrating deep into the material leading to generation of internal stresses. The third category or mechanism is the Rayleigh wave which is the surface bound wave which transmits almost two thirds of the impact energy and is primarily responsible for generation of surface cracks and pitting.

So, here we can see the schematic of shock wave propagation which is occurring upon impact of a rain droplet on a solid surface. So, we can see how the compression of the liquid rain droplet leads to generation of the Rayleigh wave, shear wave, compressional wave and the reflected wave which is of course generated from the other end of the solid part. So, the various mechanisms of rain droplet include the elastic deformation, plastic deformation and fatigue cracking. So, in terms of elastic deformation, this is basically the initial material response where material temporarily deforms under stress, but it returns to its original shape. In case of plastic deformation, the permanent material deformation occurs when the stress exceeds the material's yield strength.

Fatigue cracking is often limited to the generation of crack initiation and propagation, especially against grain boundaries and material defects. The erosion progression stages occurs in three parts. In first case, we have the incubation stage where no visible material loss is there. Micro cracks and surface roughening begins. The second stage is the acceleration stage where, erosion rate increases as pits deepen and cracks propagate.

The last stage of erosion progression is the steady state erosion where, there is a consistent material loss as erosion stabilizes leading to a significant damage on the wind turbine blades. Next is basically the life enhancing coating systems for the structure and technical composition. So, in this regard the substrate which is there is the glass fiber reinforced polymer as these are widely used in the wind turbine blade for structural support. So, they provide foundation of mechanical strength and stiffness. First of all a filler layer of 500 to 1000 micrometer is applied which consists of high plastic polymers consisting of ceramic powders.

So, the function of this filler layer is to fill the surface voids and imperfections reducing the surface roughness and enhancing the adhesion of the top coat. Next, the top coat of thickness of 500 to 1000 micron is applied. The top coat material consists of polyurethane, epoxy or nano composite formulations. So the mechanism of top coat is basically to absorb and dissipate impact energy via viscoelastic or elastic deformation which can resist crack initiation and propagation. Then we have the primer layer where, typically a reactive polymer resin is applied such as epoxy or polyurethane based primer.

The function of the primer is to chemically bond between the fiber and top coat which is critical for long term durability and performance under cyclic stress. So, here we can see the various layers which are applied here with leading edge protective coating for intermediate filler layer and additionally sometimes a primer layer may also be added to improve the adhesion between different layers to the substrate. And here we can see the substrate is consisting of the biaxial fiberglass epoxy based composites. So, next are the advanced life LEP coatings and performance evaluation where sole gel method is applied which is basically involved in formation of ceramic like network within the polymer matrix thereby enhancing the hardness and chemical resistance. The advantages include superior erosion resistance due to high adhesion and thermal stability and mechanical strength.

The nano composite coatings with incorporation of several nano reinforcements in form of graphene, silica or carbon nanotubes are also used. Such coatings are known to dramatically improve mechanical properties like tensile strength, modulus resulting in enhanced strength to high velocity impacts. Performance evaluation of such methods include single point impact fatigue testing and whirling arm water jet erosion test rig. So, this single point impact fatigue test rig simulates a repetitive impact to access the material fatigue and erosion resistance. The whirling arm and water jet erosion resistance replicate the real world condition of impact blade at the blade tip exceeding 100 meter per second.

So, we will see the details of one of the setup that is single point impact fatigue testing. So, this setup basically consists of a programming firing controller in which the compressed air is brought in and then this compressed air is fired using an electro pneumatic firing engine. So, in the path of the compressed air through this funnel we introduce these balls made up of nitrile rubber which is relatively soft and flexible material. So, these nitrile balls are then accelerated and propelled towards the target which is of course the polymer composite on which this single point impact fatigue test has to be conducted. So, as the balls of nitrile rubber, they are accelerated by the transfer of momentum from the compressed air as it expands.

They pass through the optical speed trap which captures the speed of this ball, at what speed it is going to impact. And once the ball impacts the target which is the polymer composite here, the sample this impact is captured using the video camera a high definition high speed video camera which can capture all aspects of the impact and the sample is connected to a platform which is having an acoustic emission capturing system means the whatever sound is generated upon impact of the nitrile rubber balls on the sample so by capturing the acoustic signal from the sample, we can gather information what type of defects or crack propagation etc. is taking place within the sample. Then after analysis of the data we can have the complete picture how the damage occurs on such materials and how we can extend the life of such composite materials under real life conditions. Next is basically the solid particle erosion which is basically a gradual loss of material from the surface of the wind turbine blade by repetitive impact of solid particles like dust, sand or industrial particulates.

The key factors in solid particle erosion include impact parameters like velocity, angle of incidence, particle size and shape. Surface material properties include hardness, toughness and ductility. Mechanism of solid particle erosion include ductile erosion where the material is removed through plastic cutting and maximum erosion occurs at low impact angles between 20 to 40 degrees. Example of material include the metals and polymers. Next, is the brittle mechanism in which elastic deformation is followed by a crack propagation and maximum erosion occurs at normal angles.

So, all the brittle materials like ceramics and brittle polymers come in the category of brittle erosion. Then, we have the finish model where the ductile mechanism is discussed based on the surface cutting at low to medium angles and fails to predict erosion at high angles due to surface roughness effects. Next are the protective coatings from solid particle erosion. So, polymer coating compositions consisting of micro nanofillers of ceramics like alumina, zirconia, cellulose etc.

are basically used. So, they enhance hardness and modulus reducing material loss under impact. Sometimes nano composite coatings are also used such as graphene reinforcement, improving properties, reducing erosion by dissipating impact energy more effectively. So, multilayer graphene polyurethane coatings have shown up to 38% less material loss compared to a single layer polyurethane coating. So, in the summary of today's lesson, we have seen the various types of coatings which are used on the wind turbine blade. So, we have looked at the formulations of all these coatings which are used for ultraviolet resistance.

We have used as anti-fouling coatings. We have looked at details of thermal barrier coatings. We have looked at advanced nano coatings. And then we have also looked at some of the coatings for rain droplet erosion and solid particle is used. So, in terms of these coatings we have looked at materials, methods, how they are used and it is not one coating rather several coatings being applied on wind turbine blades for their effective and reliable operation. In the next lesson, we will see the quality assurance and testing and also look at the damage prevention and repair aspects of the wind turbine blades. Thank you.