Physics of Renewable Energy Systems
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Lecture 14
Materials Aspects and Future Prospects

Welcome again to the course on physics of renewable energy systems. Let us start with the final lecture of module 3 which was dealing with wind power.

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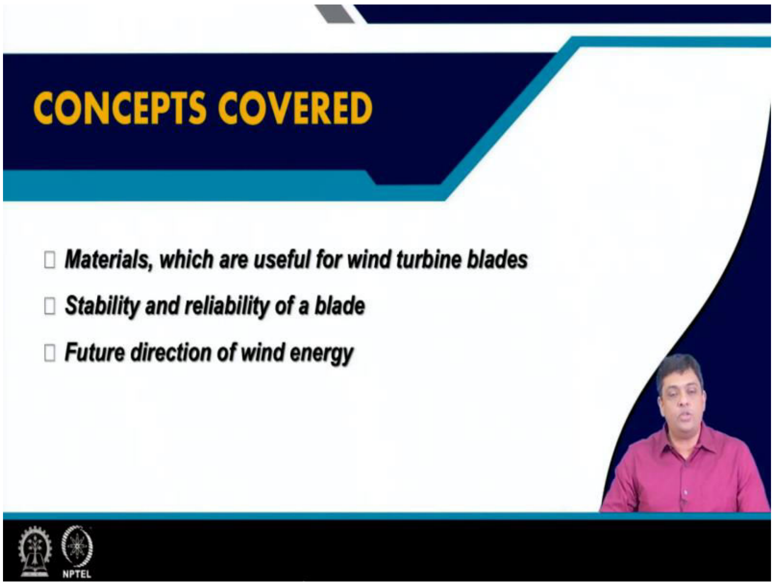

So, in today's lecture we will be talking to you about the materials aspect which are critical for making wind turbine blades. And that will lead to higher efficiency in the device. We will also talk to you about the factors which control the stability and reliability of the wind plates. And before we end this module it is critical that we also tell you that what is in store for this technology in the future. So, we will also give you the future direction of wind energy based research and industrial aspects.

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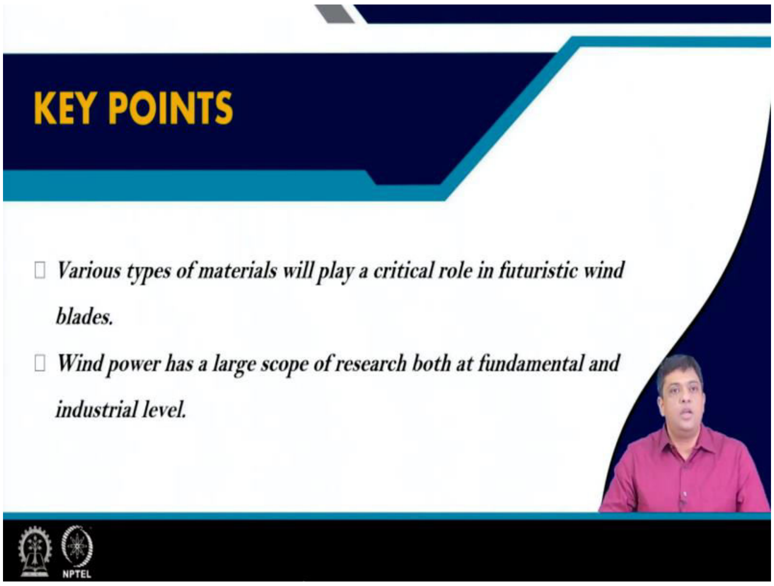

After going through this lecture and the concepts which will be covered you will be able to understand the importance of materials and the various types of materials which will be used in future wind blades or wind turbines. You will also see that wind power has a large scope of research both at the fundamental and industrial level. So, if you are interested for higher studies in this area there is a large scope.

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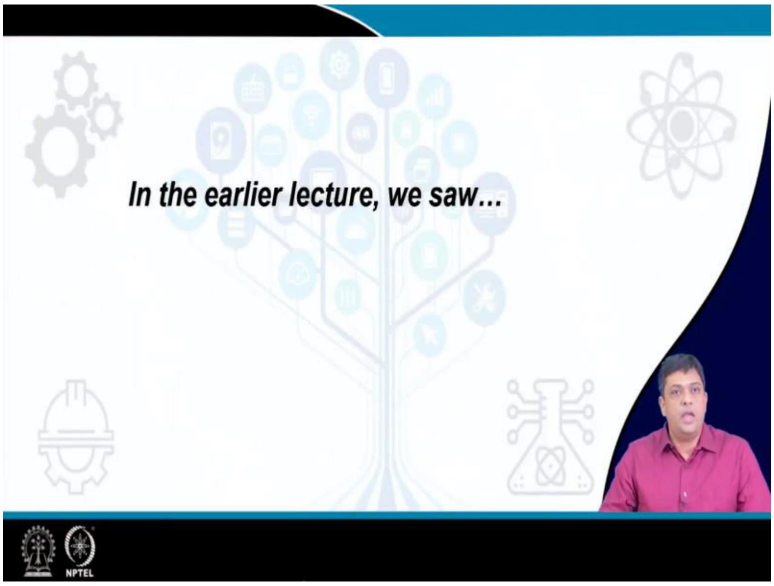

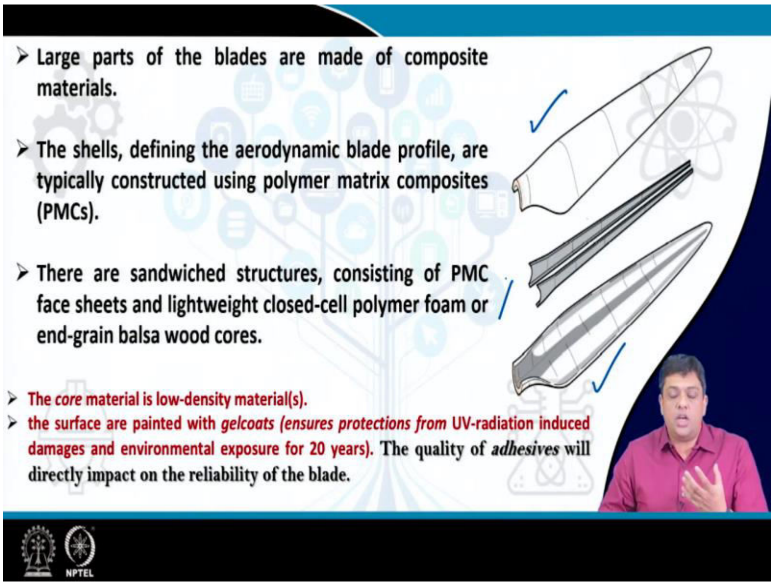

In the earlier lecture we saw that the wind turbine blade has shells, the two shells which are aerodynamic blades, they are brought together and in between you have a sandwich structure which consists of a PMC face sheets which are made of light weight close shell polymer foam or end grain balsa wood cores. The core of this blade is of low density material if I asked you this question, why do you need the low density material? Because we want to maintain low weight of the turbine.

Now, we had also seen that the surface of the blades have to be so designed that they can sustain over a large period of time. To ensure that the surface of the blades are coated mostly by gel coats. This coating protects the surface of the blade from UV radiation induced damages and environmental exposures over a period of 20 years. Because if you understand and if you realize that the wind blades are going to see different summers, winter, rainy seasons and all kinds of harsh environments.

So, you must protect the wind plate. And you will also remember that we had talked to you very briefly regarding that all these components are joined together using adhesives. Therefore, the quality of the adhesives will directly impact the reliability of the plate. And also ensure sustainability of the whole system over a period of 20 years. So, these were the terms or ideas which were briefly touched upon in the previous lecture.

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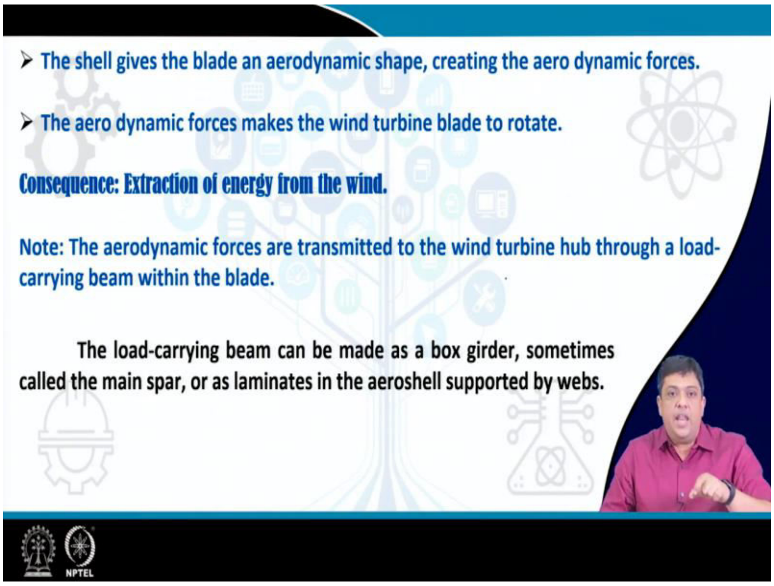

We had seen that the shell gives the blade an aerodynamic shape. Why do you need an aerodynamic shape? Because this shape leads to the appearance of the aerodynamic forces. These aerodynamic forces make the turbine blade to rotate. What is the consequence of appearance of this force and the induced rotation that you can extract energy from the wind. Because wind is leading to the rotation and if you are coupling your system with the electric motor then you can extract the energy.

Please note the aerodynamic forces are transmitted to the wind turbine hub through a load carrying beam within the plate. So, as you saw in the previous slide there is a load carrying beam and that is the use of the load carrying beam. And the load carrying beam can be made off of box girders, sometimes called as main spar or as laminates in the aeroshell supported by webs. So, you can have these two protocols to design the load carrying beam so that it can sustain the aerodynamic blades or the shells.

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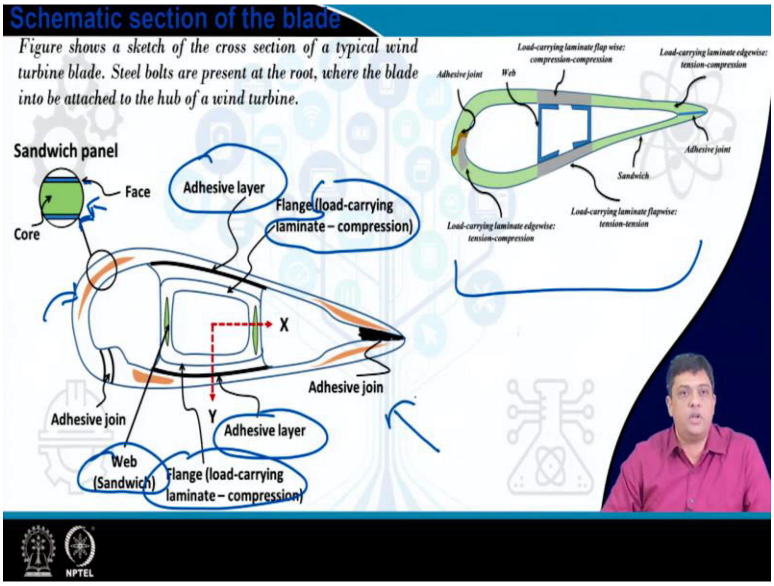

And we had seen the schematic of a typical wind blade which are used in today's wind turbines. And you see what do you have? You have two aerodynamic shells separated by the load bearing web and they are joined by various adhesives. So, you can see if you zoom this section you can clearly see that there is a sandwiched panel with the core and the faces in between.

So, you will see you have adhesive layers, you have the load carrying laminate which allows the and protects and separates the two shells and in between you have the sandwich structures. So, it is clear that the adhesive layer, the load bearing layer and the face, the top face and the bottom surface of the wind blade will play a critical role in the overall functioning of the plate. This is what we had shown to you earlier. So, it is just a much more cleaner picture of the detailed structure of a wind plate.

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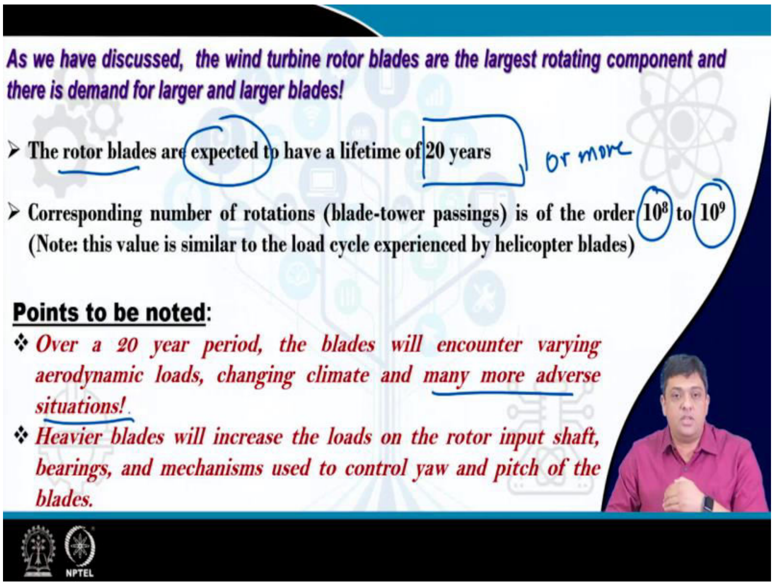

As discussed in the previous class. What do we expect from a wind turbine based system? We anticipate that the system will be working for at least 20 years or more. So, if it has to work for 20 years or more the blades should also have a lifetime of minimum of 20 years or more. Therefore, the rotor blades are expected to have a lifetime of 20 years or more. And if you count the number of times the blade will cross the axis or the number of times the blades will be passing through the tower.

Then they are of the orders of 10 raised to the power of 8 or 10 to, 10 raise to the 9 times. And just to give you a feel of what these numbers actually mean. This value is similar to the load cycle experience by the helicopter plates. So, that is the kind of load cycle which the wind turbine blades are expected to undergo or withstand. So, as to ensure that the wind turbine system is lasting for 20 years or more.

So, along with this please remember that 20 year period means that the blades will be encountering various aerodynamic loads, changing climate, and many more adverse conditions. And how do you make a wind blade? Answer is wind blade will be made using different types of materials. Materials that means you should have materials which are able to encounter varying loads changing climates and many more adverse situations over a period of 20 years.

And if you make the blades very long so that you can extract more energy, then the blades will be heavier. And if the blades become heavier what will happen, they will increase the loads on the rotor input shaft the bearings, the mechanisms used to control the yaw and the pitch of the blade.

So, your construction of the tower the point where you combine your necessarily to the tower the yaw mechanism everything become more difficult to manage if the blades become very heavy. And immediately somebody would say okay we are moving towards futuristic technologies.

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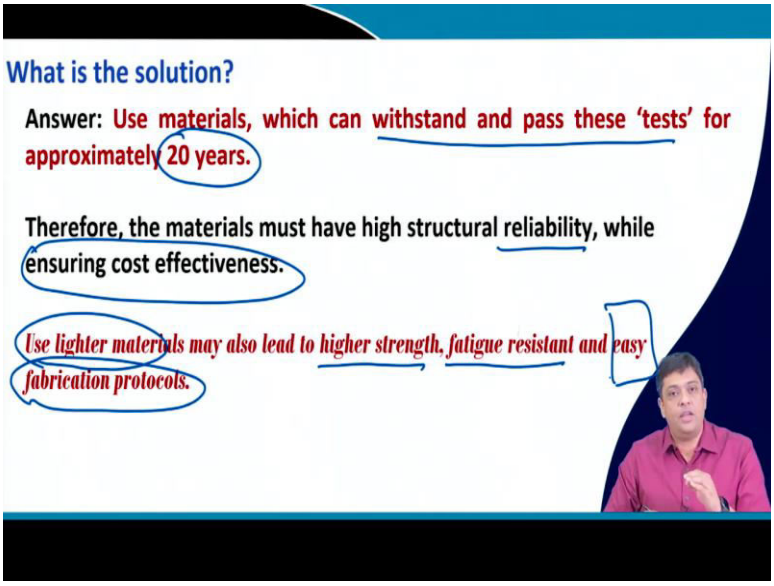

Why do you really want to have blades which are heavier please use smart materials which are light but are able to give you the desired performance, very good. This is the logical answer which people will be giving you immediately. But what materials, if you ask these are words what materials, which type of materials that is what is critical for us. We should pinpoint the materials that we will use.

And the materials which will also have the characteristics to deliver the required performance. So, we should have materials which are able to withstand and pass these tests for 20 year period they should be reliable and more so as there are many renewable based energy technologies coming into the market and forefront. And they are competing with each other also please remember that they are also competing with each other just to impress upon the end user that they are more useful both economically and industrially.

And at the end of the user with the efficiency they can deliver. So, you must have the system which you are designing which is structurally reliable while ensuring cost effectiveness. And if you are ensuring or asking for high efficiency systems with capacity to deliver more energy or extract more energy you are talking about large size wind blades then the materials should also be light.

But light while they also have higher strength they should be able to resist fatigue and fatigue is induced failures and along with that they should be easy to fabricate. Otherwise if they are difficult to fabricate their mass production becomes low or economically it is not feasible to produce them in bulk. Along with that you also increase the cost if the number of steps required to produce those materials are large.

So they should also have easy fabrication protocols. So these are the solutions which people will give immediately if you talk one to one and the answer looks quite visible. But we should now move towards a direction where we give pinpointed answers with specific materials.

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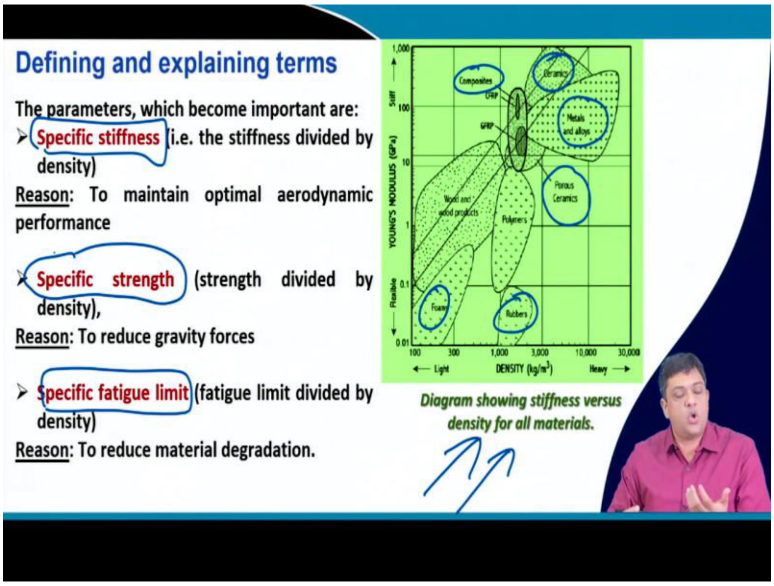

If we talk about the materials that are going to be useful to us or the various kinds of materials that are given to us, then they can be shown in the graph which is shown on the right hand side of the slide. So, if you plot the Young's modulus as a function of density you can have various kinds of materials. You can have composites, you can have porous ceramics, metals, alloys, ceramics, forms, rubbers.

But you will see that the choice of the material has to be such that it gives you low density, but high Young's modulus and there has to be an optimum choice so that you can get the desired output. For that the parameters which become important to us are specific stiffness, specific stiffness is defined as the stiffness divided by density. And why does specific stiffness become important?

Because this will be the parameter which will help to maintain the optimal aerodynamic performance of the plate, second specific strength that is strength divided by density. So, if you have very heavy materials then the effect from gravity will be much larger. And if you have slightly lighter weight material then the effect of gravity forces can be reduced. So, the specific strength will be related to the importance of reducing the effects of gravity forces.

And finally we have the specific fatigue limit that is the fatigue limit divided by density. And that is related to the materials degradation. So, if you want to reduce the materials degradation you will talk in terms of specific fatigue limit.

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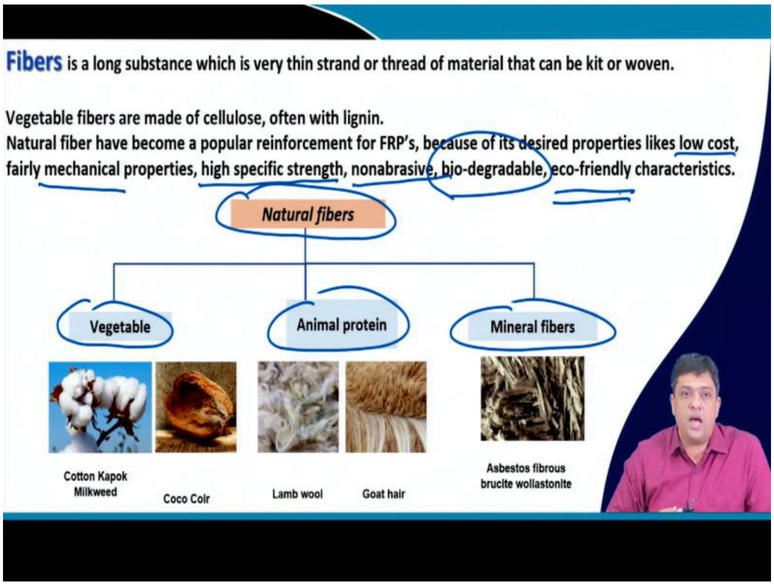

As indicated materials will be playing a critical role in giving you the desired performance. And there are different types of materials which are able to give you the desired performance. And the most important and relevant to us for this module are fibers, composites, and matrix materials. What are these three will be explained in next few minutes. Let us take the example of fibers. What are fibers?

Fibers are basically long substances which are thin strand or thread of material that can be knit or woven. And then, there are different types of fibers. There are naturally occurring fibers they can be sub classified as vegetable fibers or animal fibers or mineral fibers. The naturally occurring fibers are mostly used in reinforced polymers. And they also have the desired properties of low cost.

They are although they look to be thin, they still have a reasonably high mechanical strength both in terms of Young's modulus or if you are applying any other kind of stress they are able to sustain it. They are nonabrasive and most of these naturally occurring fibers are bio-degradable. And if they are bio-degradable they have mostly the property of being friendly towards our environment.

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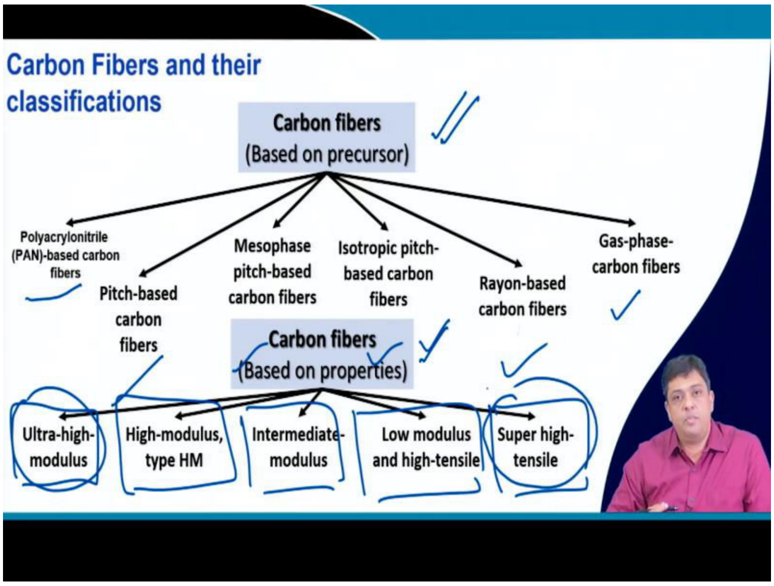

As of today the next class of fibers which I am mentioning those are based on carbon are mostly used and they have large number of applications and they are finding using various kinds of systems. The carbon fibers can be classified under various sub headings or based on the way they are synthesized or the shape and the size. So, let us say the carbon fibers if you just want to classify them based on the precursor which was used to fabricate these fibers.

They can be PAN based carbon fibers or pitch based carbon fibers or various other types of carbon fibers which are mentioned on this slide. And you should remember that these carbon fibers are basically using different precursors while they are being synthesized. Now, carbon fibers if you want to classify them based on the properties.

Then they can be classified as the ones which have ultra-high modulus or high modulus, intermediate modulus, low modulus, but high tensile strength, and then super high tensile carbon fibers. So, you can either classify using the precursors which are used to fabricate these carbons or the properties of these carbon fibers. You can clearly see if you want to have fiber which is extremely high mod, has extremely high modulus. Then you will actually use the ultra-high modulus type carbon fibers. And on the other side you have the carbon fibers which will give you extremely high tensile strengths.

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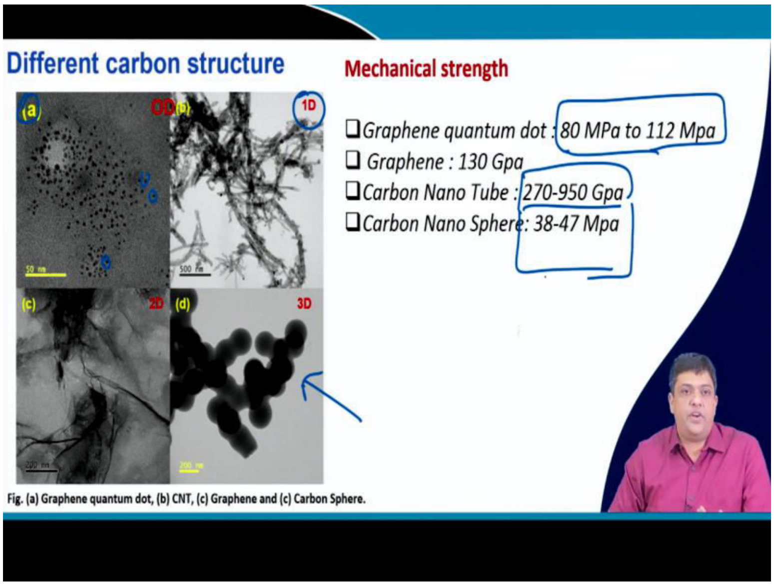

If you see the scanning electron microscope or the transmission electron microscope pictures which are shown on the left hand side of this slide you will see that there are different types of materials or morphologies or shapes of certain particles which are shown. Actually these are the different shapes of carbon structures or the structures which are formed using carbon itself.

For example, figure a gives you the typical morphology of graphene quantum dots. Now, why graphene? Because they are able to have significant amount of Young's modulus. Then you can have carbon nanotubes so these are carbon nanotube pictures. So, you have carbon structures but in the arranged in a tubular morphology. You can clearly see the values of the Young’s modulus are quite different in both the case.

From there you can actually go to a 3 dimensional carbon sphere and you will see that the Young’s modulus value changes once again. So, depending upon what type of structure you use you will have materials with different mechanical strengths.

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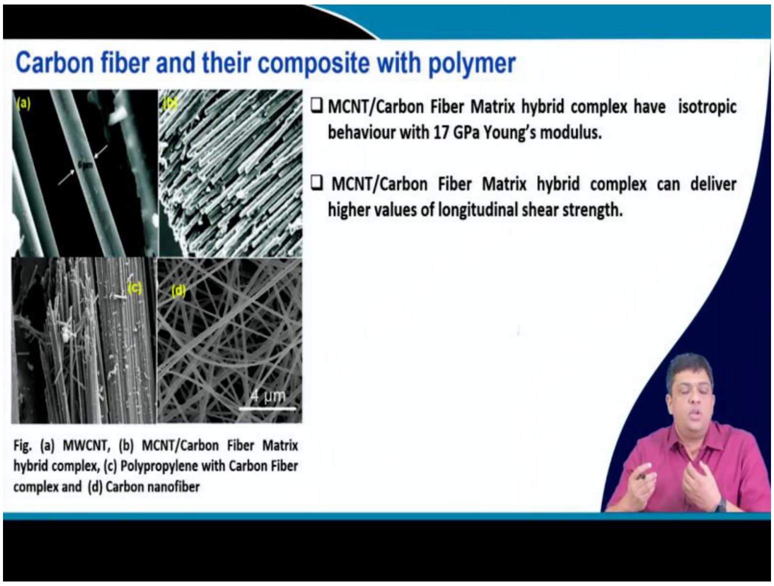

Similarly, you can see that you one can have different forms of these fibers. For example, figure a gives you the picture of a multi walled carbon nanotube that is MWCNT. So, single wall carbon nanotube you have arrangement with just in a way that you have a single tubular morphology. But if you have multiple tubes then running parallel to each other then you can call them as multi walled carbon nanotubes.

Depending upon how you use these fibers you can have multi walled carbon nanotubes, carbon fiber, matrix hybrid composites, or complex systems so you have mixed two systems and then you are getting a new structure. Or you can use them as individual fibers as shown in figure d. And again (they) these kinds of structures are able to give you varying orders of Young's modulus or longitudinal shear strength. As you will see from the picture itself that as the shape changes it is expected that the strength will also change.

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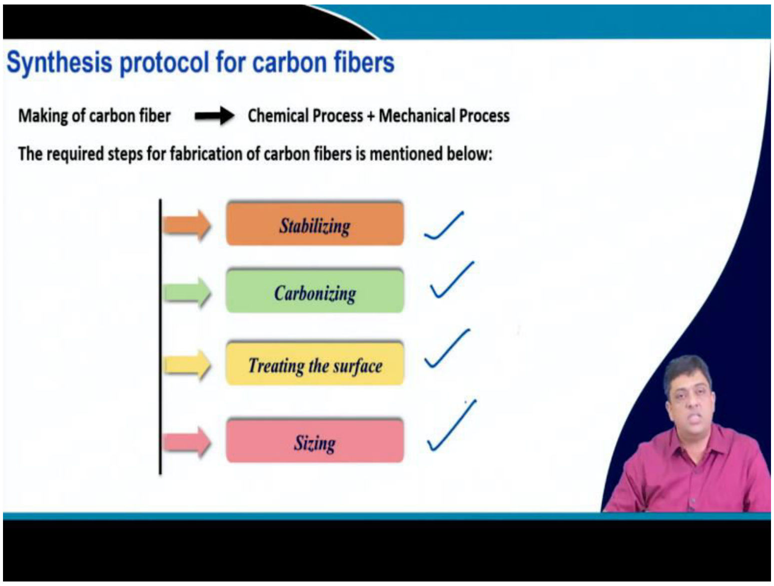

The question one must ask that if I am interested to work on these carbon structures and then use them in device, how do I obtain these carbon structures? Then mostly these carbon fibers are obtained with a combination of initial chemical process followed by a mechanical process. And typically the steps involved to obtain the carbon fibers include stabilization, carbonization of the precursors treatment of the surface and then sizing of the fibers.

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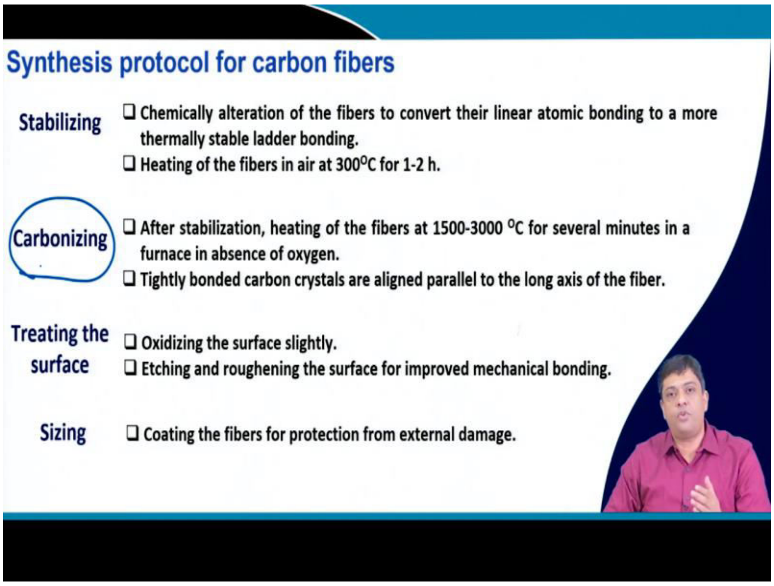

Stabilizing means that you are chemically altering the fibers to convert their linear atomic bonding to a more stable and thermally stable ladder bonding. And they are junk, for this process you heat the fibers in air. Let us say at around 300 degrees C for 1 to 2 hours. Once you have stabilized the carbon fibers you perform the carbonizing. For this, you take the stabilized carbon fibers and heat them to 1500 to 3000 degrees C's for several minutes in a furnace but in absence of oxygen.

What happens this results in tightly bonded carbon structures. And these crystals are so that they are aligned parallel to the long axis of the fiber. So, they grow along the axis of the fiber. Once you have stabilized, carbonized, or carbonization has been done you create the surface use in a oxidizing media followed by the etching and ruffling of the surface for improved mechanical bonding. And finally sizing ensures the coating of the fibers for protection from external damage.

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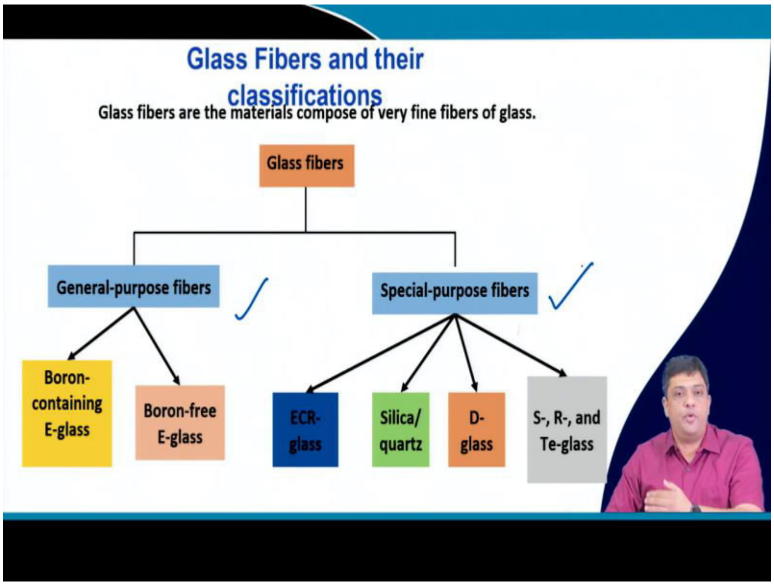

Similar to carbon fibers the other class of fibers which are useful to us are glass fibers. And then there are various types of glass fibers you can have general purpose glass fibers or special purpose glass fibers. But you will see that 90 percent of the fibers are general purpose fibers. And those are the ones which are used routinely in making composites or fiber base substrates.

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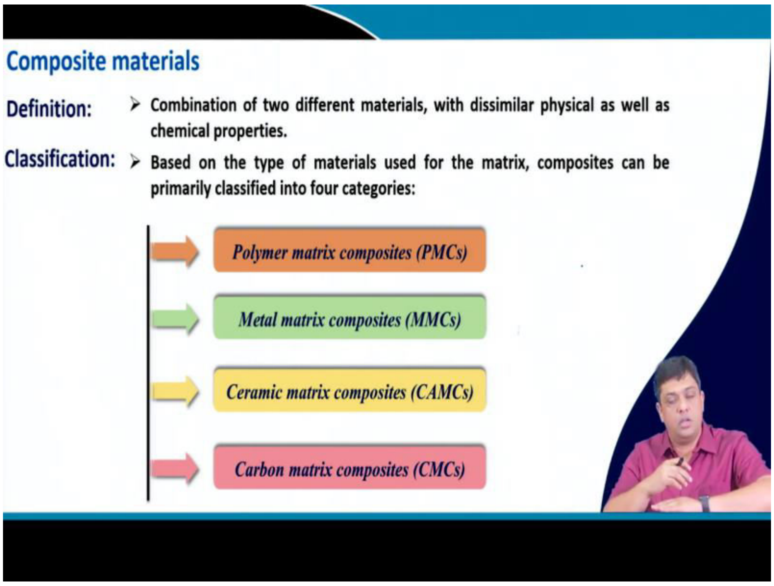

The next class of materials which are useful for wind turbine blades are the composite materials. These materials basically are obtained as a combination of two or more than two materials which have dissimilar similar physical and chemical properties. But when you bring them these two dissimilar materials together. The property you get from these mixture is very different from the individual properties of the materials which are being mixed together.

So, the composite materials are such that they do come along while they are retaining their individual properties. The overall properties which you get from a composite is very different from the individual components. And based on the type of materials used for the matrix that is the host composites can be primarily classified into 4 categories. The polymer matrix composites, the metal matrix composites, the ceramic matrix composites, and carbon matrix composites. So, in polymer matrix composite what will happen? The polymer material will play the role of being the host on which the dispersed white is being dispersed.

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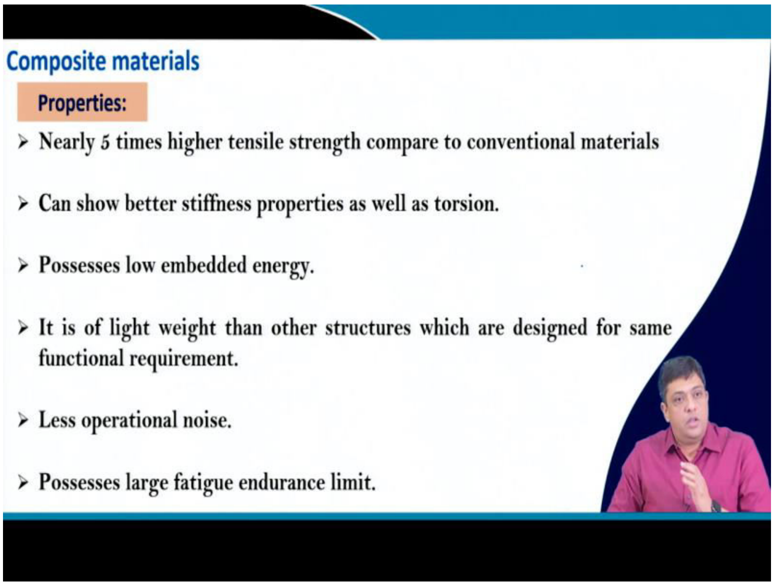

The important properties of these composites are they generally have 5 times higher tensile strength compared to the conventional materials. They show improved stiffness properties, they possess low embedded energy, and they also give you much lighter weight materials or structures but they maintain the required performance characteristics similar to those from conventional materials. And they also have higher fatigue endurance limits.

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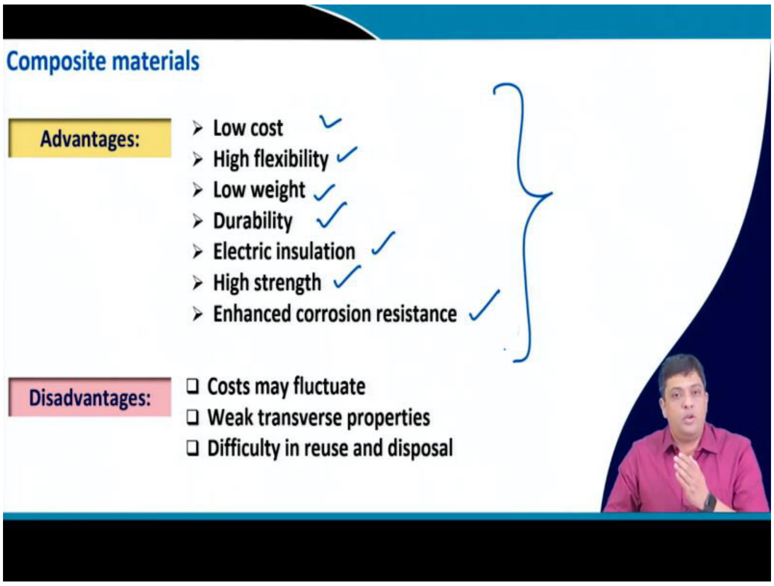

So, once again advantages low cost, high flexibility, low weight, they are more durable, mostly they are electrically insulating, while they are ensuring high strength, and enhanced corrosion resistance. So, if you talk about the properties which were required in a wind turbine blade material you can clearly see the composite materials have nearly all those properties.

They have low cost, they are flexible so they can be designed in a mold in any manner which we want, they give you low weight materials, while ensuring high strength, they are electrically insulating, and they but they also ensure that they are able to resist the effects of corrosion. So, this is what is want you want in a blade that is going to be used in a wind turbine.

As of now, mostly the disadvantages associated with composites are that the costs may fluctuate depending upon the host matrix which you use the quality of the host matrix which you use and the nature and the quality of the disposal which you use. Second they have weak transfers properties. But the most critical and the fact which you should remember that they are difficult to reuse after for example, what do we mean by they are difficult to reuse.

Suppose, you have a wind turbine blade made out of composites it runs for 20 years. Then the fatigue mechanism sets in and you get a condition that the blade is now not usable. You would like to reuse the material which were initially used to fabricate the blades and then make another blade so that it can go back to the turbine system. But to reuse composites it is not an easy task.

And finally the disposal strategies which have to be followed to discard the composites are non-trivial. So, you have a protocol which will be have to be followed before you can dispose of the composites.

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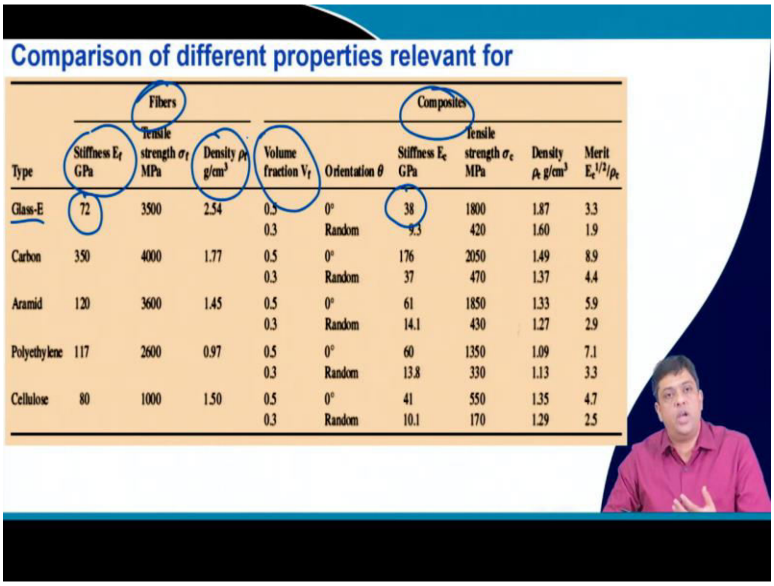

So, this table just gives you the relative properties between the fibers and the different types of composites be it be stiffness, be it be density. You will see that you get different kind of properties. So, for the commonly or routinely use glass, fiber glass E which is a low electrical conducting glass, you see the stiffness Ef has a value of 72 GPa in comparison if you talk about composites then the values may be quite different.

So, you will get different kinds of properties when you move from one material to different materials. And as I said the volume fraction plays the critical role in defining the properties in composites volume fraction means the volume of the disposal. The material which is going to be dispersed in the host matrix is called disposal, see the volume fraction of the disposal will change and as it changes the properties will also change.

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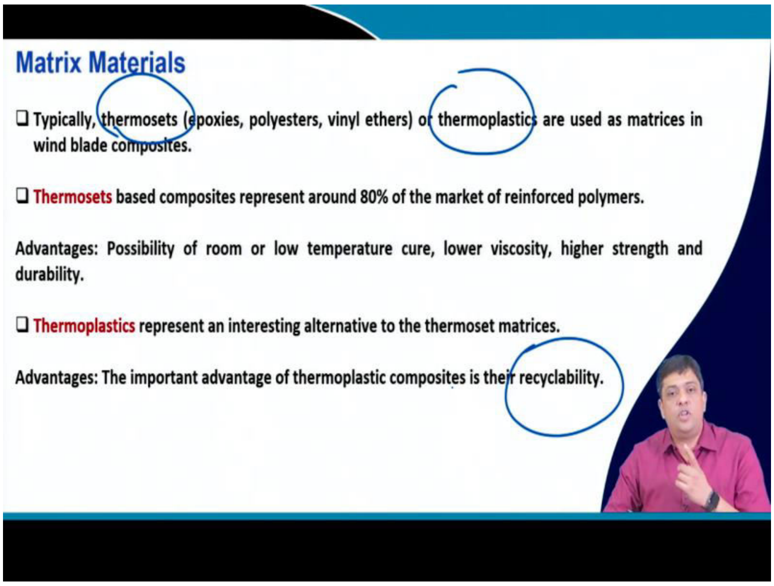

And finally you have matrix materials which are used in carbon fibers and typically thermosets are used or thermoplastics are used as matrices in wind blade components. Thermoset based composites actually as of today have 80 percent of the market of the reinforced polymers. Because they ensure lower viscosity, higher strength, they are more durable, and they can be prepared at room or slightly low temperature.

While thermoplastics are an interesting alternatives which have come up over the last few decades. And the major advantage is that they give you higher recyclability. So, depending upon the cost factors, the time duration for which you are going to use the turbine. And what are the adverse conditions which the blades are going to face you choose the material which will be or which should be used to fabricate the wind turbine blades.

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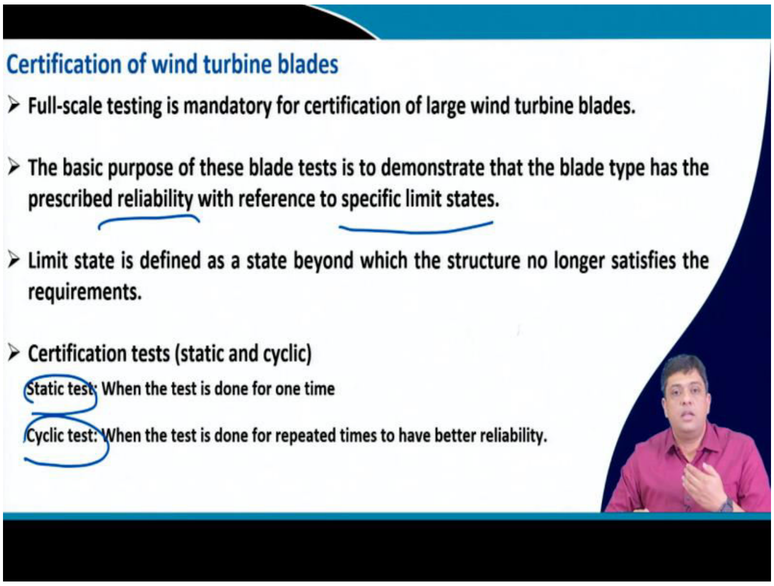

And these blades once they are fabricated using different types of materials cannot just be taken and installed in a turbine. They must go full scale testing and there is a certification process for wind turbine blades. And these blades are certified that they are able to give you the prescribed reliability and the specific limit states. And classification tests can be both static or cyclic. Static tests are what when the test is done for one time.

While cyclic tests are one the one where the test is performed repeatedly over many cycles and then you come to a conclusion about the reliability of the blades.

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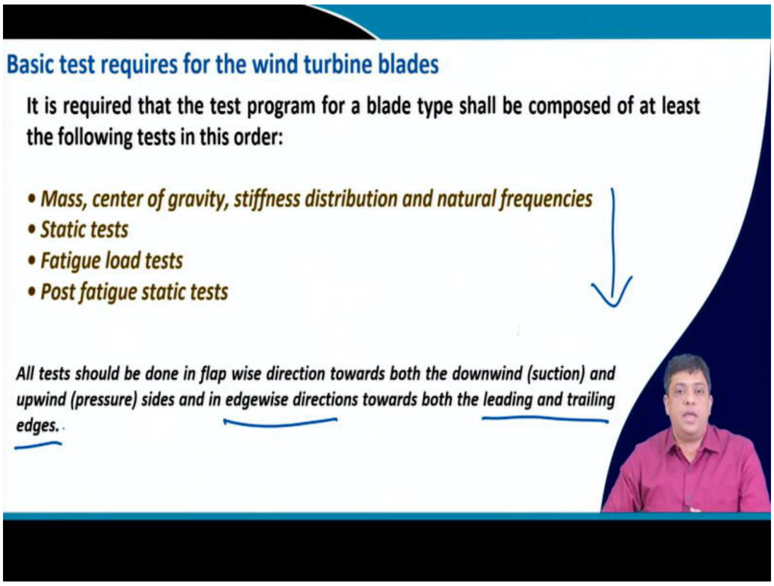

The basic tests which are required to certify or characterize the wind mill properties are the ones such as the mass, the center of gravity, stiffness distribution, or natural frequency based test, the static test, the fatigue load test, and post fatigue static test. And generally the test program includes at least one of the tests in the orders given here. And these tests whichever you choose should be done in flap wise direction towards the downwind and also the upwind side.

And finally in the edge wise direction towards both leading and trailing edges. So, if you want to have a detailed learning about the test which are carried out for wind turbines you are requested to follow the references given at the end of this lecture. Because the details about the test itself is a full time course.

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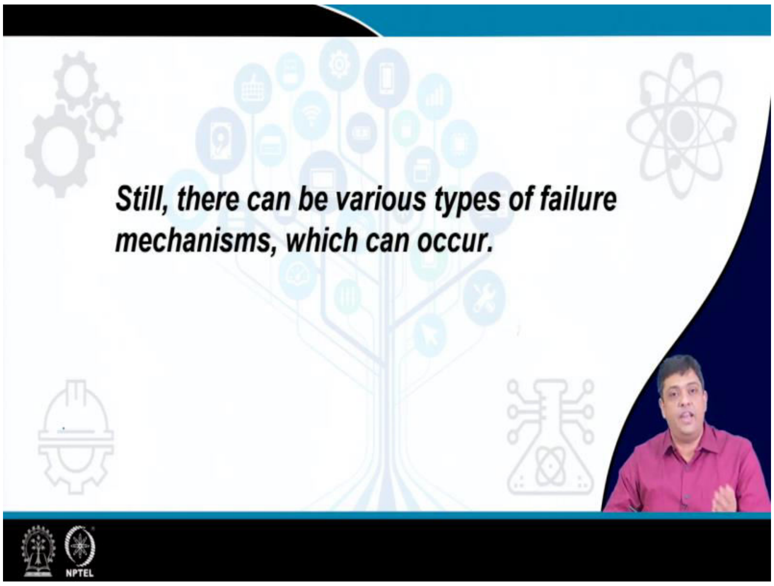

Even if I have talked to you about materials the various test with these blades have to undergo before they can be applied to turbines. Still there can be various types of failure mechanism that can occur while these turbines are operating and lead to the failure of the whole system as such.

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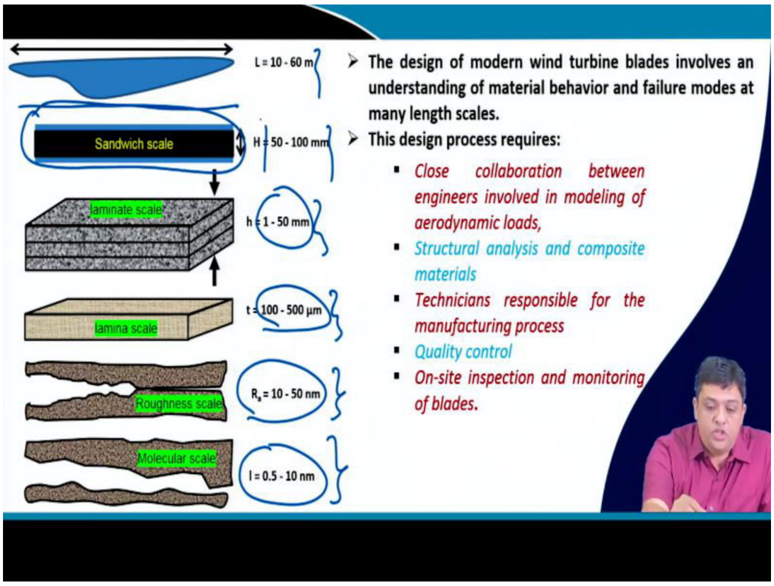

And the failure can occur at various scales. You can see they are listed under different length scales. So if I talked about a turbine which can be let us say 10 to 60 meters long then the failure mechanisms is not necessary will occur only at large scales or the places which are visible to your eye that they just you have a crack and the blade breaks it is not so. At very low length scales let us say 0.5 to 10 nano meters you can have molecular scale failure where the material is self has degraded and you have the failure of the matrix materials of the materials which are used to fabricate.

If you go to the range of 10 to 50 nano meters you can have different kind of facture mechanics which can set in. Along with that when you had these laminates which were being used to protect or the load bearing laminates which were being used between the two aerodynamic sheet. They themselves can have failures and those can lie in the range of 10 to 500 macro meters.

Or if you are talking about different laminates then they can occur in the range of 1 to 50 millimeters. And finally you had the sandwich structures the two surface and the core and in this structure itself you can have the failure. So there are various places the system itself can find degradation mechanism and leading to failure of the overall performance. And you can have for example sandwich scale failure in the range of 50 to 100 millimeters.

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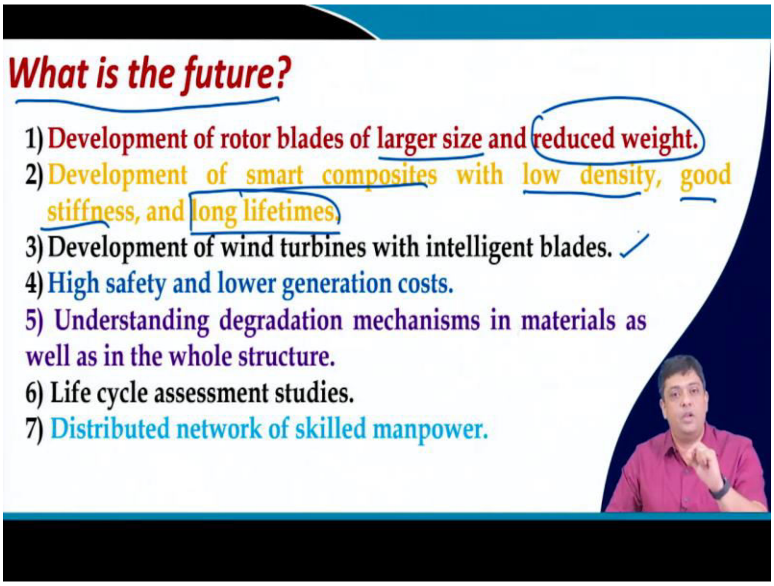

So I have talked to you about the materials. What type of materials? How do we certify the designs which have been made and the materials that have been used. Even after undergoing all these tests there can still be failures. And if that is so you will think the system itself is actually very complex and therefore it should not be used, that is not the right approach. Actually that is where the opportunities open for us.

We have to counter the limiting factors and these factors once are countered properly will give you futuristic designs of wind turbine or wind turbine blades. Therefore, the future of the wind turbine or wind energy extraction depends on the development of rotor blades of large size but reduced weight. Again this will happen then you use smart composites which have low density, high stiffness, and long lifetimes.

Along with that you will have to develop turbines with intelligent blades that means the blades which are able to sense the change in their nearby environment. And then immediately respond to the change which may take place. Once you are having these turbines which has smart, they are able to respond to changes then comes your other aspects. Obviously, they must also ensure higher safety and low production cost along with low generation cost.

Why low generation cost? Remember because they are also competing with other renewable energy systems. At the research level you have a wide variety of problems which open for us. For example, it is critical to understand the degradation mechanism in materials as well as in the whole structure that can appear and lead to the damage of the wind blade. So, if I understand the mechanism I can take corrective steps to suppress those mechanism.

And we should also take into account the life cycle assessment studies. What are these studies? These studies include the environmental impact right from the inception stage to implementation to disposal stage. So and it include the carbon footprint or the cost factors or emission of the any other gases which may take place at each and every step of production of the material or production of the towers or production of the wires.

And the overall process will give you one complete set and final carbon footprint of the whole process. So we should perform the life cycle assessment studies and then only if those values of carbon di oxide emission or any other types of parameters that are relevant to environmental impacts are low then only this technology will be called as the green technology.

As you see that this technology involves large number of components. So as you see that the whole system is a combination of various components both electrical or civil or you can have components which are going to extract the energy. So they will have mechanical aspects you have different types of materials but all of them will have to come together then only the system will work.

And for that you need a large distributed network of skilled man power who will perform their designated task and finally they will come to together to deliver one final system that is for example wind turbine.

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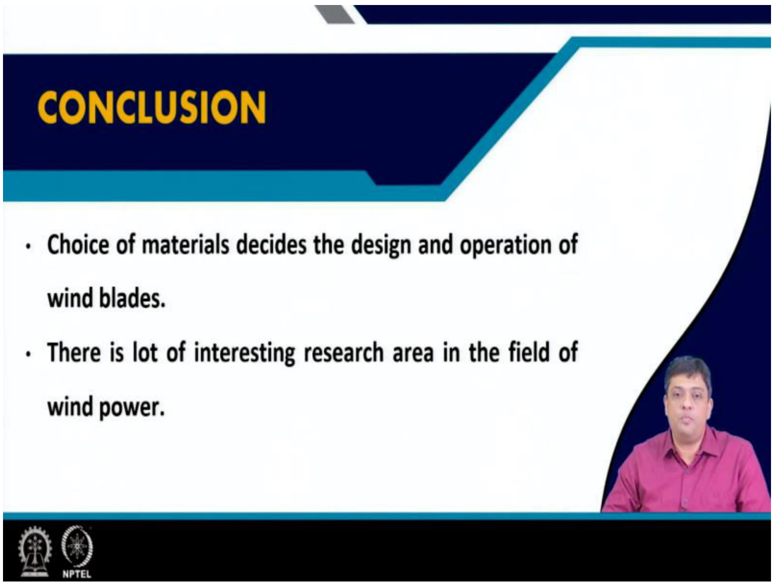

So I hope after going through today's lecture it is clear to you that the choice of material will decide the design and the operation of the wind blades. Also there are a large number of interesting research areas which are related to wind power or wind energy.

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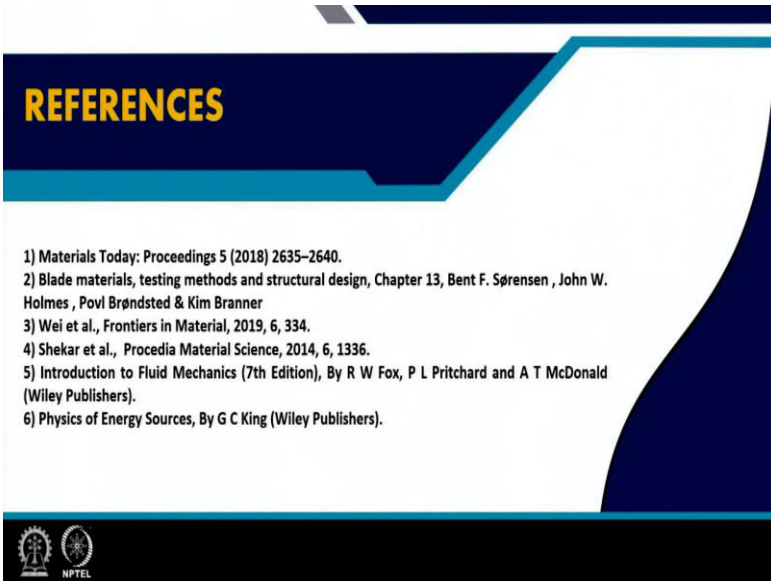

These are the references which were used to obtain data that were presented in today's lecture. And I thank you for attending today's lecture. And from next lecture we will move on to the next module have a nice day.