

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

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Lecture 30

Welcome to this course on manufacturing of turbines. So, in this lesson 30 of the course we will see the material selection for wind turbines and in this lesson specifically we will see the details about the reinforcement. The previous lectures have covered details about the matrix, the various additives which are added in the matrix. We have also seen in detail how the curing is done in the matrix. Specifically, we have looked in much detail the chemical structure, the curing characteristics of epoxy which is the popularly used matrix in wind turbine blades. And now we come to another or the second phase which is the very significant phase in any composite material that is the reinforcement.

So, in this lesson we will see introduction to reinforcements. The different terms used with respect to reinforcements which include filament, strand, yarns. We will see what is difference between all these technical terms. We will see woven and knitted fabrics, nonwoven fabrics, braided laminates, stitched laminates, three-dimensional laminates, concept of whiskers, particulates, nanomaterials.

And how these are being utilized in composite materials, fiber characteristics, fiber matrix interaction and specific strength and stiffness. So, as we know reinforcement it plays a very crucial role in composite material industry. So, the crucial role is basically in determining the final properties of the composites. So, reinforcement they come in various forms with each specific characteristic and this characteristic of the reinforcement can influence the properties of the composite as well as the manufacturing process which is used to develop the composite part. So, in this regard the terms like filament, strands, tows, roving and yarns are quite popular with the term reinforcement.

So, we will now understand what is the difference between these terms and how the technicality of these terms influences the composite materials. So, filament are basically the single fibers which are made through spinning process. Where, liquid raw material is passed through a die with many holes. So, generally in making the filaments it is the melting which takes place and this die with many holes also known as the spinneret is utilized to develop the filament as the melt cools down. This filament can be continuous, they are fragile, they are too small to be used individually.

So, usually they are gathered into groups. So, almost in none of the engineering application like for wind turbine blade etc. the filament is used but it is the group of filaments which are grouped together. So, this group of filaments so we can say that filament is basically one strand but when we basically one fiber or this melt as solidified and strand is basically combination of several filaments together. So, this becomes the strand.

So, we can say the strand, it refers to the group of filaments. So, several filaments when combined together, they form the strand. So, in context of fiberglass or sometimes we call it as glass fiber. So, in glass fiber or fiberglass, this is the same. So, this group of filaments or strands is termed as rovings.

So, technical literature, we will see that rovings are basically the term which implies strands of glass fiber and it will consist of filament of glass fiber. While, the composites which use advanced reinforcement such as carbon fiber or aramid fiber. So, in case the reinforcement is carbon or aramid fiber, so then the name of the strand it changes to tows. So, it is the same thing but in technical literature it has been used. So, wherever we see the term tow, it implies the strand of carbon fiber or aramid fiber and in literature if we come across the term of roving it implies the strand of fiberglass or glass fiber which mean the same.

So, next is basically yarns. So, yarns are basically again combined by twisting various strands together. So, we started with the filament. So, by combining various filaments which is a monofilament we get the strand. The name of the strand changes to roving if it is the fiberglass and it changes to the name of tow if it is advanced fiber like carbon fiber or aramid fiber and in several cases the strands are untwisted.

But, when we twist these strands, so this becomes yarn. So, twisting this basically enhances the structural integrity and is commonly used in textile applications such as geotextiles. So, the diameter and filament count in the strand, it greatly varies on the manufacturing specifications. So, in some countries it can be identified with some codes which indicate which is the type of fiber, whether it is glass fiber or carbon fiber, what is the diameter, what is the filament count. So, there can be different filament count ranging say from 8000 filaments to say 24000 filaments and so on.

So, it is also self understood that as the number of filaments will increase the specific mechanical or other properties of the respective fiber will also increase. So, increase in the filament size will generally also increases the GSM number for the woven type of the reinforcement. That means the reinforcement mat goes on becoming thick as the number of filament increases in the yarn or the strand. Next, is the discussion on the woven and knitted fabrics. So, woven and knitted fabrics, they somewhat resemble a cloth in which we can weave the yarn which is created in the previous case.

So, this is woven so as to keep the various reinforcement in the place and also sometimes to have reinforcement in various directions. Because composite materials they are anisotropic materials and their properties largely depend on the direction of the reinforcement whether the direction of the reinforcement it is in line with the loading direction or it is transverse to the loading direction. But when we have woven type of reinforcements as shown here, so we can weave the reinforcement in various directions thereby creating a composite having reinforcement in say all directions. And woven fabrics, they are made by interlacing warp which is the longitudinal interlacing and the weft which is the transverse interlacing of the fibers. So, type of weave, it also influences the fabric's stability, strength and drape.

So, drape is basically the ability of the fabric to conform the shape of the mold whenever it is placed inside the mold for various closed or open molding manufacturing processes for composite parts. So, based on this discussion, there are several types of weaves but some of the popular weaves which are used in several industrial products, these include plain weave, basket weave, twill weave and satin weave. So, this is not the complete list but some of the popular ones. So, plain weave is basically a simple weave in which over and under pattern is utilized. So, here we can see the same fiber going one time over the perpendicular fiber and one time it is going under the perpendicular fiber.

So, plain weave is known to provide stability and uniform strength. Then we have the basket weave. This is similar to plain weave where group of two or more warp and weft fibers, they are held together resulting in a flatter and stronger fabric with better drape. Twill weave is basically it features diagonal lines due to the pattern of crossing fibers offering better drape and less crimp. So, crimp is basically the ability to fold in places and this also misaligns the fiber.

So, less crimp is always desired with higher strength than the plain weave. Then we have the satin weave, which involves one wrapped strand weaving over multiple weft strands, giving the fabric high degree of drape and stretch, though it may be less stable than other weaves. So, next are the nonwoven fabrics. So, sometimes the reinforcement may also be used in nonwoven configuration, which is known as the mat. So, in woven configuration we call it as a fabric, in nonwoven configuration we call it as a mat.

So, nonwoven fabrics or mat they consist of fibers which are laid randomly in specific orientations and are bonded together by chemical, mechanical or thermal means. So, they also provide uniformity and are often used in several molding applications. So, non woven fabrics, they involve use of chopped strand mat. So, here chopped fiberglass bound with a light binder are used. This offers convenience and cost effectiveness, but with a lower mechanical properties compared to woven fabrics.

Then we have continuous strand mat. So, in this case, it consists of a long fiberglass strands resulting in improved properties and ruggedness compared to chopped strand mat. It is more durable but less than the woven fabrics. So, here we can see the schematic of the chopped strand mat. So, here basically short fibers are being used.

They are chopped and then used in the mat. And in case of long strand mat, so a single strand is continuously woven in a random orientation. So, this may offer better properties than the chopped, but nevertheless the properties are still less than the woven fabric. Next are the braided laminates. So, braided laminates are composite materials where continuous fibers are interwoven in biaxial or tri-axial braid pattern, creating a seamless tubular or flat structure.

So, in the construction of the braided laminates, the fibers are typically braided over a mandrel, allowing for creation of complex shapes such as tubes, cones or other contoured structures. The fibers can be braided at different angles, for example, 30 degrees, 45 degrees, 60 degrees to optimize strength and stiffness in specific directions. So, the advantages that braided laminates offer include enhanced strength which distributes fibers uniformly reducing stress concentration and improving damage tolerance. Also, they enhance the manufacturability of complex shapes where braided laminates can form intricate geometries without need for seams for joints making them ideal for aerospace automotive and goods application, sporting goods application and by changing the braid angle we can customize the properties of the braided laminates and they can be tailored to meet specific load requirements. So, next we can see applications of braided laminate.

They include lightweight structural components which include the rocket casing, aircraft fuselage, high performance bicycle frames where combination of strength, lightweight and complex shape is required. So, here we can see the schematic representation of biaxial braided laminate as well as the triaxial braid construction. Next are the stitched laminates. So, stitched laminates they offer reinforcing composite layer by stitching the reinforcement together by utilizing a thread often made up of the same or compatible material such as of the laminate fibers. So, construction of fabrics or unidirectional fibers are stacked and needle is passed through to insert a thread creating a through thickness reinforcement.

So, this stitching can be done in various patterns and properties can be tailored as per the need of the end requirement. So, here we can see the schematic of non crimp fabric with various layers of reinforcement aligned in various directions such as 45 degree, 90 degree. 45 degree like both ways plus and minus 90 degree and zero layers and we can see this needle this is passing through and stitching these various laminates of the reinforcement in various directions together using this thread. So, this thread can be made up of the same material of which the fibers are made to enhance the overall performance

of the stitched laminate. So, advantage is that stitch laminate offer include improved delamination resistance.

So, delamination is a very well known mode of failure in composite material where various layers of reinforcement they come apart under various loading conditions. But, as we have seen that by utilizing the stitch laminates the various fibers are held together using a thread. So, the tendency of delamination, it reduces considerably, therefore improving the delamination resistance. The enhanced because of this the overall durability of the stitch laminate is enhanced having better impact resistance and damage tolerance making them suitable for application where durability is critical. And they also result in cost effective manufacturing as this stitching exercise can be automated and this can reduce the manufacturing cost for large scale production of stitched laminates.

Stitched laminates, they are also popular in various applications also in the wind turbine industry and aerospace industry which are popular to make large structures like wings, wing skins, fuselage, blades where resistance to delamination and high fatigue life is crucial. Next, are the three dimensional laminates. So, three dimensional laminates are advanced composites incorporating fibers oriented in all three axis, that is X, Y and Z providing reinforcement in the three dimensions. So, unlike the construction of two-dimensional laminates which are built up in a layer by layer manner in a plane, three-dimensional laminates are woven and knitted and braided in such a way that fibers they also integrate in the thickness direction. This can involve complex weaving techniques that interlace the fibers both vertically as well as horizontally.

And here we can see by providing the such type of three-dimensional laminates, we can enhance the overall performance of composites not only in the plane direction, but also in the out of plane direction. So, advantage is that the three-dimensional laminates, they offer superior strength and stiffness. So, three-dimensional fibers architecture provide improved mechanical properties, especially in out-of-plane strength and stiffness. Reduced delamination as the reinforcement is integrated in the Z direction. So, reinforcement prevents separating of the layers even under extreme mechanical stresses.

Complex geometries can be formed utilizing the three-dimensional laminates, making them ideal for intricate structural components. So, applications of such three-dimensional laminates involve aerospace structures, automotive crash components, sport equipment where high strength, durability, and resistance to impact and fatigue are required. Next are use of whiskers in the composites. So, whiskers are basically single crystal fibers with very high aspect ratio and they can be made as long as wide and they are also wide. So, they are typically made up of materials involving ceramics like silicon carbide, aluminum oxide or boron carbide.

And it is the purity of the whiskers which renders very high properties in these whiskers because of extremely low number of defects per unit volume. So, whiskers are extremely strong and stiff because of their near perfect crystalline structure and lack of defects. Furthermore, their small size and high strength make them excellent in reinforcing the composite materials. Application of whiskers involve advanced composites especially in case of aerospace and defense applications where, mechanical properties of matrix are needed to improve tensile strength, wear resistance and fracture toughness. So, here we can see a whisker, short whiskers being suspended in the reinforcement.

Particulates are different small particles dispersed in the composite material to enhance specific properties like wear resistance, thermal stability and electrical conductivity. Particulates can be made from various types of materials. This includes ceramics, metals and polymers. They are often added to the matrix to create composite materials with specific properties. Reinforcements are commonly used, this type of particulates are commonly used in applications like automotive brake pads where particulates improve wear resistance of the composite.

Electronic packaging where they can also enhance the thermal conductivity. Next are the nanomaterials. So, use of nanomaterials has been widespread in composite materials especially to develop nanocomposites. So, use of nanomaterials involves use of nanofibers, nanotubes, nanoparticles having at least one dimension in the nanometer scale that is within 1 to 100 nanometers. So, their characteristics involve having unique properties such as high surface area to volume ratio which significantly enhance the mechanical, electrical and thermal properties even at low concentrations.

Nanomaterials are used in composites to develop high performance composites for electronic, aerospace, medical devices and to create materials with enhanced strength, conductivity and biocompatibility. So, they also have high fiber aspect ratio where length to diameter ratio is critical for load transfer. Their molecular orientation can also be aligned along a specific direction for increased strength and stiffness. So, fiber formation technique involve drawing process which involves aligning the molecular chain and the fiber length enhancing mechanical properties. Die extrusion may contribute to molecular alignment though it may be less effective than drawing.

Fiber geometry may include circular, non-circular cross sections. Non-circular fibers such as, tri-lobes designs may be explored for enhanced matrix adhesion but are not widely adopted in commercial applications. So, here we can see relative size of common fibers. So, for example the vapor deposition fibers such as boron or silicon carbide etc. So, these are often deposited on some substrate like tungsten using process of vapor deposition be it chemical or physical vapor deposition.

And, we can see the size of coarse whiskers which is relatively smaller than the vapor deposited fibers and then our conventional reinforcements like glass fibers, boron, nitride, carbon fibers and fine whiskers are having even relatively smaller diameters. So, if we see the various fiber characteristics especially which are used in case of the wind turbine blade, these include the glass fibers. Glass fibers are also available in different types such as E glass fiber and S glass fiber. So, we will see the details of these in the next few lectures. But for now we can see the various thermophysical properties which include density, tensile strength, modulus and elongation.

S glass fibers generally these have high tensile strength and elastic modulus compared to E glass fibers and they are specially used in high strength and impact resistance applications. The second class of fibers which are used in wind turbine blade include the carbon sometimes also referred to as graphite fibers. They have relatively low density compared to the glass fibers and tensile strength is also significantly higher and modulus almost three times or four times the modulus of the glass fibers. And they are specially used with high tensile strength modulus applications in wind turbine, not only wind turbine blade, but also aerospace automotive and sports equipment. Other fibers, which are may be used in composite materials in general include boron based fibers which are used in aerospace structures, silicon carbide based fibers.

And these fibers are often developed on a metallic filament like tungsten using vapor deposition techniques. Other than this we have some fibers which are derived from natural resources like plants or animals etc. So, they offer of course less mechanical properties, but they are having widespread used in making sustainable composites with lightweight characteristics. Next are fiber matrix interactions. So, it is very important to have strong fiber matrix bond for crucial load transfer between the fiber, between the matrix and the fiber in the composite, which can overall influence the composite's performance.

Factor include adhesion, fiber surface treatment, matrix type and processing condition, effect of fiber length and loading. So, in this case longer fiber increase the tensile strength, modulus and elongation up to a certain limit and continuous fibers used in application require high performance composites. Fiber loading, optimal fiber content up to 60 to 70% are essential for maximizing the mechanical properties and excessive loading sometimes may lead to poor wetting and decreased mechanical performance of the composites. So, significance in case of composites of mechanical properties like specific strength and stiffness, this make the composite material especially competitive and ideal for application like wind turbine, blade, aerospace, automotive and sporting equipment. If compared with metals, the specific strength of composite is magnitude greater than the specific strength of the metals.

Example, the graphite fibers can support 140 miles of suspended cable compared to steels 20 mile only. And specific stiffness of fibers like carbon, aramid, ultra high molecular weight polyethylene fibers demonstrate superior stiffness relative to the weight. Glass fibers, while they are strong, they offer low stiffness, but nevertheless this is still better than the metals. So, in summary we can see that we have discussed the different types of reinforcements used in composites. We have seen classification of reinforcements based on the weave patterns.

And lastly, we have looked at some of the important properties of reinforcements which are helpful in making parts of wind turbine blade and other high strength lightweight applications. So, in the next lecture, we will see the manufacturing of the glass fiber in detail. Thank you.