Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 18
Introduction to Composites, Types and Characteristics

Hello friends, welcome to the NPTEL online certification course Retrofitting and Rehabilitation of Civil Infrastructure. Today we will discuss module D. The topic for Module D is Fiber Reinforced Polymer Composites and its Characteristics.

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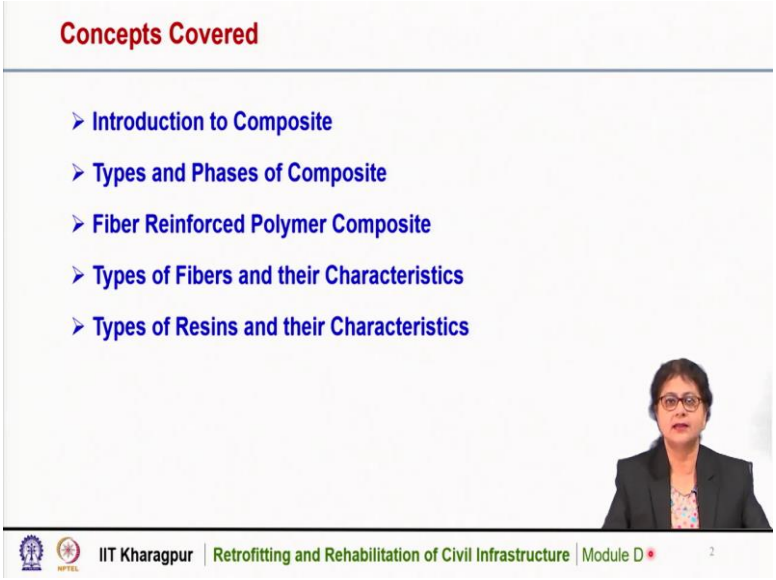

In today's lecture, we will discuss Introduction to Composite Material, Types and Phases of Composite, and Understanding of Fiber Reinforced Polymer Composite, the Types of Fibers and their Characteristics and also Different Types of Resins and Types of Resins and their Characteristics.

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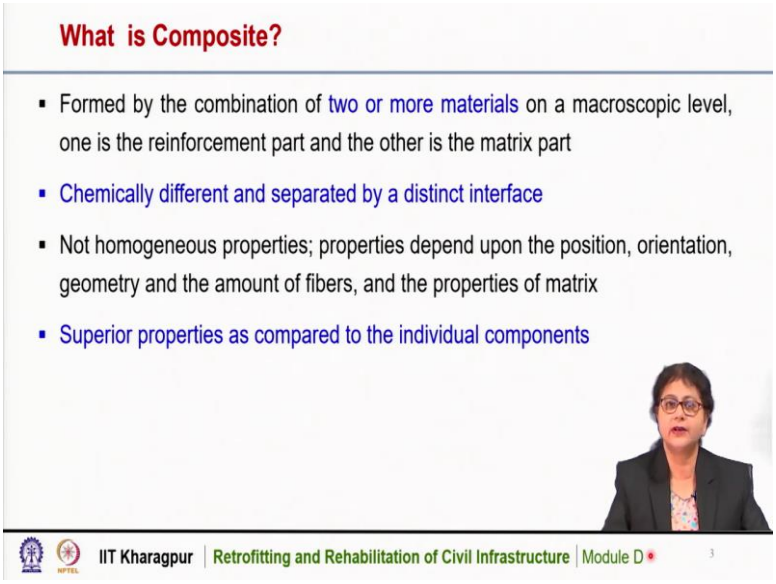

What is a composite? A composite is formed by the combination of two or more materials on a macroscopic level, one material is the reinforcement part and the other is the matrix part. The two or more materials are chemically different and they are separated by a distinct interface. The composite does not have any homogeneous properties, the properties depend upon the position, orientation, geometry and the number of fibers and also on the properties of matrix.

The composite has superior properties as compared to the individual components. So, composite is not a compound, but it is formed by the combination of two or more materials at macroscopic level, one part is the reinforcement part or the fiber part and the other part is the matrix part. The reinforcement part is suspended into the matrix part and they are chemically different. And these two materials have a distinct interface.

The advantage of composite is that we can alter the properties of composite by changing its position, orientation and the amount of fibers in it. So, we can tailor made the properties of composite and that makes it very popular in today's world. The concept of composite is age old. In ancient years also people have used composites, for example, in old age or even in today's rural areas, we are building the mud houses.

In mud houses, we use the straws and that resembles the modern days fibers and the mud resembles the matrix part in it. So, when the fibers that is the straws are placed within the mud, they form the fiber reinforced polymer composite. The same concept is used in today's world with advanced materials to develop the fiber reinforced polymer composites that are used in different fields.

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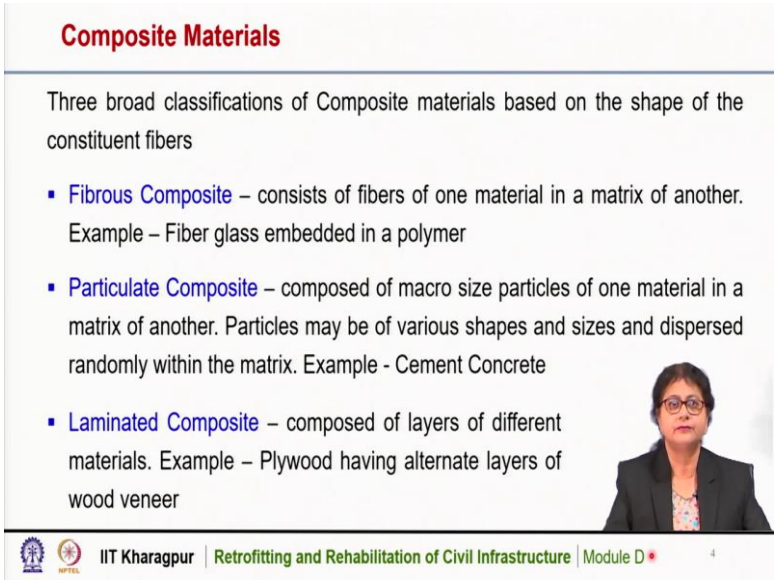

There are three broad classifications of composite materials based on the shape of the constituent fibers. One is fibrous composite, another is particulate composite, and the other is laminated composite. In fibrous composite, it consists of fibers of one material in a matrix of another. For example, fiberglass embedded in a polymer. Particulate composite consists of macro sized particles of one material in a matrix of another.

Here it is not a long fiber, but the reinforcement part is the particles maybe of various shapes and sizes and they are dispersed randomly within the matrix. Example is cement concrete. In cement concrete, the cement paste is the matrix part and aggregates are the particles or the reinforcement part. Laminated composite composed of layers of different materials. For example, plywood having alternate layers of wood veneer, here the layers may be arranged in different orientations, and we can have a laminated composite.

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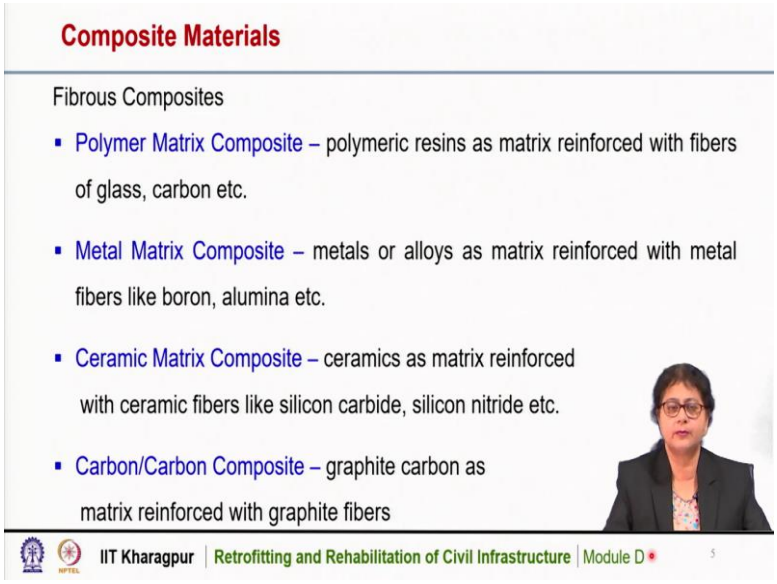

Fibrous composites may have different types, depending on the type of matrix, it could be polymer matrix composite, metal matrix composite, ceramic matrix composite, carbon-carbon composite, etcetera. In polymer matrix composite, polymeric raisins are used as matrix reinforced with fibers of different materials like glass, carbon, etcetera.

In metal matrix composite, the metals or alloys are used as matrix and they are reinforced with metal fibers like boron or alumina, etcetera. In ceramic matrix composite, the ceramic is used as matrix and it is reinforced with ceramic fibers. The ceramic fibers may be silicon carbide, silicon nitride, etcetera. Carbon-carbon composite consists of graphite carbon as matrix and it is reinforced with graphite fibers.

So, depending on the type of matrix, we can differentiate the fibrous composite as polymer matrix composite or metal matrix composite, ceramic matrix composite or carbon-carbon composites.

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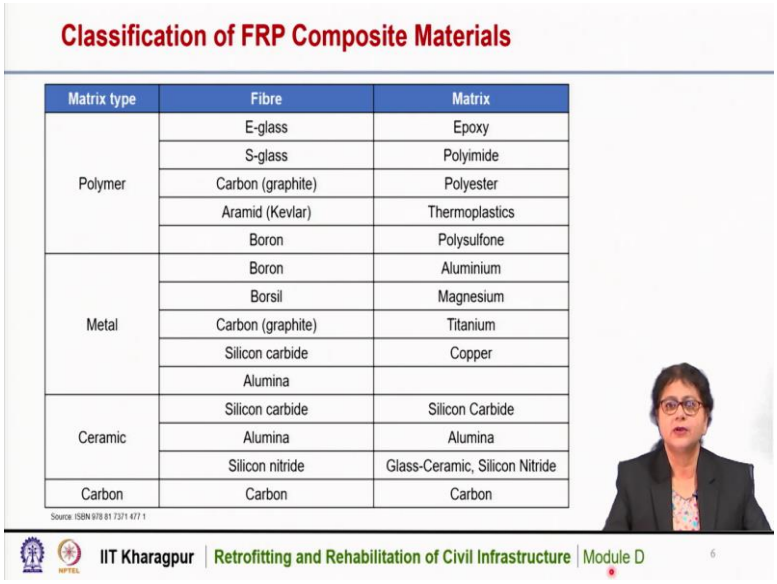

Here, this table gives us the different types of fibers and different types of matrix used in the FRP composite. We can see here this is depending on the type of matrix it could be polymer matrix composite or it could be metal matrix composite, ceramic matrix composite or carbon matrix composite.

So, here these are the different types of fibers that are used in this type of composite and these are the different types of matrix. Fibers may be glass fibers, carbon fibers, boron fibers, etcetera. And matrix may be different types of epoxy, polyimide, polyester, etcetera. So, these things we will discuss in detail in subsequent slides.

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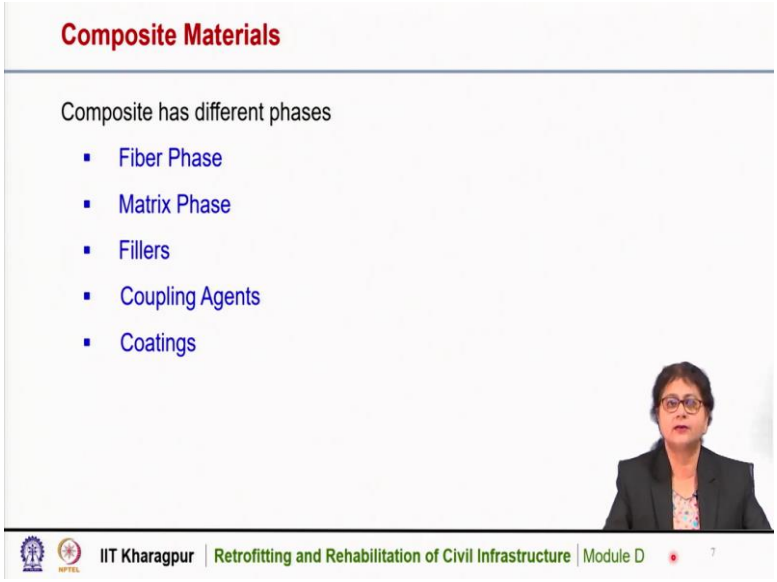

Composite has different phases; the most important phase is the fiber phase and next is the matrix phase. It may also have fillers, coupling agents and coatings.

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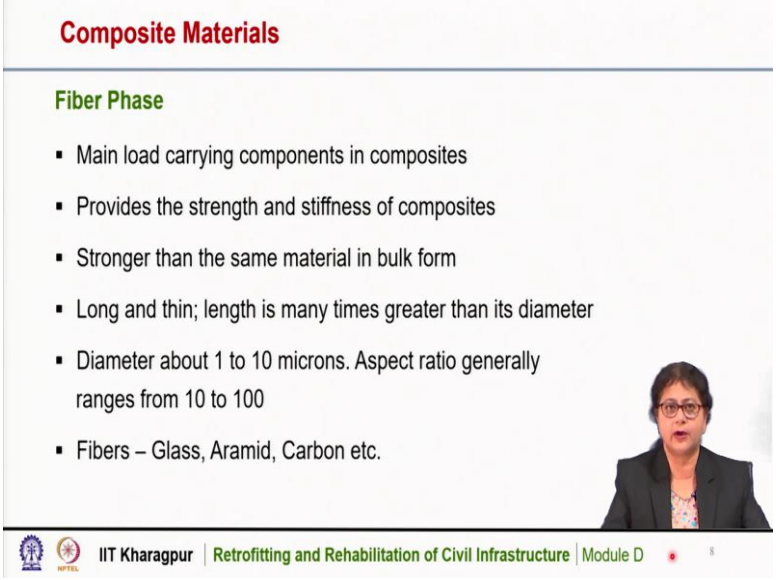

Fiber is the main component in a matrix, it is the main load carrying component in a composite. Fibers provide the strength and stiffness to the composite. The fibers are stronger than the same material in bulk form, because if the material is used in a bulk form, there is a possibility that a number of flaws maybe there or defects maybe there but in case of fibers, the defects are much, much less.

So, the material in fiber form is much stronger than its bulk form. The fibers are long generally with very thin in lateral dimension, the diameter is much small, it is about 1 to 10 microns and the length is many more times than its diameter. The aspect ratio that is the length by diameter ratio is very high, it may range from 10 to 100 maybe even more.

So, fibers are formed by some material and it has very high length as compared to its diameter or lateral dimension. There are different types of fibers like glass fiber, aramid fiber, carbon fiber or some natural fibers are also used like jute fibers or quiet fibers, etcetera. So, fiber is the important component of a composite material, it gives the strength and high stiffness to the composite and it is the main load carrying component in a composite.

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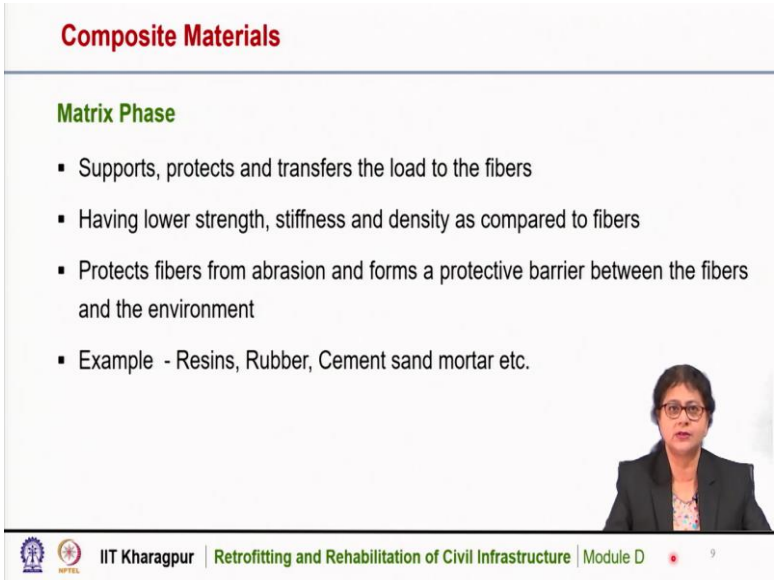

The matrix phase is supporting, protecting and transferring the load to the fibers. The fibers are suspended into the matrix and the matrix has lower strength as compared to fiber. The stiffness and densities are also less as compared to the fibers in it. So, it has generally much lesser strength as compared to fibers. The fibers are suspended into the matrix and the matrix protects the fiber from abrasion and forms a protective barrier between the fibers and the environment.

Since the fibers are suspended into the matrix, the matrix actually protects the fiber from abrasion or from the environment, there are different types of materials which are used as matrix. Resins or rubber or cement sand mortar or different types of chemicals may be used as matrix in a composite material. So, fibers and matrix part are very important components in a composite material. And in addition to that, we may also have fillers.

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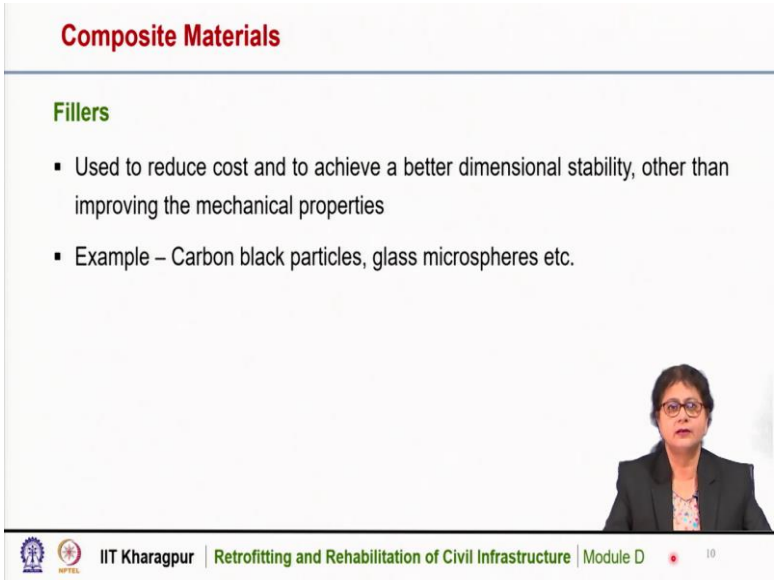

Fillers are used to reduce the cost of the composite and to achieve a better dimensional stability. The fillers are used not for improving the mechanical properties, but to have a better dimensional stability in the material. There are few materials which are used as fillers in a composite like carbon black particles or glass microspheres, etcetera.

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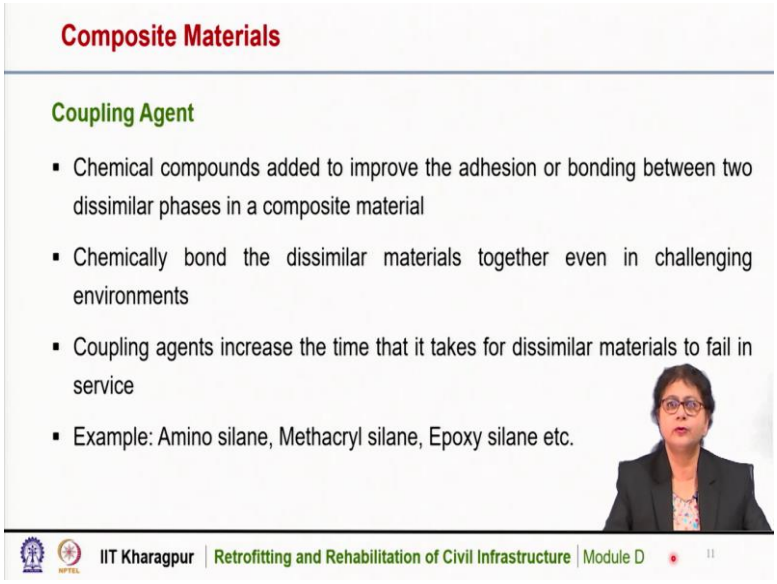

Coupling agent is another component that may be used in a composite material. This is a chemical compound added to improve the adhesion or bonding between two dissimilar phases in a composite material, the two dissimilar phases maybe the fiber part and the matrix part. So, coupling agents can be used as to improve the bonding between these dissimilar phases.

It chemically bonds the dissimilar materials together even in a challenging environment. Coupling agents increase the time that it takes for dissimilar materials to fail in service. In modern days of composite, sometimes coupling agents are used and they are used to improve the bond between the two. The example of coupling agents is Amino silane, there are different silane compounds like Methacryl silane, Epoxy silane, etcetera. That are used as coupling agent in a composite material.

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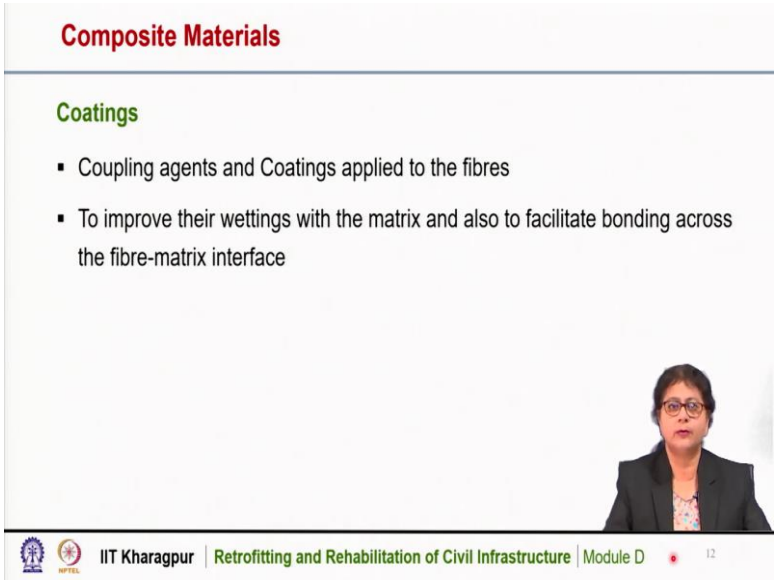

Coatings are also used in composite. Actually, coatings and coupling agents are used in the fibers to improve their wettings with the matrix and also to facilitate bonding across the fiber matrix interface. So, in a composite material, the two main constituents are the fiber part and the matrix part. We can also have coatings or coupling agents and fillers. The fiber part is the main load carrying member and it gives the strength and stiffness to the composite.

The Matrix holds the fiber and their position and protects the fiber from abrasion and environmental effects. The coatings or coupling agents are used to improve the bonding between the two phases and fillers are used for dimensional stability and also to reduce the cost of the composite. So, composite we can manufacture as per our requirement and by altering the amount of fiber and resins or the matrix and by altering the amount of fiber we can create our composite material.

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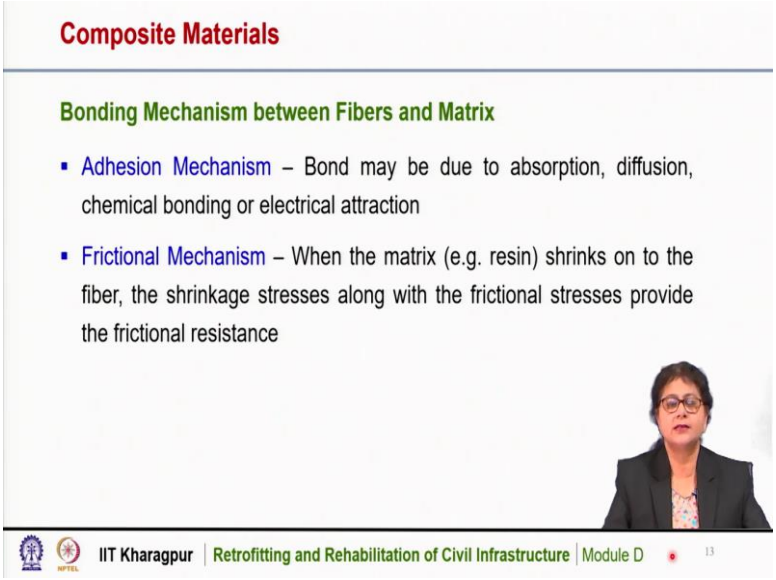

The bonding mechanism between fibers and matrix may be two types, one is adhesion mechanism and the other is frictional mechanism. In adhesion mechanism, the bond may be due to absorption, diffusion, chemical bonding or electrical attraction of the two phases. In case of frictional mechanism when the matrix shrinks on to the fiber, the shrinkage stresses along with the frictional stresses provide the frictional resistance.

So, one is the adhesion mechanism and the other is the frictional mechanism and with these two mechanisms the bonding between the fiber and matrix can take place.

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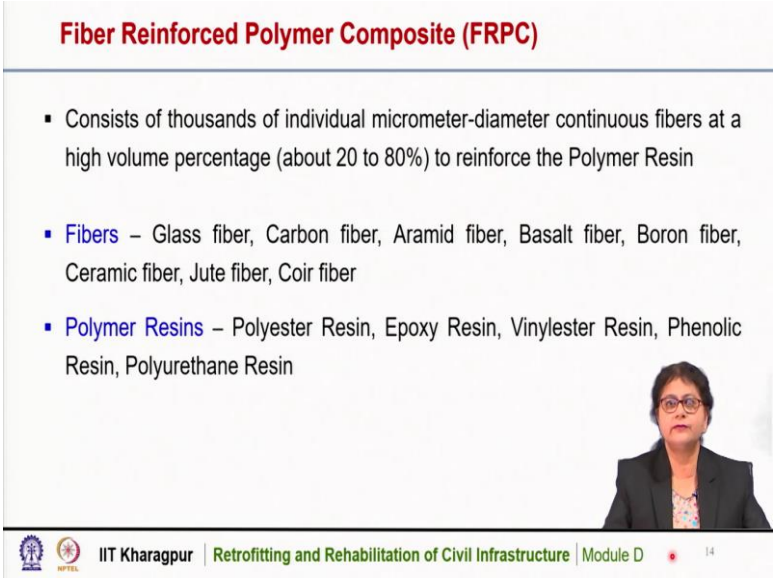

Now we will tell you that, what is a fiber reinforced polymer composite or FRPC. Fiber reinforced polymer composite consists of thousands of individual micrometer-diameter

continuous fibers at a high-volume percentage about 20 to 80 percent or so to reinforce the Polymer Resin. Fiber reinforced polymer composite consists of thousands of individual micrometer-diameter continuous fibers at a high-volume percentage to reinforce the polymer resin.

Here, the fibers are used of different materials like glass fiber, carbon fiber, etcetera. And the matrix is used as the polymer resin. There are different types of polymer resins, polyester resin, epoxy resin, vinylester resin, etcetera. So, in fiber reinforced polymer composite or in short FRPC there are different types of fibers which are used like natural fibers or synthetic fibers and different types of polymer resins that are used as matrix to hold these fibers. The volume percentage of fibers are quite significant about 20 to 80 percent in the composite.

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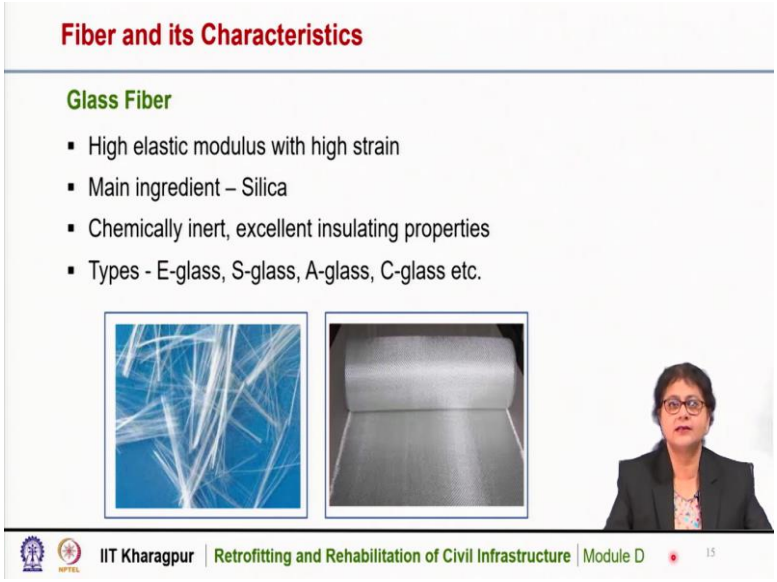

Now, we will discuss the different types of fibers and its characteristics. Glass fiber is one of the most common fibers used in fiber reinforced polymer composites. Glass fiber has high elastic modulus with high strain that is its advantage in glass fiber. The main ingredient of glass fiber is silica. The silica is chemically inert. So, glass fiber is also chemically inert and it has excellent insulating properties.

There are different types of glass fibers, e-glass fibers, s-glass fiber, a-glass fiber, etcetera. Depending upon the characteristics of the glass fibers we can name these types of glass fibers that we will discuss. And these are the pictures of glass fiber. These are individual glass fibers as you can see, they are very bright and white in colour. This is glass fiber and

this is the glass fiber reinforced polymer composite. It is like a cloth and available in rolls. So, this is glass fiber reinforced polymer composite.

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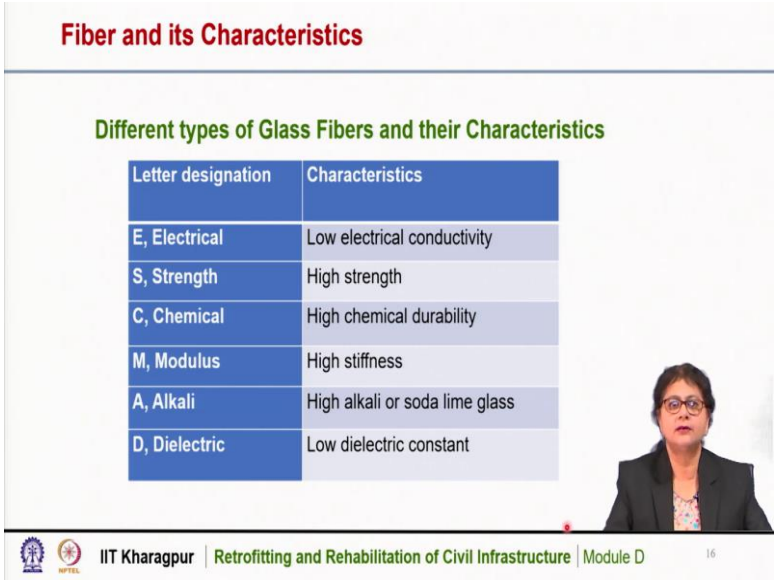

Different types of glass fibers are there and based on their properties they are designated as E-glass fiber or S-glass fiber. So, E stands for low electrical conductivity, S stands for high strength, C stands for High chemical durability, M is for high stiffness, A is for high alkali or soda lime glass, and D or dielectric is the low dielectric constant. So, with these characteristics different types of glass fibers are designated.

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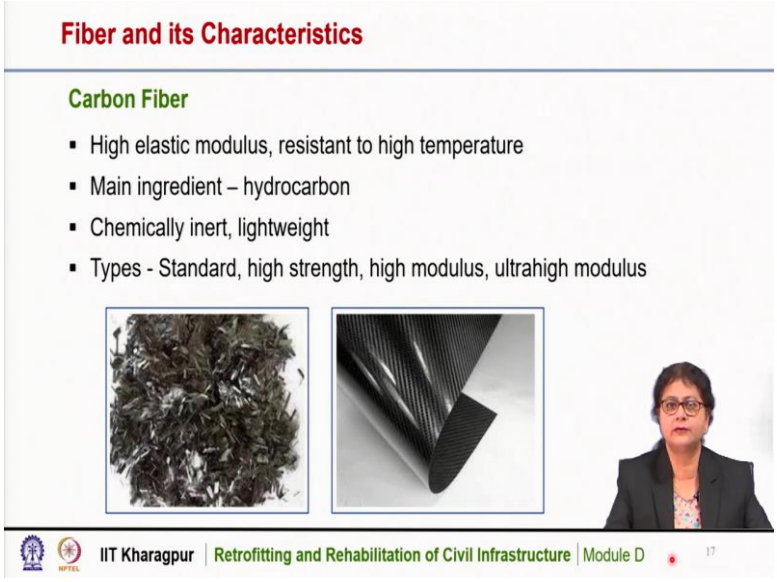

Carbon fiber is also very popular for its wide application; the main ingredient for carbon fiber is hydrocarbon. It has high elastic modulus and it is resistant to high temperature that

is why it is used in various fields. Carbon fibers are chemically inert and they are very lightweight as compared to glass fibers.

There are different types of carbon fibers available, standard carbon fibers or high strength carbon fiber, high modulus carbon fiber or ultra-high modulus carbon fibers. Here are some pictures of carbon fiber. We can see here these are individual carbon fibers and this is a carbon fiber reinforced polymer composite sheet. So, this is a very thin carbon fiber composite.

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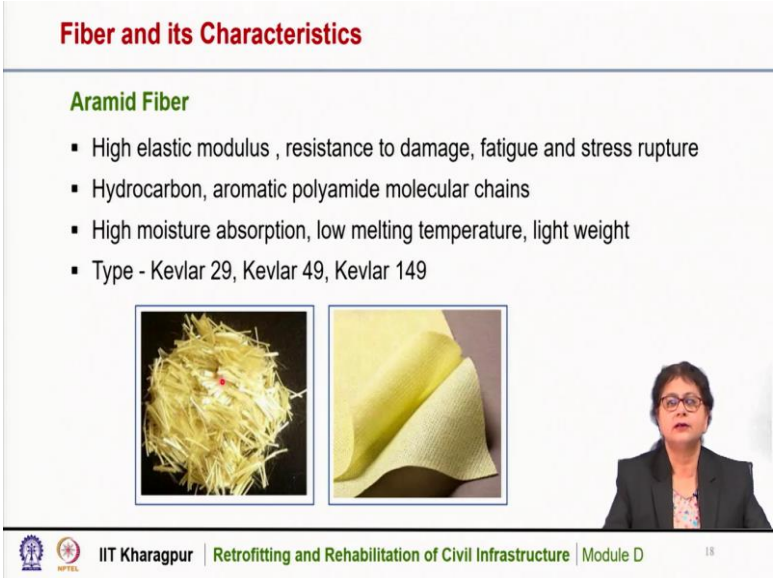

Aramid fiber is also used, the main ingredient for aramid fiber is hydrocarbon and it is the aromatic polyamide molecular chains. So, it consists of hydrocarbon which is aromatic polyamide molecular chains. Aramid fibers also have high elastic modulus and it is resistance to damage fatigue and stress rupture. It is of high moisture absorption value and low melting temperature and it is also lightweight.

There are different types of aramid fibers that are available like Kevlar, Kevlar 29, Kevlar 49, etcetera these are the different types of aramid fiber. Here are some pictures of aramid fiber they are bright yellow in colour. These are individual aramid fibers and this is the aramid fiber reinforced polymer composite. Aramid fibers are used in special applications like as they are resistant to damage and fattening, they are used in bulletproof jackets and in special applications of aircraft and so.

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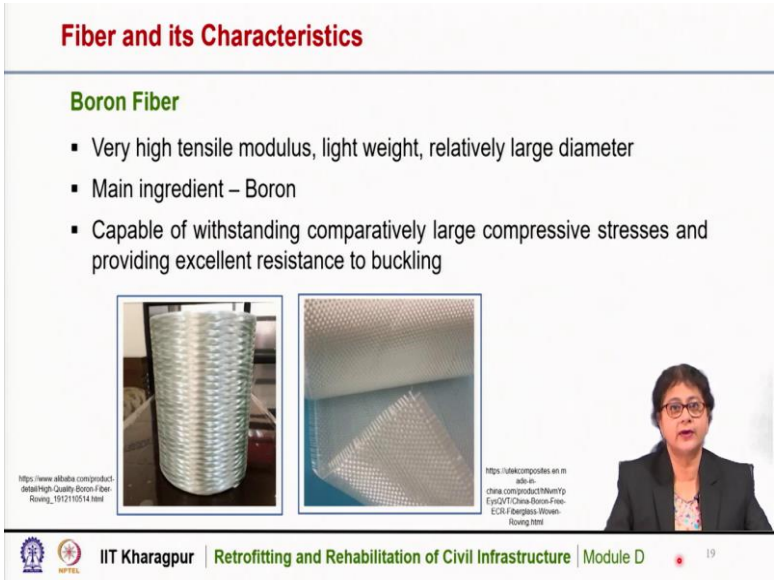

Boron fiber is also used, the main ingredient for boron fiber is boron. It also has very high tensile modulus and it is very lightweight. It has relatively larger diameter as compared to carbon fiber or aramid fiber and that is why it is capable of withstanding comparatively large compressive stresses and providing excellent resistance to buckling. Here are some pictures of boron fiber, we can see here this is a bright colour boron fiber reinforced polymer composites, they are also available in rolls and used in very special applications.

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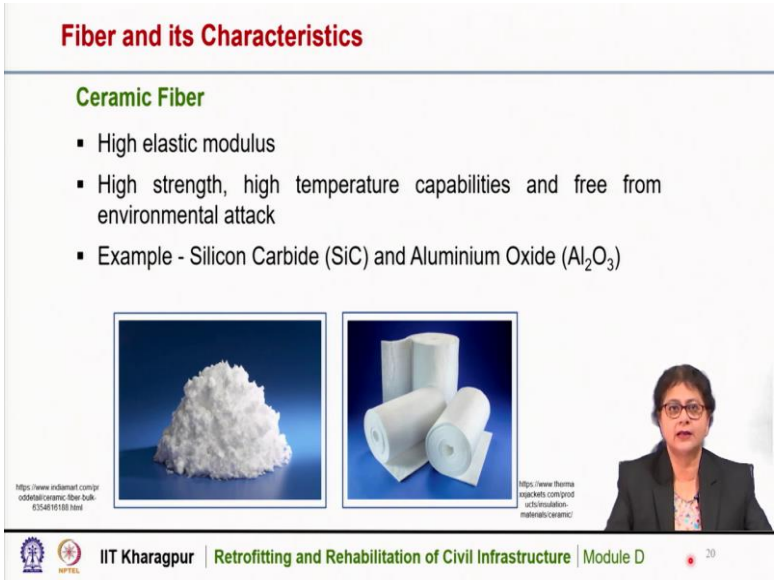

Ceramic fiber is another type of fiber that is used particularly in high temperature where it is required to have high temperature. It has high strength, high elastic modulus and is

capable of resisting high temperature and it is free from environmental attack. So, ceramic fibers have the advantage of resisting high temperature.

The example of ceramic fiber is silicon carbide and aluminium oxide. Here are some pictures of ceramic fiber. This is the ceramic fiber and this is the ceramic fiber composite. As you can see, this is the ceramic fiber composite available in rolls.

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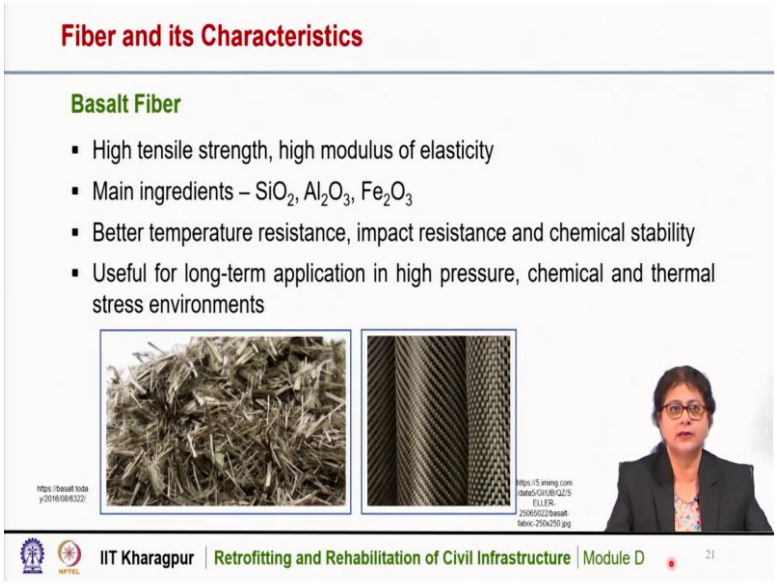

Basalt fiber is also used recently and it also has high tensile strength and high modulus of elasticity. In recent years in retrofitting work also, basalt fiber has started its application, the main ingredient of basalt fiber is the silica, aluminium oxide and ferric oxide. It has better temperature resistance as compared to glass fiber.

And it has high impact resistance and chemical stability. The basalt fiber is useful for long term application in high pressure, chemical and thermal stress environments. So, basalt fiber as you can see here, these are some pictures of basalt fiber, this is individual basalt fiber and this is the basalt fiber reinforced polymer composite.

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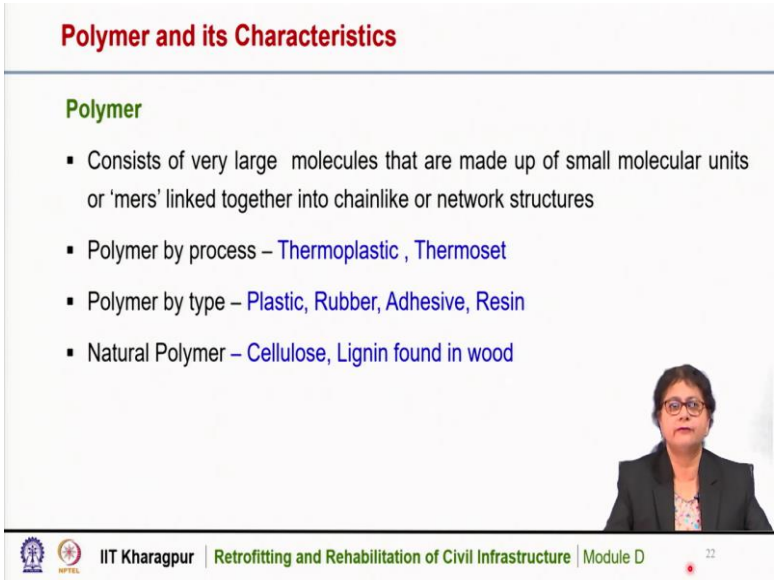

So, these are the different types of fibers we have discussed and they have specialized applications. And we have discussed carbon fiber, glass fiber, basalt fiber, boron fiber, ceramic fiber, etcetera. Now, we will discuss the polymer and its characteristics.

So, polymer is of large molecules that are made up of small molecules units, this is called mers, that are linked together into chain like or network structures. Polymers may be of different types, by process we can differentiate a polymer as thermoplastic or thermoset. By type also polymer can be distinguished as plastic or rubber or adhesive or resin.

They are natural polymers as well like cellulose, lignin, etcetera that are found in wood. So, polymers there are different types of polymers used in fiber reinforced polymer composites like plastic, rubber, adhesives or raisins or we can also differentiate as thermoplastic or thermoset.

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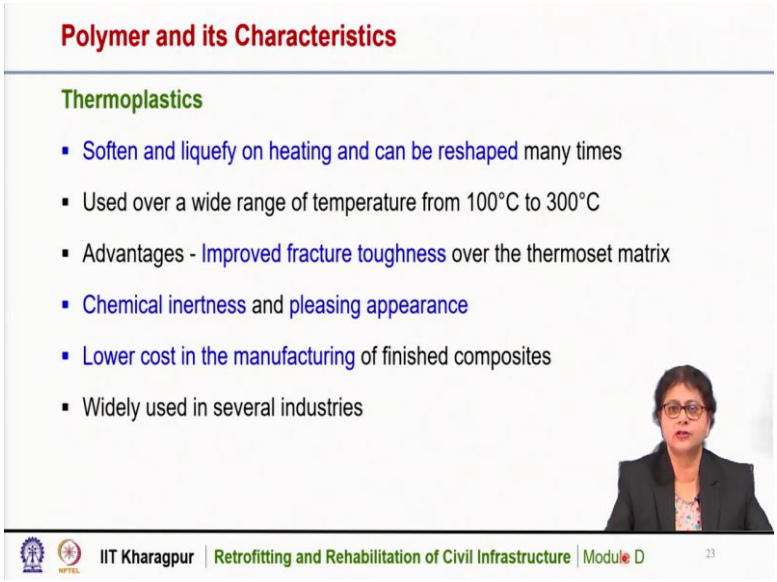

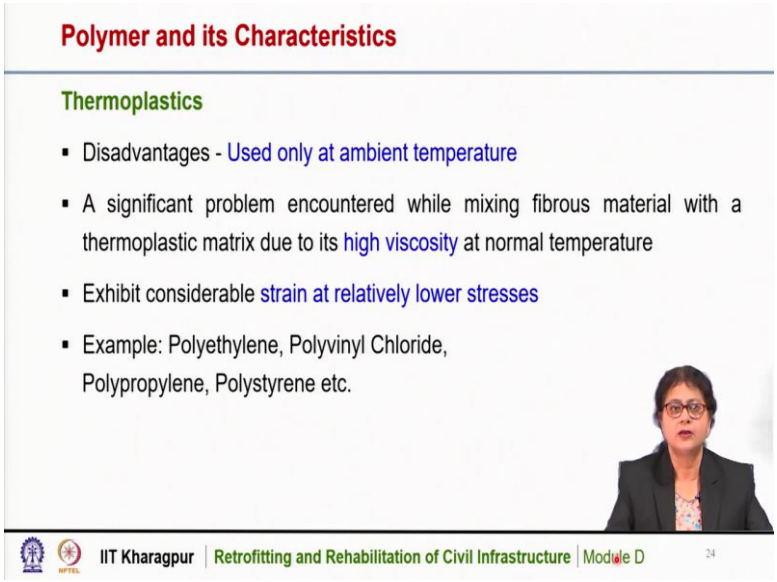

Thermoplastic are materials which softens and liquefies on heating and can be reshaped many times. So, we can heat a thermoplastic and then we can again use it by reshaping it. It is used over a wide range of temperature from 100 degrees centigrade to 300 degrees centigrade. Thermoplastic have several advantages like improved fracture toughness over the thermosetting plastics and it is chemically inert and also has pleasing appearance.

The thermoplastics are of lower cost in the manufacturing of finished composite and that is why it is used widely in several industries. However, there are several limitations of thermoplastic. It is used only at ambient temperature. A significant problem may be encountered while mixing the fibrous material with the thermoplastic matrix due to its high viscosity at normal temperature.

It executes considerable strain at relatively lower stress. So, that is one disadvantage of thermoplastics. And there are several examples of thermoplastics like polyethylene, polyvinyl chloride, polypropylene, etcetera. So, thermoplastics are such type of polymer which can be heated and then it can be reused by reshaping it.

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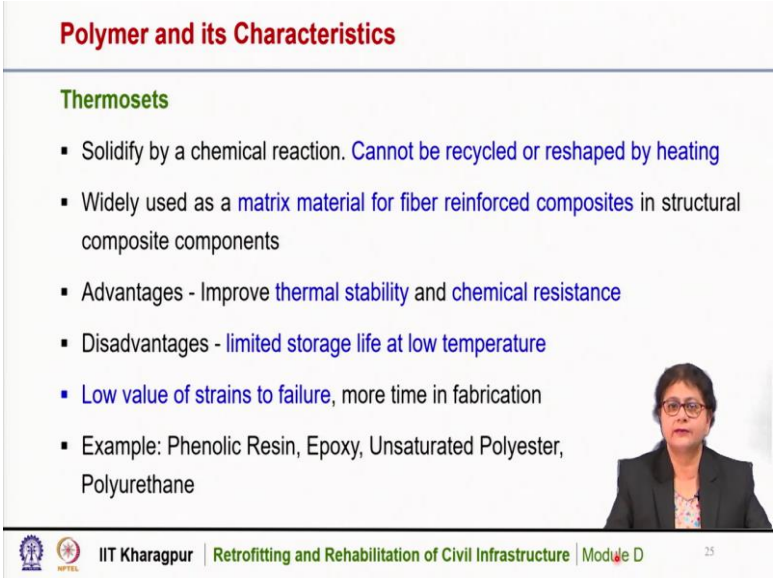

Thermosets solidify biochemical reaction and it cannot be recycled or reshaped by heating like thermoplastics. So, in thermoplastic, we can heat it and reuse it by reshaping but in thermosets once it is done, we cannot recycle it or cannot reshape it by heating. It is widely used as a matrix material for fiber reinforced composites in structural composite components.

There are several advantages of thermosets. It has improved thermal stability and chemical resistance as compared to thermoplastics. The disadvantage is that it has limited storage life at low temperature, low value of strains at face and taking more time in fabrication as compared to thermoplastics. There are different types of thermosets and example of thermosets are phenolic resin, epoxy, unsaturated polyester, polyurethane, etcetera.

So, thermosets are formed by solidifying with the chemical reaction and it cannot be recycled and it is widely used as a matrix material in fiber reinforced composite in structural applications. The advantages, it has improved thermal stability as compared to thermoplastic and it has a lower value of strains to failure.

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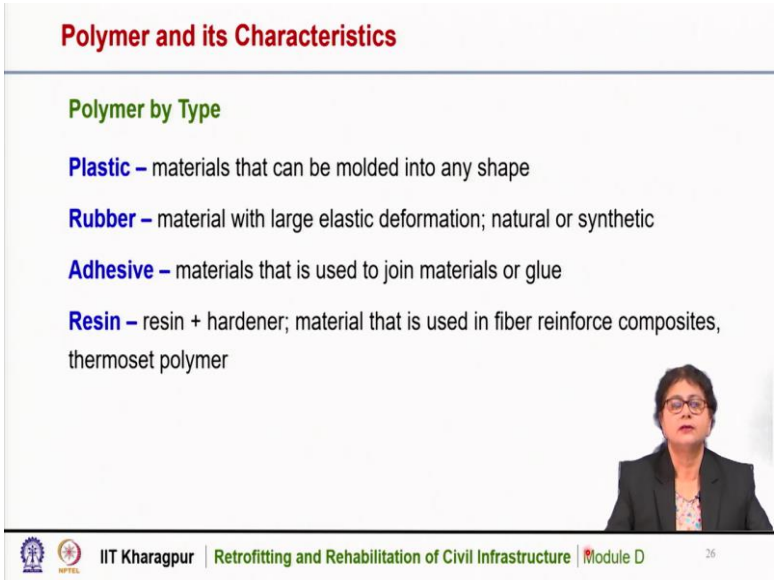

There are different types of polymers by type, we have mentioned one is plastic, plastic is a material that can be moulded into any shape. Rubber is also a polymer, it is a material with large elastic deformation, natural or synthetic rubber is available. Adhesives are materials which are used to join two materials or as a glue. Resin is generally available as resin plus hardener and the material is used in fiber reinforced composite and it is thermoset polymer.

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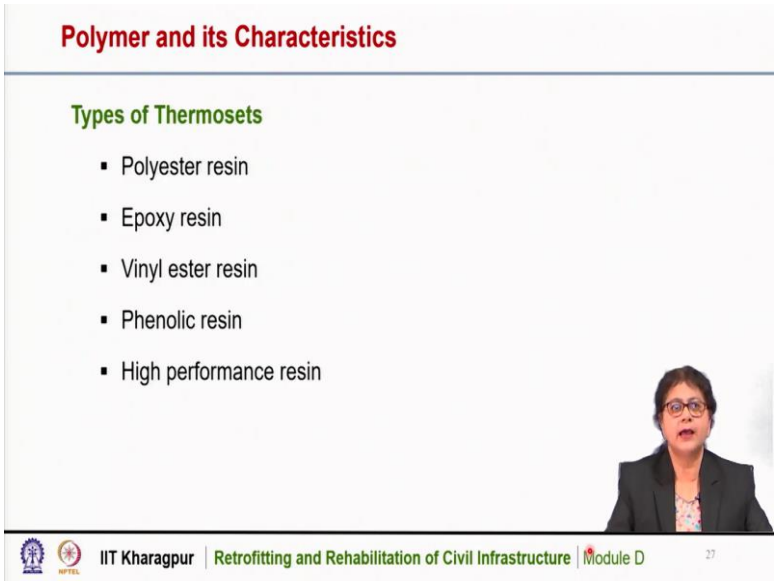

There are different types of thermosets, polyester resin, epoxy resin, vinyl ester resin, phenolic resin and high-performance resin.

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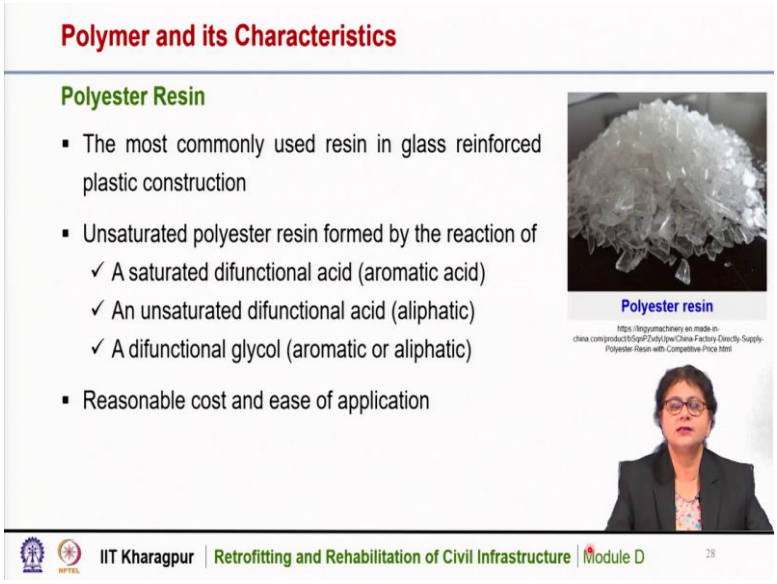

Polyester resin is the most commonly used resin in glass reinforced plastic construction. The unsaturated polyester resin is formed by the reaction of three different types of materials, one is saturated difunctional acid, which is an aromatic acid, another is unsaturated difunctional acid, which may be aliphatic acid.

And one is difunctional glycol, which may be aromatic or aliphatic. So, the polyester resin is formed by the reaction of these materials and it is of reasonable cost and ease of application and that is why it is used widely in different industries. Here is a picture of polyester resin as we can see here.

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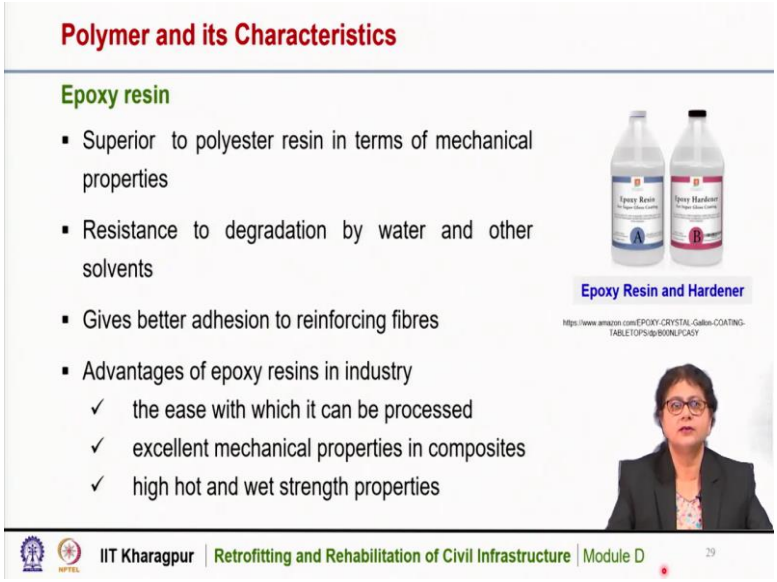

Epoxy resin is another type of polymer which is superior to polyester resin in terms of mechanical properties. It is resistant to degradation by water and other solvents. And it gives better adhesion to reinforcing fibers. The advantages of epoxy resin in industry are the ease with which it can be processed. It has excellent mechanical properties in composite and it is of high hot and wet strength properties.

So, epoxy resins are generally available with along with hardener as we can see here. And the resin and hardener are to be mixed in definite proportions.

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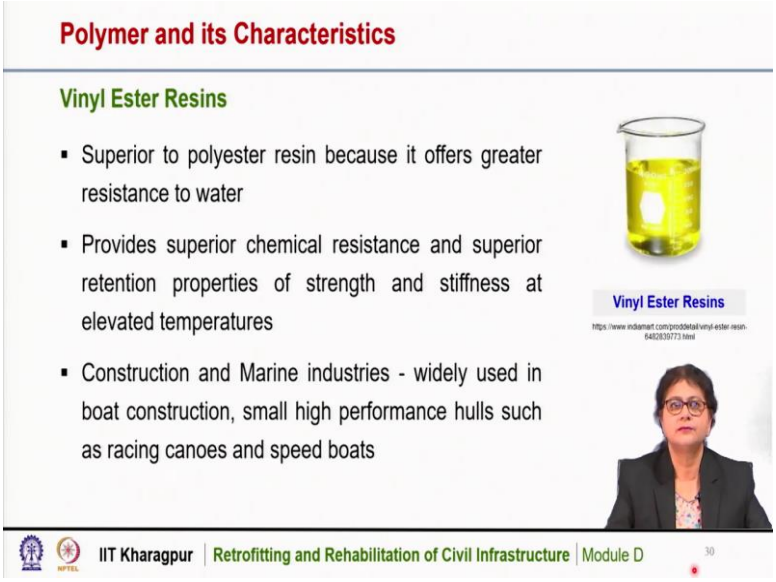

Vinyl ester resin is superior to polyester resin because it offers greater resistance to water. It provides superior chemical resistance and superior retention properties of strength and stiffness at elevated temperature. And because of its resistance to water, it is used in several marine industries, widely used in boat construction, small high-performance hulls such as racing canoes and speed boats, etcetera. This is a typical picture of Vinyl ester resin in this container.

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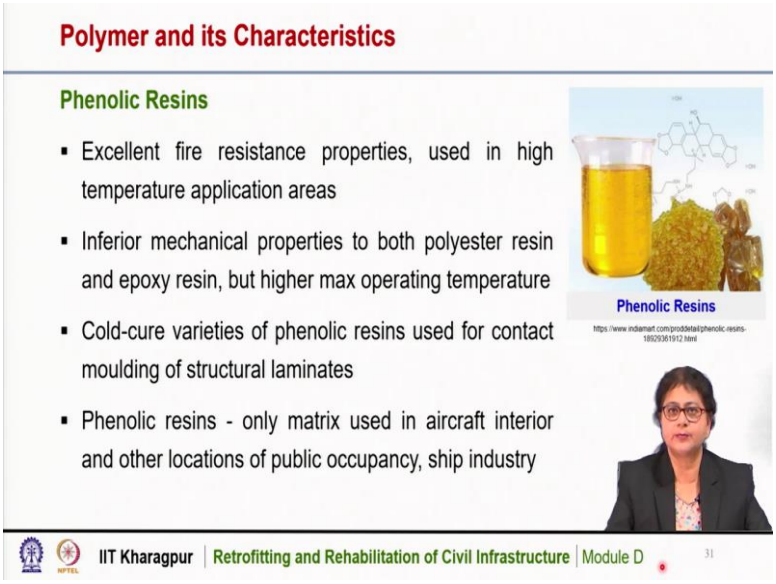

Phenolic resin has excellent fire resistance properties and that is why it is used in high temperature application areas. It has inferior mechanical properties as compared to both polyester resin and epoxy resin, but higher maximum operating temperature. So, this is the advantage of phenolic resin, it is high temperature resistant.

Cold-cure varieties of phenolic resins used for contract moulding of structural laminate. Phenolic resins are the only matrix that is used in aircraft interior and other locations of public occupancy, shipping industry, etcetera. This is a picture of phenolic resin as we can see here in this container.

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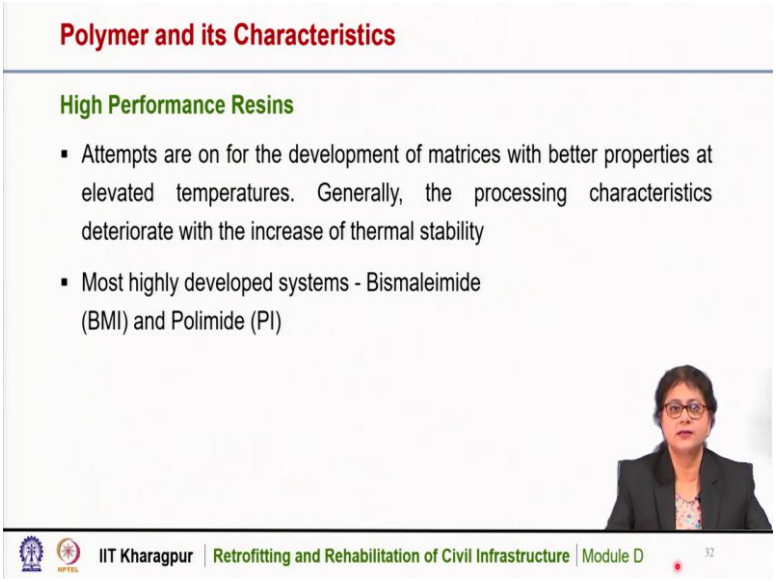

High performance resins, this is actually in research stage and attempts are being made for the development of matrices with metal properties at elevated temperatures. Generally, all these polymers are very susceptible to temperature. So, the research is going on for the development of matrices which can perform better at high temperatures. Generally, the processing characteristics deteriorate with the increase of thermal stability. Most highly developed systems are BMI or Polimide, etcetera.

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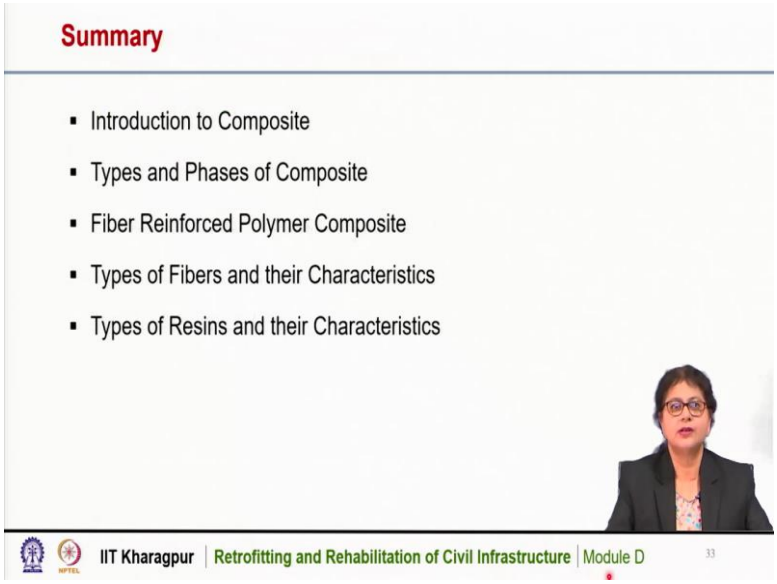

So, to summarize, we have discussed what is a composite and the basic characteristics of a composite, what are the different types and phases of composite, the fiber phase, the matrix phase, there may be also fillers and coupling agents. We have discussed what is fiber reinforced polymer composite and different types of fibers and their characteristics have also been discussed.

There may be natural fibers or synthetic fibers like glass fibers, carbon fibers, etcetera which have excellent properties high strength, high modulus values, and we have also discussed different types of resins and they are characteristics, which are used as matrix in fiber reinforced polymer composites. Thank you.