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

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**Week - 06**

**Lecture 26**

Welcome to this course on manufacturing of turbines. So, in this lesson 26 of this course, we will start the manufacturing of wind turbines. So, we will start the wind turbine by looking at material selection for the wind turbine. So, the outline of this particular lesson will be as follows, where first we will discuss the wind turbine. parts of the wind turbine, nomenclature, their blade profile, evolution, how the rotor diameter size has increased. Then, we will move on to the materials which are used in the wind turbine, which are of course the composite materials.

We will look at introduction to composites, properties, how composites compare with conventional metals and the comparison of the property, wages properties. In the composites, we will look at specific which composites are used to manufacture the wind turbines, where we will see the role of matrix, reinforcement, classification of composites, comparison of fiber, conventional bulk materials, basic building blocks, introduction to matrix, polymerization, addition and condensation polymerization. So, wind turbines as we know are basically the devices or basically it is an energy conversion device which converts energy from the flowing wind. So, kinetic energy of the flowing wind is converted into electricity.

And wind turbines are often installed in as farms in offshore locations as seen in this photograph or they may be also installed on the land based sites. So, wind turbines as we know are interacting with the working fluid as wind and we know that the wind it is continuously changing its direction and velocity. Of course the conditions, the local weather conditions they are also constantly changing. So, sometimes it may be clear weather, sometimes it may be stormy weather with lightning etc. So, wind turbines, they have to function according in the all type of weather conditions.

In addition to the weather conditions, it is the installation sites where the wind turbines are often installed in population sparse areas or in offshore areas because of the constraints of the large size of these components. So, given all this background, we will see the different components in the wind turbine. So, wind turbine in the wind turbine it is the blades which are of course visible because they are having extremely large size and they are generally aligned in the direction of the wind. So, here from the blades is basically the drivetrain part of the wind turbine starts where the blades are mounted on the hub and from the drivetrain we can see that we  move on to the gearbox. Before the gearbox, a brake is also available in the wind turbine in case we want to  decouple the rotation of the blade from this mechanical gearbox behind the wind turbine.

So, the role of the gearbox is basically to increase the number of rotations because very often we see the wind turbine rotating very slowly, but the slow rotation is converted into higher number of rotations using this gearbox and the output of the gearbox is then connected to a generator. which is then able to generate electricity and which is then supplied to the grid. In modern wind turbines, there may be some control systems which may be controlling the pitch of the blade, yaw of the or the direction of the wind turbine and they may be able to change these important parameters such as yaw, pitch or angle of attack of the blade depending on the local wind conditions. And if we look at the contribution of all these components in the wind turbine, so it is the rotor that is basically consisting of 10 to 14 percent by weight. So, behind the blade part, so whatever all these components as shown here including the drivetrain, gearbox, generator, control system is housed inside a box which is known as the nacelle.

So, nacelle covering is also generally made with lightweight high strength materials. The gearbox and drive terrain, they contribute to 5 to 15 percent of the weight of the wind turbine. The generator system, it is 2 to 6 percent. The weight of the top of the tower is 35 to 50 percent and the tower itself is 30 to 65 percent. But if you look at the cost in this wind turbine machine, so it is the rotor that significantly cost almost one-third the cost of the wind turbine around 20 to 30 percent.

The nacelle and the other machinery consists 25 and 15 percent respectively while the generator system they consist 5 to 15 percent in the total cost of the wind turbine. The tower also costs  almost one-fourth in manufacturing of the wind turbine. So, in this module of this course on manufacturing of turbines, our focus will be more on towards the manufacturing of the blades because all other components are basically manufactured with conventional manufacturing processes as several of the processes are discussed earlier. It is rather the blades which are unique compared to other turbines such as gas turbines, steam turbines or the hydro turbines. So, if you look at the wind turbine carefully, so wind turbine it has to withstand several forces.

So, these forces may include gyroscopic forces, gravity forces, then centrifugal forces and at times because of the varying wind conditions there may be unsteady aerodynamic forces. So, because of this the wind turbine may undergo bending blade torsion leg deflection pitching rolling etc and to manage all these forces which are there and of course sometimes the wind direction may also result in crosswinds, which develop which are basically flowing perpendicular to the axis of the blade because of which there are a lot of unsteady conditions generated. Furthermore, the wind turbines are always installed at a certain height where the vertical wind shear is much higher compared to the surface of the earth. So, considering all these complex operating conditions here, the tower of the wind turbine is generally made up of steels as of now. But going forward, the towers of the wind turbine will be made from glass fiber reinforced bars in concrete.

The nacelle that is the behind part of the blade. So, this part is the nacelle is generally made up of again lightweight high strength materials which are known as fiber reinforced plastics so specifically the glass fiber reinforced plastics are used here. The blades of the wind turbine they are made up of again fiber enforced plastics but in the blades because of their large size so this combination of carbon fiber enforced plastic that is CFRP and glass fiber enforced plastic which is used to make the blades. We will look at the construction of the blade of the wind turbine. So, in the construction part of the wind turbine blade, we can see that it is the hollow blade reinforced with the balsa core.

So, balsa is basically a high density wood which is obtained from the balsa tree. And then we have the shear webs and spars which hold the balsa core together. So, these caps are then basically shear caps are applied upon which the skin of the FRP material is placed. So, we can see because of this complex structure we end up with this aerodynamic shape of the wind turbine blade and here what is there, that, we can see that as the size of the wind turbine has increased because the work with the wind turbine it started in the 1980s at that time the rotor diameter was approximately 20 meters and the wind turbine could generate approximately 50 kilowatt of energy. But, as the progress in materials and manufacturing processes has taken place, the size of the wind turbine has increased drastically and presently the diameter of the Rotor, may be of the order of more than 100 to 120 meters in case of land-based wind turbines and it may go to as high as 160 meter for offshore wind turbines.

And now the one wind turbine may be able to generate approximately 5 megawatt to maybe more energy in the same one wind turbine. So, here we can appreciate the evolution of the commercial wind technology, how the size, increased size of rotor has resulted in more energy generation. So, just for the sake of comparison, we can say that how the increased size of the wind turbine has resulted in the higher power generation. And it is expected to further increase to approximately 17 megawatt and this type of wind turbines will be popularly installed in offshore locations given the large size. So, we have to see how the large size wind turbines will be manufactured.

So, if we look at the material constraints for the wind turbine so now in this case the working fluid here as we have discussed is the wind so working fluid because it is wind so the density is nearly one gram per cubic centimeter, So we have to choose materials which are able to extract energy from the blowing wind. So, we have to consider materials with low weight or density in order to reduce the gravitational forces. We also need to consider materials with high strength to withstand strong loading of wind and gravitational force of the blade itself. Furthermore, because of the varying wind conditions, there are situations of high cycle fatigue and because of which we need to select materials which are having high fatigue resistance and high stiffness is also needed to ensure the stability for optimal shape and orientation. So, furthermore high fracture toughness is also needed and ability to withstand the other environmental impacts such as lightning strike, humidity, temperature etc.

has to be also put in the material. So, all these properties are found in materials known as composites and composites as we know they are widely used not only in wind turbines but in several other applications be it from the aerospace, automobile or other infrastructural applications. So, we can see the summary of all the applications of the composite materials which are known for their high strength and less weight and given this unique property because if we talk of metals they have very high  weight, because of their high density and if we talk of ceramics so they may not be able to have sufficient stiffness under these varying wind loads. So, polymer based composites are basically the choice of material for the wind turbine. So, what are composites then? So, composites are basically multiphase materials consisting of two or more materials which are combined at a macroscopic level giving a unique property to the resulting material.

So, above definition may also include sometimes some alloys, polymers, copolymers, plastics, mineral wood etc. And it is in principle generally mentioned that composite materials they result in performance which is unattainable by individual constituents. So, we can say that use of composite materials offers great advantage to flexible design and in principle it is mentioned that we can tailor the property of composites which are specific to the application. So, if we see some example of naturally occurring composites, these include wood, then also they include the human bone or some different type of rocks. So, here we can see composite it refers to all the generally the composites which are used in such applications such as wind turbine blade are solid materials composed of more than one component.

and the different phases of the component are separated using an interface. So, wide assortment of definition of composite includes fiber reinforced plastics, regular and steel reinforced concrete, particulate filled plastic, rubber reinforced plastics, wood laminates, ceramic mixtures, some alloys. And composite materials may also consist of a binder or a matrix which surrounds and holds the reinforcements in the place. So, here we can see comparison of some composite materials with respect to conventional metals and alloys so here comparison is being done with aluminium 6061 in T6 heat treatment condition, with another material is the mild steel 1010 mild steel then titanium aluminium vanadium alloy being compared with some polymer like polyamide Then of course, the some composites being compared here. So, here what we will observe that density of the composite materials is much less than conventional materials.

It does not exceed 2 gram per cubic centimeter. And at the same time the tensile modulus of such composite materials is also comparable or higher. But it is the specific modulus and strength which is when we divide the modulus with density and the ultimate tensile strength with density. Here is when the composites they basically outperform the conventional materials. Wherein, we can see for example the specific modulus of the unidirectional carbon fiber epoxy based composite is 88.

9 and this is significantly higher than titanium or maybe steel or aluminium. Similarly, if we look at specific strength so specific strength of this composite is also 1000 Newton meter per kilogram which is significantly higher than other values mentioned in this table. So, because of this specific properties composite materials offer unique advantages. So, these advantages include their lightweight, high specific stiffness, high specific strength. So, here specific with respect to the density of the composite.

So, the properties of the composite can also be tailored, they can be easily molded into complex shapes. The part can be consolidated with overall lower cost they are easily bondable they have good damping and fatigue resistance they have good internal energy storage low thermal expansion low electrical conductivity lower stealth. But at the same time composite material they also have some limitations or disadvantages which include high cost of materials because we are combining the matrix and fiber. Lack of proven design rules so because composite materials are heterogeneous and anisotropic so the conventional design rules are not useful here so sometimes the metals and composite may be seldom interchangeable because specially in the high temperature conditions. Composite materials are also known to have long development time like they take a lot of time to manufacture.

They have manufacturing difficulties. Use of fasteners is much complex here. Joining of such composite is more challenging. They are more susceptible to solvent and moisture attacks. They have some temperature limits that is they cannot be used in high temperature.

They are also susceptible to damage and sometimes this damage may be hidden, may not be visible directly on the surface. So, in any composite which is used so there are primarily two parts which is the matrix and the reinforcement. So, both of the components they have their own specific roles. The matrix as we know from the discussion on engineering materials it can be either polymer based, metal based or ceramic based. But, for the application in wind turbine blades it is the polymer based matrix which is having low density and high specific strength and stiffness is widely used as the choice of material in as the matrix.

So, the different roles the matrix has to play in a composite include giving shape to the composite part so the basic shape of the composite part comes from the shape of the matrix. The matrix also protects the reinforcement from the environment. It transfers the load to the reinforcement. It also contributes to the properties that depend upon the matrix and the reinforcement such as toughness. The reinforcement is the significant proportion in the composite generally more than 50 percent and it can go to as high as 60 to 65 percent by weight.

The main role of the reinforcement is to give strength, stiffness and other mechanical properties to the composite. It has to dominate all other properties such as thermal expansion, conductivity and thermal transport also. So, given this important role, the roles of both matrix and reinforcement is divided. And it is the interface between the matrix and reinforcement the continuity of the interface that decides the final properties of the matrix because if there is a discontinuity in the interface, so then effective load transfer from the matrix to the reinforcement will not take place and perhaps the composite by itself may fail at an earlier stage. So, if we see the classification of composite materials based on matrix, so there are three possibilities which include polymer-based, metal-based or ceramic-based.

Again, in respect to all these sub-classifications also exist. For example, in polymer there may be thermoplastics, thermosets or rubber. In metal-based there may be ferrous based metals or non-ferrous based metals. Ceramic based composites are also there which you utilize oxides, carbides and nitrides. Based on the reinforcing material, so there may be the particulate type composites or fibrous composites.

In particulate type composites, it is basically the particulate reinforcement where the aspect ratio is nearly equal to 1 are used as the fillers or the reinforcement. So, these particulates can either be randomly oriented or they can be oriented in a preferred direction. The fibrous composites can have bidirectional or unidirectional layers of single layer of reinforcement or they can be multiple layer of different type of reinforcements. So, these reinforcements can be available in short fiber or long fiber and depending on the either it is a single reinforcement. So, we can develop fibrous laminates or we can have hybrid composite where different type of reinforcements will be used to develop the laminates.

So, here we can see the classification of composites based on the reinforcement. So, with increased alignment we achieve the unidirectional composites where all the reinforcements are oriented in one direction. So, then there may be cross direction where of course these are having the bidirectional reinforcements are there. So 0 and 90 degrees. So, we can also have multi-directional composites where reinforcements are oriented in multiple directions or we can have a continuous strand mat.

So, with the decreased length by size, so there is increased homogeneity, but as we move away from this aspect, so homogeneity reduces. And of course, as we achieve to the randomly oriented particles and viscous, so there is quasi-isotropic properties being achieved in the composite material. So, because of these properties, there may be again comparison of several fibers with respect to their mechanical properties. So, in composites, specifically the synthetic composites, several fibers are used which include the glass fibers, graphite fibers, boron fibers, silicon fibers, tungsten fibers, beryllium based fibers or Kevlar. So, we can see all the properties of these fibers listed in this table and again it is with respect to the specific properties the fibers outperform several metals such as steel, aluminum alloys as mentioned in the table on the right hand side.

So, because the fibers they have the less number of defects per unit volume. So, the probability of encountering a defect is much, much less when the same material is available in form of fiber. So, that is the main reason why the fibers are able to exhibit much higher properties compared to their bulk counterparts. Another important consideration is why most of the structural composites such as used in wind turbine blades they exist have the reinforcement in form of the cylindrical form. So, if we look at this ratio of the area to volume.

So, in this case we see as we move from the platelet to the fibre. So, it is the maximum area to volume ratio in the fiber where the length to diameter ratio is maximum especially with continuous fibers. So, this ensures that there is a maximum contact between the fiber and the surrounding matrix which results in effective load transfer from the reinforcement to the matrix. From the matrix the load is of course transferred to the reinforcement and maximum surface area ensures this aspect. So, composites we can say that they then are combination of fiber matrix and sometimes some coupling agents may also be added and by combining them we can get various type of composites which include, unidirectional with continuous fibers, bidirectional, multidirectional or we can have unidirectional with discontinuous fiber or randomly oriented fibers.

And by combining or stacking these fibers oriented in one or specific direction or more direction we can generate lamina and then this laminae can be combined to develop the laminates which are of course used in the components such as wind turbine blades as we are discussing. So, depending on the matrix we can have metal, polymer or ceramic. So, for most of the wind turbine based application it is the polymers which are used. So, polymers as we know they consist of repeating units of monomers which consist of long chain like structure and monomers they are having specific and consistent grouping of short polymers known as the repeating units. So, in some cases the polymers are also referred to as resins which are not yet in their final form.

So, resin is basically generated or originated from a Greek word meaning tree sap and plastic also referred to polymeric materials which are generally shaped also known as plasticos that is a Greek word meaning it is form or molded. So, in several polymers the resin may change from the liquid to solid upon curing and the resin may also be derived naturally or synthetically but of course for consistent properties, the synthetic plastic or resin is more preferred and plastics associated with low cost composites, word is associated with low cost composites and resin is of course considered with high cost composites. So, all this we have just seen that matrices, role of matrices it is there to protect the fibers against the chemical and environmental attack. For fibers also to carry the maximum load the fiber matrix must have a lower modulus and greater elongation. The matrix selection is performed based on the chemical treatment and thermal treatment on several other properties like chemical, thermal, electrical being flammable etc.

And matrix also determines the service operating temperature of composite for processing of parts and there are all these three types of matrices and details of matrices also include thermoplastics and thermosets in polymer. And thermosets and thermoplastics differ on the behavior to heat where thermoplastics basically they can be reheated and remelted but thermosets cannot be reheated and remelted because of the permanent crosslinks which are generated. Examples of various thermosets and thermoplastics are listed here in the slide and which are the popular metals and ceramic used as matrices are also mentioned here. So, next is the polymerization process where the process is to combine the small units into long chain. Then, this long chain are connected using covalent bonds which gives high strength to this joining polymers and the repeating units are known as monomers.

So, commonly two type of polymerization may be used which is the addition polymerization and the condensation polymerization so in the addition type of polymerization the reaction begins with activation with some molecule usually a peroxide to form a free radical. So, heating of the peroxide may be required to form a this type of a free radical and unpaired electron may couple to form another pair from the electron bond. So, in this case generally biproducts are not produced. Then, there are condensation polymers where two type of monomers with active end groups for example x and y are utilized and condensation monomers in the end with active group of one monomer X must react with the active group of the other monomer that is Y to form a linkage L in which the two monomers M1 and M2 are linked to form a molecule and sometimes a byproduct or a condensate may be generated during this process. So, with this we will summarize what all is covered in this lesson.

So, we have covered the basic parts in wind turbines. Then, we have also looked at the material selection and criteria for wind turbines. We have then looked at the use of composites. We have looked in case of composites, their properties then we have looked at applications and then we have looked at classification of composites. And lastly, we have looked at what are the different type of polymer based composites, how they are formed by repeating the monomers using condensation type reaction or addition type of reaction. So, in the next lesson, we will see the properties of the various matrices. Thank you.