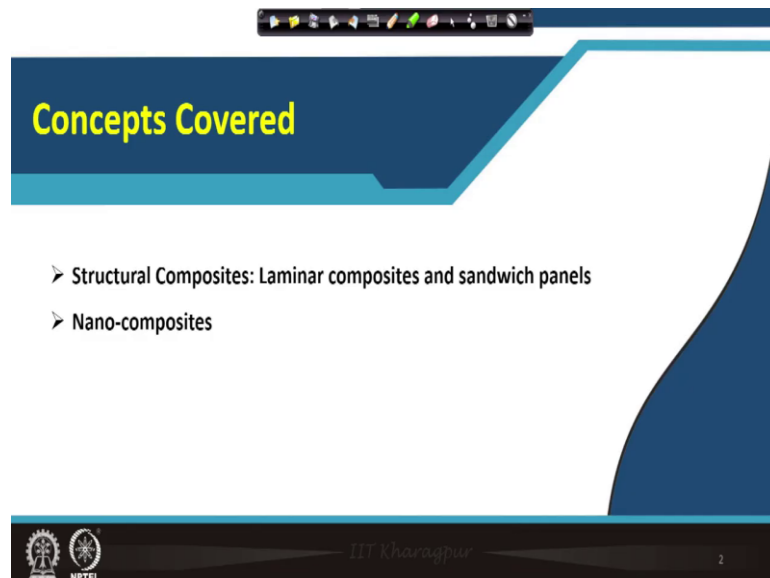


Non - Metallic Materials
Prof. Subhasish Basu Majumder
Department of Materials Science Centre
Indian Institute of Technology, Kharagpur

Module – 04
Mechanical properties of non – metallic and composite materials
Lecture – 22
Structural composite

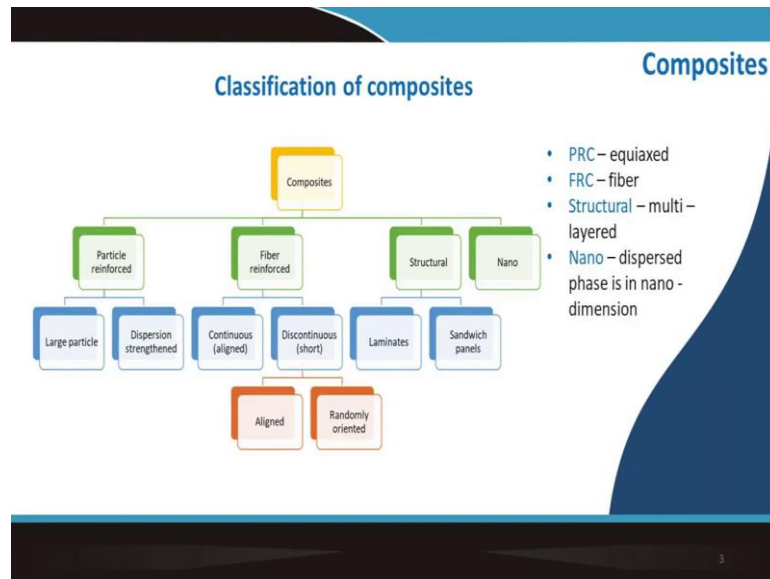
Welcome to my course, Non-Metallic Materials. And, today we are in module number 4 Mechanical properties of non metallic and composite materials. And, today part of lecture number 22, I will cover Structural composite.

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Now, if you remember the last lecture these two topics were left out. The first one I will cover structural composites, mostly laminar composites, and sandwich panels that will be covered and finally, I will cover the nano composite.

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To give you the brief overview of the classification, which already I have described part of my earlier lectures. We have already talked about particle reinforced composite; where both large particle reinforcement and dispersion strengthened reinforcements were covered.

Then, I took fiber reinforced materials, composite materials, and we talked about continuous alignment of the reinforced fiber, and also discontinuous, that is short reinforced fibers. And, part of this short reinforcement, we discussed about the aligned fibers, which were discontinuous and also randomly oriented fibers.

Now, today we will talk about the structural composites and mostly I will be talking about laminates and sandwich panel type composite. And, just to brush up PRC this abbreviation stands for Particle Reinforced Composite, where equiaxed particles, were dispersed in a matrix.

Particularly concrete we discussed, then we also talked about fiber reinforced composites, where fiber is the strengthening reinforcing agent. And, structural composite is multi layered type, we will be talking about it. And, finally, I will talk about the nano composite, where the dispersed phase for the reinforcement, they are of nano scale order.

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Structural composite

A structural composite is a multilayered and low density composite used in application requiring structural integrity, ordinarily high tensile compressive, and torsional strengths and stiffness. The properties of these composites depend not only on the properties of the constituent materials but also the geometrical design of the structural elements. **Laminar composites** and **sandwich panels** are two of the most common structural composites.

Laminar composites

A laminar composite is composed of two dimensional sheets or panels (plies or laminate) bonded to one another. Each ply has a preferred high – strength direction, such as is found in continuous and aligned fiber – reinforced polymers. A multilayered structure such as this is termed laminate. Laminate properties depend on several factors, including how the high – strength direction varies from layer to layer.



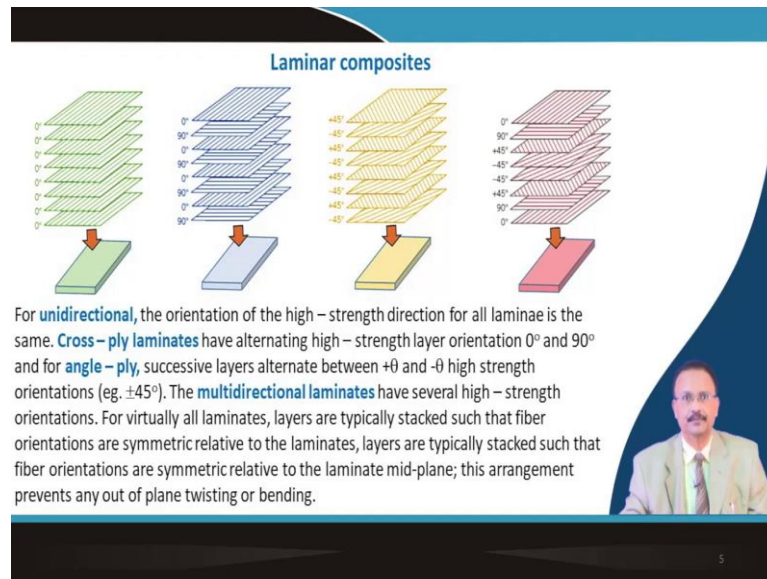
Now, a structural composite mostly it is multi layered and it is having very low density. These composites are having a low density and this is actually meant for structural integrity. And, high strength tensile composite this is one of the characteristics, other than that torsional strength is also quite good and they are relatively stiff.

And, these composites basically it depends not only the properties of the constituents material, but also the geometric design of the structural elements. So, we will be talking about it. And, laminar type composite and sandwich panel, these are the two most common type of structural composites.

So, in a laminar composite, this is composed basically of two dimensional sheet or panels. We call it is laminate; they are bonded with each other. So, each of this ply they are having high strength in a particular direction. So, normally they are an isotropic. And, usually as you have seen the continuous fiber aligned fiber reinforced polymer structure, which I have talked about.

Usually, they are directional, but we can make it isotropic as well. And, it depends on various factor this property of these laminates. And, usually they are of having reasonably high strength. And, layer to layer variation is there, because they are bonded structure, but within each of this laminate structure, they are reasonably strong.

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So, if you see the configuration of this laminate structure, you can see the first one this is unidirectional. So, all the fibers of course, they are having much higher tensile strength as compared to the matrix. So, they are all oriented in one particular direction. So, therefore, these are 0 degree, we have mentioned it.

Then, you can have a cross ply laminate, where both 0 and 90 degree. So, they are cross like this. So, this kind of composite we call cross ply laminate. Then various angles are possible. Here, I have shown either plus 45 degree or minus 45 degree of the fiber reorientation.


So, this is angle ply, we defined it as an angle ply. And, finally, the multi directional laminates, they have very high strength and layers are stacked, they are quite symmetric. And, they are typically stacked such that the fiber orientation are symmetric relative to the laminate mid plane, this arrangement prevents any fiber to come out of the matrix.

So, usually if you have this kind of orientation, there are different types of you can denote it in different times 0 degree slash 45 degree, then slash minus 45 degree, then slash 90 degree. So, that composite is defined by this. So, you can just define the composite structure by this kind of notation, which I have not shown in the slide, but in many places you will be finding that this kind of notation is possible.

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Laminar composites

- In plane properties (eg. modulus of elasticity and strength) of **unidirectional** laminates are highly anisotropic. **Cross – angle and multidirectional laminates** are designed to increase the degree of in plane isotropy; **multidirectional** can be fabricated to be most highly isotropic; degree of isotropy decreases with angle – and cross ply materials.
- For simple alignments (longitudinal and transverse alignment) we had already derived the elastic modulus . For aligned fiber reinforced composites the relations are a bit complicated and beyond the scope of this course.
- Overall strength and degree of isotropy depends on fiber material and number of layers, as well as orientation sequence. Most laminate materials are carbon, glass, and aramid. Subsequent to lay – up, the resin must be cured and layers bonded together; this is accomplished by heating the part while pressure is being applied. Techniques used for post – lay – up processing include autoclave molding, pressure bag molding, and vacuum bag molding.
- Laminations may also be constructed using **fabric material** such as cotton, paper, or woven – glass fibers embedded in a plastic matrix. In plane degree of isotropy is relatively high in this group of materials



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So, in laminar composite the plane properties, that is the modulus of elasticity and strength particularly for the unidirectional laminates are highly anisotropic. Because, if you remember that, if I apply a longitudinal stress, then the fiber carry all the load. So, this is much better as compared to the transverse orientation.

So, in this kind of composite they are anisotropic and cross angle and multi directional laminates, they are designed to increase the degree of in plane isotropy. The other two, the second and third one and multi directional can be fabricated to the most isotropic degree of isotropy decreases with the angle and cross ply materials.

So, the simple alignment of longitudinal and transverse alignment, we had already reviewed, derived this equation, the elastic modulus both for longitudinal and for transverse. And, if it is a aligned fiber then it is slightly complicated, if not following that rule of mixture. That is beyond the scope of this particular lecture, but mechanical calculations that one can do to exactly predict the elastic modulus and other mechanical properties of this material.

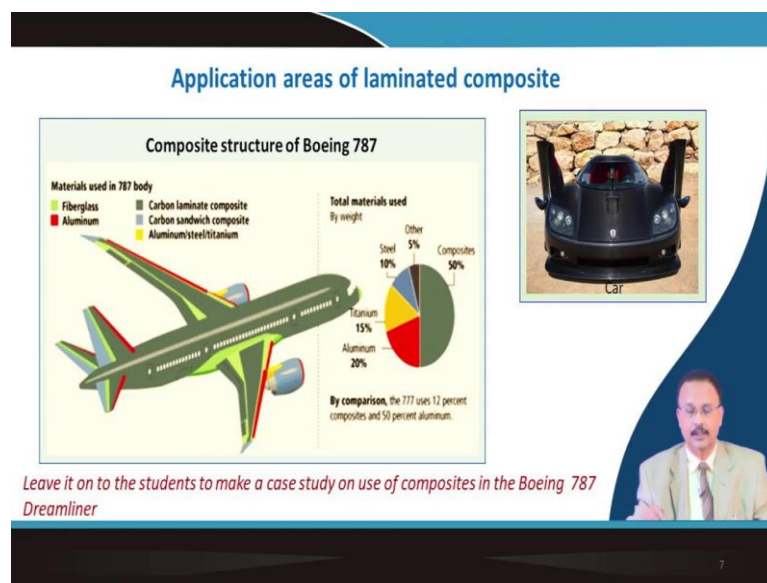
So, overall strength and degree of isotropy, as I have discussed that depends on the fiber material of course, and the number of layers as well as the orientation sequence. So, most of the laminate materials are carbon, glass fiber, aramid, they are the reinforcing agent. And, subsequently they are layup and in between matrices is resin.

So, this resin must be cured before you put the layer on top of it. And, finally, there are various processing steps involved. So, including a high pressure autoclaving you can do,

or pressure bag molding you can do, or vacuum bag molding in order to laminate this whole structure, whole structural stack. So, instead of discontinuous fiber, it is also possible for you to use fabric material.

And, cotton is one of them paper or woven glass fiber embedded in a plastic matrix, they are very common for this kind of composite. So, in plane degree of isotropy is relatively high in this group of materials. So, mostly the matrix is resin type and the fiber may be of various types.

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Very interesting structure that, you can get out of this laminated composite. So, I will cite one example as you can see this is the dreamliner flight. And, here you can see that different types of composite materials and other materials, they are being used for this kind of aircraft.

And, as you can see the composite constitutes mostly 50 percent of the whole material including the metal, aluminum, titanium, steel, and other materials they are also used, but mostly it is various types of composite. And, this kind of car the racing car, this also use carbon reinforced composites material.

So, this is very interesting progressively more and more composites are being used in the aircraft. So, Boeing 787 dreamliner is the ultimate flight, which uses lot of composites

and other models of Boeing also they use. So, I am just leaving it on you to find this information either from a text book or internet is a good source.

And, just make a case study that, what kind of composite they are used after once you go through all these lectures, then things will be clear to you that what are the various types of composites, and where exactly these composites are used in this two special aircraft. So, I just leave it on you as an assignment or as a case study to identify the composites and correlate with the class lecture, whatever you have learnt part of this course.

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Sandwich panel

- A sandwich panel consists of two outer sheets, faces, or skins that are separated by and adhesively bonded to a thicker core. Outer sheets are aluminum alloys, steel, FRP, and plywood. They carry bending loads applied to the panel.
- Core material is lightweight and has low modulus of elasticity. It serves several functions
 - Provides continuous support to the faces
 - Thick enough to provide shear thickness
 - Provide bending stiffness and resist buckling of the composite.
- **Three categories** of core material : Rigid polymeric foams, wood, and honeycombs.

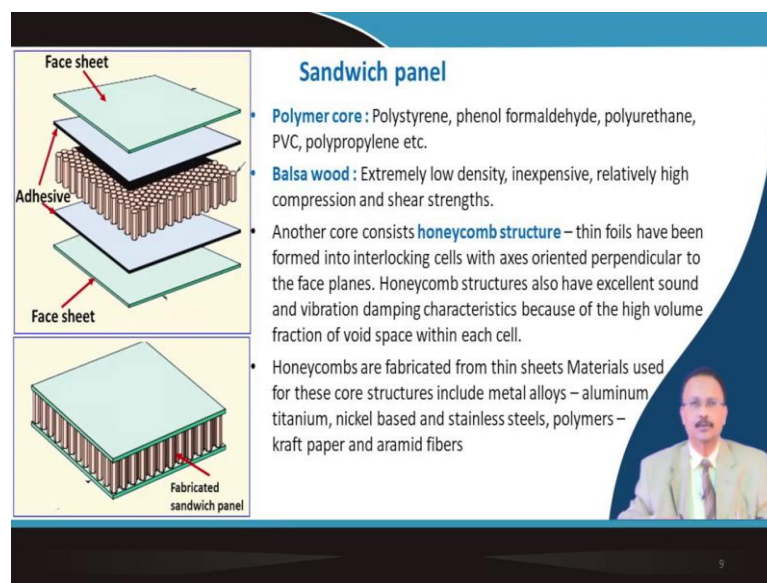
The second types of structural composite is sandwich panel type. And, you can see that, basically it is having a core, which is having a thicker structure. And, on top of this core you have a relatively stiffer, outer sheets at the face. So, actually this face strong material they are separated by this core material, which are relatively softer. So, this outer sheets they are usually aluminum alloy steel can be used, fiber reinforced plastic can be used, plywood can be used.

So, they carry the bending load, most of the bending load is carried by it. And, the core material is a light weight material. So, it has relatively low modulus of elasticity. And, basically it serves three purposes. Number 1 is it provides a continuous support to the face that is obvious here.

And, also it is thick enough to provide the necessary shear thickness. Shear thickness is due to the thicker layer of the core. And, provide bending stiffness and resist buckling of the composite, which is important for various applications. So, here you can see this kind of rooftop. Nowadays, that is quite popular where a polymer or metal sheet a corrugated one that forms this outer structure.

And, the core is relatively soft material and followed by another corrugated sheet. And, this kind of thing is being used as a building materials. So, this is a quite interesting for this kind of sandwich panel kind of composite. So, the core material they can be of various types. Either they can be a rigid polymer foam, which is light weight to make the structure quite light for the rooftop application. They are strong, but they are light weight, wood can be used and honeycomb structure also can be used.

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So, this is the actual structure of this kind of sandwich panel. As you can see the first one is the face sheet, the first part. The second one is the adhesive layer and then you have this core layer. Here typical core is of honeycomb structure; then again you have another adhesive layer and finally, the face layer. So, all of this are laminated they are pressed to form this kind of light weight, but strong composites.

So, for the polymer core usually polystyrene is used phenol formaldehyde that is used, polyurethane that is another thing, or in some cases this balsa wood, that is having extremely low density inexpensive and relatively high compression and shear strength.

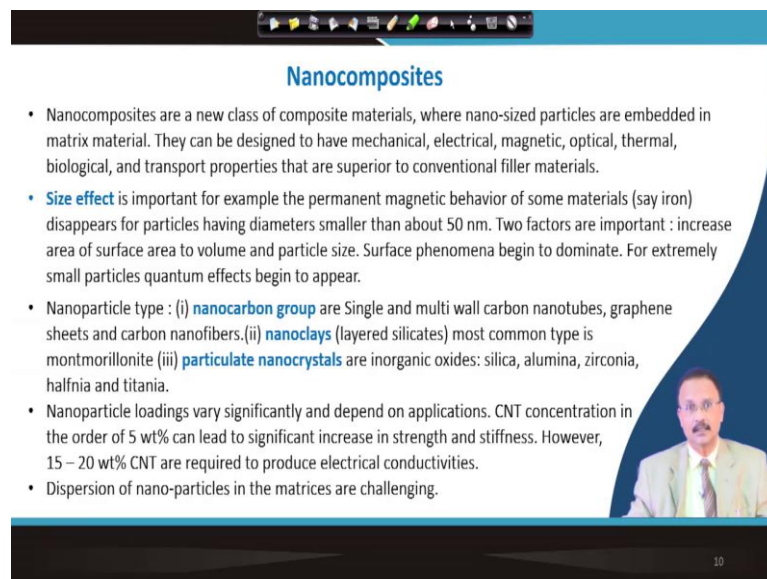
So, that is also used as core. As, I said that it can be a honeycomb structure a thin foil is formed into interlocking cells as you can see here, the axes is perpendicular to the face of the plane.

So, it is axially oriented something like this. So, it has lot of it is a basically a porous structure like beehive structure you know it is porous, but it is very regular. So, this can be it can entrap air.

So, it can be used as sound proofing also the panels in the studio acoustic studio that is used, so, because of their high volume of free space available. And, material used for this core structures, they are various types of metal alloys including aluminum, which are light weight, titanium is expensive but sometimes it is also used.

Nickel based material, stainless steel, or it can be polymer, it can be even craft paper to make this kind of corrugated composite, in packing material also you have seen that this kind of honeycomb sandwich panel is used. So, commercially they have quite lucrative to make this kind of composites and they are having good commercial values.

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Nanocomposites

- Nanocomposites are a new class of composite materials, where nano-sized particles are embedded in matrix material. They can be designed to have mechanical, electrical, magnetic, optical, thermal, biological, and transport properties that are superior to conventional filler materials.
- **Size effect** is important for example the permanent magnetic behavior of some materials (say iron) disappears for particles having diameters smaller than about 50 nm. Two factors are important : increase area of surface area to volume and particle size. Surface phenomena begin to dominate. For extremely small particles quantum effects begin to appear.
- Nanoparticle type : (i) **nanocarbon group** are Single and multi wall carbon nanotubes, graphene sheets and carbon nanofibers. (ii) **nanoclays** (layered silicates) most common type is montmorillonite (iii) **particulate nanocrystals** are inorganic oxides: silica, alumina, zirconia, hafnia and titania.
- Nanoparticle loadings vary significantly and depend on applications. CNT concentration in the order of 5 wt% can lead to significant increase in strength and stiffness. However, 15 – 20 wt% CNT are required to produce electrical conductivities.
- Dispersion of nano-particles in the matrices are challenging.

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Now, the final thing that, I would like to address is the nano composite. So, nano composite as you understand this is a new class of material, where the reinforcing agent it is in nano size. Dimension nano is a bit blurred, but whatever below 100 nanometer

people call it nano, but what is more important is a size effect. Not only the specific size, but if that specific size is altering the property that is more important.

So, this nano composite they have found a wide range of applicability, electrical properties, some of them I will review in this lecture. Magnetic optical thermal properties, biological functionalities, and also its transport property of the conducting charge, that is also important for this kind of nano composite. So, as I have told size effect is important some material, those material are permanent magnet.

For example, I will be taking it in forthcoming classes the magnetic properties of nonmetallic materials. You will find that ferrosferric oxide, is a ceramic oxide, it shows ferric magnetic characteristics, but once the dimension is below a certain limit, we call this is the size effect around 50 nanometer or so then the properties changes. So, actually two important factors are important for this type of nano composite.

First whenever you are dispersing it the surface area is increased many times as compared to the bulk dispersion. And, the surface phenomena is begin to dominate, for extremely small particle you can even consider the quantum effect and this quantum effect is beyond the scope of this particular course. But, very very exotic properties, very many more exotic property one can achieve out of this nano composite.

So, usually for our purpose we use nano particles which are carbonaceous type. And, already I have introduced the carbonaceous material part of my earlier lecture. So, it could be either single or wall carbon nanotube, graphene sheets can be used, carbon fibers can be used, that is one type of material that is used for the strengthening agent for this type of nano composite.

Second class of materials are nano clay mostly montmorillonite is used or in some instances vermiculite is also used, the clays are having layered structure it can be easily you can separate this clay structure, the layer by layer structure you can separate it. Or particulate nano crystals of silica, alumina and zirconia, hafnia, titania, nanoparticles also can be dispersed.

So, the loading of these nanoparticles they are important and that depends on what type of application you want out of this nano composite. CNT concentration in the range of about 5 weight percent that can lead a significant increase of strength and stiffness of the

composite. But, if you want the electrical conduction for certain application, then you will have to increase its weight percent up to 15 to 20 weight percent of CNT should be added.

The problem of this nanoparticle is the dispersion, lot of techniques are adopted, and which is part of research issue, that how in a matrix you can evenly distribute it. But, as I understand that if due to the finer particle size it is having enormous surface energy. So, it will try to attract other nanoparticles to form a soft agglomerate. And, they will not be dispersed very evenly inside the matrix. So, the way you are dispersing it is really important to get the full advantage of this nano composite materials.

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Nanocomposites: application areas

- Gas – barrier coatings: The freshness and shelf lives of foods and beverages may be increased when they are packaged in nanocomposite thin film bags/containers. Montmorillonite nano-clay particles are exfoliated and during incorporation into the polymer matrix are aligned such that the lateral axes are parallel to the plane of the coating.
- The presence of nano-clay particles accounts for the ability of the film to effectively contain H₂O molecules in the packaged foods and CO₂ molecules in carbonated beverages and also keep O₂ molecules from the air outside. These platelet particles act as multilayer barriers to the diffusion of gas molecules.
- Nanocomposites coatings are also used to increase air pressure retention for automobile tires and sports balls. Exfoliated vermiculite platelets are aligned in rubber

Food packaging plastics

Nano-clay particles

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So, applications area of this nano composite, they are really very versatile. And, some of them I will just introduce in the course and you can just think of other exotic properties, the first one is the gas barrier coating. So, for example, this kind of polymeric film you are familiar with and usually the beverage is covered with this food items are covered with this.

So, it keeps the freshness of the food and beverage and when you use it as a packaging material. So, usually montmorillonite nano-clay particles, they are used as a dispersing agent and they are exfoliated. So, this is the kind of exfoliation you have a clay particle here. So, either chemically or by ultrasonic wave it is possible for you to exfoliate this

layer structure and disperse it inside the composite. So, that they are favorably aligned to the composite plane.

And, this nano clay particles account for the ability of the film to effectively contain the H₂O the moistness of the food item, they it will not let it to go out. So, it obstruct the diffusion of this gaseous molecule. For the beverage also carbon dioxide will not get out. So, the so, called fizz of this cold drinks, they will be intact if you just pack it once you take it out of the bottle.

So, that is there and also it will not allow the oxygen from the ambient to get in to the food item oxidize it and make it still. So, that is also another advantage. This type of clays, they are nowadays also being introduced in elastomer. So, for example, in tire it maintains the air pressure, because it retards this diffusion this exfoliated clay particles.

And, also for tennis ball it is important that it retains its pressure. So, for those kind of application instead of montmorillonite, we use another type of clay which is vermiculite platelet us. They are aligned in rubber matrix and this kind of application one can get.


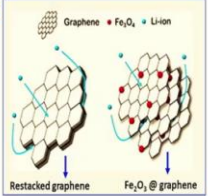
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Nanocomposites: application areas

Energy storage Graphene nanocomposites are used in anodes for lithium-ion rechargeable batteries that store electric energy in hybrid electric vehicles. Surface areas of nanocomposite electrodes that are in contact with the lithium electrolyte are greater than for conventional electrodes. Battery capacity is higher, life cycles are longer and double the power is available at high charge/discharge rates when graphene nanocomposite anodes are used.

Flame-barrier coatings The coatings composed of multi-walled carbon nanotubes dispersed in silicone matrices exhibit outstanding flame barrier characteristic. Also they offer abrasion and scratch resistance. Do not produce toxic gases and are extremely adherent to most glass, metal, wood, plastic and composite surfaces.

Dental restoration Known as filling materials are polymer nanocomposites. Nano filler Ceramic materials include 20 nm SiO₂ / or SiO₂-ZrO₂. Polymer matrix materials belong to dimethacrylate family. Have high fracture toughness and are wear resistant. Have short Curing time and curing shrinkage.



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Another thing which is coming up quite extensively is in the area of energy storage. You know the graphene is being used or reduced graphene oxide, which is having reasonably good electronic conductivity. They are used with the anode material, I have cited one example, which is ferrosferic oxide Fe₃O₄ and this is embedded in a graphene sheet.

Of course, it is not a single graphene sheet, multi graphene sheets are there and you embed this ferrosferric oxide.

And, you use it for lithium and intercalation as an anode material. So, in lithium and rechargeable battery although I will take it separately part of my other lecture, you know that lithium comes in during charging it comes out of the cathode, and it is inserted in the anode material. So, if anode is an intercalated compound like clay based material, which is a layered structure, then lithium can peacefully come and it can sit in between the layer, but ferrosferric oxide it is an oxide material.

So, lithium actually reacts with this. So, it is a conversion type of reaction that takes place. So, the structure is completely destroyed and iron oxide is formed of different balance state FeO or Fe_2O_3 . And, then you have this iron oxide is embedded in lithium oxide. So, each time lithium coming in and going out, there is tremendous volume expansion takes place.

So, if you use bare ferrosferric oxide, then this scramble the electrode is scrambled. So, you embed it in a graphene layer, graphene sheet. So, that acts as a buffer layer. So, these composites are quite good. So, here the graphene is having two different functions. The first one it imparts the necessary electronic conductivity within the electrode itself.

So, the power rating of this battery is very high. And, second one is it buffer the stress which is arising because of the lithium coming and going this conversion reaction. So, it is proved to be a very good material and various other type of research is also going on. It can be used as a flame barrier coating so, it will not catch fire.

So, usually a multi layered carbon nanotubes, they are dispersed in silicon matrix, that exhibits outstanding flame bearing characteristics, which is used nowadays as a wear shield, Havel's they use it. And, the toxic smoke will not come out of this. So, they are flame retardant coating. For dental restoration also you know the some kind of plastic mass is used.

So, that is basically a polymer nano composite as a nano filler ceramic material, which is typically 20 nanometer silicon dioxide or SiO_2 , ZrO_2 composites are used mixed powder or composite powder. And, polymer matrix material belongs to dimethacrylate family.

So, they are very strongly very quickly cured up and very short curing time and shrinkage is also not that prominent. So, in case of a cavity you can use it as a dental restoration material. And, as I have already described the crown made out of glass ceramics is used to cover the bad tooth. So, this is quite interesting.

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Nanocomposites: application areas

Mechanical strength enhancement High – strength and lightweight polymer nanocomposites are produced by the addition of multi – walled carbon nanotubes into epoxy resins; nanotube contents that range between 20 – 30 wt% are normally required. These nano composites are used in wind turbine blades as well as tennis rackets, baseball bats, skis, bicycle frames etc.

Electrostatic dissipation The motion of highly flammable fuels in automotive and aircraft polymer fuel lines can lead to the production of static charges. If not eliminated, these charges pose the risk of spark generation and the possibility of explosion. However, dissipation of such charge buildups can occur if the fuel lines are made electrically conductive. Adequate conductivities may be achieved by incorporating multi – walled CNT into the polymer. Loading contents as high as 15 to 20% are required.

Bonding wire to bind two ends of metal piping

Static dissipative hose

Proper hose connections for conveying system hose

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Mechanical strength enhancement takes place with a light weight polymer nano composite that is basically again use carbon nanotube into epoxy resin. And, here we use about 20 to 30 weight percent are normally required to make this kind of nano composite. And, wind terminal sorry wind turbine blade for generation of the electricity or also tennis racket, you know or baseball bat they are used out of this composite.

Another good use is electrostatic dissipation once with a hose pipe you are putting oil into aircraft or in automobiles, then there is due to the static electric charge there is a possibility of explosion. So, if you can increase the electronic conductivity of this kind of polymer composite by adding CNT. Typically, 50 to 20 percent addition is required. So, then this charge can be dissipated and various the possibility of this explosion is grossly reduced.

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So, there are various other activities also for this kind of composite. So, I have the study material for this particular lecture is the book by Callister and I have marked it red and apart from that the book by B.D. Agarwal or Chawla is also quite good.

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Conclusions

- Structural composites Laminar composites and sandwich panel
- Laminar composites are composed of two – dimensional sheets that are bonded to one another; each sheet has a high strength direction
- In plane laminate properties depend on layer – to – layer high strength direction sequencing – unidirectional, cross ply, angle ply, and multidirectional.
- Sandwich panels consists of two strong and stiff sheet faces that are separated by a core material or structure.
- Nanocomposite material applications

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So, in this lecture we talked about structural composite laminar and sandwich type. Laminar composite composed of two dimensional sheets, they are bonded to one another in the high strength direction. And, sandwich panel consists of a strong stiff sheet faces that are separated by a core, which are softer in nature. And, finally, we talked about nano composite and their perspective applications.

Thank you so much for your attention.