Non - Metallic Materials
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Module – 01
Polymer materials
Lecture – 05
Polymer Composites and Issues related to Recycling

Welcome to my course Non Metallic Materials and today we are in module number 1 which describes Polymer materials and this is lecture number 5 which will we will discuss Polymer Composites and Issues related Recycling.

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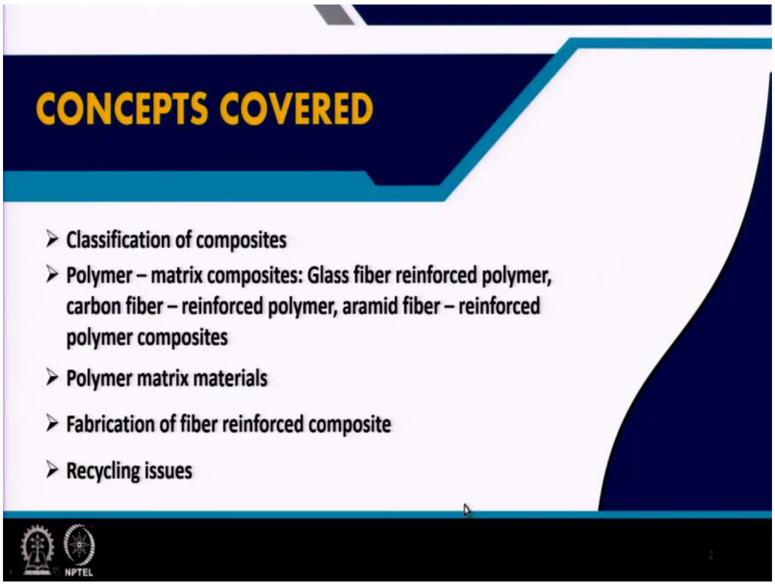

Earlier in my last lectures, we talked about the structure of the polymers and then we talked about mechanical properties, various types of mechanical properties and also we introduce various processing roots of the polymer. And in today's lecture first I will show you various important composites material and part of it will be polymer based composite which is reinforced by various fibrous material.

So, polymer matrix composite where glass fiber, carbon fiber, aramid fibers they are used as reinforcing agent to make this composite. We will also talk about the polymer matrix material; what are the typical matrix is used in the matrix, what are the different polymers that is used and fabrication of this kind of fiber reinforced composite and then their recycling issues.

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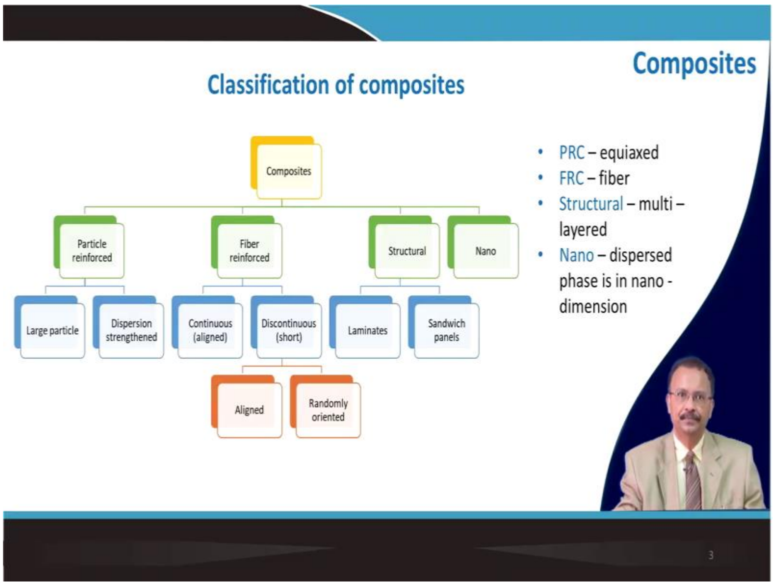

Now, basically this composite is a very wide term and in fact, in my subsequent lectures; I have thoroughly revised various concepts of composites. And in this particular lecture, particularly I will be concentrating on the fiber reinforced plastic composite.

So, there are various other types of composite like particle reinforced composite which I will be talking later, then structural composite, laminated structure of multi layer composite or nano composites this all will be described; so that will justify the full classification scheme.

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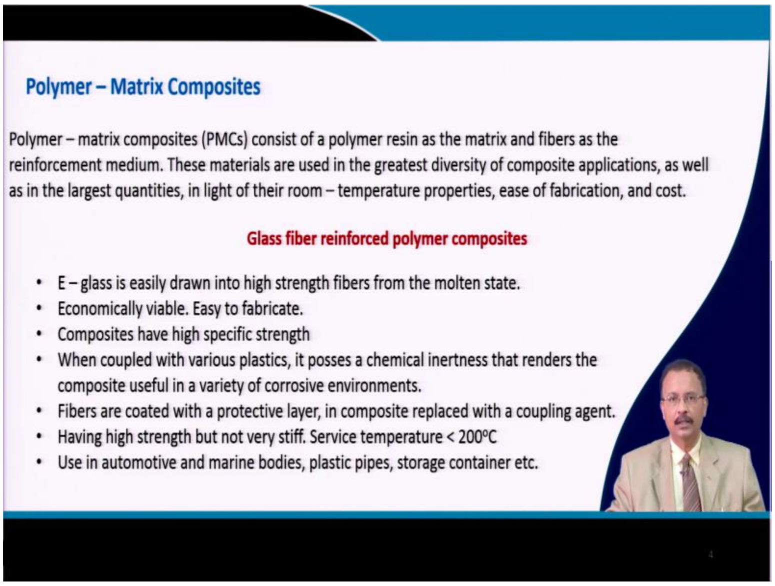

So, it will be taken in details, but here in this lecture particularly I am concentrating on polymer matrix composite. And this consists of basically a polymer resin as the matrix which are relatively softer and fibers as the reinforcing medium.

And this particular composite is having diverse kind of use and it is used in bulk quantities and their room temperature, mechanical properties are important. So, later I will explain each and every aspects of this kind of polymers in subsequent lecture. And it is relatively easier to make these types of composite and of course, they are economic.

So, mostly first let us consider what are the different types of reinforcing agent that is used and glass is one of them. I have already talked about glass, so this specialty glasses they are made in the form of a fiber. So, we call it E glass and this can be easily drawn and basically they are having very high strength because of their high elastic modulus, but they are brittle in nature.

They are economically viable because the raw material that we use they are cheap and they are relatively easy to fabricate. And the composite they have high specific strength, as you can understand although the glass density is a little bit high about 2.5 but the polymer matrix is light weight, so the specific strength of this composites are quite high.

So, it is coupled with various plastics; it poses a chemical inertness that renders the composite useful in a variety of corrosive environment. Because you know that the matrix they may be softer, but they gives some kind of protection to the fiber because these are brittle material, so any surface crack can be detrimental; they will lose its reinforcing properties. So, therefore they are; they should be actually protected by this composite.

And fibers are whenever you use a fresh fiber; that is why they are coated with a protective layer and when you put in the composite, they are replaced by a coupling agent so that good bonding between the matrix and fibers takes place.

And they are having a high strength, but they are not very stiff and service temperature of this composites are less than 200^{o} C mainly because of the polymer resin that is used as a matrix. And various automotive part bodies, plastic pipes, storage container etcetera is used is made by this glass reinforced composite.

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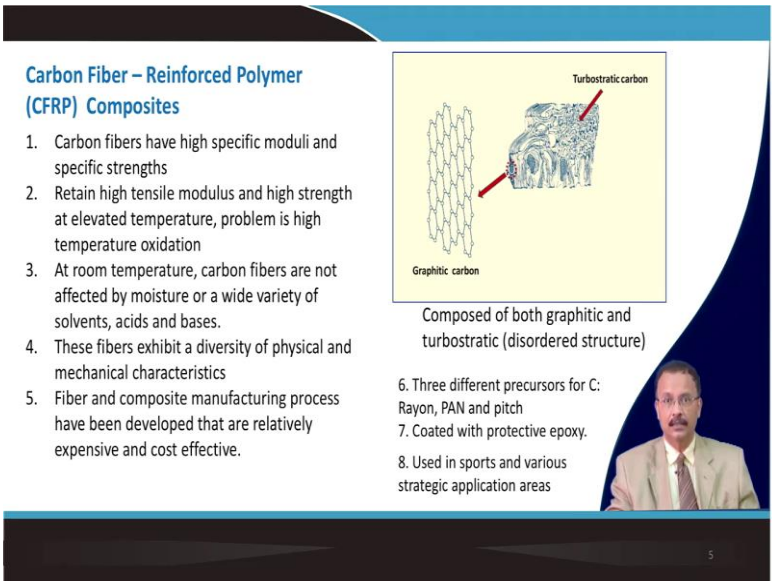

Another fiber that is used is carbon fiber and accordingly we term it as Carbon Fiber Reinforced Polymer Composite and it is abbreviated as CFRP; Carbon Fiber Reinforced Plastic Composite. So, carbon fibers they are used because they have high specific modulus and specific strength is also quite high and they retain high tensile modulus and high strength; even at high temperature.

But there is a problem because if you use in a high temperature in oxidative ambient, then this carbon fiber they could get oxidized. But at room temperature, this fibers they are not affected by moisture or a wide variety of solvent, acid, bases and other relevant chemicals. These fibers exhibit a diversity in physical and mechanical characteristics because of the nature of this carbon fiber.

We already talked about various types of carbonaceous material in earlier lecture; in fact, a detail carbonaceous material lecture will be covered subsequently. In the introductory slide, I just mentioned about the carbon composite and this fiber and composite manufacturing process; they have been developed that are relatively less expensive and therefore, this composites are cost effective.

Here in this view graph, you can see that this carbon fiber if you take a cross section; it is having both graphitic nature where this hexagonal layer structure is maintained. And also turbostratic that is a disordered region that is also there in this carbon fiber; fibrous material. So, this also I will explain in one of my subsequent classes.

And usually three different precursor is used for carbon and prominent among them is PAN and pitch also is used Rayon; they are also used to make this carbon fiber and they are coated with protective epoxy. And mainly they are used for various sports article and material for strategic areas; mostly in defense this kind of composites are pretty well used.

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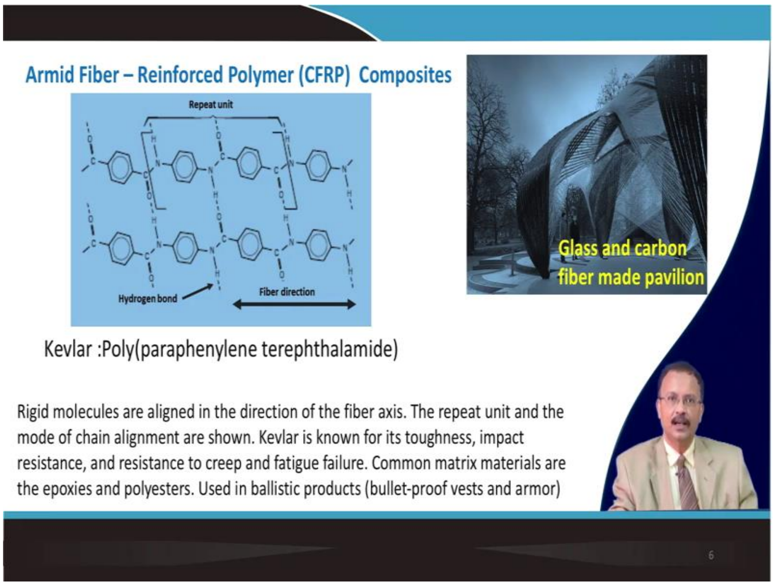

This aramid fiber which is having a technical term Kevlar which is poly paraphenylene terephthalamide; so, that is the technical name of this fibers. So, they are basically rigid molecules along with the fiber length; along with this direction and then they are bonded by hydrogen bonding they are very strong.

And this Kevlar fibers they are known for its toughness, good impact resistance and also resistance to creep and fatigue failure. All these properties again I will be describing in my subsequent classes, for a better detail what is toughness, what I mean by impact resistance or creep and fatigue kind of failure.

Matrix material that is used for this composite; they are basically epoxies and polyester and they are particularly used in ballistic product like bulletproof jacket; it is a very popular material, this kind of composite. In this viewgraph, you can see that the glass and carbon fiber which was discussed in the earlier slide; out of that this beautiful pavilion is made and this is light weight and very strong in nature.

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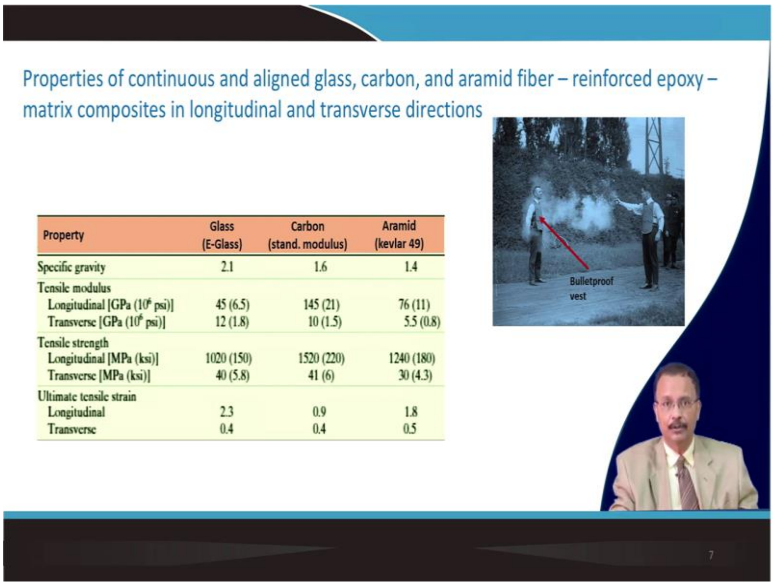

So, I have compared here three different types of fiber reinforcement; the E glass, then you have the carbon and you have the aramid fibers. And you can see their tensile modulus both in the longitudinal and transverse direction and also the ultimate tensile strength of this material and the ultimate tensile strain that you can achieve out of this material; this is an example of bulletproof jacket use of this aramid fibers.

And you will see in my subsequent class on composite material that it is important that how the fibers are oriented inside the matrix. Whether it is a longitudinal kind of orientation and you are applying a tensile load along with the direction of the fiber or you are making a transverse kind of loading; so, depending on that the elastic modulus of the composite will be grossly changed. Sometimes you can use chopped fiber as well, sometimes it could be oriented, and sometimes it could be completely random.

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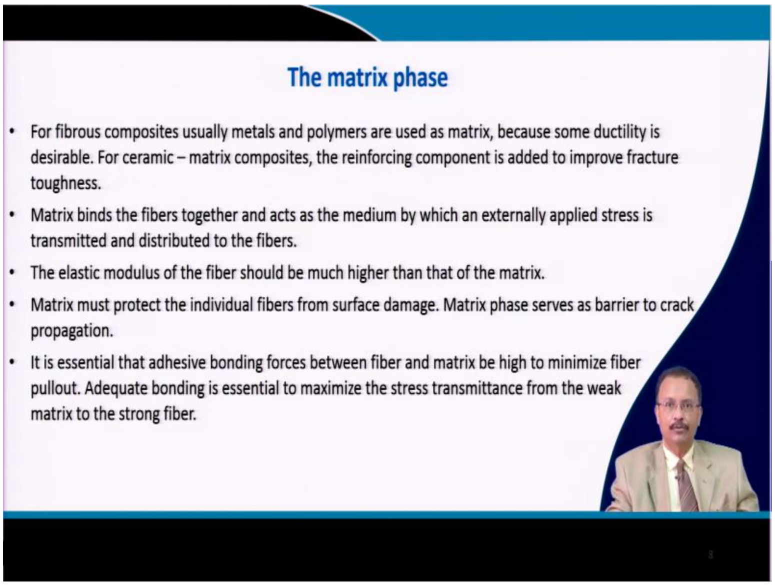

So, depending on this kind of fabrication protocol you will have; the mechanical property will be grossly affected. Now, in the matrix phase if you consider for fibrous composite; usually metal and polymers are used because of the simple reason that metal and polymer, they exhibit some kind of ductility.

So, we will be talking about the crack propagation inside a material and the crack intensity at the crack tip which actually is the driving force for the crack propagation. And if you have an embed this kind of fiber inside a ductile matrix; then of course, this part of this energy will be dissipated; so, it will have higher toughness.

So, that is the idea of using this metal; as well as the polymer material to make this kind of composite, but also we have ceramic composite. So, the reinforcing component that is added to improve the fracture toughness and alumina zirconia composite is one of the examples, where due to transformation toughening which again I will describe in part of my other class.

You will see the transformation toughening is very important in aluminum zirconia composite, to increase the overall fracture toughness. What is fracture toughness? How they are measured? They all will be covered subsequently. Now, this matrix they binds the fibers together and act as a medium by which the externally applied stress is transmitted to the fiber.

It is the idea because as I said that the matrix phase is softer and fiber is strong; so you would like that whatever stress you are applying; particularly the tensile stress that tensile load is mostly carried by the fiber.

And you can have a small calculation to see that if it is longitudinally oriented and the fiber volume is as low as 10 percent inside the whole matrix, then about 70 percent load is in fact, carried by the fiber, but you will have to maintain the longitudinal direction; so it should be aligned with the direction of the applied tensile stress; so that is important, one can work it out also.

Elastic modulus, as I have said the fiber should be much higher than that of the matrix; usually 20 times higher that is assumed, as compared to the softer matrix material. And matrix must protect the individual fibers from surface damage because as I told, they are all brittle material. So, surface damage a small crack introduction; the surface that reduces the strength as compared to its theoretical strength.

And it is essential that the adhesive bonding force between the fiber and matrix should be high; so that will minimize the pull out of the fiber. So, it will be strongly adhered into the matrix. So, I adequate bonding is essential to maximize the stress transmittance I talked about from the weak matrix to the strong fibers.

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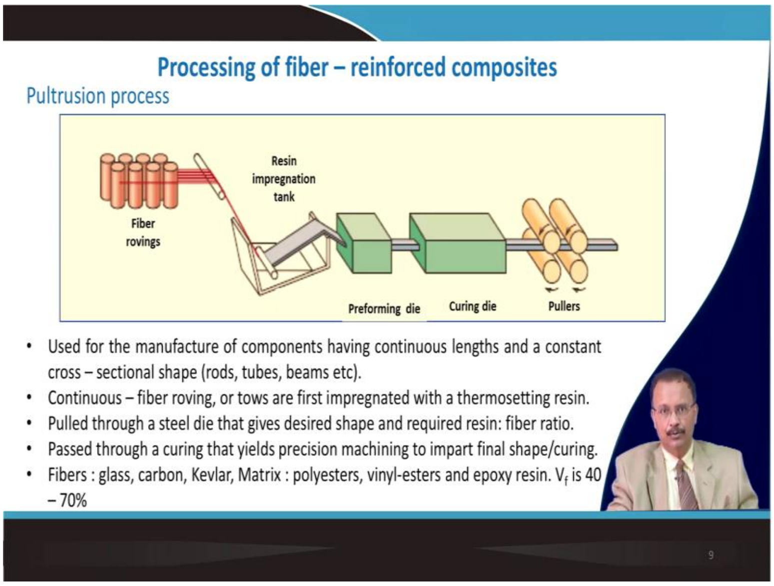

Now, the processing of this fiber reinforced composite basically three prominent process I will be describing. And the first one is pultrusion process and here as you can see the fiber roving is here and it is being carried through the resin matrix; so here the fibers are getting coated. So, this is a continuous process; so usually this kind of process, this pultrusion process is used to make bars like this or you can also make material with uniform cross section.

So, bar is shown; beam is shown and raw tubes etcetera also can be made. So, first this fiber from we call it a fiber roving or sometimes it called toes, they are first impregnated with the thermosetting resin. So, thermosetting resin as you know that they are cured at high temperature. And they are basically pulled once they are put in the resin bath; they pull through a steel die that gives the desired shape of the required resin and maintain the resin and fiber ratio here.

Then subsequently they are passed through a curing chamber; so first they are preformed. So, the first one is a preforming die and second one is a curing die, where they are heated; so that yields precision also, precision of this rod.

So, the final shape is given and then you have passed this through a set of pullers, a ruler which will pull the beam and you get the composite; is a continuous process and it is applicable to glass fiber, carbon fiber, Kevlar; typical matrix that is used is polyester, vinyl ester or epoxy. And usually about 40 volume percent to 70 volume percent of the fiber is used to make this kind of composite.

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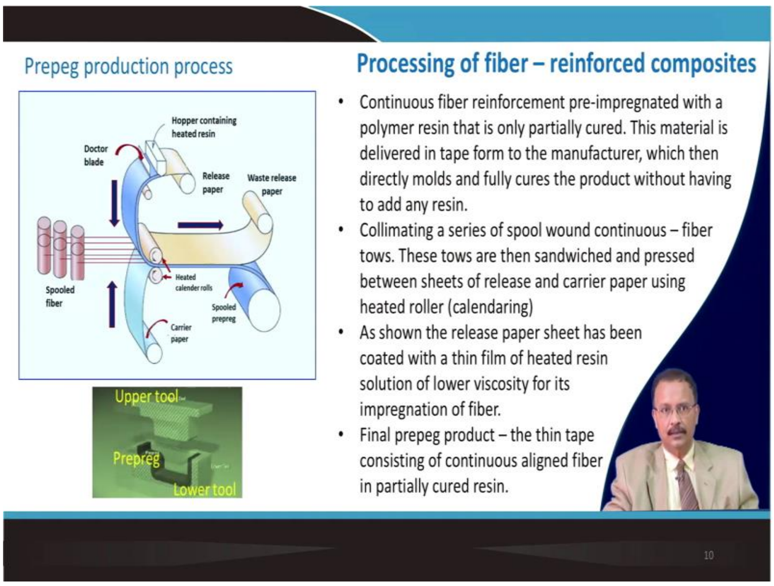

Second one is we called a prepeg production process and here this is a pre coated fiber; as you can see. So, pre coated fiber it is lightly cured and then it is sold, so whoever is using it; they have a resin impregnated fiber piece already and then they do the final processing and followed by curing etcetera. So, it is also a continuous fiber reinforce; pre ignited with a polymer resin that is only partially cured.

And this material is developed in the form of a tape to the manufacturer and this manufacturer then they can subsequently process this. Like, I have shown one types of process where several of this kind of; this kind of prepeg is placed here with a hydraulic press to make this kind of article, any complicated shape is possible. So, the process is described here; as you can see the fibers are coming here and you have a, bath where you put the resin here and there is a small doctor's blade.

So, this doctor's blade; they will apply a thin coating of the resin on top of this stream of fibers and then they are pulled here, in this region and this paper coater they are coming out. So, this is the carrier paper; this is actually holding the fibers together and then finally, these two rollers are heated; so it is partially cured.

And then this waste paper whatever is there; it is coming out and it is also collected and the pre peg is pulled in this pool and the pre peg is actually wind up and this is in the form of a thin tape consisting of continuously aligned fiber with partially cured resin. So, this is also a standard process; prepeg production process we call it.

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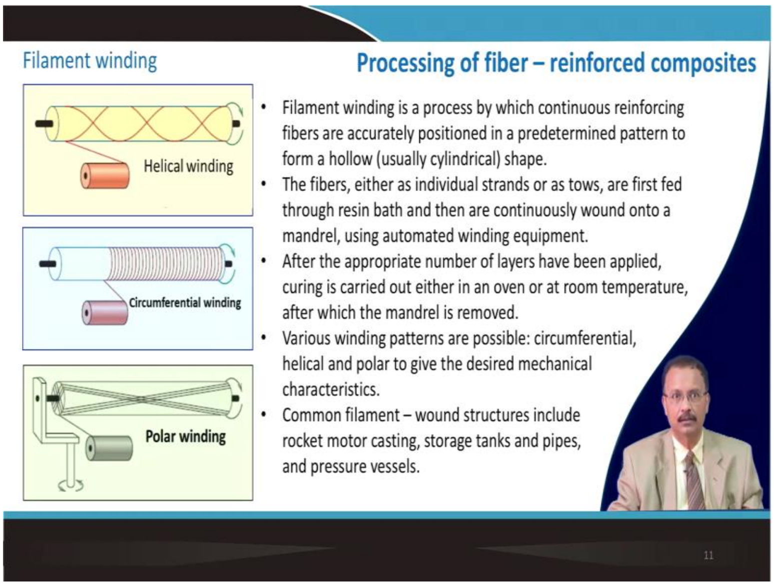

The third one is a filament winding; so filament winding, this is a process by which continuous, reinforcing fibers are accurately positioned in a predetermined pattern. So, you can see various types of pattern you can make; the first one is a helical winding, the second one is circumfacial; circumferential winding along with a spool and the third one is a we call it is a polar winding.

So, it is basically wind up on a hollow cylindrical shape and the fiber; they can be used either as a single strand or they can be already fed through a resin and partially cured and after you apply certain numbers of layer, the curing is carried out in fact, either in a oven at a slightly elevated temperature and then this mandrel is removed. So various winding process, as I as you can see the three different winding process that is used.

So, this filament winding; they basically own structure which include rocket motor casing that is one very popular thing or in storage tank also that they can be used or pipes and various pressure vessels, they are very useful to make like this.

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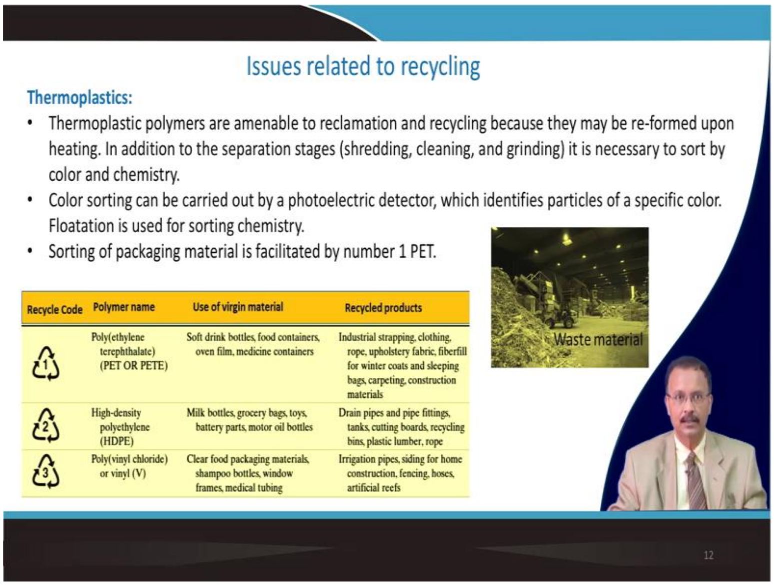

So, now, we will briefly describe the recycling issue because as you can see in this view graph; it is a company in Germany, they have lots of this kind of polymer based composite material and once your use are concluded, then of course, you will have to recycle this.

And this recycling is sometimes it is difficult, sometimes it is not that difficult. So, for example, you know what is thermoplastic and what thermosetting polymers is. In case of thermoplastic, this is easier to recycle because they may be reformed up and heating; so this is a recycled process.

So, this that is why the thermoplastic is important for recycling and first there are several stages. For example, you have to collect it and then you shred, then you will have to clean it; sometimes the grinding is required. So, then finally, you will have to sort it out; so you can sort it out by their color or by their chemistry, what types of thermoplastics are they.

So, depending on that you can sort it out. So, color sorting is usually done by a photoelectric detector so that it can identify as a particular color and discard the others. So, that is can be easily sorted or normal mining engineering process like flux flotation etcetera that can be used for sorting the polymer; based on their chemistry, based on their density they can be sorted out.

Now, the sorting of this packaging material they are facilitated by some kind of number. So, as you can see that this is a sign that you will see any polymer based composite materials or normal polymer materials with certain numbers 1, 2, 3 etcetera. So, if it is 1; then it is internationally a quite common kind of thing; so it is a PET base polymer or if it is 2; it is high density polyethylene, if it is 3; then it is PVC and something like that.

So, here the virgin material; where it is exactly used and where after recycling they can be used so this tables show you that. So, in your study material you will find a elongated list of this table that how exactly this thermoplastics are recycled.

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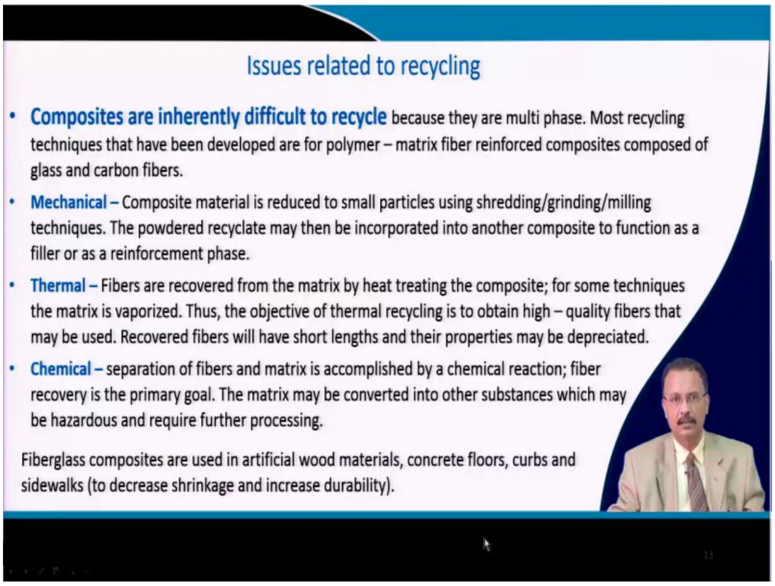

Now, with respect to the thermo plastic material; it is difficult to recycle the composite because they are having multi-phase material; fiber is there, resin is there. So, most recycling techniques that have been developed are for the polymer matrix fiber composite; whatever has been developed so far; that is to get out the fiber because the fiber material is relatively expensive.

So, one could be a mechanical based recycling; the composite materials are reduced to small particles using shredding or grinding or milling etcetera. The powdered recycle is then incorporated into another composite to function as a filler or as a reinforcing agent; so that is one idea to recycle this. It could be thermal recycling; fibers are recovered from the matrix by heat treating; so it is not very environmental friendly process because lot of fumes can be generated.

So, but the fibers particularly the glass fiber you can take it out; remember the earlier picture that I showed there is a dump of various types of composite material, particularly glass reinforced composite where this glass fiber you can take out. And the glass fibers sometimes they will be chopped because no longer this continuous fiber will remain inside the composite; so those are collected or it could be chemical way of recycling; that separation of fibers and matrix is accomplished by a chemical reaction.

So, fiber recovery is a primary goal and matrix may be converted to other substance which may be hazardous during processing, as I have just mentioned. So, the fiberglass composite; they are used in artificial wood. Nowadays, it is very common in our country also or concrete floor, pavement tiles; so there are various types of views after recycling.

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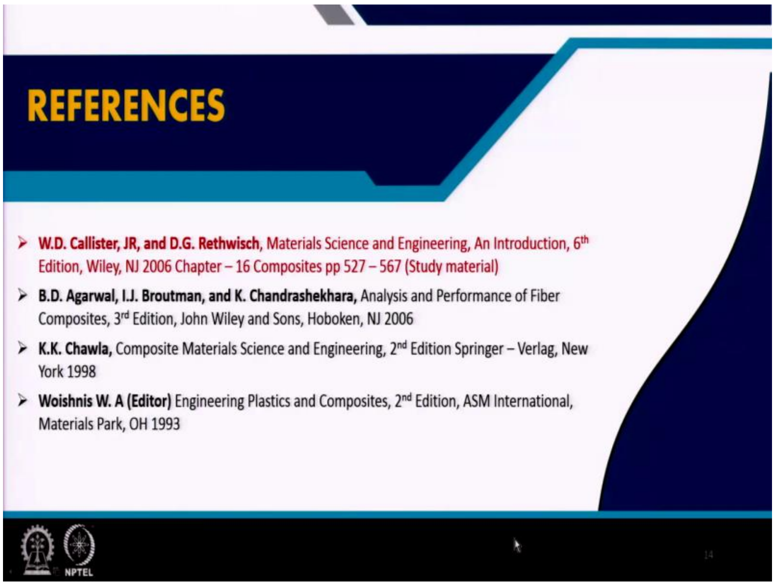

So, the study material is from the book by Callister; apart from that there are excellent textbook which I have mentioned.

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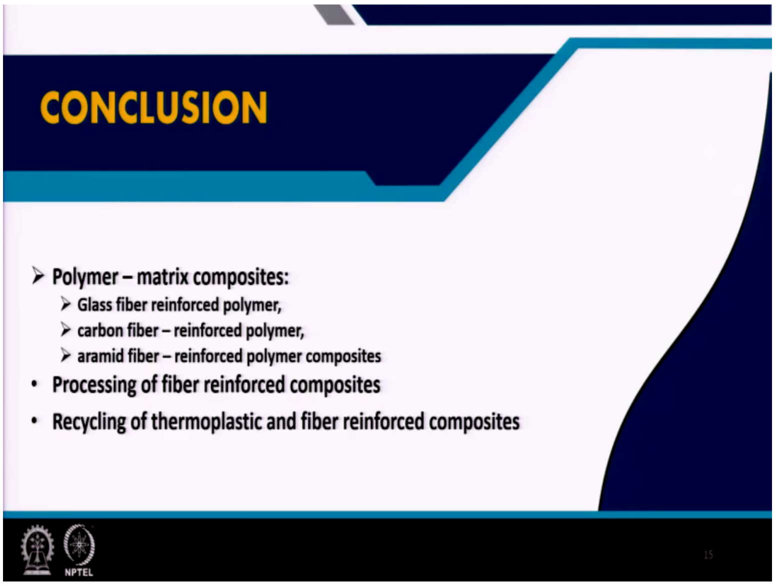

And in this particular lecture, we talked about polymer matrix composite and particularly glass fiber reinforced polymer, carbon fiber reinforced polymer and Kevlar reinforced polymer composite for bulletproof shield that is covered. And then we talked briefly about the processing of the fiber reinforced composite, three techniques were discussed. And then finally, we shed some light on the recycling of particularly thermoplastic polymer and fiber reinforced composite.

Thank you for your attention.