Science and Technology of Polymers
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Lecture - 33
Polymer Composites (Contd.)

In the last lecture I was discussing about the multifunctional epoxy resin as matrix resin for composites.

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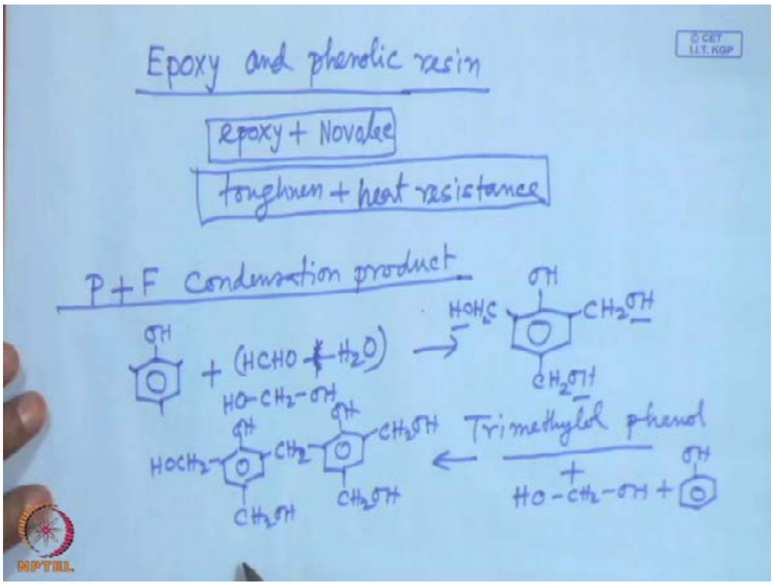

Epoxy and phenolic resin

epoxy + Novolac

toughness + heat resistance

P + F condensation product

I discussed about a combination of epoxy and phenolic from the phenolic resin. From the suitability point of view here the novolac grade, novolac grade resin was used for novolac grade phenolic resin was used with epoxy and these combination gives a very good curing characteristics, curing properties, cost intensity leading to stronger composites. Now, this novolac resin phenol formaldehyde resin that gives a thermal stability, heat resistance etcetera and this epoxy gives contribution to toughness.

So, toughness, strength, thermal stability these properties are combined in a composite, made from epoxy resin and phenol formulate resin in the form of novolac. Then there can be other multifunctional epoxy resin, increasing the functionality means that it will lead to have higher cost intensity. Now, if you look into this molecule.

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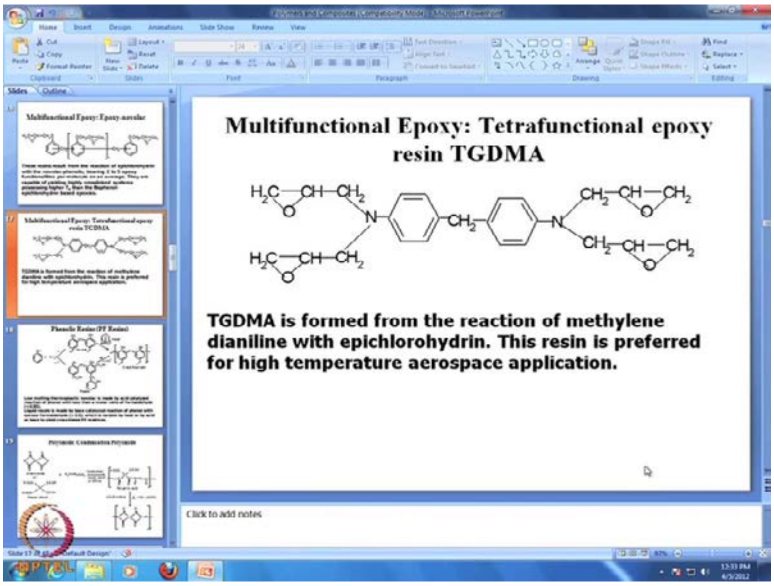

Multifunctional Epoxy: Tetrafunctional epoxy resin TGDMA

TGDMA is formed from the reaction of methylene dianiline with epichlorohydrin. This resin is preferred for high temperature aerospace application.

This, this is diamino diphenyl methane. This diamino diphenyl methane was reacted with 1 mole of, diamino diphenyl methane was reacted with 4 mole of epichlorohydrin having this nitrogen as trifunctional, nitrogen is tri functional. So, it combines with, this nitrogen combines with aromatic moiety and this is epoxy groups. So, 4 epoxy groups are combined to this molecule. So, when this is polymerized that leads to huge cross link density and it contains this C H 2 linkage, C H linkage, all these things as well as here C H 2 linkage and aromatic linkage and oxygen, these atoms.

So, this gives a combination of very strong and tough as well as thermally stable composite. So, this is, this can be a good characteristic of multifunctional epoxy resin and this TGDMA is formed from the reaction of methylene dianiline. You can say this as methylene dianiline or diamino diphenyl methane with epichlorohydrin. As I told this resin is preferred for high temperature aerospace application. So, you can say this kind of multifunctional epoxy resins are used for high performance applications in aerospace industries in aircraft, for aircraft application.

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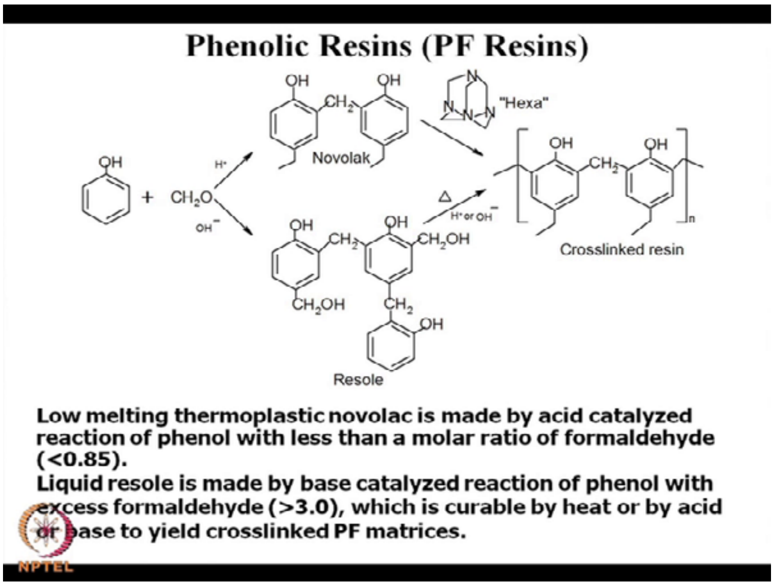

Phenolic Resins (PF Resins)

Low melting thermoplastic novolac is made by acid catalyzed reaction of phenol with less than a molar ratio of formaldehyde (<0.85).
Liquid resole is made by base catalyzed reaction of phenol with excess formaldehyde (>3.0), which is curable by heat or by acid or base to yield crosslinked PF matrices.

Now, let us look into the phenolic resin. We are discussing about the epoxy resins, epoxy resin, novolac phenolic formaldehyde combination. Now, let us look into phenolic resin. What is this phenolic resin? Now, this phenolic resin is age old resin. Actually, this phenolic resin are found the commercial scenario when Dr Baekeland, he discovered this bakelite, he developed this bakelite that was the first thermoset resin and first composition bakelite phenyl formaldehyde composite developed by Dr Baekeland and from his name this bakelite was given to this kind of product.

Till date, there is continuous research going on with this phenol and formaldehyde condensation product. What is the reason behind this? This is a very good matrix resin till today, unbeatable system one can say H C H O. We can, formaldehyde, this formaldehyde available in the form formalin, it gives basically methylene glycol, formaldehyde with water it forms methylene glycol. This methylene glycol reacts with phenol; that means formaldehyde reacts with phenol in the form of methylene glycol forming this kind of product. This is known as trimethylol phenol.

You see this trimethylol phenol it has got three functional, reactive functional groups. When this trimethyol phenol further reacts with this phenol and formaldehyde, say gradually this chain increases, same length increases, go on increasing C H 2. It can link up with another phenol unit. This way it continues. Now, this chemistry is a complicated chemistry dealing with different rectal reactive functional sides. Now, one thing here it can be explained that while phenol, formaldehyde these are present either it will grow in this direction or in this direction because these are also reactive, these can also react with another phenol, these can also react with another phenol.

So, in all these directions, this direction, this direction, this direction it can react. Ultimately it can grow and it can form a product high viscous as well as gel like three dimensional product. But in order to make, in order to have this suitable fabrication and processing facilities it should not gel or cross link during the, before the final fabrication, final setting. For that reason it must be control, the reaction must be controlled.

Now, there are two different catalysts. Here you see there are two different catalysts that is one acid catalyst H plus and the, another is O H minus alkali catalyst. So, phenol and formaldehyde can condense in acid catalyzed medium as well as in base catalyzed medium while it reacts in presence of acid catalyst, the ratio of phenol to formaldehyde is different than that of the base catalyst reaction. Here in case acid catalyst reaction the ratio of phenol to formaldehyde is 1 is to less than 1 mole of formaldehyde.

Now, this formaldehyde can be considered as a condensing agent as well as a cross linker for this is kind of reagent system. Here if this, the quantity of this formaldehyde is kept less, say 1 mole react with less than 1 mole of this formaldehyde the resin formed that will be available in the form of linear molecule which will remain as thermo plastic and that grade is known as novolak, novolak resin. Now, this novolak resin will not cross link itself.

To make it cross linkable or to cross link this novolak resin another cross linking agent known as hexamethylenetetramine, its formula is little complicated here. hexamethylenetetramine known as hexa technically. This hexa decomposes to form amine and formaldehyde. This amine and formaldehyde basically becomes the reactive cross linking agent with this novolak resin to form a three dimensional network. In case of bakelite switchboards, switches, sockets etcetera are electrical that insulators.

In those cases this novolac resin was used to mixed with along with hexa and after compression, during compression molding under heat and pressure that converts this novolac resin to a thermoset bakelite resin p f phenyl formaldehyde resin product. In case of resole here this formaldehyde in the form of formalin, formalin basically solution of formaldehyde say 40 percent sol, 37 percent solution of formaldehyde in water.

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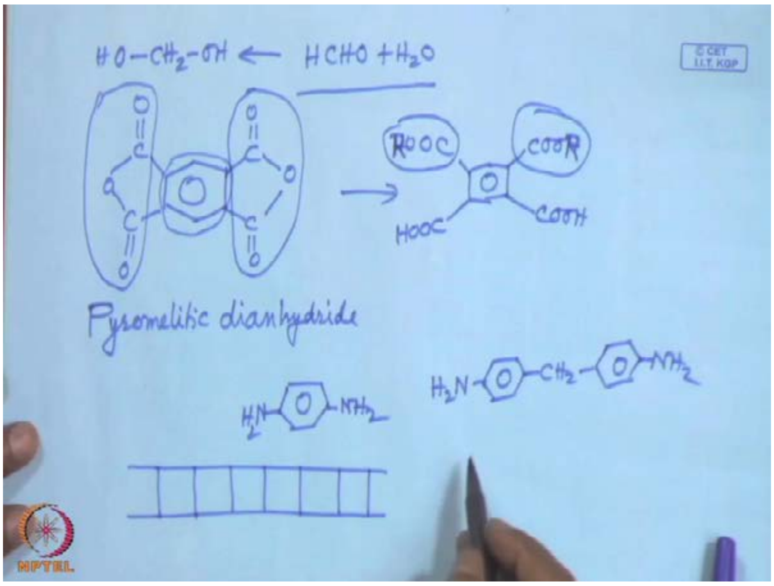

When it remains soluble in water that is represented as methylene glycol as I told just few minutes back this C H 2 O H this methylene glycol. This is formed from formaldehyde and water. So, this is a water based system, water based system. This water based system in presence of alkali can form resole resin when the ratio of formaldehyde or amount of formaldehyde is more than one mole of this phenol. Here you see if you compare this two different structures here this is a para position, para position, some growth is there, para position some reactive group is here whereas in this case this para position remains free which will be used up during cross linking, but here these are also formed by much of the higher amount of the formaldehyde over here.

And this remains, this resin remains liquid, a water based resin, a liquid resin. In this case during the condensation reaction, this is also, this proceeds in water medium, but after certain, growth of certain molecular weight this separates into a different phase, organic phase and there will be separation of water and organic phase. In the organic phase this resin will be there in the water phase, other things will remain and this organic phase water will be taken out and on cooling it becomes a brittle solid. And these reactions are carried out at around 80 to 90 degree Celsius temperature for more than 1 hour time. So, this is a little in brief the chemistry of phenolic resin which is a good thermoset matrix resin for making composites.

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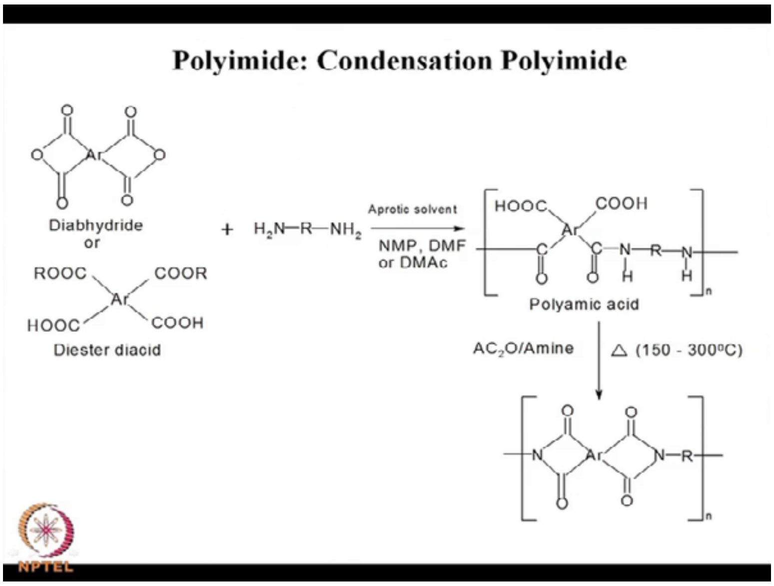

Polyimide: Condensation Polyimide

Now, again another kind of condensation polymer is polyimide. Now, polyimides are high performance resins. One can say engineering polymers, engineering thermo plastics and that can lead to high performance composites. Now, these polyimides are made from dianhydrides, dianhydrides. See, typical example is, this is known as pyromellitic dianhydride. This is the, this is one anhydride, this is another anhydride. So, this is called dianhydride.

Anhydride means it is in dry condition, it from this anhydride ring in contact with moisture or water, this anhydride ring will open up forming carboxyl groups. That means, you can say this can be tetra carboxylic acid. Basically, it is a tetra functional compound. In this formula this A r here is this phenyl ring. Basically, this compound and this compound are same. This compound and this compound are same. So, one can take dianhydride or diester diacid, that means here aromatic ring is there.

So, one carboxylic group here in this case can be in the form of 2 carboxylic group, in the form of ester group say in place of H if we write r some alkali group, this is an ester and this two acid groups. So, these two are the precursor, these two are the starting raw material, starting material for making polyimide. Now, this such type of compounds react highly with this diamine. Now, this diamine for this high performance resin, high performance resin basically they are aromatic diamine; that means there can be some aromatic ring, one or more than one aromatic ring. So, this is phenyline diamine or one can have diamino diphenyl methane, this is kind of diamine.

So, this dianhydride or diester acid reacts with diamine in aprotic solvent like say not N methylpyrrolidone, dimethylformamide or dimethyl acid amide. So, these compounds are dissolved in this solvent and heated. On heating what happens? This amino group react with this acid group, this acid, the acid groups or this anhydride group forming this (( )) the anhydride ring we have to treat this amine group forming amide linkage. C O N H, N H. So, this is known as polyamic acid.

Now, this polyamic acid it is further reactive. It is further reactive having this N H functional group. This N H functional group can react with this carboxylic group. This carboxylic group can from to form a ring when it is heated at high temperature. Gradually, it is heated from say ambient to or say 150 degree Celsius to 300 degree Celsius temperature in dry condition, dry condition it forms a ring. This is called amide ring. Here you see this amide linkage is converted to amide link while reacting with this carboxylic group. See amide ring. So, basically it forms a double strand polymer or multi strand polymer or leather polymer which looks like this ladder like structure.

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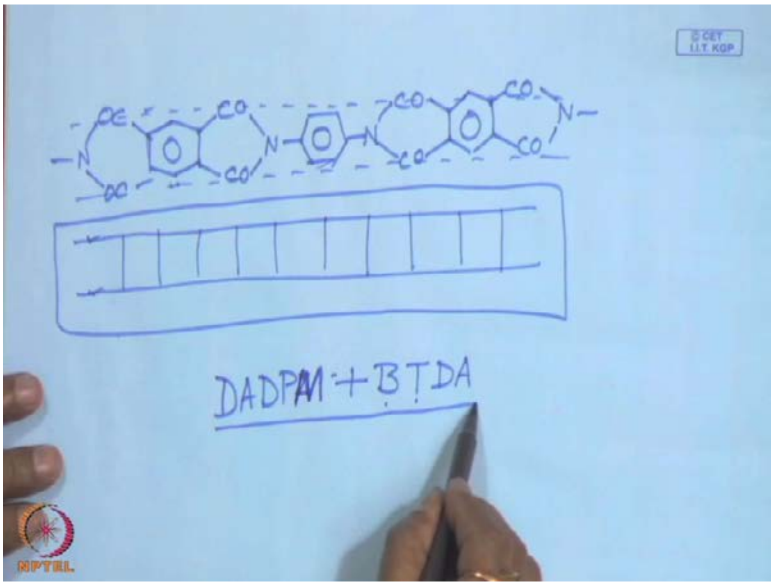

How? See, if we write the formula it continues this way like this, this side also. Here you see this; basically the backbone of this polymer molecule is rigid having this ring configuration, amide ring, phenyl ring, amide ring, phenyl ring, amide ring, phenyl ring.

So, we can consider this molecule like this. So, this line resembles this dotted line. This line resembles, this line resembles this dotted line and these linkages are the steps of the ladder known as double strand or you can say multi strand polymer.

So, this is highly thermally stable or thermo stable polymer and once this structure is formed it becomes insoluble and infusible. So, this polymers can be high performance polymers and in high temperature applications, in aerospace applications, in airspace applications or in spacecrafts these polymers are used for making composites with again high performance strong fibers say carbon fibers or aramid fibers. So, this polymer is known as polyimide, polyimide and this polyimide is formed out of condensation of dianhydrides and diamines.

Now, one thing I should mention at this point of time, now in this polyamic acid stage it is soluble in solvent. So, the product is to be fabricated say if somebody wants to make composite. A composite, a composite is to fabricated at this polyamic acid stage which remains in a solution in a solvent. So, these solvent of polyamic acid should be used for soaking a fabric then that polyamic acid, soft fabric or ply or layer can be heated at elevated temperatures from say 100 to through 150. In stepwise the temperature is to be increased, then after 300 degrees it completes the digestion this ring, amide ring formation becomes complete.

Once, this imide ring is formation is complete it becomes insoluble and infusible. Although, initially, so at this point of time I should mention that although initially at the, till the polyamic acid stage this polymer remains thermo plastic, but once this imide ring is formed it becomes thermoset and by that time it has already been covered, this polymer has already covered the fiber in the composite. So, that and also it gives a very good bonding with the fiber, this matrix resin gives a very good interface bonding with the fiber surface. So, if a high aspect ratio fiber is used as the enforcement and this polyimide is used as the matrix resin one can obtain a very high performance thermally stable and strong composite.

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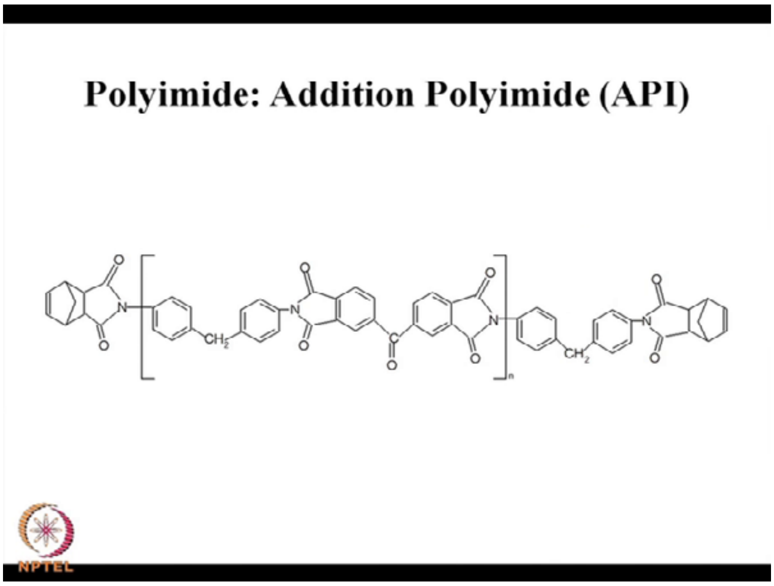

Polyimide: Addition Polyimide (API)

There can be other category of polyimides known as addition polyimide. Addition polyimide in the sense as you have seen in the previous case that imide means that must have had imide linkage like this. Now, that the property of flexibility, mechanical properties, shock observation, top tests all this things can be controlled or tailored if we tailor this part of the polyimide resin. Here you can have one rigid phenyl ring or you can have a flexible linkage like in this structure you see here C O group is there or one can have some ether linkage in place of C O, one can have ether only oxygen over here.

Now, this particular polyimide was made from diamino diphenyl methane and benzophenone tetracarboxylic dianhydride say diamino diphenyl amine D A, D A D P A or D A D P M which one is convenient you can say diamino diphenyl sorry methane sorry it will be D A D P M diamino diphenyl methane D A D P M. D A D P M plus B T D A, B T D A is benzophenone, benzophenone tetra carboxylic dianhydride. This D A D P M and benzophenone tetra carboxylic dianhydride, this is the benzophenol tetra carboxylic, this tetra carboxylic means it originated from one carboxylic group, it originated from another carboxylic group, another carboxylic group, another carboxylic groups.

So, four carboxylic group. So, this is benzophenone tetra carboxylic dianhydride that was reacted with diamino diphenyl methane. So, this amino group, this nitrogen is from amino group and that amino group is reacted with this anhydride group forming imide linkage. So, here you see methyline linkage is there, C O linkage is there. That imparts some flexibility to this polyimide. This is also a polyimide and this is also another polyimide, but there properties are different. Properties of this polyimide is different from the properties of this polyimide. Apart from this flexibility this polymer can be further kept in the reactive form known as addition polyimide. You see the N groups are reactive groups. That is actually formed from this bismaleimide moiety; bismaleimide moiety having this double bond over here this system becomes reactive.

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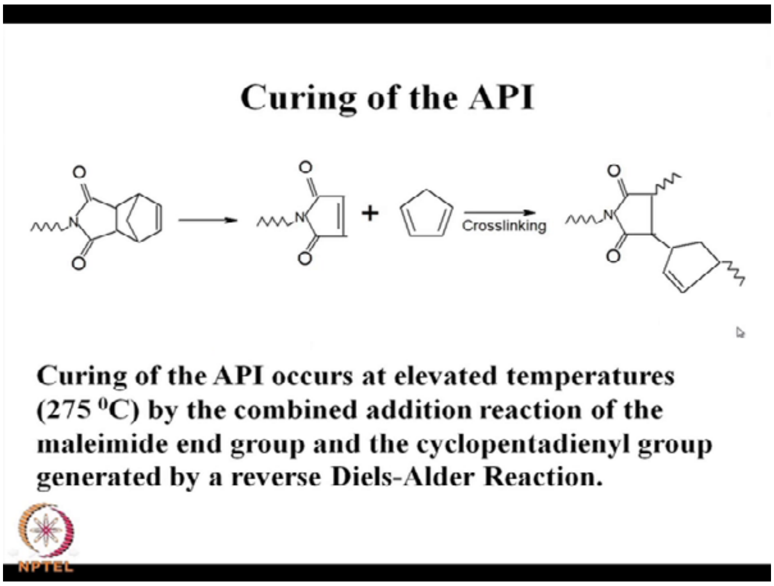

Curing of the API

Curing of the API occurs at elevated temperatures (275 ^{0}C) by the combined addition reaction of the maleimide end group and the cyclopentadienyl group generated by a reverse Diels-Alder Reaction.

Look into this. Here this API addition polyimide is a reactive system and that is curable or cross linkable. So, that cross linking or curing of that addition polyimide occurs via this reaction. So, this curing of the addition polyimide occurs at elevated temperatures say around 275 degree Celsius by the combined addition reaction of the maleimide end group. This is the maleimide end group, malei maleic imide, maleimide means maleic anhydride, this is the malefic anhydride imide, malefic anhydride when reacted with amine it forms maleimide, this maleimide.

This maleimide end group is there in the polymer. So, this maleimide combined with addition reaction of the maleimide end group and the cyclopentadienyl group which was generated by a reverse Diels Alder reaction from this end group of this polymer. Once again I am going back to this thing sorry this N group. These are the N groups, these N groups actually, these N groups breaks into maleimide and cyclo di penta, cyclopentadienyl group.

Now, these two groups once it is formed from the end groups of that addition polyimide that help in undergoing cross linking reaction in this form either rest part of the, rest part of the polymer chain, rest part of the polymer chain. So, this is one direction of the polymer chain and this is another direction of polymer chain which can be linked up in another polymer molecule. So, it forms a cross linked configuration. So, that is generated by a reverse Diels Alder reaction. So, this two are formed by reverse Diels Alder reaction. When they combine to form this kind of thing that is known as the Diels Alder reaction, in this direction it is called reverse Diels Alder reaction.

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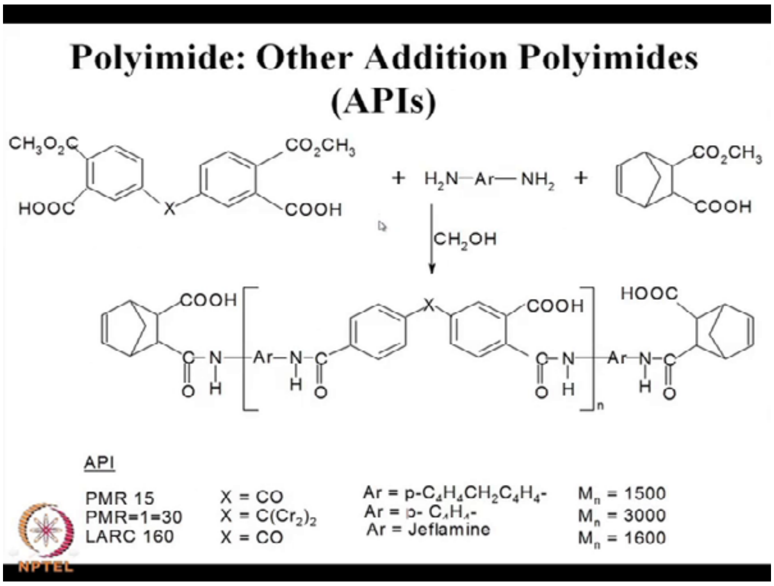

Polyimide: Other Addition Polyimides (APIs)

API			
PMR 15	X = CO	Ar = p-$C_4H_4CH_2C_4H_4$-	M_n = 1500
PMR=1=30	X = $C(Cr_2)_2$	Ar = p- C_4H_4-	M_n = 3000
LARC 160	X = CO	Ar = Jeflamine	M_n = 1600

Other examples, so other addition polyamides are again this can be a benzophenone tetra carboxylic dianhydride type of molecule or compound having, it is not anhydride, but it is a derivative of that anhydride. These are the two ester groups, diesters and diacid having, a molecule having 2 diester and diacid. So, all of them can react with diamine, aromatic dyamine or aliphatic dyamine. In presence of these molecule having this cyclopentadiene vinyl group or actually basically this is (( )) type of structure.

So, having this carboxyl and ester group that forms this kind of polyamic acid, again this is polemic acid. This polemic acid having this group then this polyamic acid will lead to imidine, imidine formation, imidine formation here also one group is missing over here.

So, that can also form the imidine, it is missing here. This similar carboxyl group can be will be there in this at this position. So, this will form on imidine, this will form another imdine and this reactive N groups are there as before, it will be cross linkable as well as polyimide structure we form at the sometime this flexible linkage it is there. So, toughness, stiffness, strength, thermo stability all these things are tailored in the form of thermo plastic or thermo set configurations to have a broad spectrum properties of this kind of matrix resin for high performance, for making high performance composites.

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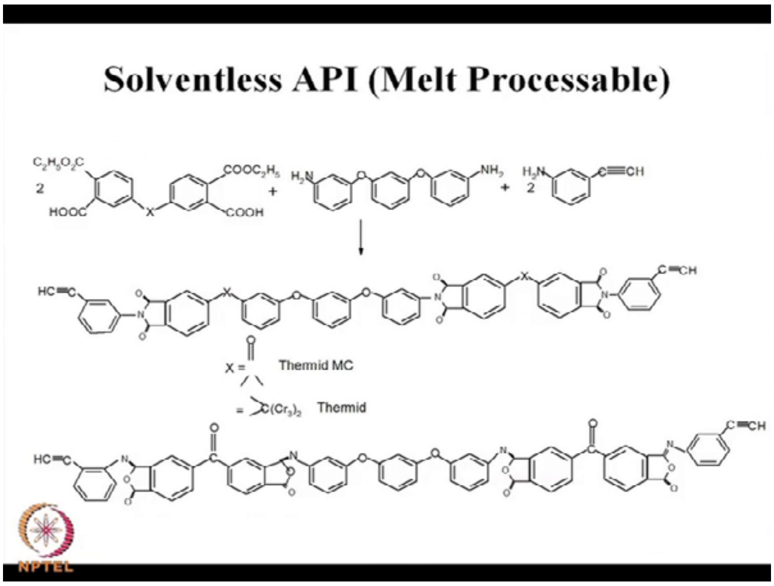

Solventless API (Melt Processable)

Now, the previous two cases, formation of polyimide’s that involves organic solvents those are basically high profile, one can say high boiling solvents having very strong solution power. Ordinary solvents cannot dissolve such polyamic acids. But involving solvents for making composites, that is not a good approach from the point view of this environmental pollution. So, if a process of composite preparation is without using any solvent or solvent less then that is most acceptable in industry.

So, people try it with, without using any solvent that means they took the reactant and on heating if those reactants can melt and if such chemicals reactions can occur in melt conditions that is highly welcome. So, there is solvent less aromatic polyimide, addition polyimide, polyimides without using any solvent they are known as melt processable. So, here you see as before these are the carboxylic or anidride or multifunctional aromatic acids you can say.

These are amines, acids and amines having ether linkages, having phenyl rings and again another system having acetylene group at the ends, acetylene and amine group. This amine group can react with these carboxyl groups or ester groups and acetylene groups remains at the end. So, inside the molecule there can be amide linkage, there can be ether linkage, there are phenyl rings, so that contributes to the rigidity, thermal stability, flexibility, toughness all those will be tailored by the presence of such groups and moieties whereas at the end group the acetylene groups are present which will help in curing of the resin. So, ultimately from thermostat system it can lead to a thermoplastic system, it can lead to a thermostat system although having such phenyl ring and ethyl linkage flexible as well as rigid system inside. So, that will leading to the thermal stability of the polymers.

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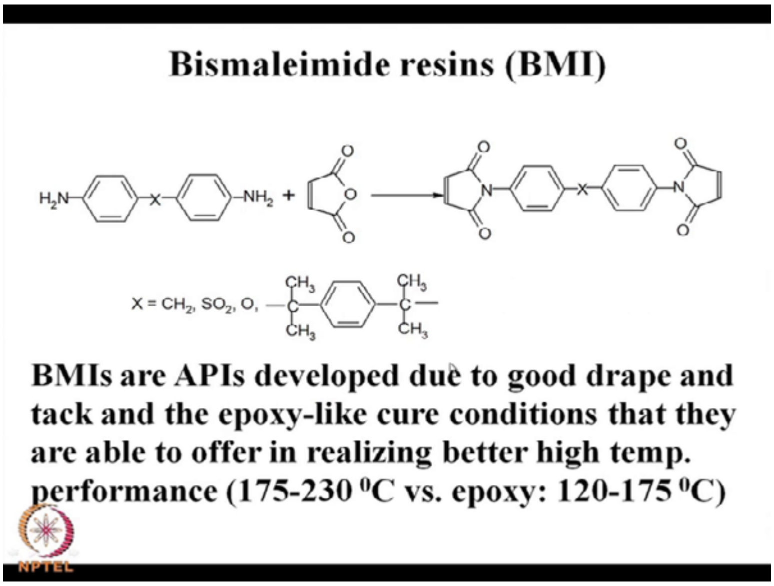

Bismaleimide resins (BMI)

BMIs are APIs developed due to good drape and tack and the epoxy-like cure conditions that they are able to offer in realizing better high temp. performance (175-230 ^{0}C vs. epoxy: 120-175 ^{0}C)

Bismaleimide maleic anhydride imide maleimide resins. Now, this is a diamine. Again, here X means X can be either methelyne, can be sulfone, can be ether that means if there is C H 2 it will be diaminodiphenyl methane, if there is S O 2 in place of X that will be diaminodiphenyl sulfone, if there is oxygen that can diaminodiphenyl ether, if there is such groups then it will be again a different diamine. So, all those possibilities are there in diamine part of the reactants then take the maleic anhydride, this is maleic anhydride.

This maleic anhydride in dry condition that can react with this amine group in melt conditions and reactions forming this polyimide and having these your maleic anhydride, maleic imide group at the, as the end groups the, which are reactive. So, inside inside there can be this phenyl ring flexible units, imide linkage all these things, but at the end group there will be some reactive. So, ultimately that compound, that polymer can be curable also.

So, these bismaleimides are addition polyamides developed due to good drape and tack and epoxy like cure conditions due to the presence of these many imide groups that they are able to offer in realizing better high temperature performance say service performance can be between 175 to 230 degree Celsius versus epoxy resin which perform little lower at the little lower range 120 to 175. So, if somebody wants to use a composite beyond 170 degree, 175 degree Celsius temperature so that epoxy composite will be not be suitable in that case one has to use these type of bismaleimide resin composite or polyamide other addition polyamide composites which can stand beyond 175 degree Celsius temperature for a prolonged exposure.

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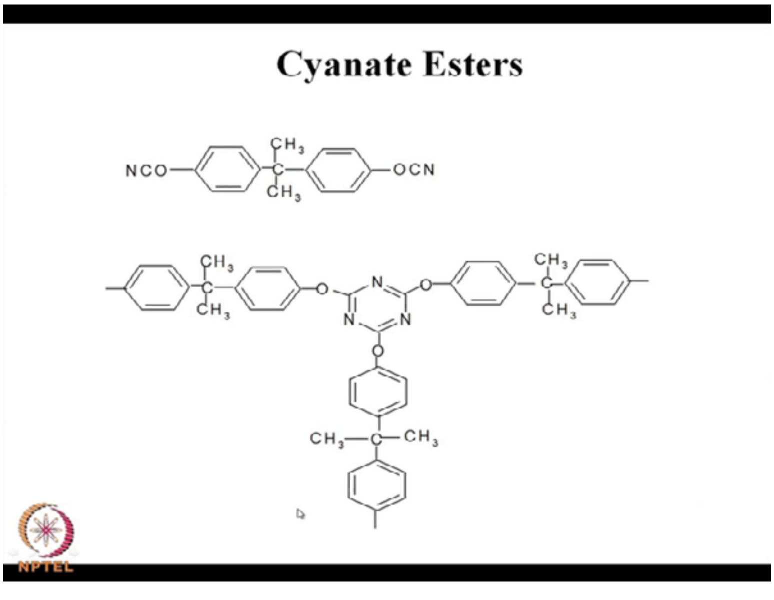

Cyanate Esters

Other examples cyanide esters are also, cyanide esters forming these O C N groups, O C N groups, cyanide esters can be formed. The formula is like this.

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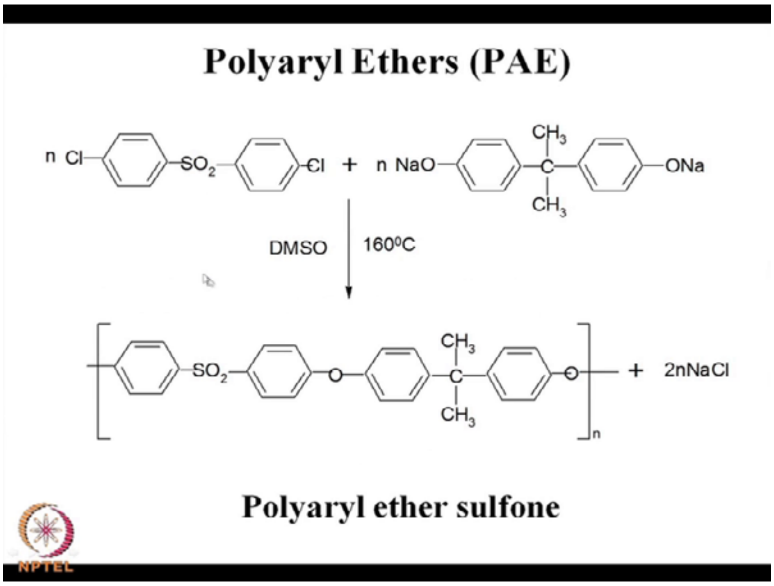
Polyaryl Ethers (PAE)

Polyaryl ether sulfone

And polyaryl ethers, polyaryl ether, polyaryl ether sulfone you see this is diamino, this is actually sulfonyl diphenyl sulfone, sulfonyl fluoride. I have some doubt over the nomenclature of this polymer. So, this is reactive chlorine groups are there, this sulfone group and this sodium salt of (( )) a in dimethyl sulfoxide solvent, if this reactants are heated. So, this kind of poly ether, this kind of poly ether sulfone are formed, again this is very good high performance, high temperature resistant polymer or one can say again this is a multi strand polymer or leather type polymer providing high thermo stability as well as strength.

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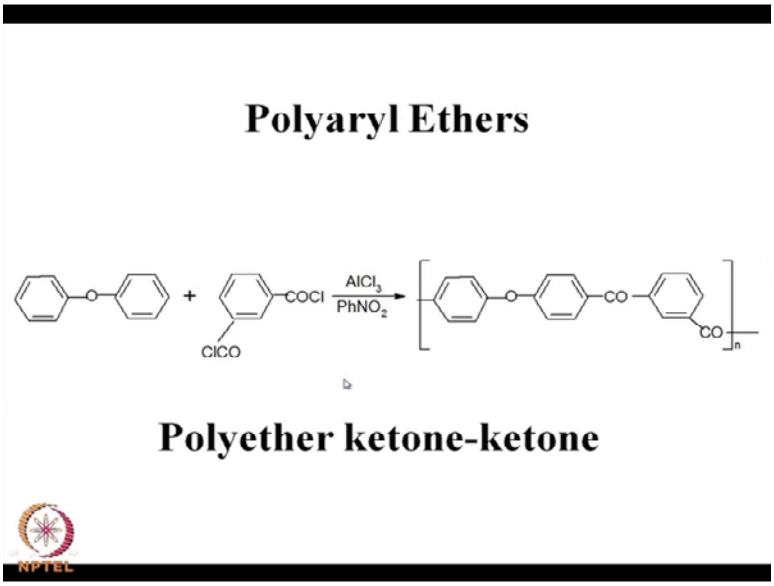
Polyaryl Ethers

Polyether ketone-ketone

Polyaryl ether, polyaryl ethers this is actually aromatic groups, ether group, ketone group, ketone group. So, the name of this polymer is polyether ketone ketone, polyether ketone ketone.

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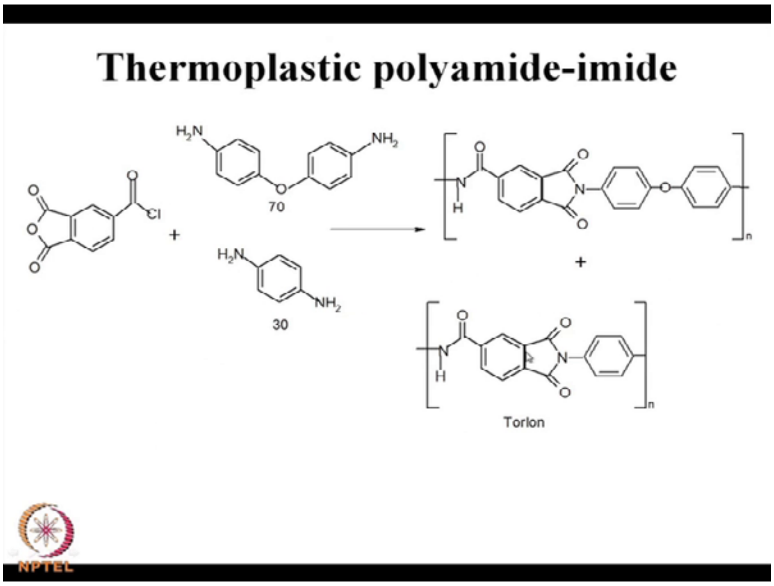

Thermoplastic polyamide-imide

Thermoplastic polyamide imide. Now, we were discussing about the polyimides. Now, in one polymer backbone one can have both imide as well as amide linkage that is known as polyamide imide that gives a combination of properties of polyamides say nylons if the polyimides. So, these polyamide polyimide characteristics are developed in this polymer by reacting suitable monomers or reagents to form this polyamide imide linkage. This is the imide linkage, this is the amide linkage. So, in the polymer backbone if these two imide and amide linkages are there, that is known as polyamide imide. It is a torlon, the trade name of this polymer is torlon.

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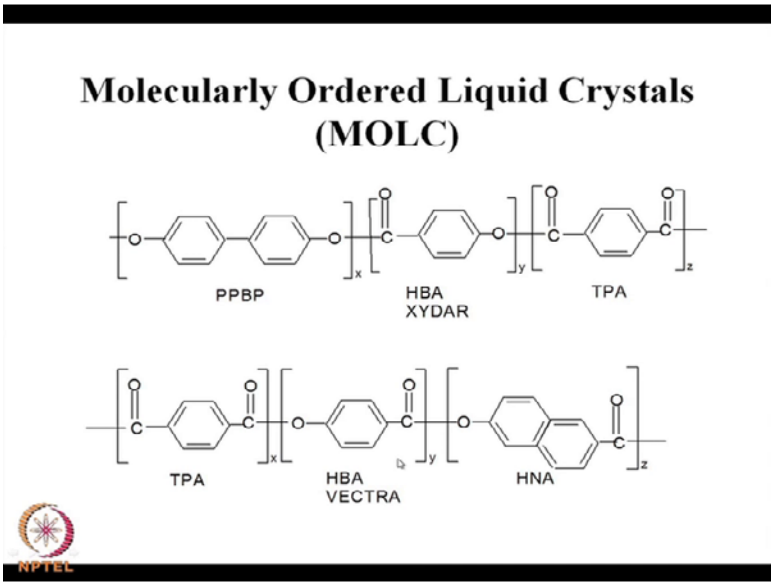

Molecularly Ordered Liquid Crystals (MOLC)

There are liquid crystal polymers in other lectures I have already developed the liquid crystalline polymers, discuss the liquid crystalline polymers which are having ordered structures. These are actually (( )) polymers that means, in the liquid state these polymers show crystalline or liquid state means in solution or in melt condition there shows anisotropic behavior. So, this anisotropic behavior in liquid phase is known as liquid crystalline phase.

So, this liquid crystalline phase that occurs due to rigid rod like configuration structures of the molecules when such units are present in that polymer, those units are known as mesogens. If those mesogens are present then that gives long range order in the liquid phase. So, in a polymer so this kind of biphenol, this kind of biphenol if that is reacted with say hydroxybenzoic acid again that is also reacted with that is terephthalic acid. So, terephthalic acid, hydroxybenzoic acid, biphenolmoiti all these are linked in one molecule and due to the presence of these phenyl ring, ester linkage etcetera that forms a long range or rigid rod like configuration and that is known as molecularly ordered liquid crystal polymers used as matrix resin or making high performance strong composites.

This xydar polymer, this is vectra polymer here, these terephthalic acid, hydroxybenzoic acid and hydroxyl nitric acid, these are there. Now, here you see the melting temperature or glass tension temperatures are varied from one polymer to the other polymer by selecting a suitable architectural unit, this is known as one can say this is known as crankshaft unit where you see by because of this kind of linkage it decreases the melting temperature from this polymer. These are different types of liquid crystalline polymers.

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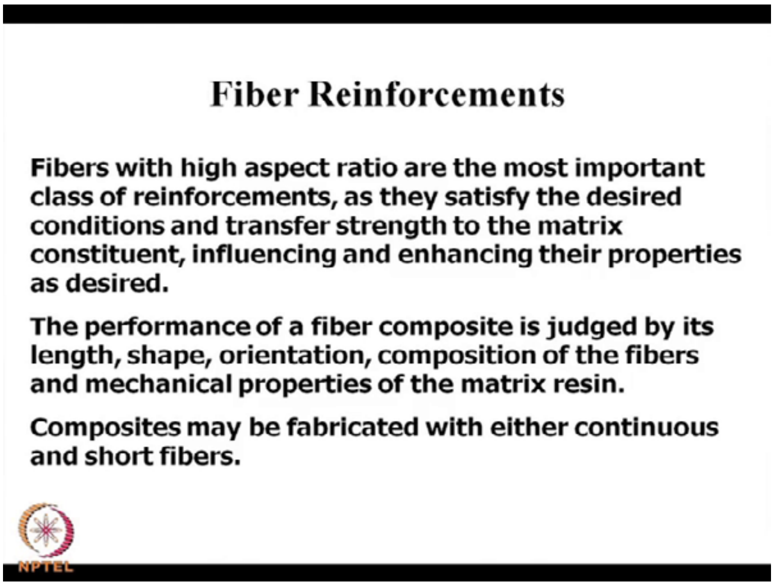

Fiber Reinforcements

Fibers with high aspect ratio are the most important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent, influencing and enhancing their properties as desired.

The performance of a fiber composite is judged by its length, shape, orientation, composition of the fibers and mechanical properties of the matrix resin.

Composites may be fabricated with either continuous and short fibers.

Now, let us look into the, till now we have discussed at length the different types of matrix resins, polymers as the matrix continuous phase for making composites in both the thermostat and thermoplastic category. That is one component of the composite and the other component of the composite is fiber which is most important. And this fibers what would be the characteristics of the fiber.

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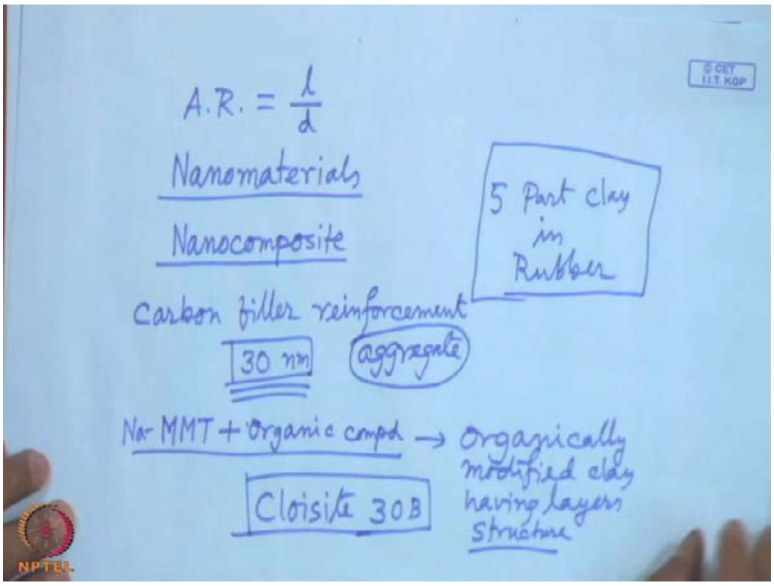

$A.R. = \frac{l}{d}$

Nanomaterials

Nanocomposite

5 Part clay
in
Rubber

Carbon filler reinforcement

30 nm

aggregate

Na-MMT + Organic compd → Organically modified clay having layers structure

Cloisite 30B

The fiber must have high aspect ratio means the aspect ratio is the ratio of the length of the fiber to diameter; that means, thinner the fiber higher would be the aspect ratio. That means higher would be the surface area of the fiber and that will provide more interface area between the matrix and the fiber and that can lead to a very strong composite. So, that is why if the aspect ratio is very high and that will keep very strong composites as they satisfy the desired conditions and transfer strength to the matrix constituents.

So, this strength, transfer of strength as transfer of load that will be maximum that will be higher if the aspect ratio is very high, if the interface area is very high and that influence and enhance the properties of the composite as is planned or as is desired for one particular grade of product. The performance of the fiber composite is judged by its length, shape, orientation, composition of the fibers and mechanical properties of the matrix resin. Composites may be fabricated with either continuous and short fibers.

As you have seen a composite may be made from particles, particles. Today is the era of nano materials. If the reinforcement is of nano dimension the composite we get is known as nano composite for example in the last lecture I referred the example of automobile tire where carbon black was the fiber, was the filler, reinforcing filler. The diameter of this carbon particles, carbon filler particles were around say for example, 30 nanometer, but the problem is with this 30 nanometer carbon black if we need the particle size of 30 nanometer dimension, but the form (( )) of their high surface area and since these are incorporated in a high viscosity polymer like rubber.

So, these carbon particles form aggregates or agglomerates, aggregate. So, in the rubber matrix these carbon black fillers are no longer nano filler that way because they form the aggregates. Until and unless they are dispersed or broken to such dimension that cannot be a nano filler. Anyway by virtue of their chemical and physically characteristics carbon fillers are reinforced the, carbon black fillers reinforce the properties of the rubber composite that is why we get that very good strength performance of the tire.

Now, in place of carbon filler if somebody uses some other kind of nano filler like say mont M M T clay, montmorillonite clay modified with organic compound known as organically modified clay having layer structures as well as this is sodium M M T sodium montmorillonite clay having layer structures in nanometer dimension. Such clays are, such clay fillers M M T clay is known as this organically modified clay known as cloisite. One grade is say suppose 30 B, organically modified clay.

Only a 5 part of such clay in say rubber can provide huge (( )) properties because if somebody calculates the surface area of this cloisite 30 B would be as high as the surface area provided by 40 to 45 parts of carbon black used in 100 part of rubber. So, 100 part of rubber are with 5 part of clay can reach the mechanical properties of this say tensile strength by using 45 parts of carbon black. So, one can get nano composites using nano fillers say clay or other nano particles say metal nano particles if those are incorporated in a polymer matrix one can get very good strong composite because of high surface area of the nano particles.

So, here the performance of a fiber composite is judged by its length, shape, orientation, composition of the fibers and mechanical properties of the matrix resin. So, if the surface area of the reinforcement is very high the composite properties of the composite would be very high. Strength properties will be very high. That will, it can give very good (( )) in properties, synergistic properties can be available.

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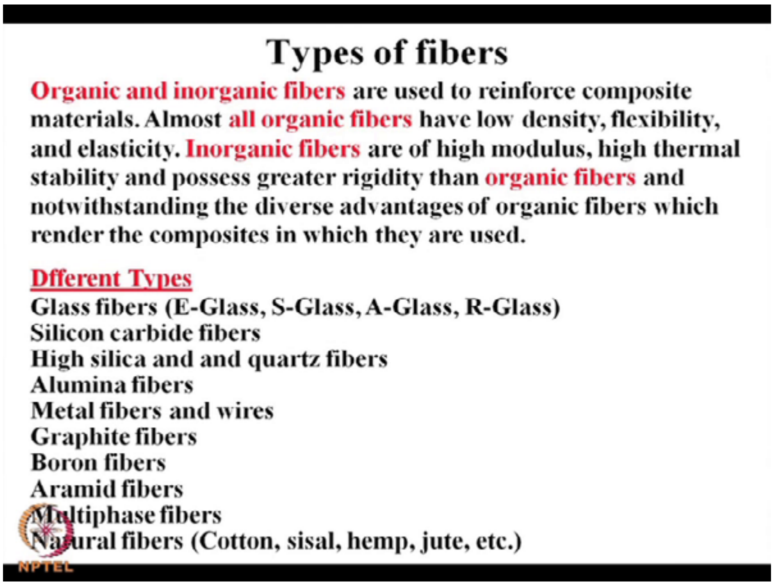

Types of fibers

Organic and inorganic fibers are used to reinforce composite materials. Almost all organic fibers have low density, flexibility, and elasticity. Inorganic fibers are of high modulus, high thermal stability and possess greater rigidity than organic fibers and notwithstanding the diverse advantages of organic fibers which render the composites in which they are used.

Dfferent Types

Glass fibers (E-Glass, S-Glass, A-Glass, R-Glass)
Silicon carbide fibers
High silica and and quartz fibers
Alumina fibers
Metal fibers and wires
Graphite fibers
Boron fibers
Aramid fibers
Multiphase fibers
Natural fibers (Cotton, sisal, hemp, jute, etc.)

Now, let us look in to the fibers, different types of fibers which will be suitable for making such composites. So, organic and inorganic fibers are used to reinforce composite materials. Almost all organic fibers have low density, good flexibility and elasticity. Inorganic fibers are of high modulus, high thermal stability and possess greater rigidity, rigidity than organic fibers. And one can have diverse advantages of organic fibers which render the composites in which they are used.

So, different types of fibers say glass fibers, E glass, S glass, A glass, R glass already I mentioned. Silicon carbide fibers mostly one can say viscous, silicon carbon viscous which are actually single crystals of silicon carbide they, that can lead to high performance composites; high silica and quartz fibers, alumina fibers, metal fibers and wires, graphite fibers, boron fibers, aramid fibers.

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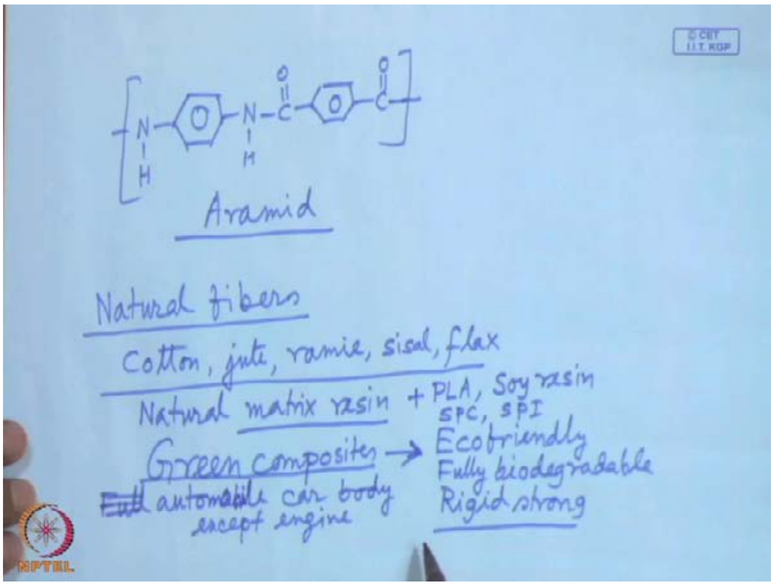

Aramid

Natural fibers

Cotton, jute, ramie, sisal, flax

Natural matrix resin + PLA, Soy resin
SPC, SPI

Green composites → Ecofriendly
Fully biodegradable
Rigid strong

~~Full~~ automobile car body
except engine

Aramid fibers are basically aromatic nylon having these para linkage. This is a repeat unit of a aromatic nylon, aramid. Aramid fiber these are very strong fiber, strong aromatic nylon fiber for making high purpose composite. Natural fibers, now this is another area, natural fibers cotton, jute, ramie, sisal, flax and so many. This cotton, these natural fibers with natural matrix resin can lead to green composites. These green composites are mean they are eco friendly, fully biodegradable as well as rigid and strong.

A full automobile, automobile car body except engine, automobile car body except engine can be made from these green composite. After the life of the car then that car can be disposed and nature itself will take care of its disposal and management by degradation, degrading it. So, it will not, it will not evolve any pollution to the environment. So, this green composite can be made from natural fibers. Out of these natural fibers these ramie, sisal, flax and jute they have shown a good promise for such composites.

Therefore, such green composites, this natural resin, natural matrix resin could be polylactic acid PLA or one can take soy resin from soy bean, soy seeds. There are commercial soy resins available in the name S P C soy protein concentrate or soy protein isolate. They are basically proteins, protein molecules having peptide linkage, vegetable protein, they are used as matrix resin which are biodegradable and naturally occurring.

Now, this soy resin S P C and S P I along with this sisal or ramie or flax have been found to yield very strong strong green composite which is rigid, stiff, tough, but it is biodegradable. The resin is hydrophilic. So, in, if it is not exposed to humid atmosphere or if it is not kept immersed in water this resin can perform for longer period of time, but ultimately when it is disposed it will degrade. This is the nature of the green composites.

Thank you.