Science and technology of polymers
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Lecture - 32
Polymer Composites

Today, we shall discuss about the polymer composites; to start with let us think of the gift of nature. What kinds of composite have been gifted by nature?

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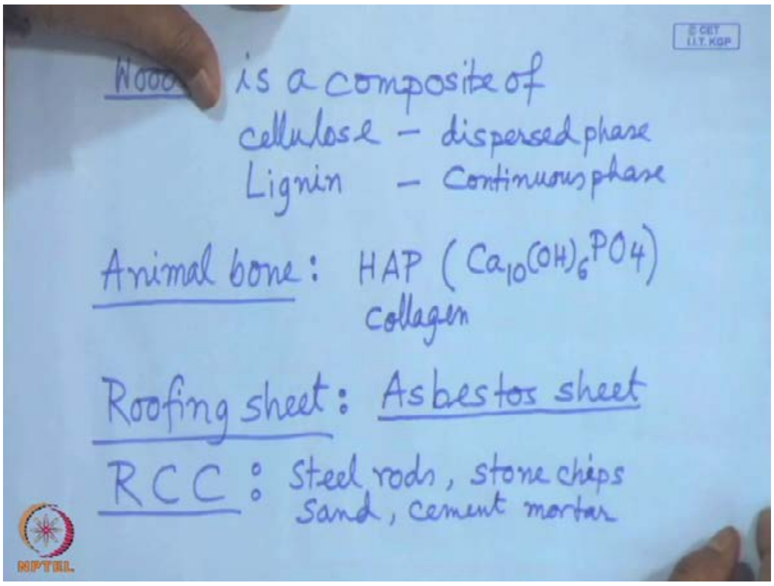

Wood is a composite of
cellulose – dispersed phase
Lignin – Continuous phase

Animal bone: HAP ($Ca_{10}(OH)_6PO_4$)
collagen

Roofing sheet: Asbestos sheet

RCC: Steel rods, stone chips
Sand, cement mortar

Number one, nature gifted composite is wood. Wood is a composite of cellulose and lignin, cellulose is the reinforcement or dispersed phase, lignin is the continuous phase known as matrix. And because of that cellulose reinforcement of cellulose as fibers in molecular level in the lignin matrix, which is also of very high molecular weight in wood, wood is a very strong material, available in nature from plant origin; and by virtue of that composite characteristics the branches of a, big branches of a tree can be a such load as cantilever. From this naturally occurring composite, we can understand the load bearing capacity of composites.

Second example of nature's gift is animal bone; it is we can also consider this animal bone as another natural composite from animal origin. This bone is a composite of hydroxyl hepatite. In brief you can write HAP; its formula is it contains 10 calcium 6 hydroxyl groups and phosphate.

So, this is the calcium hydroxyl hepatite. This is the bone mineral, remaining as dispersed phase in a continuous phase called collagen; as matrix, collagen is the matrix and this hydroxyl hepatite is the dispersed phase; looking into this natural bone, if you have tried to mimic this natural bone and developed artificial bone. In case of bone injury, broken bones are being replaced by artificial composites prepared from this dispersed hydroxyl calcium, hydroxyl, calcium hydroxyl hepatite in some synthetic polymer matrix.

That may be collagen or some other biodegradable polymers like polylactic acid or you even ketones. So, these are artificial synthetic composites are used in big used in biomedical engineering as biomedical in plants. There can be other synthetic composites, these are two natural composites. There can be other synthetic composites, we find their frequent use one is roofing sheet, say known as asbestos sheet. Asbestos sheet, which is actually made in the in the form of colligated sheet.

This colligated sheet are used for roofing purpose to protect form rain and sun light. This is a strong composite, the strain is continued by the presence of asbestos fiber in disperse condition in a cement layers combined matrix. So, this asbestos sheet is a good example of composite of inorganic character whereas wood is a composite of organic character. Animal bone is a composite of inorganic organic character. So, here we find that the matrix, there are two different phases. One is the continuous matrix phase and other is dispersed phase known as reinforcement.

We come across another huge composite all of us well known such composite that is RCC rein force cement concrete. What is this reinforcement cement concrete? In this RCC steel rods are used as reinforcement or disperse phase in a continues fiber form continues rod form, which is, which remains a embedded in a continues phase known as cement, sand, mortar and there is another reinforce dispersed phase that is stone chips. This steel rods and stone chips are embedded in sand cement mortar after setting that gets very strong composites out of which we prepare huge use building structural bodies like use building bridge. So, and so, these are few examples of composite where we find, there are two different phases, one is the continuous phase and other is the matrix phase to start with.

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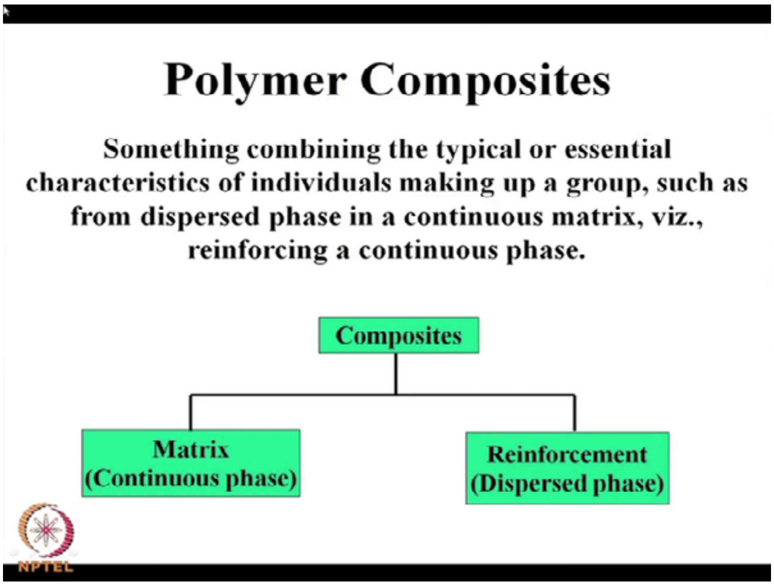

Polymer Composites

Something combining the typical or essential characteristics of individuals making up a group, such as from dispersed phase in a continuous matrix, viz., reinforcing a continuous phase.

Composites

Matrix (Continuous phase)

Reinforcement (Dispersed phase)

So, we can define this composite as a combination of individual components of matrix phase and reinforcement phase. Both this individual components have continuation to the properties of the final component. Although we find that either of this components are not that strong. Whereas that of your composite strength of that composites. So, composite is very stranger, than the either of component phases like matrix and reinforcement.

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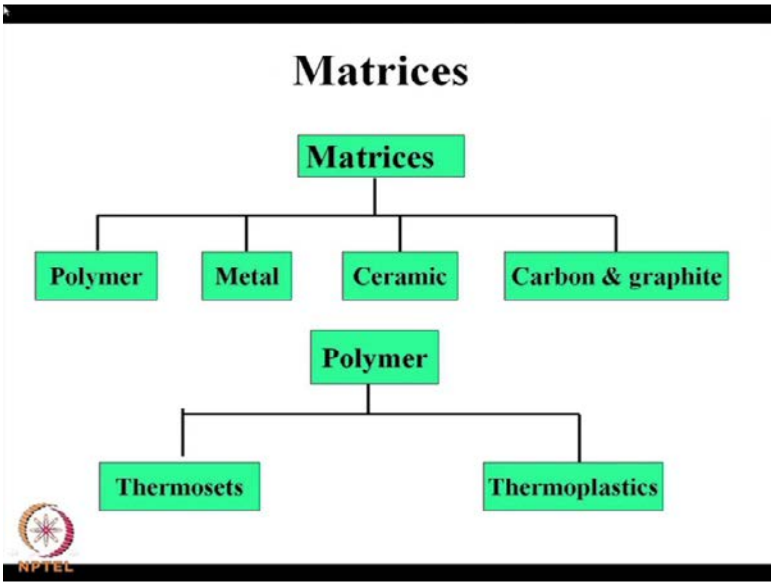

Matrices

Matrices

Polymer

Metal

Ceramic

Carbon & graphite

Polymer

Thermosets

Thermoplastics

If you look into the classification, this matrix or matrices in plural form, we find that can be polymer composites. That can be metal composites, that can be ceramic composites, that can be carbon and graphite composites; that means, you can use any type of matrix or continuous stage, using a suitable polymer, using a suitable metal or using a suitable ceramic material or you can carbon and graphite.

Why these are, why such matrix define? Matrix materials are necessary for making composites because then, we have to think of the purpose for which such composites are been met. From the point of view of strength, ultimate strength rigidity stiffness, their stability, their response towards temperature extremes like low temperature, very low temperature secrigenic temperature or very high temperature. Like even it can, some components can go beyond 2400 degree Celsius without any loss in properties.

Now, this carbon and graphite matrix composites can go to that extent where this carbon matrix and graphite matrix do not decompose. In fact, such matrix is prepared by taking a pores (( )) then it is spiderlised in atmosphere where this carbon or graphite formation solution occurs and it becomes a matrix good and strong matrix, and which can stand very high temperature.

You know a ceramic materials are also very high temperature material; that means, the ceramic materials can stand can withstand, very high temperature without losing properties although it is brittle in nature. Metal matrix composite can also be there. Very high strength performance is a one can go for metallic composite. Polymer matrix composite where it may not provide very temperature resistance, but it is very good matrix material for common or general purpose composites. By virtue of some special features of polymers starting from the low specific gravity, their easy prossesibility, good teller ability and good resistance to corrosion.

Other things is polymer matrix, can become a very good choice for making composites. Now, within the class of polymerm which is the subject matter of our discussion today is within the polymer there can be of two major categories. One based on the response to thermal environment, one is thermosets type of polymer and other is thermoplastics types type of polymer. Now, this thermoplastics they behave like this the thermoplastics can soften on heating and it hardness on cooling.

This process is reversible where as thermosets is softens on heating, but gradually it undergo some chemical reactions. It fall a 3 Dimensional cross linked network bonds. Ultimately it becomes rigid and strong and permanent, which cannot be reverted back to the initial condition. So, it cannot be it cannot be soften further on cooling after cooling; that means, once a thermosets structure is formed by heating, then on cooling such thermosets structures become solid and rigid. Such rigid and solid structures cannot be softened or it cannot become flexible.

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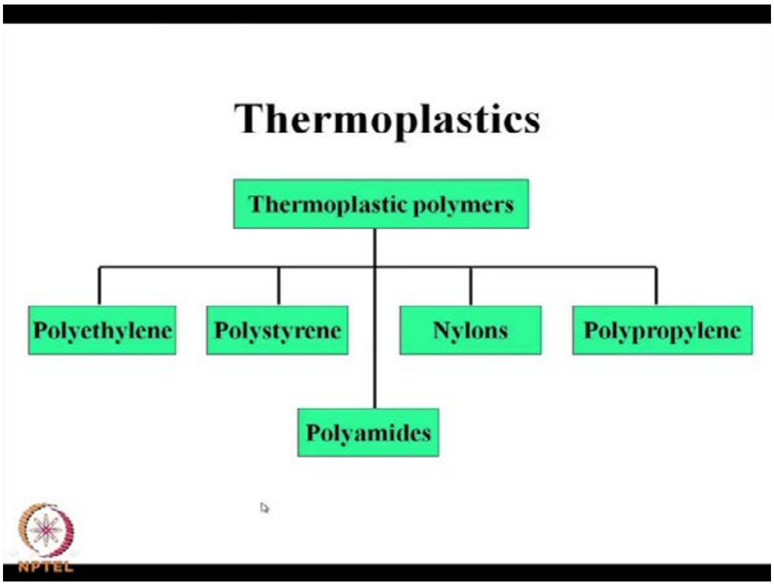

Thermoplastics

Thermoplastic polymers

Polyethylene

Polystyrene

Nylons

Polypropylene

Polyamides

After further heating within the thermoplastic category of polymers. there can be several example, several polymers available. There is huge versatility of finding this thermoplastic polymer matrix for making composites. We can start with the polyethylene, polystyrene, polypropylene, which are polyalephene polymers. Purely hydrocarbon polymers and which are thermoplastic in nature. Other categories are say nylons and polyamides nylons, they are condenses type of polymers these are polypropylene, polystyrene, polyethylene. They are addition type of polymers

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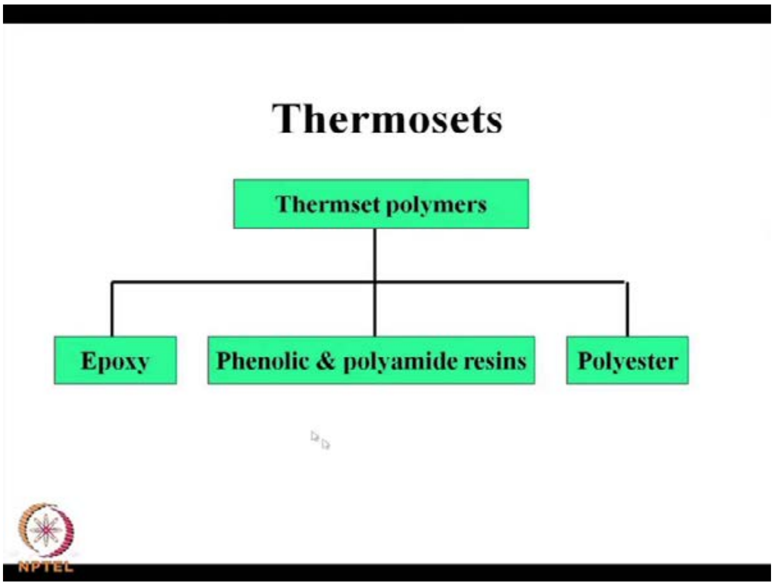

Thermosets

Thermset polymers

Epoxy

Phenolic & polyamide resins

Polyester

So, these are the in general, these are the categories of polymers, thermoplastic polymers, which can be used for making used as matrix resin for making composites. Now, in the thermosets category, we can have epoxy polymers epoxy polymers are made from this phenyl a from chlorine dehydroxyl epoxy. This phenolise or epoxy polymers and epoxy polymers are good in one sense, from one angle that these polymers can be processed or can be applied or these composites can be made from epoxy polymer at room temperature and slowly at room temperature it converts to a thermoset product.

This epoxy polymers, you know there is example of errorlite, which is a commercial adhesive. It contains two, it is a two pack systems one is the rigin and other one is the ordinar. When this resin and ordinar after mixing in a proper ratio, then slowly its start starts reacting to form a 3 Dimensional cross linked thermoset product and it becomes ultimately hard, and for this reaction it takes around 20 or 24 hours, which can also be further this curing time can be or reaction time can be decreased by application of heat. For that also some cross linking system or curing system could be different.

Another thermo thermoset category is the thermo unsaturated polyester. Now, this polyester is a ethylene terithalate, that is a thermo plastic material, whereas unsaturated polyester, that means, polyester containing some unsaturated moltees unsaturated functional sites, that undergoes slow cross linking reactions. So, that it leads to a thermoset product, so that thermoset unsaturated polyester is also used for making composite alematrix resins.

Phenolic reisns covers a good volume of this composite industry, phenolic reisns. Phenolic resins are basically a condensed product of phenon and polyamide and in different proportions. This different proportions makes a several composites this phenolic resins leading into a wide spectrum of properties of the polymer as well as the composite in which the resins was used as a matrix agent.

Polyamides resins are polyamides, basically it can be aliphatic polyamides as well as aromatic polyamides, having that CONAH amide linkage, this polyamide resins are actually basically polar polymers, polar polymers and by virtue of this polar groups. They undergo several hydrogen bond interactions, intermolecular hydrogen bond, interactions and that lead to very strong matrix bonding and leading to very strong composite.

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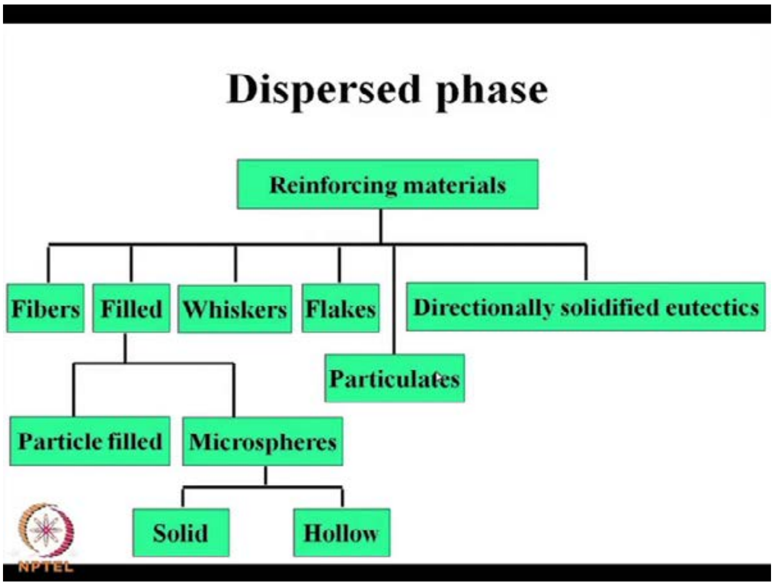

Dispersed phase

- Reinforcing materials
  - Fibers
  - Filled
    - Particle filled
    - Microspheres
      - Solid
      - Hollow
  - Whiskers
  - Flakes
  - Particulates
  - Directionally solidified eutectics

Now, let us look into the dispersed phase. This dispersed phase means the reinforcive material, that of the reinforcement. Now, reinforcing materials again there are huge examples, huge materials available which can be a put inside a matrix continuous phase to form a composite. Now, this reinforcing materials can be in the form of fiber. In the form of filler say particle filler in the form of whiskers, in the form of flakes, in the form of particulates or directionally solidified eutectics.

Now, you know this you are configuration say dimension etcetera of this different kinds of reinforcement in reinforcing materials are different. The geometry they are having their different geometries. Now, fibers can be again many natural fiber, starting form natural fiber one can have synthetic fibers. Different kinds of synthetic fibers again those fibers can be continuous fiber or chopped fiber. Again those fibers can be used for making rowing, fabrics, cloths in different forms.

Those fibers are used for making composites. In the filled composites, this particle filled composite can particle filled composites as well as those particles may be in the form of, a solid particles or in the form of microspheres. Again this microspheres are solid and hollow. So, this way we find a good range of materials available for making composites from such dispersed phase. One good example I can tell that is in particle filled composites say automobile tyre.

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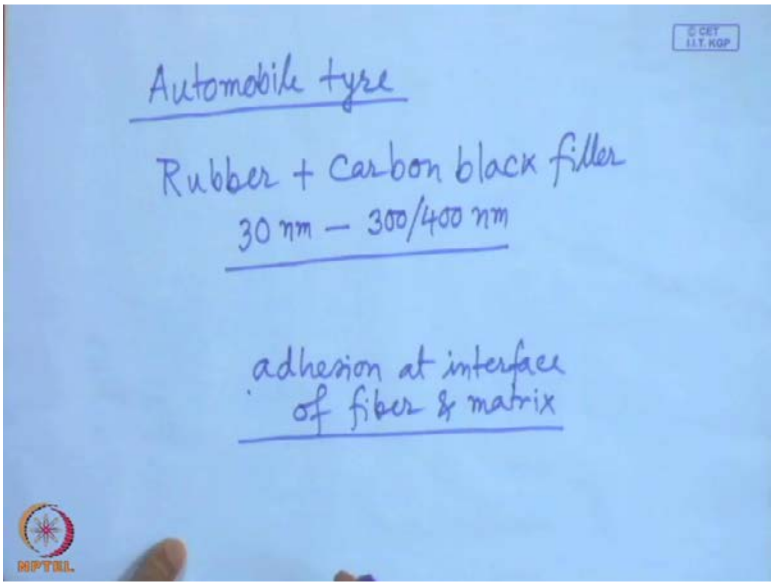

Automobile tyre

Rubber + Carbon black filler

30 nm – 300/400 nm

adhesion at interface
of fiber & matrix

Automobile tyre, the wheels of cars or vehicles and these are made of rubber filled the carbon particle known as carbon black filler. Their particle size can range from say 30 if less than that 30 nano meter to 300 400 nano meter like this. There are several grades of this carbon blacks, which are incorporated in rubber matrix. Natural rubber or styrene butyrene rubber or poly butyrene rubber or combination of natural butyrene, natural styro buthyrene etcetra.

When this carbon filler is incorporated and dispersed, semi homogeneously or you can say uniformly, these amount of carbon black can say 40 to 45, 50 volume parts or parts, parts by weight, that can increase the strength enormously, sure that is why get such loop bearing capacity of such carbon back filler loaded tyres.

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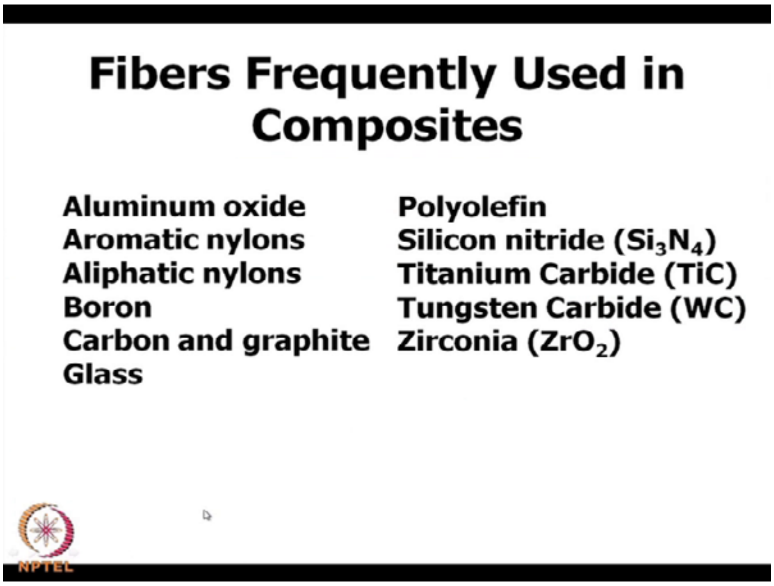

Fibers Frequently Used in Composites

Aluminum oxide
Aromatic nylons
Aliphatic nylons
Boron
Carbon and graphite
Glass

Polyolefin
Silicon nitride (Si_3N_4)
Titanium Carbide (TiC)
Tungsten Carbide (WC)
Zirconia (ZrO_2)

That is a composite of rubber and carbon black. Now, if you look into the different types of fibers, which are used for making composites say aluminum oxide is very good example of fiber is a ceramic fiber aluminum oxide. Similarly, we can have boron fibers, carbon and graphite fibers, glass fiber. This glass fiber can be drawn in very thin dimension. Then silicon nitride fiber titanium, carbide fiber, tungsten, carbide fiber zirconia fiber, of these are ceramic fibers.

Apart from these ceramic fibers, there are some organic fibers say polyalephenic fibers can be available. Aromatic nylons and alephatic nylons polyesters. So, that means, different types of nylons polyesters, polyaliphase, polyethylene polyprophelene, these fibers are used as a continues, continues fiber or chopped fiber as reinforcement material or dispersed phase in composites. Now, one thing we should consider at this point of time, here you see the nature the chemical nature of the fibers are different. In order to have a very strong composite, we must keep an aspect in mind that is the adhesion. Adhesion at interface of fiber and matrix.

For this adhesion, for adhesion for a food adhesion to obtain there must be some chemical similarity between the dispersed phase and the continuous phase, then only a miscibility or a compatibility will be available. There can be some physico chemical bonding between the fiber and the matrix, that is what is required. Now, if such type of similarity is not there, then there will be separation into different phases. Fiber phase and the matrix phase and in that case, the vinyl a structure component made of such composite, will be will be loaded.

The load will not be transmitted from fiber to the matrix or matrix to the fiber. The interface region will be a weak region, but this trace will be concentrated at the interphase region and the composite will fill. So, we have to think of selecting a good reinforcement, which is strong as well as a good matrix, which is also strong. But when such two different dispersed and compound matrix phases are used for making the composite, after forming the composite, the composite is supposed to bear huge load.

That means the loading bearing capacity will be much higher, than that of the component reinforcement and matrix phases. You know to get that you have to have very good interface adhesion provided, they have some chemical identity. Now, if you think of using aluminum oxide fiber in say organic matrix like say polyolefin, say polyethylene, that cannot be good bear of your dispersed phase. The continuous matrix resin phase that composite cannot be a strong composite. Whereas if some nylons are used for as fiber in polyolefin, that can be a very good composite. Say in case of fiber reinforce polymer composite. For example, glass fiber reinforced polyester GRP.

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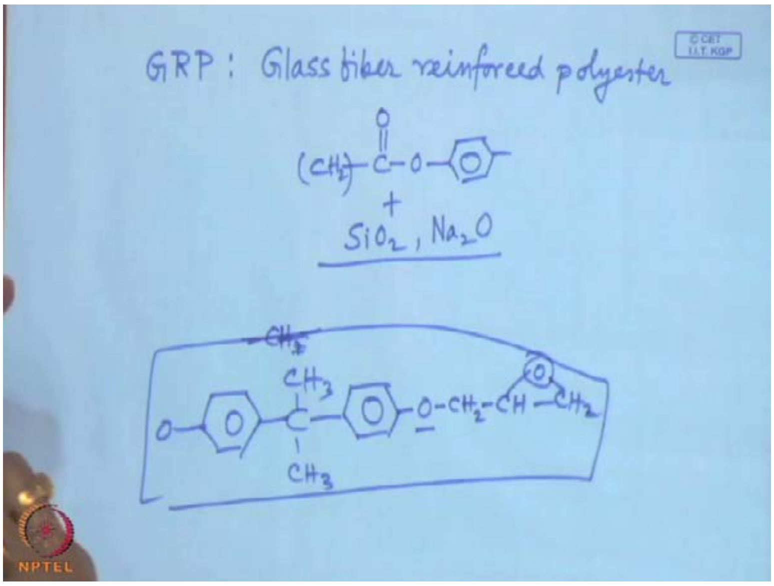

GRP : Glass fiber reinforced polyester

Now, here polyester being a polar polymer having this ester group, in this polymer along with some other alephatic groups like this C H 2 etcetera, aromatic linkage like this, aromatic ring some organic portion. Polar portion having due to this oxygen, they can have a good interaction between the components of a glass. A glass contains Si O 2 silica. Silica and other oxide materials, say there can be some little bit of sodium oxide depending on the what kind of glass it is? Some magnesium or boron. So, say boron silicate is there.

Glass is a oxide material, through with this oxide material this polyester can have good interaction. That very composites, so glass fiber reinforced polyester say unsaturated polyester or polyethylene, teritalite, that gives a very strong composite. So, we have to have a judicious selection of this fiber reinforcement for one suitable matrix, which else no one can get good composite.

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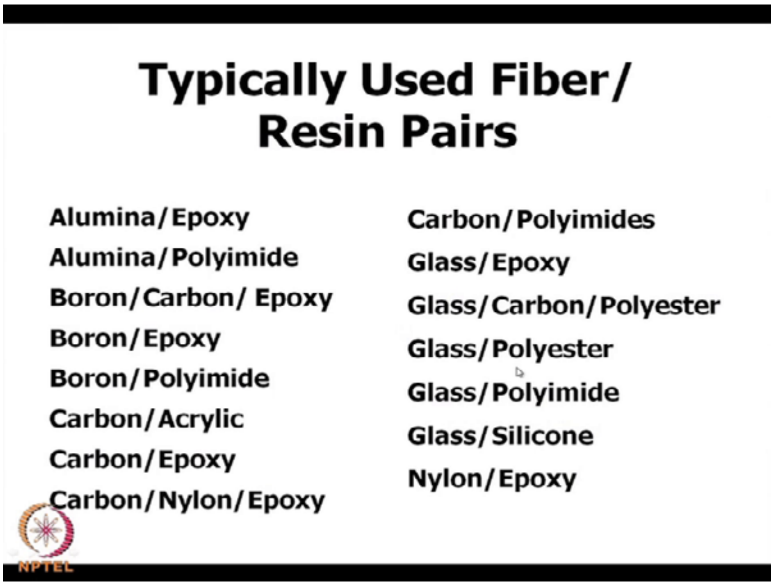

Typically Used Fiber/ Resin Pairs

Alumina/Epoxy
Alumina/Polyimide
Boron/Carbon/ Epoxy
Boron/Epoxy
Boron/Polyimide
Carbon/Acrylic
Carbon/Epoxy
Carbon/Nylon/Epoxy
Carbon/Polyimides
Glass/Epoxy
Glass/Carbon/Polyester
Glass/Polyester
Glass/Polyimide
Glass/Silicone
Nylon/Epoxy

Now, if you look into typically used fiber resin pairs, which are successful pairs for making good strong composites, having very good interfacial adhesion interfacial interaction, they lead to very strong properties. Apart from their components properties of the component materials say, alumina fiber reinforce epoxy is a good compare, alumina fiber polyamide in the case. You see it is obvious in this alumina a 1, 2, 3 that fiber and epoxy polymer that can also contain oxygen.

The epoxy polymer is basically a polymer of epiclo, bisphenyl a sorry, bisphenyl a. Other side this groups is, so this group phenyl is you see oxygen is there. This oxygen epoxy group is there. So, this leads to very good matrix material for alumina because of the presence of this oxygen atom there. So, polyimides nylon epoxy group and alumina is good combination. Then boron fiber or carbon fiber in epoxy matrix, that is also another good combination.

Boron epoxym, boron polyimidem, carbon acrylicm acrylic polymers means say a acrypolyacrynitel or acrylate polymersm, polyacrynitel pan polymer, polyacrynitel, having this, this is the polar site polyacrynitel are some acrylate say PMMA like this or other copolymers or other derivatives. So, by virtue of these oxygen atoms or these groups or this C O O group O group and or this C N group is a polar groups, that can be very good combination for composites.

So, this carbon polymides, glass epoxy, glass carbon polyester, glass polyester, glass polyimide, glass silicone, nylon epoxy and carbon acrylic as I was telling and carbon epoxy, carbon nylon epoxy. Carbon fiber carbon fiber, there is a basically a graphite fiber a carbon can have a matrix material or a fiber material this carbon fiber is made from this pan picasar.

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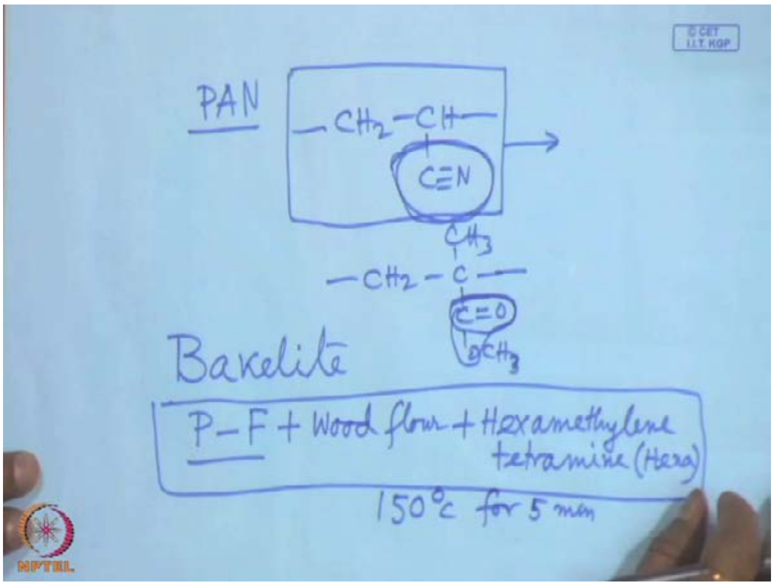

This is a polyacnalitel, this polyacnalitel picasa is used for making carbon fiber. This C N group cyclises with adjacent methyl linkage after cyclisation. Gradually when it is heated, it cyclises and it is heated in ordered atmosphere. It cyclises and this hydrogens are spelled out and then it form a hexagonal graffiti structure, grafitic structure.

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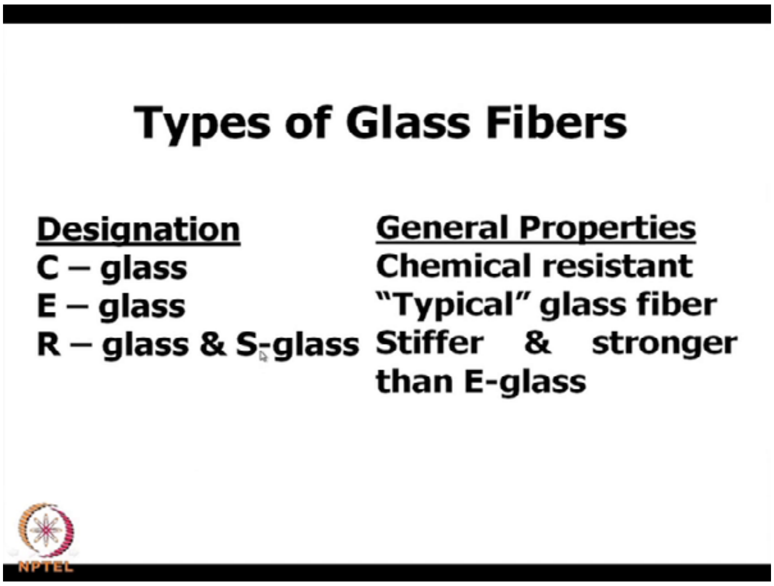

Types of Glass Fibers

Designation	General Properties
C – glass	Chemical resistant
E – glass	"Typical" glass fiber
R – glass & S-glass	Stiffer & stronger than E-glass

So, that will becomes stable, that is stable as well as strong. So, that carbon fiber is used for making high performance composites, which can withstand very high temperature as well as very strong. Different types of glass fibers, which are used for making such composites, there are categories different categories of glass fiber, C glass which is chemically resistant glass, E glass. This is a typical glass fiber and these are used for making some having good electrical properties and this R glass, which is R glass and S glass these two different categories R and S glasses are stiffer and stronger than E glass.

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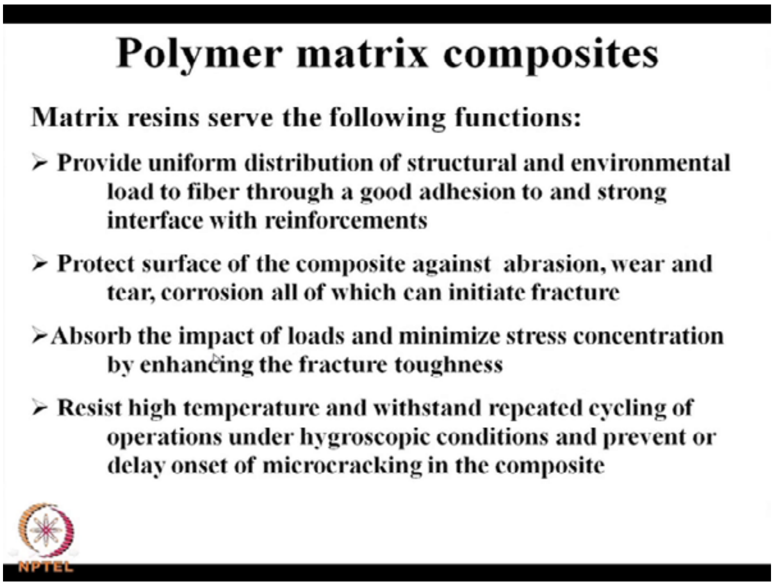

Polymer matrix composites

Matrix resins serve the following functions:

- Provide uniform distribution of structural and environmental load to fiber through a good adhesion to and strong interface with reinforcements
- Protect surface of the composite against abrasion, wear and tear, corrosion all of which can initiate fracture
- Absorb the impact of loads and minimize stress concentration by enhancing the fracture toughness
- Resist high temperature and withstand repeated cycling of operations under hygroscopic conditions and prevent or delay onset of microcracking in the composite

Now, in polymer matrix composites, the matrix resins are supposed to serve certain functions like they provide uniform distribution of structural and environmental load to the fiber through a good adhesion as I was telling to a strong interface with reinforcements. That means, the requirement is very good adhesion and reinforcement to the matrix. So, that the load will be transmitted distributed in a structural component structural body from the fiber to the matrix and matrix to the fiber.

So, that no weak site is created at the interphase region for this concentration and ultimate failure. This polymer matrix also apart from load bearing characteristics. They also protect the surface of the composite against abrasion wear and tear as well as corrosion all of which can initiate fracture. So, this corrosion wear and tear abrasion, so this can initiate some week zone, weak point or week site, where stress will be concentrated and failure can occur. So, this poly matrix gives protection to all such drawbacks short comings.

Now, they absorb also the impact load and minimize stress concentration by enhancing the fracture toughness. This now actually, this matrix resin that on application of load sudden impact load or gradual loading. That if that can deform the deformation will be here, that is elongation here of that matrix resin matrix polymer matrix component beep certain toughness character. This because toughness is nothing but the ability to absorb energy, if by through deformation resist high temperature and withstand repeated cycling of operations under hydroscopic conditions and prevent or delay onset of micro cracking in the composite.

So, polymer matrix can resist degradation at elevated temperature and that can withstand cyclic load cyclic load. That means, the hepatic property as well as the creep property or the relaxation property of the composite body, all these can be controlled by the matrix resin, so that, that prevent any microcrack initiation and propagation. So, that it does not allow the composite to fail.

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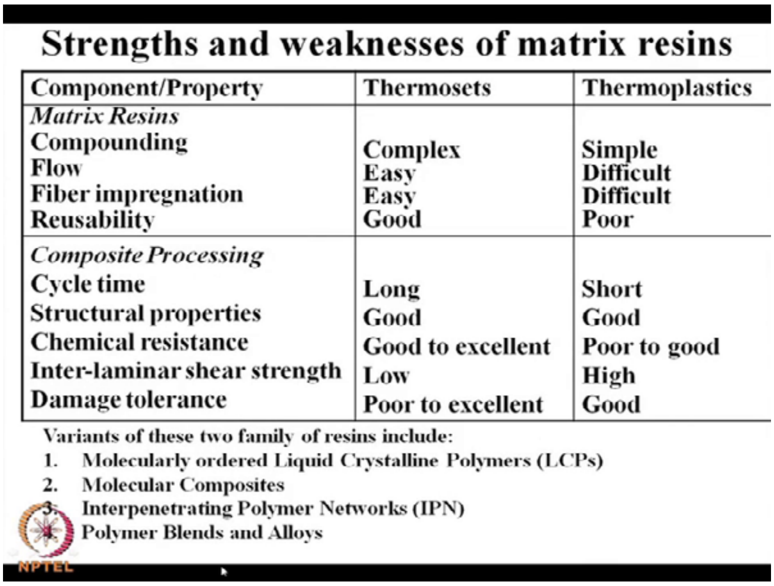

Strengths and weaknesses of matrix resins

Component/Property	Thermosets	Thermoplastics
Matrix Resins		
Compounding	Complex	Simple
Flow	Easy	Difficult
Fiber impregnation	Easy	Difficult
Reusability	Good	Poor
Composite Processing		
Cycle time	Long	Short
Structural properties	Good	Good
Chemical resistance	Good to excellent	Poor to good
Inter-laminar shear strength	Low	High
Damage tolerance	Poor to excellent	Good

Variants of these two family of resins include:

1. Molecularly ordered Liquid Crystalline Polymers (LCPs)
2. Molecular Composites
3. Interpenetrating Polymer Networks (IPN)

Polymer Blends and Alloys

Now, that can be certain strengths and weaknesses of matrix resins. There are this is just in this table is not exhausted it indicates. Taking some few examples of thermosets and thermoplastics, say in terms of compounding. Compounding in the sense, now in polymer product a virgin polymer is mixed with certain function of that additives. So, that it can perform in during processing fabrication as well as during service period through some chemical reactions chemical or physical reactions.

So, those are those need to mix with the base matrix base polymer that kind of process you known as compounding. Now, in case of this thermoset polymers that compounding process is complex. In case of thermoplastics it is very, it is very simpler than thermosets. Flow behaviour of thermosets are easy because thermosets polymers are formed from either low molecular allows or medium molecular allows to a finally high molecular weight 3 Dimensional network.

Whereas thermoplastics start with very high molecular weight and that needs very high temperature to soften or to melt, which is actually required during stepping operation or compounding operation. So, that flow characteristics are little difficult. Flow behaviour is a little difficult as compared to thermosets before its setting. Then fiber impregnation becomes easy in case of thermosets, which is difficult in case of thermoplastics because thremosets starts with low molecular rate global analog.

Similarly, composite processing cycle time is long for thermoset because one has to allow the chemical reaction to brief the final 3 Dimensional network structures, network configuration. Whereas in the case of thermoplastic it is solved because on cooling only it can harden, whereas this thermoset hardens due to chemical reaction, which may require a longer period of time. In case of epoxy hardening epoxy may take 12 to 24 hour even more than 24 hours provided, it is carried out at ambiane condition ambiance temperature.

I mean room temperature, but if temperature is increased the period of curing can be shortened, but structural properties of good for both chemical resistence are also good for these thermosets. But it is little poor in case of thermoplastics. Say you think of the bakelite, bakelite is a composite of phenol and formaldehide, is a matrix resin with this wood floor particle. Wood floor particle is a particularly filled or wood dust you can say, that is mixed with phenol and formaldehyde resin, then in and along with hexa methylene tetramine known as hexa.

This is a cross liking agent, all this three together, when heated at around 150 degree Celsius temperature, say for 5 minutes, provided with the thickness is not very high. That leads to a rigid composite like bakalite switch electrical gadgets these are used for with this Bakelite material, which is black. With that Bakelite is stable back is once. Although it is brittle if it is not actually broken, but it can solve for a you can more than 20 30 years without any loss in their property, electrical and mechanical properties. So, this way we here it shows a compression of this strengths and weaknesses of thermosets and thermoplastics in terms of their processing, fabrication and their properties.

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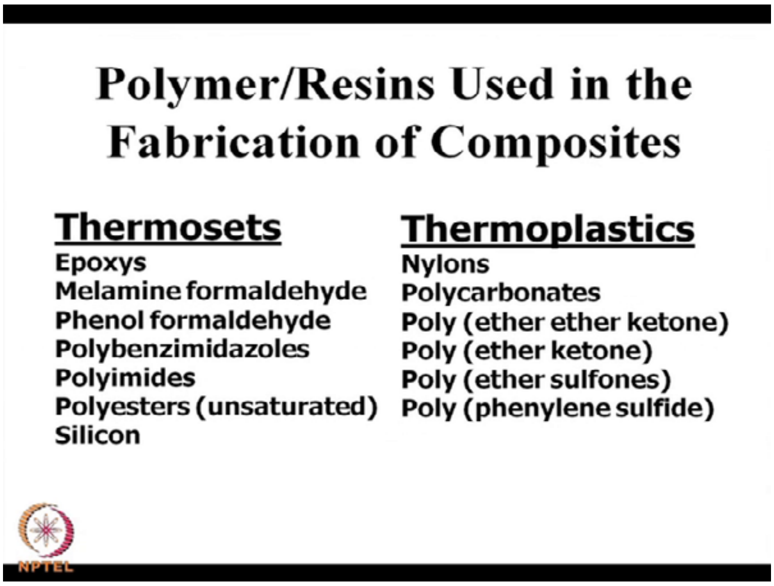

Polymer/Resins Used in the Fabrication of Composites

Thermosets	**Thermoplastics**
Epoxys	Nylons
Melamine formaldehyde	Polycarbonates
Phenol formaldehyde	Poly (ether ether ketone)
Polybenzimidazoles	Poly (ether ketone)
Polyimides	Poly (ether sulfones)
Polyesters (unsaturated)	Poly (phenylene sulfide)
Silicon	

Once again, let us see how many other polymers are used for a polymers or resins? Actually polymers are also called resins when we deal with this composite for fabrication of composite. Now, there are again as I told earlier to different categories in the thermosets categories, you can have epoxys, we can have melamine formaldehyde. Now, melamine formaldehyde is well known known material. Now, everyday we use some crokeries, plastic crokeries, melamine utensils, such as cups, dishes etcetera and even cutleries. All this things in general is cutleries.

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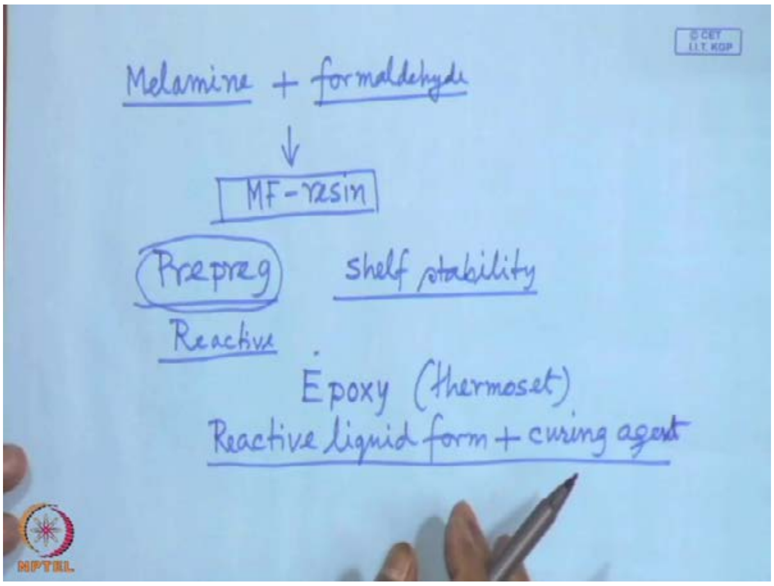

Melamine + formaldehyde

↓

MF-resin

Prepreg

shelf stability

Reactive

Epoxy (thermoset)

Reactive liquid form + curing agent

These are made of melamine and formaldehyde melamine and formaldehyde. They combine to form M F resin. This M F resin with some particular reinforcement that can form melamine crokeries. Similarly some particle reinforcement that can form melamine and crokeries. Similarly, poly phenoyl and formaldehyde show some reactions, how it is formed later. Phenol and formaldehyde resin, polybenzimidazoles polyimides that can be alephatic polyimide or hydromatic polyimide. Polyesters mostly unsaturated polyester, then silicone, silicone here it is worng, cone. Then thermoplastics category in nylons, polycarbonates, poly ether ether ketone, poly ether ketone, polyether sulfones, poly phenylene sulfide.

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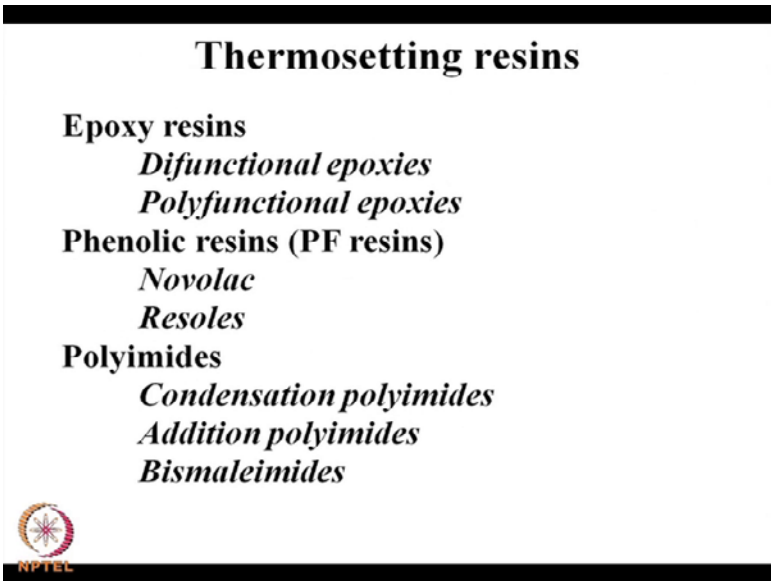

Thermosetting resins

Epoxy resins
  Difunctional epoxies
  Polyfunctional epoxies
Phenolic resins (PF resins)
  Novolac
  Resoles
Polyimides
  Condensation polyimides
  Addition polyimides
  Bismaleimides

Now, in the thermosetting category, we can have many other polymers. Now, a within the epoxy ethylene category, we can chase the number of functional sides of the epoxys, so that one can tailor the ultimate or final properties of the epoxys. I will show you how it actually chances by changing the functional functionality of epoxies resins. It can be difunctionality, it can be tetra functional, this way we can say we can have different category like difuncitonal category epoxies, poly fuctional category functional epoxies resins.

Then phenolic resins we can have in different form novolac, which is solid solid in thermoplastic stage, as it resoles is water based is also phenolic resins. So, this novolac can be used in in one process one kind of processess for making composite, this resoles are used adhesives or liquid resins for making laminates and composites. Say a commercial laminates, commercial ply woods for those making commercial ply woods composites, those are also composites where wood vinious are assembled with the help of this phenoyl formaldehide polymer resins. In this kind, in that product, resoles are the only choice for giving very good bonding between the wood viniars inter inter or laminates and performing a very strong and rigid composite. In the polyimides category, these are they can be condensation polyimides, addition polyimides and bismaleimides.

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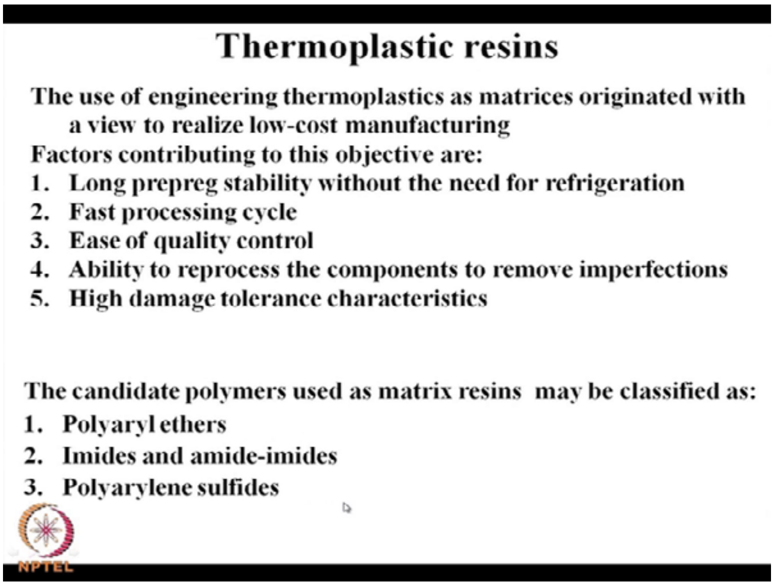

Thermoplastic resins

The use of engineering thermoplastics as matrices originated with a view to realize low-cost manufacturing

Factors contributing to this objective are:

1. Long prepreg stability without the need for refrigeration
2. Fast processing cycle
3. Ease of quality control
4. Ability to reprocess the components to remove imperfections
5. High damage tolerance characteristics

The candidate polymers used as matrix resins may be classified as:

1. Polyaryl ethers
2. Imides and amide-imides
3. Polyarylene sulfides

In the thermoplastic resins category, the use of engineering thermoplastics as matrices originated with a view to realize low cost manufacturing, low cost composite manufacturing. Now, in this taking, this engineering thermoplastics the factors contributing to this objective are long free prepreg stability. Now, let me explain what is called prepreg? Basically basically these composites are made from rowing, fabrics etcetera. So, cloths oven fabric although oven fabric those oven fabrics are soaked with the resin in green condition.

So, that after shoaking, then if there is some solvents, solvent is removed or dried. So, that resin soft fabrication is prepreg. Then those prepregs can be assembled, number of prepreg can be assembled to give a thicker composite. So, that are the shelf stability of prepreg is important. Now, this prepregs are, prepreg containing resin it is in reactive condition. That means it is very it is reactive. So, it should be properly stored either in refrigerated condition or in ambian condition, we have to see how it is reactive and how long it can remain stable.

Say for example, epoxy resin I tell you, epoxy resin ultimately it leads to a thermosets, it is a thermoset product. Initially epoxy resin is liquid, it is available in the liquid form, in the reactive liquid form. Since, it is in the reactive liquid form, it mix, it is mixed with curing agent epoxy curing agent or cross linking agent. This reacts immediate, starts reacting immediately with the curing agent and starts changing its viscosity and gradually it hardens and ultimately it becomes solid.

Now, since this resin epoxy resin is a reactive liquid form, slowly without effect without decreasing agent. Slowly it decreases its viscosity and which will become unsuitable for this application. So, this aspect is known as, is known as the stability of the resin as well as the prepreg. Now, in industrial practice, what happens? It is not there only few such as fabrics are soaked with the resin and do that immediately immediately assembled and placed under the hot place, for making the composite it is not like that.

In once of such prepregs are made in huge quantity, which is shifted to other moulding shop where it is compression moulded. So, there can be some filling up of this prepreg sheets and which should remain stable without changing any properties. Because during compression this prepreg material containing the resin, that must melt and show some flow characteristics under application of heat and pressure. So, that it can give a due to resin flow that can give provide very good consideration and binding of the several layers.

So, that is called prepreg stability and it is better in industrial practices to energy and to minimize the cost of the product. The prepreg should remain stable at ambient condition, it does not it should not be require refrigeration, refrigerated storing. Then first processing cycle, now this composites are made by a after soaking, the resin to the fabric, then assembling, then putting in the mould and hot placing at elevated temperature.

Now, this such curing cycle hot starting from prepreg to the curing cycle and curing cycle, cooling, cooling stage, the time requirement should be as minimum as possible, so that the productivity of the composite will be high. That is in another way the processing cycle should be minimum. So, that it can provide high productivity to have maximum profit. Then ease of quality control is of quality control in the sense that each and every batch should be uniform in properties after analyse analysis and testing.

It is evaluated the properties of the composites or products are evaluated and that should not be very lengthy. Only one or two representative test should, should be sufficient to indicate the quality of the composite product made. Then the ability to reprocess the components to remove imperfections. Reprocessing of components say, if there is some imperfections is found in a composite item fabricated, that can be huge item. So, it cannot be totally discarded or disposed off, but it can be reppeared.

So, that the imperfection which has been found in the product can be removed. That ability, that provision, that ability should be there in the product, high damage tolerance characteristics this is also should be considered. The candidate polymer used as a matrix resin may be classified as in thermoplastic resin category, polyaryl ethers, imides, amide imides, polyarylene arylene sulfides, these are of high performance category matrix resins, thermoplastics matrix resin. High carbon in the sense, these matrix resins leading to some composites, which are supposed to withstand very high temperature and very strong, say one can say this can be considered as a engineering thermoplastics and these engineering thermoplastics can give very good high performance composites.

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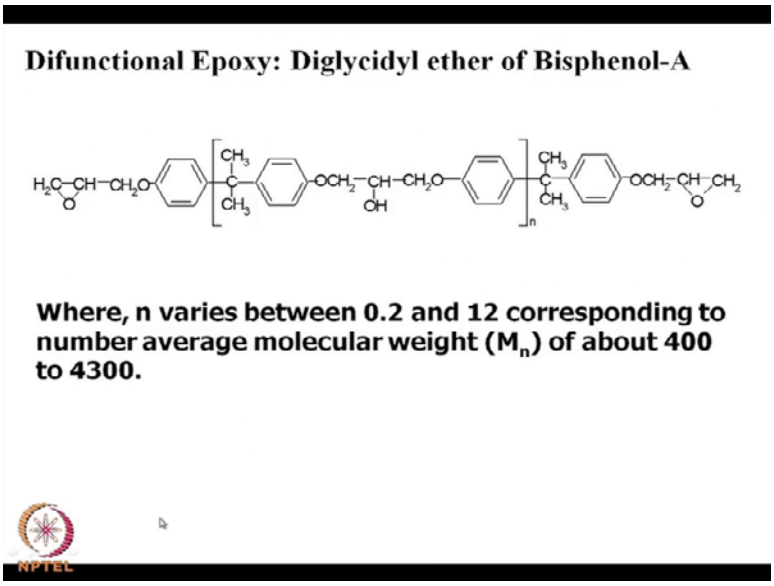

Difunctional Epoxy: Diglycidyl ether of Bisphenol-A

Where, n varies between 0.2 and 12 corresponding to number average molecular weight (M_n) of about 400 to 4300.

As I was talking about the functionality of the epoxy, so here this structure or formula you can say, so difunctional epoxy resin this is entire diglycidyl ether of bisphenol a. This is the bisphenol a malty, this is bisphenol a malty and this is the epicloridin malty. So, this reacts epicloride reacts with bisphenol a on the both sides and forming a polymer chain.

Now, these are the reactive sides of this epoxy resin and difunctional here is one functionality reactive, here is one functionality reactive in the polymer, this is called difunctional reactivity, bifunctional reactivity.

So, by virtue of this difunctional reactivity, it can give a linear polymer leaving behind some reactive site, which remains dormant and when some cross linking agent is mixed with this thing, it form a three dimensional network structure. So, here this molecular weight of this polymer can vary shown. So, here you can see the hollow of this varies from 0.2 to 12 corresponding to number is molecular weight of about 400 to 4300. So, depending on the nature of composite to be prepared, one can judge to what length this polymer can be formed? So, that, so that good strength properties of earth propogation properties could be available.

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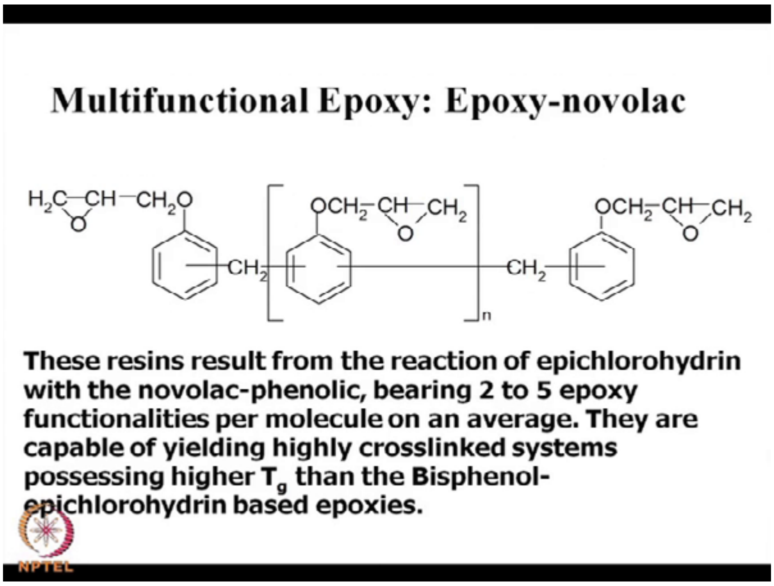

Multifunctional Epoxy: Epoxy-novolac

These resins result from the reaction of epichlorohydrin with the novolac-phenolic, bearing 2 to 5 epoxy functionalities per molecule on an average. They are capable of yielding highly crosslinked systems possessing higher T_g than the Bisphenol-epichlorohydrin based epoxies.

Next is multifunctional, beyond difunctional we call it multifunctional epoxy. Now, in that case epoxy resin is actually coupled with novolac, phenyl novolac originates from phenol and formaldehyde. It is one grade of phenol formaldehyde resin, thermoplastic grade of phenol formaldehyde resin. So, this phenol formaldehyde, this is actually phenol malty, phenol malty this another phenol malty. So, these are reacted with formaldehyde forming this methyl linkage through methyl linkage and epichlorohydrin.

So, epichlorohydrin, phenoyl, long formaldehyde all these three compounds together form a polymer giving a phenolic resin functionalities or phenolic resin properties as well as epoxy resin characteristics and functionality. That gives the advantage of epoxy resin as well as that of phenolic resin. This resins result from the reaction of epichlorohydrin with the novolac phenolic bearing 2 to 5 epoxy functionalities per molecule on an average. They are capable of yielding highly cross linked systems, possessing higher glass transition. Then the bisphenol epichlorohydrin based epoxies. So, when the, when one needs higher glass transition characteristics of the composite, they can blend novolac along with the epoxy system.

Thank you.   .