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

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**Lecture 31**

Welcome to this course on manufacturing of turbines. So, in this lesson 31 of this course we will see the manufacturing of glass fibers which are used to make the wind turbine blades. So, the outline of this lesson will be mainly focusing on discussion on manufacturing of glass fibers. So, we will start with introduction to fibers then introduction to glass fibers We will look at the chemical composition of glass fibers, their properties, the manufacturing process which is itself used to make the glass fiber, the various forms in which the glass fiber is available, their properties and advantages and we will also look at some microstructural details and end applications other than wind turbine blades for the glass fibers. So, as we have seen that composite material are multiphase materials in which there are primarily two constituents where fibers are basically the reinforcing constituent and then we also have the matrix. So, fibers are basically the principal constituents in any fiber reinforced composite material.

The fibers, they often occupy the largest volume fraction in the composite laminates and they share the major portion of the load acting on the composite structure. Proper selection of fiber types, fiber volume fraction, fiber length, as well as the fiber orientation is very important to decide the properties of the composite components. Following characteristics of fibers are of interest in composite laminates. So, this includes density of the fibers, tensile strength and modulus, compressive strength and modulus, fatigue strength as well as fatigue failure mechanisms, electrical and thermal conductivities, and the cost of the fiber.

So, all these factors they largely decide which fiber and what quantity of fiber will go into any composite component. So, here we will see the table which highlights the comparison of some of the properties of fibers compared to the monolithic metals. So, these properties include density, tensile strength, Young's modulus and elongation at failure. So, here some of the fibers as mentioned above are basically natural fibers. So, these are derived from plant or animal sources.

Primarily here these are plant based fibers which are flax, hemp and bamboo. So, then these fibers mentioned in the blue color are basically the fibers which are synthetic fibers and below we have the monolithic metals which include steels, titanium, magnesium. So,

this is basically a comparison on some of the important properties like density. So, we will observe that some of the synthetic fibers especially the carbon fiber or the glass fiber they have extremely low density compared to metals like titanium or maybe magnesium and steel. Of course, once we are comparing with steel it is much much less.

At the same time the fibers are also able to exhibit very high tensile strength because of which they all these reasons the fibers are much used in composite materials, which are used to make components which are having light weight and high strength and the wind turbine blade is one such example. So, now we see how the fiber and say the composite or the matrix of the composite when separately brought under mechanical loading, how the behavior is exhibited. So, if we see here example of a composite made up of a Kenaf fiber. So, Kenaf here is basically the plant derived fiber. This is a natural fiber, a plant derived fiber.

And we have the polylactic acid based matrix. So, when we look at the matrix only and under the influence of say loading at 70 percent volume of fiber content. So, we see that the matrix it takes a load up to stress level being induced around 18 megapascals and then the stress is almost constant because such type of polymers they are known to exhibit good elongation. Similarly, if we separately load the kenaf here and then we see it exhibits slightly higher stress or the higher stress value of around 22 megapascals. So, we can say that when we separately use the fiber and the matrix, so there is not much improvement in the mechanical properties.

But when we combine these here, as we can see the combination of kenaf in the polylactic acid based composite with 70 percent fiber volume fraction, so in this case we can see the tensile strength of the composite, it directly jumps to around 61 megapascals. This is almost threefold increase in the tensile strength. And this increase in the tensile strength is because of the unique properties that the composite material is able to offer. So, here we can see another comparison of various type of fibers and here the comparison is done based on the specific modulus. Difference between modulus and the specific strength.

So, here specific strength relates to strength of any material with dividing it by the density. And we will see that most of the synthetic fibers as shown here they exhibit very high specific strength. So, with this background we introduce the glass fibers which are used in one of the large quantities in manufacturing the wind turbine blade. So, glass fibers were originally invented in the Renaissance Venice where the artisans have been using these glass fibers to make objects with strands of glass. In terms of modern development, continuous filament glass fibers were developed at the Illinois Corning Glass Company which began commercial production of such glass fibers in 1937.

And since then the glass fibers have been initially used to act as a thermal insulation.

And they gained prominence during the World War II duration in which they found widespread applications of glass fibers in aircraft, automobile and several consumer products. So, if we see what is the raw material that goes into making the glass fiber. So, the name glass fiber is derived from the same components which used to make the glass which is used in various applications. So, chemical composition of glass fibers includes use of silica which is basically the structural backbone of the glass fibers providing it strength and thermal stability.

Other than silica, we have presence of alkaline earth oxides which include calcium oxide, magnesium oxide, which improve glass fiber rigidity. We also have boric acid, which lowers the melting point and enhances thermal resistance. Alumina is also added to enhance the durability and chemical resistance. Along them, some alkali oxides like sodium oxide or potassium oxide may also be added to control melting point and improve processability of the glass fibers. Other than these chemicals, some additives may also be occasionally added in manufacturing of the glass fibers.

So, these additives may include minor compounds like iron oxide or feldspar which are added sometimes to adjust the optical and chemical properties, also to optimize viscosity during processing, tailoring glass composition for the specific applications. So, the popular fibers which are used in structural application composites of the glass fiber family, they include the E glass fiber, C glass fiber and S glass fiber. So, these varieties of glass fibers are having their own set of unique properties and this set of unique properties is extracted based on the varied composition of these various compositional or constituent elements or compounds. So, these constituent materials in the glass when varied in these specific weight percentages, we can end up different types of glass fibers like E glass fiber, C glass fiber and S glass fiber. So, here the S glass fibers are generally known for good strength, C glass fibers are good known for good corrosion and chemical resistance and E glass fiber they have a balance between good strength as well as the electrical and thermal insulation as well.

So, the manufacturing of any of the glass fiber will follow a certain route which is fixed to all the type of glass fibers. The only thing which will vary will the composition of the glass fiber. So, if you look at comparison of all these different type of glass fibers that is E, S and C glass. So, we can see these properties of the various glass fibers how they are varying. And here we will see that the different properties give wide variety of applications to this glass fiber in various types of composites.

So, next we will look at the manufacturing process of the glass fiber. So, as we have seen, the various raw materials which are utilized to manufacture the glass fiber, they include silica sand, limestone, feldspar, boric acid, clay. Silica, it accounts for more than 50% of the total ingredients. So, by varying the amount of raw materials and processing parameters, other type of glass fibers can also be produced using the same process. The

raw materials are generally mixed thoroughly and melted in a furnace at 2500 to 3000 degrees Fahrenheit.

Once the constituents they get melted they flow into one or more bushings which contain hundreds of small orifices. The glass filaments are formed as the molten glass passes through these orifices and they successively undergo quenching where water or air is used to quickly cool the filaments below the glass transition temperature. The filaments are then pulled over a roller at a speed of around 50 miles per hour and the roller also coats them with a sizing. So, sizing is basically a chemical which is applied on the surface of the glass fiber so as once the glass fibers are rubbing with each other during packaging or other applications, they do not abrade the surface as the constituents that we have seen are ceramic constituents which are quite hard and once the glass fibers they come in contact with each other in absence of sizing they may abrade and cause some surface related defects and which may ultimately compromise with the properties of the glass fiber. So, the amount of sizing which is used, it varies between 0.

25 to 6% of the original weight, original fiber weight. And then all filaments, they are pulled into a single strand and wound over the tube. So, this pulling of the strand basically it aligns the molecules in the glass fiber in a specific direction that is the preferred direction of loading. And the sizing it also acts as a lubricant material on the surfaces of the glass fiber to prevent wear and tear during handling or processing in general. So, we will schematically see how the process which is used to manufacture the glass fiber is executed.

And this process is originally known as the marble melt process. So, in the marble melt process, the process starts with basically the raw material storage. So, we have a raw material storage here. So, from the raw material storage we weigh and mix various constituents which are used to make the glass fibers. So, once the mixing is done so then we subsequently blend the various constituents properly and after blending what happens the constituents they are brought into the furnace.

So, this is basically the furnace where the melting will take place. And in the melting, some refining is also needed. So, melting and refining, they happen together. And after the refining, what happens? As the refining is taking place, the molten glass is solidifying in form of marbles here. So, this type of marbles are reduced upon solidification.

So, these marbles may then be sorted, graded and then they are again fed to another melting facility. So, all these marbles are then again brought here to a melting facility here where they are remelted. And upon remelting, so they form the filament. So, the filament of the glass fiber is produced here. And this filament is basically passed through a orifice, having openings with small holes and then from here the strand is produced, a

single strand is produced from here which is then traversed and subsequently it is wound on a cylinder, that is how generally this glass fiber is produced.

So, I will just now include the naming of various components. So, this is basically the raw material storage. So, after the raw material storage, so here we perform the weighing and mixing. So, all the various components constituents they are weighed and mixed. So then it is brought here in the blending so from the blending the constituents are brought into a furnace.

So, this is basically the melting so your melting and refining is done in this furnace. And then these marbles are formed where specified amount of the melt is allowed to come out of this furnace and it solidifies in the form of these marbles. And then these marbles are taken again for remelting. So, here the remelting of the marbles is done and then various these filaments are produced here as the melt is allowed to pass through the orifice, various orifices on a bushing as discussed previously. and then here after they pass after all the filaments pass and they are combined to form the strand so then sizing that is the chemical applied which acts as the lubricant is done.

So, sizing application is this at this stage and then the strand whatever is produced is then traversed and this is then mount here on a cylinder So, we can see that we started with the material here. That was the raw material which was available in form of powder. We melted it, we created these marbles here. These are glass marbles. And remelting these marbles after purification and sorting and grading, we could generate these filaments of glass fiber.

These are glass fiber filaments and then after applying sizing and so on we develop this strand. That is how the glass fibers are manufactured using the marble melt process. So, we can see that the glass fibers they are available in various configurations. So, glass fibers may be available in form of chopped strand. So, where we have some short fibers this type of short fibers as shown here, or it may be available in form of a continuous yarn.

So, like a thread it is available or this yarn sometimes we may have a roving. So, if we can recall, so roving is basically combination of several filaments. Or this roving can then be utilized to basically weave it into various fabrics. And just we have seen in the previous lesson that we can have different weave patterns which can lead to generation of different type of fabrics like plain weave, twill weave, basket weave, satin weave etc. So, if we see various properties and advantages of glass fibers, so this includes high specific strength and stiffness.

In general they have high strength. So, they may also be very cost effective compared to glass fibers because the manufacturing process as well as the raw materials are of relatively low cost, making them a dominant reinforcement in several consumer goods as

well as lightweight high strength products like wind turbines. Because of their versatility, the glass fibers, they also find very favorable industrial applications where performance to cost ratio is of significance. So, if you look at the microstructure and properties of glass fibers, so unlike crystalline materials, glass fibers, they lack long-range atomic order. So, this means over a long range, the atoms are not arranged in a definite order, which contributes to their isotropic and mechanical properties.

Tensile strength it ranges from 2.5 to 5 gigapascals for E-glass and depending on the various processing condition in case S-glass is being considered. So, in that case the tensile strength can go as high as 7 gigapascals. Specific modulus and strength they offer excellent specific properties making them suitable for weight sensitive application. The different glass fibers which are used we can see they are unique properties like e-glass fiber is widely used due to balance of strength stiffness and cost effectiveness. S-glass is preferred in high performance applications with elevated strength and impact resistance.

C-glass is specifically designed for chemical environments particularly in acidic conditions. Quartz fiber are also a type of glass fiber which offer superior thermal and electrical properties but are significantly more expensive and are reserved for specific or specialized applications. Other than the application like the wind turbine blade, the glass fiber are also used, glass fiber based composites are also used in applications like boat hulls, light, rail cars, building roof structures, housing cabinets, tub shower units, wall bathroom panels, automobile bodies, duct for air conditioning and heating, vaulting poles, bows, arrows, surfing boards, snowboards, etc. Snowmobile housings are also made up of fiber-enforced plastic containing glass fibers as the reinforcement. So, with this we have seen the manufacturing of glass fibers.

So, we will summarize this lesson. So, we have essentially looked at the manufacturing of glass fibers. We have looked at the constituents of glass fibers. So, what all material go into making the glass fiber, we have looked at the marble melt manufacturing process, which is used to make the glass fibers and then we have looked at properties and applications of glass fibers in general. And in the next lesson, we will see the manufacturing of carbon fibers which are also used in manufacturing of the wind turbines. Thank you.