Science and Technology of Polymers
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Lecture - 40
Engineering and Speciality Polymers (Contd.)

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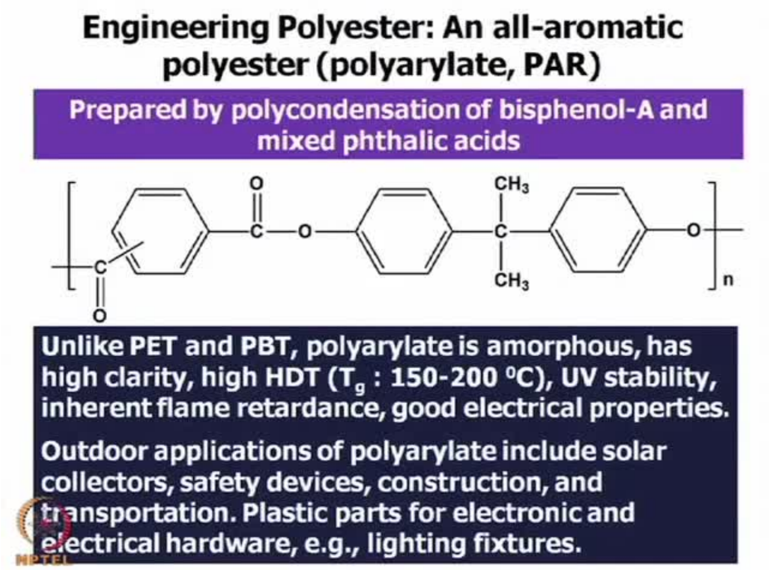

Engineering Polyester: An all-aromatic polyester (polyarylate, PAR)

Prepared by polycondensation of bisphenol-A and mixed phthalic acids

Unlike PET and PBT, polyarylate is amorphous, has high clarity, high HDT (T_g : 150-200 ^{0}C), UV stability, inherent flame retardance, good electrical properties.

Outdoor applications of polyarylate include solar collectors, safety devices, construction, and transportation. Plastic parts for electronic and electrical hardware, e.g., lighting fixtures.

In the last lecture, we were discussing about the engineering speciality polymers. We were discussing about the aliphatic as well as aromatic polyesters PET, PBT and other polyesters. Now in the, those PET and PBT, some part of the repeat unit was aliphatic and other part of the repeat unit was aromatic. Now, a polyester can be made of fully aromatic that means, both the acid part as well as, as well as the alcoholic part could be aromatic. That is known as all, all aromatic, all aromatic polyester known as polyarylate PAR, all aromatic polyester.

Now, this all aromatic polyester can be prepared by poly condensation of bisphenol-A and mixed phthalic acid. This is the, this is the bisphenol-A mighty this is the bisphenol-A mighty and this is a I mean this up to this o and this o here. Now and this is the diacid part, this is a mixed phthylic acid. Mixed phthalic acid phthalic acid in the sense that linkage linkage of 2 carboxyl group, groups to this aromatic ring can be either at the para position or at the ortho position or at the meta positions.

That means 1-2 linkage or 1-3 linkage or 1-4 linkage. Any of these three linkages can be there, that is why it is shown like this. So, this is a mixed phthalic acid. When that mixed phthalic acid is condensed in melt condition at high temperature with bisphenol-A, it leads to all aromatic polyesters. Here you see no aliphatic methylin, you need some or methylin linkage is there. A full the or the entire chain contains phenyl ring in between two carboxyl phenyl ring, carboxyl polyester group is there. There in case since bisphenol-A mighty is there so bisphenol-A mighty contains one carbonate between two phenyl rings and this carbon link to this methyl groups. So, that is very good engineering polyester.

Here unlike PET polyethylene terephthalate or polybutylene terephthalate this type of polyarylates, polyarylate is amorphous and it is not crystalline. Has and shows very good clarity and provides high heat deflection temperature. It is glass station temperature is quite high, 150 to 200 degree Celsius. This range is given because of this mixed phthalic acid mighty from one linkage to other linkage is glass station temperature of the polymer varies.

This polymer is stable to UV radiation and it provides inherent resistance to flame. That means fire retardant polymer and shows very good electrical properties. Since there is no ionic group present over here electrical properties of this polymer is good. But oxygen atom is there, but it cannot be fully resistance to high voltage electrical high voltage electric it filled, but at low voltage this polymer so good electrical resistance. Outdoor applications of this polyarylate include include solar collectors, safety devices. They are also used construction purpose, transportation purpose, plastic part for electronic. Electrical hardwares are also made from this aromatic polyesters poly polyarylates for example, lighting fixtures.

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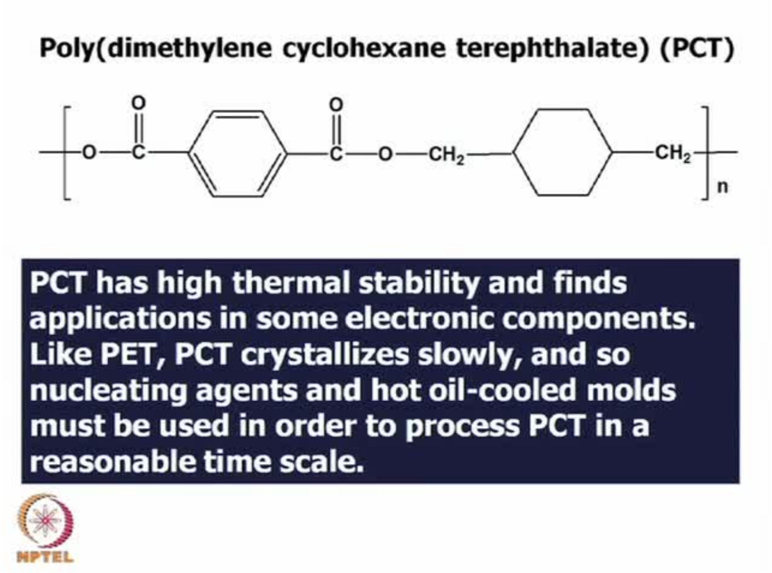

Poly(dimethylene cyclohexane terephthalate) (PCT)

PCT has high thermal stability and finds applications in some electronic components. Like PET, PCT crystallizes slowly, and so nucleating agents and hot oil-cooled molds must be used in order to process PCT in a reasonable time scale.

So, this polymer is also a very good engineering special type of polymers speciality polymers special polymer. I think very good thermal resistance property, dimensional stability at high temperature, resistance to UV and this parameter characteristics etcetera. Other example of such polyester is poly dimethylene cyclohexane terephthalate PCT poly dimethylene has a methylene group is here methylene group is here. This two methylene groups are a link to cyclohexane ring. This is the actually alcohol part this is the alcohol part alcohol part and this is the acid part. Here aromatic link is there, one cyclohexane link is there link is there.

So, this dimethylene cyclohexane terephthalate cyclohexane terephthalate PCT has high thermal stability. And finds applications in some electronic components like PET polyethylene terephthalate. PCT crystallizes slowly PET is crystallizes PCT also crystallizes, but slowly. So, addition of some nucleating agents; and if the molded ethyne in hot condition, there is cooled by oil cold oil; that is this mold is cooled by circulating cold oil that can develop crystallization in the polymer. So, during processing of that PCT some nucleating agent as well as hot oil cooled mold facility should be used to process PCT in a reasonable time scale.

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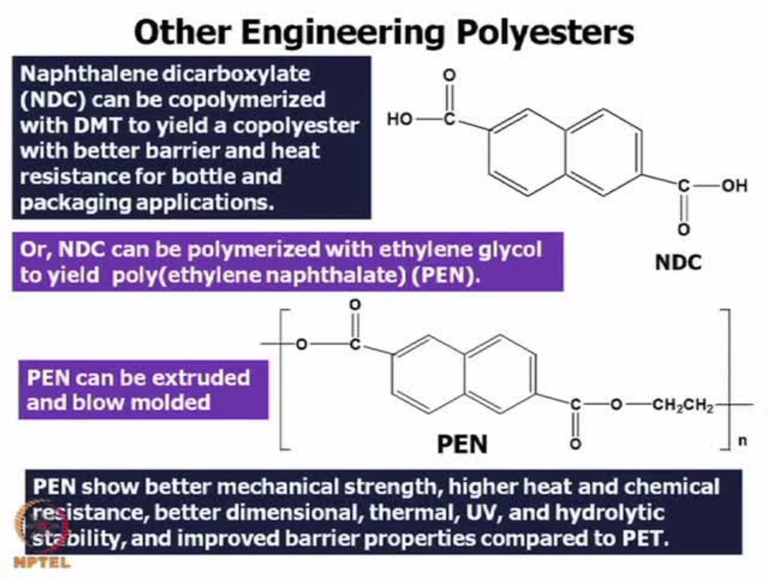

Other Engineering Polyesters

Naphthalene dicarboxylate (NDC) can be copolymerized with DMT to yield a copolyester with better barrier and heat resistance for bottle and packaging applications.

Or, NDC can be polymerized with ethylene glycol to yield poly(ethylene naphthalate) (PEN).

PEN can be extruded and blow molded

PEN show better mechanical strength, higher heat and chemical resistance, better dimensional, thermal, UV, and hydrolytic stability, and improved barrier properties compared to PET.

Other still there are more engineering polyesters available and those have already developed and commercialized. Now instead of one phenyl ring there could be more than one phenyl ring, say naphthalene ring is there. In this naphthalene ring two carboxyl groups are attached, that is known as naphthalene dicarboxylate naphthalene dicarboxylate. This is symmetrical molecule symmetrical molecule and this naphthalene dicarboxylate can be copolymerized copolymerized with DMT dimethyle terephthalate. In fact when PET or PBT is manufactured in that case DMT dimetyle terephthalate is one of the raw material instead of terephthalic acid terephthalic reactivity terephthalic acid is not good.

That is why this DMT is used to manufacture PET or PBT to through ester interchange reaction. Here also in case of this polymer using naphthalene dicarboxylate monomer based polyester, these also done through ester interchange reaction. So, DMT this if this copolymerize to this DMT, this acid part DMT (( )) also another acid part and alcohol part would be different. So, one can make a co polyester that mean in the polyester these NDC as well as terephthalic acid mighty will be present. Terephthalic acid mighty comes from this DMT dimetyle terephthalate through ester interchange reaction.

Such type of co polyester due to the presence of these naphthalending and one phenylanding that polymers shows better barrier properties and better heat resistance for bottle and packaging applications. Or this naphthalene dicarboxylate, it can also be polymerized to with ethylene glycol, ethylene glycol to yield poly ethylene naphthalate PEN P E N PEN poly ethylene naphthalate. So, you have seen PET is prepared by reaction of ethylene glycol with DMT or terephthelate acid. Here naphthalene dicarboxylate instead of ethylic acid can be reacted with ethylene glycol to form poly ethylene terephthelate.

Poly ethylene naphthalene naphthalate is poly ethylene naphthelate is a good polyester. This PEN can be extruded as well as blow molded blow molded for making bottles or hollow items, this is the formula of the PEN. So, this naphthalene mighty naphthalene structure adds to the rigidity of the polymer in the back bone and this ethylene mighty ethylene mighty contributes to the flexibility of the polymer. So, rigidity and flexibility these two make a combination of properties likes toughness, it can produce a very tough polymer.

That is why this poly ethylene naphthalete shows better mechanical strength, higher heat and chemical resistance. Better dimensional stability, thermal stability, resistance to ultra violet radiation and resistance to hydrolytic de-gradation in presence of acid and alkali and improved barrier properties compared to poly ethylene terephthelate. So, this PEN can compete with PET. PET is made from a single phenyl ring containing acid; that is terephthalic acid or DMT. Whereas this PEN contains naphthalene ending, so this in to the presence of naphthalene ending it shows improve properties over PET poly ethylene terephthelate.

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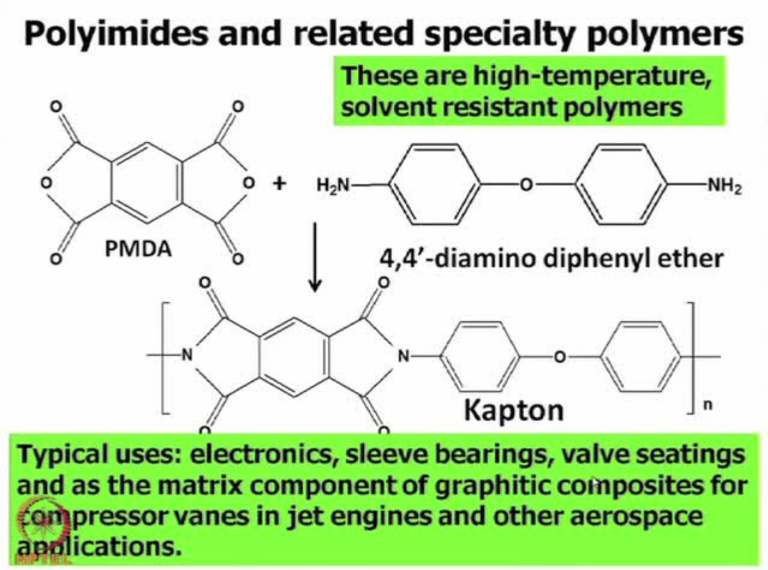

Polyimides and related specialty polymers

These are high-temperature, solvent resistant polymers

Typical uses: electronics, sleeve bearings, valve seatings and as the matrix component of graphitic composites for compressor vanes in jet engines and other aerospace applications.

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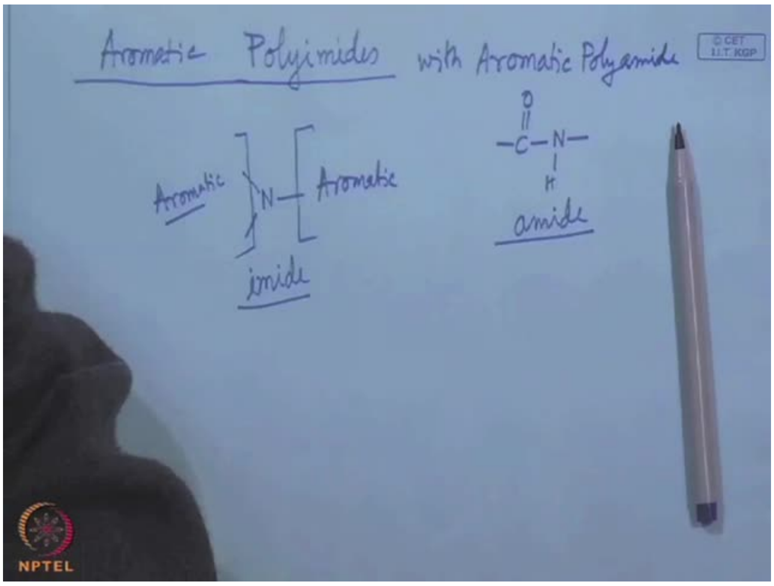

So, these are about these polyesters engineering, engineering polyesters containing phenyl rings, containing cyclohexane rings, containing naphthalene rings. Now, let us see another class of polymer engineering polymer or speciality polymer, polyimides. So, today we are discussing about the speciality polymers starting from polyimides, polyacetal, poly carbonates, polyesters then polyimides. Now, this polyimides is a class of polymers having this imide linkage have been imide linkage. These, this part this site is aromatic, this site is also aromatic in the polymer backbone.

So, a polymer is found through such linkage nitrogen connected to three different functional sites. If those three sites are all aromatic we get one aromatic polyimide polyimide aromatic polyimide. One should not confuse with aromatic polyimides with aromatic polyamides. This polyimide contains this linkage, amide linkage CONH where as polyimide contain this imide linkage, this is imide linkage. So,if there is presence of amide linkage we call it polyamide or call nylons aromatic nylon for aliphatic nylon and if there is imide linkage we called polyimide.

Now, there can be possibility of many different polyimides depending on the groups on this site and depending on the groups on this site. Let us looking to different types of polyimides possible; these polyimides are high temperature resistance polymer as well as they are resistant to solvents and chemicals. The one polyimide can be made from a compound, which is known as pyromellitic dianhydride this is a pyromellitic dianhydride. Now, when water molecule is removed from removed from the two carboxyl group we get an anhydride. On hydrolysis of an anhydride we get diacids, so this this is an anhydride ring.

This anhydride ring can be opened by hydrolysis forming two carboxyl groups. This site also this anhydride ring can be opened by hydrolyzing these anhydride ring and will get two carboxyl groups. So, basically this is a tetra functional monomer, this pyromellitic dianhydride is a tetra functional monomer. This tetra functional monomer in the form of anhydride or tetra carboxyllic acid when it reacts with a diamine this is diamino diphenyl ether at the four and four prime position to amine groups are present. This is four four prime diamino diphenyl ether, this contains this two aromatic rings, in between two aromatic rings there is the oxygen linkage.

Whether is the purpose of using such type of monomer because the presence of this oxygen at over here, it contributes to the flexibility of the polymer back bone because there can be rotation around this oxygen linkage so the polymer will be flexible. So, if this and you see the difference between amide and imide, this amide can also be formed by reaction of a amine group with a carboxyl group. Since here two hydrogens of these amine group can be taken away by this anhydride group. That means, this oxygen will be taken by these two hydrogen. So, what time molecular will be released and one linkage between this carbon, this carbon and this nitrogen will occur to form that amide linkage this amide linkage.

So, when this pyromellitic dianhydride reacts with such diamine aromatic diamine is a kind of aromatic diamine. It can be one diamine instead of this part if this part is removed this part is removed. One can have this amine linkage at this position, but purposefully this ethyl linkage had input over here were to contribute the flexibility of the polymer. So, these when these two monomers or these two chemical compounds are allowed to condense the condense at this position eliminating a molecule of water one gets a polymer.

This is repeat unit of the polymer and this is a amide ring this is a amide ring, N attach to carbon CO group. Here this N is attached to this c o group and this N is attached to this phenyl ring, this attached to another phenyl ring through oxygen and this way it repeats. So, this is the repeat unit formula of Kapton, a polyimide made from pyromellitic dianhydride and diamino diphenyl ether. This is one engineering polyimide in the name in the name Kapton. This Kapton is made in the form of fill, typical use of such Kapton polymer polyimide polymer is found in electronic field as sleeve bearings, as valve seatings and as the matrix component of graphitic composites, that means carbon fiber reinforced composite.

So, one can use Kapton as the matrix region, continues space region and fiber can be made of graphite or carbon carbon fiber or graphitic fiber or graphite fiber. So, carbon fiber reinforced polyimide region can produce a very high performance composite that is used as compressor vanes in jet engines and other aerospace applications. So, you can understand the the behavior or characteristics of this kind of polymers, so this vanes can be made of metals. Those metallic parts replaced by this type of composite which is made from carbon fiber, reinforced polyimide Kapton.

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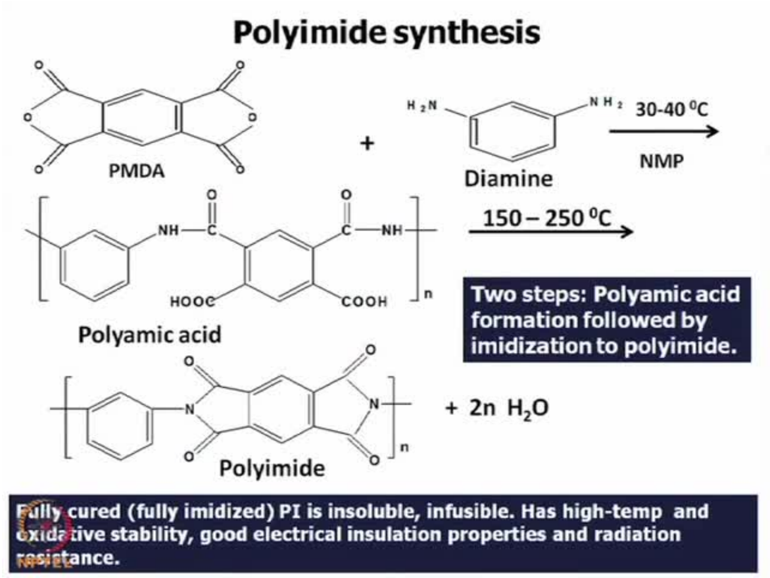

Polyimide synthesis

Two steps: Polyamic acid formation followed by imidization to polyimide.

Fully cured (fully imidized) PI is insoluble, infusible. Has high-temp and oxidative stability, good electrical insulation properties and radiation resistance.

There can be other way of synthesis of this polyimide, basically this polyimide synthesis is a two step process polyimide synthesis is two step process. In contrast to synthesis of polyimide nylon, nylon is synthesized by a reaction of a amine group with a carboxyl group, acid amine or acid base type of reaction there. In this case pyromellitic dianhydride, it is the basically it contains two carboxyl groups when it reacts with this amine group of diamine compound. That is actually that reaction is carried out in presence of a solvent say N methylpyrrolidone, NMP.

Now, these two reactive chemicals are dissolved in NMP and they are heated at 30 to 40 degree celcius. This amine group condenses with this of course, it should be done in anhydrous condition so this will condense to form one amide linkage over here leaving behind one carboxyl group free. Here you see both site of this PMDA two carboxyl groups are made freed and two amide linkages are formed. This kind of inter mediate is precursor is known as polyamic acid. Now this polyamic acid made by the reaction of PMDA and this diamine, this is soluble in N methylpyrrolidone solvent.

Then in the next step, this is the first step of polyamic acid precursor formation. After this precursor is made, then that is heated slowly to remove the solvent, solvent will be evaporated out. Then beyond 150 degree slowly this amic acid this amide group will condense with this carboxyl group liberating a molecule water one H from this N H and O H from this carboxyl group. So one molecule water will be eliminated out from here and here, also another molecule water will be eliminated from O H and H. So, two imide linkage will be formed. Here you see this imide linkage this imide ring has been formed over here this is known as polyimide this is the repeat unit formula of polyimide.

Now, why this is the step why this is two steps are necessary? Although polyimides are synthesized by melt poly condensation of a diamine and diacid, but polyimides cannot be done by such melt poly condensation process, because once some imide linkage is formed actually this imide ring is formed. This imide ring containing polymers does not melt rather to melt this polymers if temperature is increased that undergo de gradation or pyrolysis. So, these the intermediate will be pyrolised instead of melting. Such type of polymer synthesis cannot be done through melt poly condensation rather this would be prepared to a precursor stage as polyamic acid stage.

Actually this was done after facing the problem of degradation or processability. This polyimides are not processable by melting or they are not melt processable. So, the process ability of polyimide is very poor, once a imide ring is formed or once a polyimide formed this is neither soluble not fusable. So, neither it can be dissolved the solvent nor it can be melted to reduce the viscosity to make it flyable or to make it fluid. To overcome that problem people have developed this polyamine acid intermediate precursor step form this polyamide, but one cannot avoid the use of is organic solvent. This is a highly ah polar solvent a protic solvent and this is used for making this polyamide in the laboratory or even industrially.

So, whatever device is to prepared whatever object is you prepared that should be prepared with the help of this polymic acid. Say if one wants to make polyimide film, that polyimide film can be made through this polymic acid. This polymic acid is dissolve in (( )) NMP solvent as solution then that can be cast as a film. Slowly that casted film this solvent is removed and then followed by heating that film over at high temperature gradually stepwise in a increasing temperature from 150 to 250 degree sometimes up to 300 degree that leads to a polyimide film. So, fully cured means fully imidized this is this is fully cured this is not fully cured this is not imidized. Here it is imidized so it is called fully cured or fully imidized. Polyimide is insoluble in solvent, infusible also and has high temperature and oxidative stability, good electrical insulation properties and resistance to high energy radiation like ultraviolet light.

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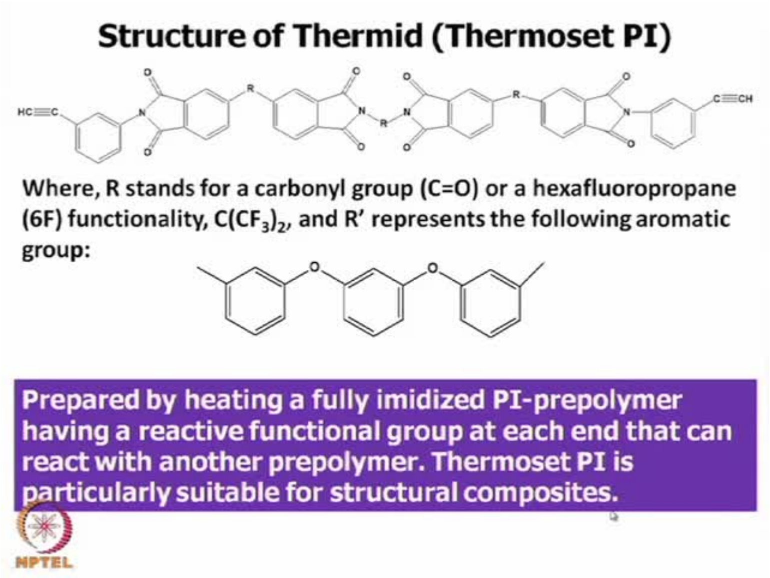

Structure of Thermid (Thermoset PI)

Where, R stands for a carbonyl group (C=O) or a hexafluoropropane (6F) functionality, $C(CF_3)_2$, and R' represents the following aromatic group:

Prepared by heating a fully imidized PI-prepolymer having a reactive functional group at each end that can react with another prepolymer. Thermoset PI is particularly suitable for structural composites.

Let us look in to other types of polyimides, say this is a thermoset polyimide. Now previously previous polyimide say say Kapton that is not a thermoset polyimide although it is insoluble and infusible, but we cannot call it thermoset. A polyimide, if in can be converted to a three dimensionally crosslinked network polymer, that means thermoset polyimide. That polyimide can be made if some reactive group, say like acid ending group or imide group mily imide group at the end chains, chain end of the polymer is present over there that leads to cross-linking or further linkage of this polymer to form a thermoset structure.

Now in this case, in this case, this name of this polymer basically this polymic formula here you see this formula the name of this polymer saying this formula is a thermid thermid. It is kind of thermoset polyimide where this R stand for a carbonyl group either a carbon group C O or a hexafluoropropane having 6 F atoms functionality say CCF 3 whole 2 and R prime represent the following aromatic group. So, R can be C O hexaflouropropane, then or C C F 3 whole 2 and R prime R prime it should be either this R should be not prime, it is mistake over here. So, this R prime should be aromatic linkage like this aromatic groups like this.

So, there this type of polymer is prepared by heating a fully imidized polyimide pre polymer having a reactive functional group at each at each end. Like say in this is case it is acetylene group present here and here acetylene group that can react with another prepolymer thermoset polyimide. Thermoset polyimide is particularly suitable for structural compound as you seen in the case of Kapton matrix and carbon fiber. Here also this polymer can also be used as matrix along with graphite fiber or carbon fiber that can give high performance structure composite particularly for aerospace field application.

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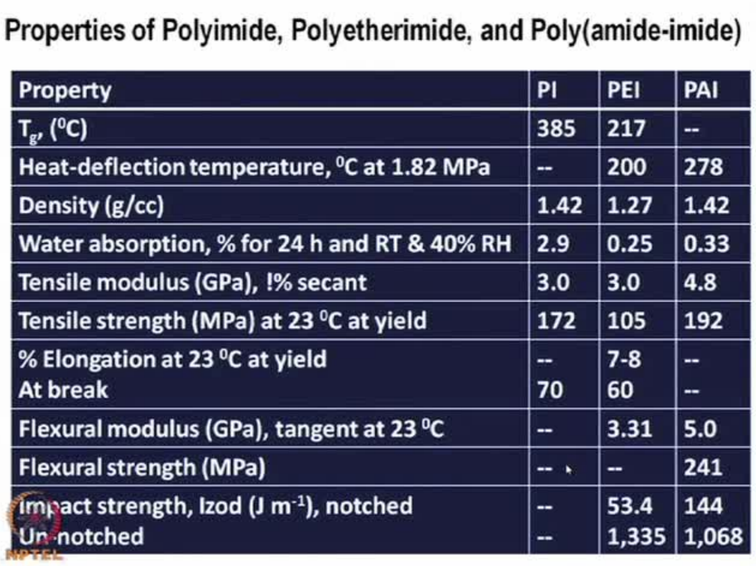

Properties of Polyimide, Polyetherimide, and Poly(amide-imide)

Property	PI	PEI	PAI
T_g, (^{0}C)	385	217	--
Heat-deflection temperature, ^{0}C at 1.82 MPa	--	200	278
Density (g/cc)	1.42	1.27	1.42
Water absorption, % for 24 h and RT & 40% RH	2.9	0.25	0.33
Tensile modulus (GPa), !% secant	3.0	3.0	4.8
Tensile strength (MPa) at 23 ^{0}C at yield	172	105	192
% Elongation at 23 ^{0}C at yield	--	7-8	--
At break	70	60	--
Flexural modulus (GPa), tangent at 23 ^{0}C	--	3.31	5.0
Flexural strength (MPa)	--	--	241
Impact strength, Izod (J m^{-1}), notched	--	53.4	144
Un-notched	--	1,335	1,068

That is comparison of in this, this table compares the properties of polyimide PI poly ether imide PEI and poly amide imide PAI. The glass transition you see is higher than that of poly ether imide or higher in P I than poly ether imide. Heat deflection temperature 1.82 megapascal pressure is higher for poly amide imide, amide imide means a polymer can having a more amide linkage as well as imide linkage. A polymer in this case of PEI it is having a poly imide linkage and oxygen linkage, ether linkage and it is purely polyimide and water absorption for this polymer is very good for this poly ether imide than poly imide poly amide imide.

Tensile modulus is quite good for poly amide imide. Tensile strength highest in case of poly imide amide and elongation at break (( )) elongation at 23 degree celcius at yield and at yield this at yield and, this break at yield quite low for this polymer, at break it little higher. It elongates to more length at during breaking and yielding starts below before that, so yielding value yield elongation is lower. Flexural modulus is highest for poly amide imide, flexural strength is again upper (( )) other two polymers are not available. This is for poly amide imide is 241 megapascal, impact strength again at to different either this is either impact strength either notched conditioned or un-notched conditioned this is highest for this poly amide imide.

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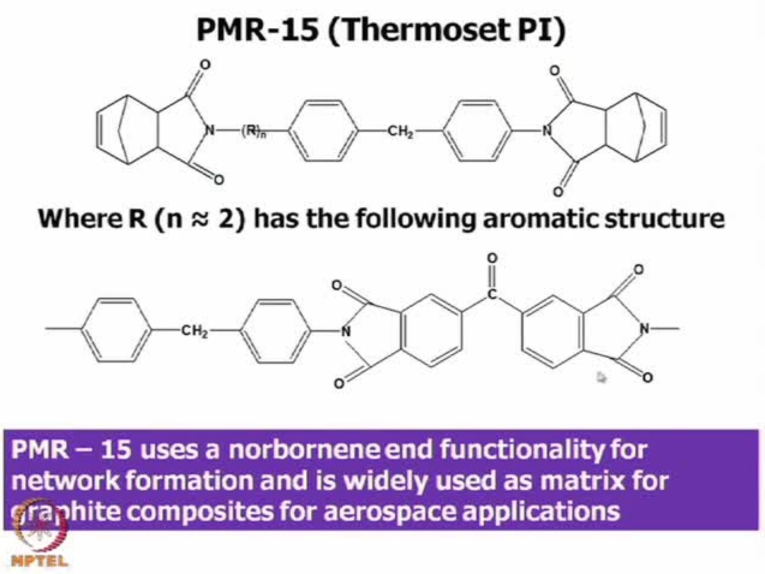

PMR-15 (Thermoset PI)

Where R (n ≈ 2) has the following aromatic structure

PMR – 15 uses a norbornene end functionality for network formation and is widely used as matrix for graphite composites for aerospace applications

Another case of thermoset poly imide is known as name is PMR-15, where this R is when n is about equal to 2 this R has the following aromatic structure. That means here R is replaced by this huge aromatic link containing this imide linkage and ketonic. So, it is a kind of high performance polymer having huge number of aromatic linkages as well as the end end of this polymer chain contains this reactive norbornene end functionality norbornene end functionality ethylene norbornener functionality this is reactive group.

So, these reactive groups at the two ends of the polymer chain where insite of the chain contains such huge aromatic group. So, they react further to developed develop linkage with inter molecular linkage forming a cross link type of structure and later to a thermoset polyimide. And such type of polymer as as found wide application as matrix resin, for again this graphite composites for aerospace applications. So, it appears that these polyimides Kapton or that thermoset different thermoset polyimide as I have shown you the example with the structures and formulas. They find very high performance, strong thermally stable, high strain, high impact resistance, high flame resistance, matrix resinsfor making composites to use in the air caps structures or aerospace structures.

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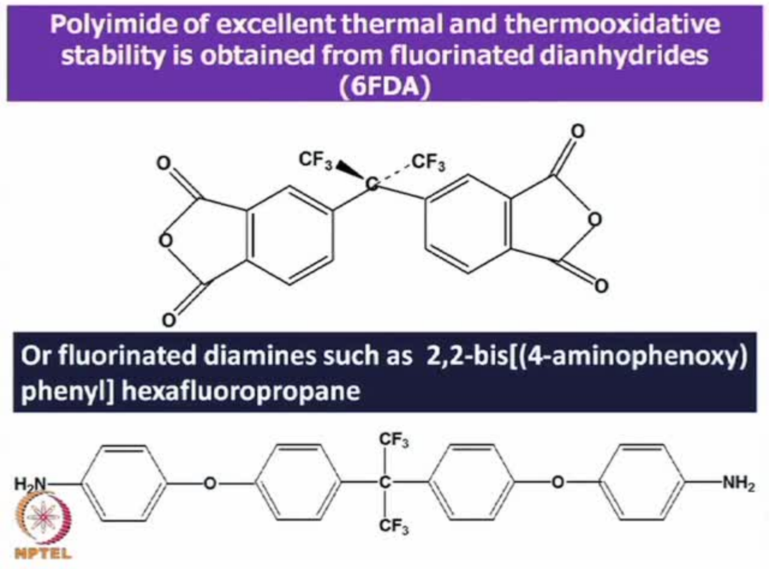

Polyimide of excellent thermal and thermooxidative stability is obtained from fluorinated dianhydrides (6FDA)

Or fluorinated diamines such as 2,2-bis[(4-aminophenoxy) phenyl] hexafluoropropane

One, we can have the further better polyimide if it take this kind of monomer. This shows excellent thermal and thermo oxidative stability if people can use fluorinated dianhydride of this type of structure. Now here, this methyl groups, hydrogen of two methyl groups are replaced by fluorine atoms. So, this polymer is known as 6FDA polymer 6 FDA polymer having a hexafluoro linkage hexafluoro functional groups. Six fluorine containing polymer at least say polyimide, so polyimide with fluorine atoms also.

So, it adds to further chemical stability, so this can perform at very harsh environment at high temperature or one can use fluorinated diamines fluorinated diamines such as this formula. Diamines having two amine groups at the two end of this chemical compound, at the middle methyl groups, hydrogen sub methyl groups are replaced by a fluorine atoms. So, is this is known as fluorinated diamine diamines name as two two bis four aminophenoxy phenyl hexafluoropropane. So, this polymer leads to very excellent thermal and thermoxidative stability for aerospace applications for making composites in aerospace huge.

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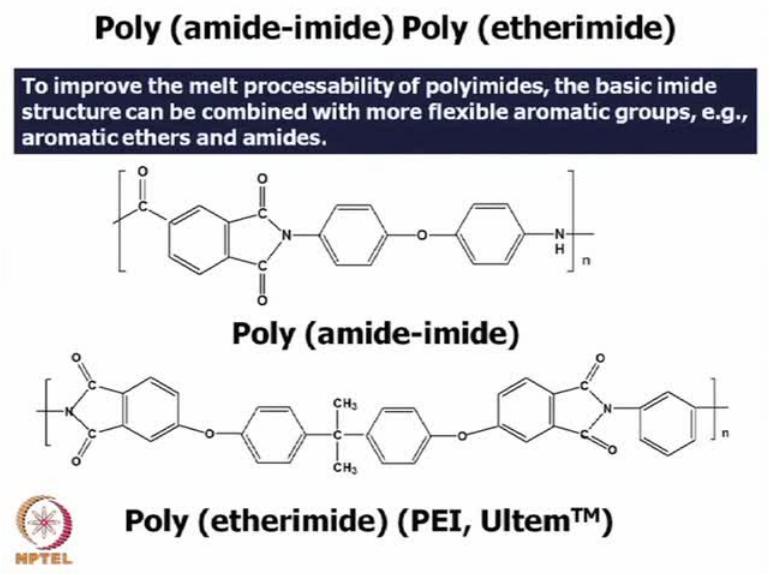

Poly (amide-imide) Poly (etherimide)

To improve the melt processability of polyimides, the basic imide structure can be combined with more flexible aromatic groups, e.g., aromatic ethers and amides.

Poly (amide-imide)

Poly (etherimide) (PEI, Ultem™)

Let us look in to poly amide imide or poly etherimide, that to improve the melt processability of polyimides because I mentioned that melt processability of polyimides are inferior and that can be improved provided the basic imide structure can be combined with more flexible aromatic group for example, aromatic ethers and amides. Here you see the imide link is there as well as amide link is there. So, poly amide imide poly etherimide, here you see this is poly amide imide, this is poly etherimide. So, here this is this is this is a poly imide having ether linkage, this is a polyimide as well as amide having ether linkage.

So, here it is shows that tolerability of such polymer materials depending on the requirement of properties say thermal properties, mechanical properties, chemical resistance properties, radiation resistance properties. Those can be developed by selecting a suitable combination of reactants, suitable combination of functional groups along the back bone chains, say can be aliphatic, can be aromatic, can be ether linkage and imide linkage, can be amide linkage can also be substituted with florins, fluorine atoms.

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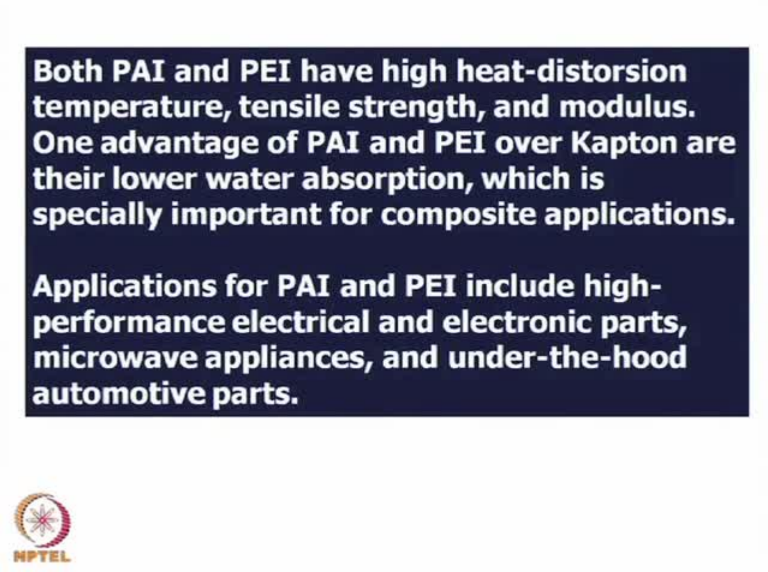

Both PAI and PEI have high heat-distorsion temperature, tensile strength, and modulus. One advantage of PAI and PEI over Kapton are their lower water absorption, which is specially important for composite applications.

Applications for PAI and PEI include high-performance electrical and electronic parts, microwave appliances, and under-the-hood automotive parts.

Now both this poly amide imide and poly esterimide poly etherimide they have high heat distorsion temperature, means the rigid dimensionally rigid at very high temperature provides very high tensile strengths, high tensile modulus. One advantage of this poly amide imide and poly etherimide over Kapton. Kapton is produced from the reaction of pyromellitic dianhydride and diamino di phenyl ether are their lower water absorption, which is especially important for composite applications. So, it shows the such type of poly amide imide or poly etherimide shows further less water absorption than that of Kapton.

So, applications of such poly amide imide and polyether imide include high performance electrical and electronic parts because where this moisture absorption is are deterrent, deterrent to this applications. If there is moisture absorption the electrical or electronic conduction or resistance properties are highly affected, so in this cases the water absorption should be as minimum as possible or low. That is why this type of polymers were developed over Kapton. Kapton is a very good insulator for electrical applications, but over Kapton this polyamide imide and polyether imide are further better polymers. They are also suitable for making microwave appliances and under the hood automotive parts.

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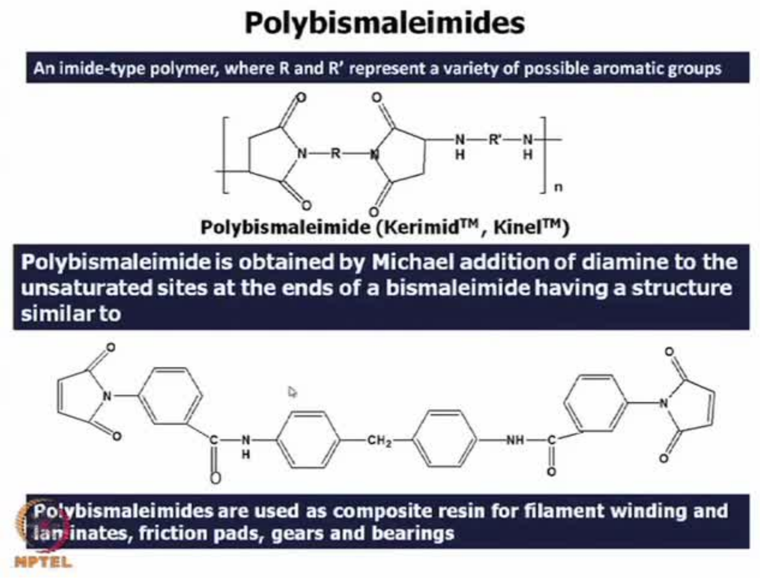

Polybismaleimides

An imide-type polymer, where R and R' represent a variety of possible aromatic groups

Polybismaleimide (Kerimid™, Kinel™)

Polybismaleimide is obtained by Michael addition of diamine to the unsaturated sites at the ends of a bismaleimide having a structure similar to

Polybismaleimides are used as composite resin for filament winding and laminates, friction pads, gears and bearings

Now we were discussing about polyimides. Now here is an example of a polymer known as polybismaleimides that means, some maleic anhydride has been used as one of the reactant to form a polyimide. In case of Kapton synthesis you have seen that a dianhydride was used; that means two anhydride groups where attached to a phenyl ring. Here there is no phenyl ring, but maleic acid, maleic acid, when it is actually water molecule of maleic acid is removed, mono water molecule is removed it forms an anhydride. That maleic anhydride can react with a diamine to form an imide keeping this structure.

So, this (( )) type of polybismaleimide trade name is a commercial polymer, trade name is kerimid or kinel, this is possible. There can be other polybismaleimides obtained by Michael addition of diamine Michael addition of diamine to the unsaturated sites at the ends of a bismaleimide having a structure similar to. So, here this this bismaleimide this bismaleimide this maleimide structure is present at the two ends having unsaturated sites, is one unsaturated site here is another unsaturated site.

So, that can be that will exploited to form polybismaleimide by Michael addition of this the diamine this is a diamine to the unsaturated sites at the ends of bismaleimide having a structure similar to this. Now, this polybismaleimides are used as composite matrix resin used as matrix resin for making composites for filament winding and making laminates, for making friction pads, for making gears and bearings.

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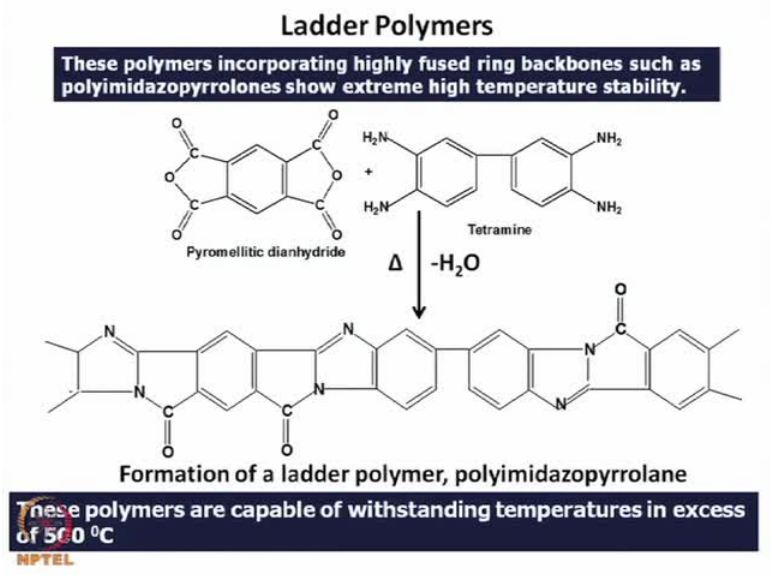

Ladder Polymers

These polymers incorporating highly fused ring backbones such as polyimidazopyrrolones show extreme high temperature stability.

Formation of a ladder polymer, polyimidazopyrrolane

These polymers are capable of withstanding temperatures in excess of 500 °C

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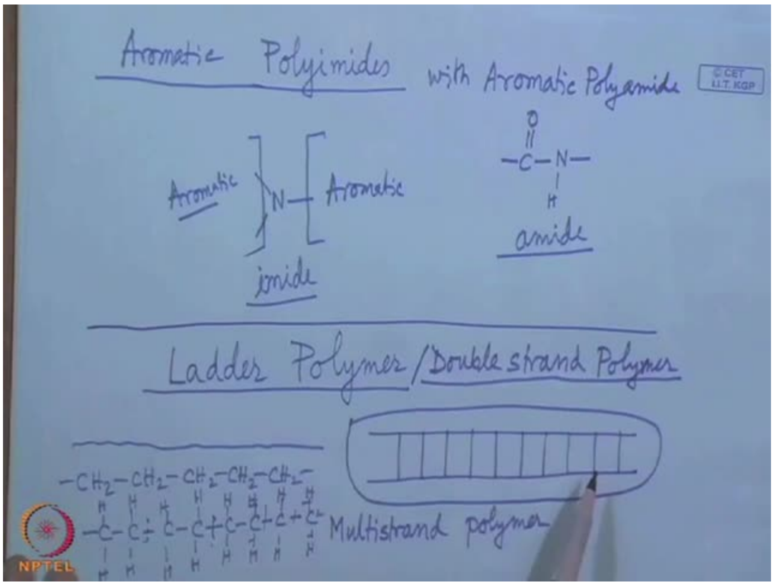

Now, let us look into another nomenclature of polymers, ladder polymer. A polymer which looks like a ladder. This is the steps of the ladder. This is ladder, that means it can also be called as double strand polymer or these type of polymers havings such configuration can also be called as multistrand polymer. What is the specialty of this multistrand or double strand polymer or ladder strand polymer? In contrast to a single strand polymer say polyethylene, the formula can be like this having carbon chain backbone or it can be look like this a backbone made of carbon atom only and dialysis of carbon are satisfied with hydrogen atoms.

Now, this is a single strand polymer. Now, if this polymer is exposed to thermal or radiation environment what will happen that thermal or radiation energy conclave any of anywhere of this primary covalent bonds that conclave other conclave also this things. So, the existence of the polymer or the or the identity of polymer is lost due to such cleavage by that thermal energy or radiation energy or any chemical energy, that polymer becomes unstable. Now in this case having double strands or multistrands this is a one line, this is another line link to these two lines are linked with the intermediate linkage, these are these looks like cross link bonds.

So, if there is some chance of breaking at this site the polymer will make its identity will maintain its identity, continue its identity; even if there is simultaneous breaking at another place here and here still the identity of the polymer can be restored or even there is breakage over here, simultaneously still their identity be restored by the presence of other bonds. Here is the important of such double strand or multistrand polymers or ladder polymers. Why they are call ladder? Because it looks like ladder like their configuration look like ladder like structure.

Such ladder polymers are formed by incorporating highly fused ring backbones such as polyimidazopyrrolones showing extreme high temperature stability as I explained through this sketch if even if there are breakages it maintans its identity. Now, if you look into this formula this structure, this is a poly imide or this is a this is a this is not a polyimide, but imidazopyrrolane pyrrolane imidazol imidazol group is there imidazol group imidazol group is there. Here you see this is a line, this is another line and these are connected this two lines are connected by this linkages these are primary covalent bonds primary covalent bonds. So, this looks like a ladder types of structure and they shows extreme high performance properties of thermal stability, radiation stability etcetera and these polymers are capable of withstanding temperature in excess of 500 degree Celsius.

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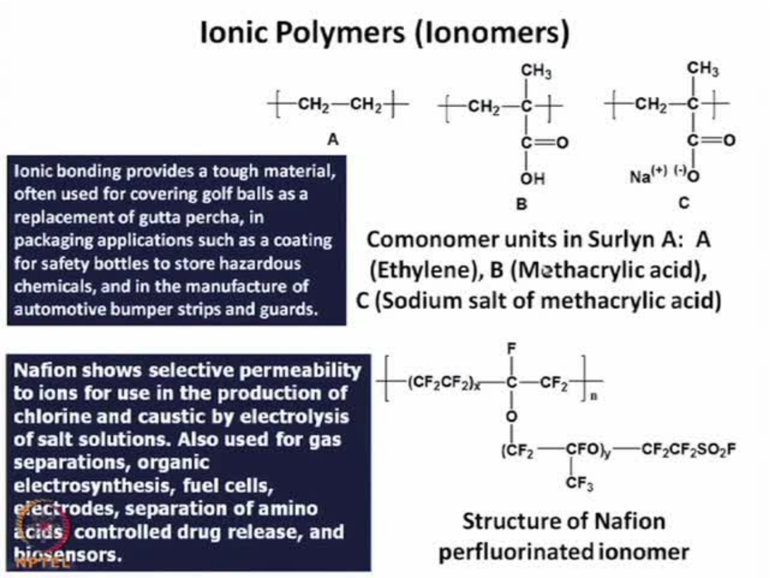

Ionic Polymers (Ionomers)

Ionic bonding provides a tough material, often used for covering golf balls as a replacement of gutta percha, in packaging applications such as a coating for safety bottles to store hazardous chemicals, and in the manufacture of automotive bumper strips and guards.

Comonomer units in Surlyn A: A (Ethylene), B (Methacrylic acid), C (Sodium salt of methacrylic acid)

Nafion shows selective permeability to ions for use in the production of chlorine and caustic by electrolysis of salt solutions. Also used for gas separations, organic electrosynthesis, fuel cells, electrodes, separation of amino acids, controlled drug release, and biosensors.

Structure of Nafion perfluorinated ionomer

Let us look into other categories of polymers ionic polymers known as ionomers that means, polymers containing ionic groups. Look at these three different formulas A, B, and C, this is actually ethylene polyethylene reap ethylene repeat unit. This is methacrylic acid repeat unit, this is sodium salt of methacrylic acid, so as you move from this formula to this formula here you see this hydrogen is substituted with this carboxyl group, another hydrogen of this carbonic substitute methyl group. So, this ethylene has been converted to methacrylic acid. When methacrylic acid is reacted with sodium hydroxide, it forms a sodium salt, so this is a sodium salt of methacrylic acid.

So, polyethylene can be converted to a ionic polymer methacrylic acid or acrylic acid and salt of acrylic acid. So, this group is ionisable, this portion is ionisable that is why this polymers are known as ionic polymers. Ionic bonding provides a tough material because there will be ionic bond. Intermolecular ionic bond through these sites so that increase a toughness limited often used for covering golf balls as replacement of gutta percha which is naturally occurring polymer having trans configuration. As in contrast to sis configuration of natural rubber and these are used in packing applications such as a coating for safety bottles, to store hazardous chemicals and in the manufacture of automotive bumper strips and guards.

There is one excellent commercial available ionic polymers or ionomer known as Nafion this is nothing but a perfluorinated polymer per having all the hydrogens of this repeat unit are replaced by fluorin atom, this is known as Nafion. This Nafion shows selective permeability to ions for use in the production of chlorine and caustic soda by electrolysis of salt solutions. This Nafion is also used for gas separations because this same permeable membrane permeable membrane to some extent for some materials some compounds. This is used in organic electrosynthesis, used in fuel cells, used in electrodes separation, used for the separation of amino acids, used also as a devise for controlled drug delivery and also used in biosensors for use for making biosensors.

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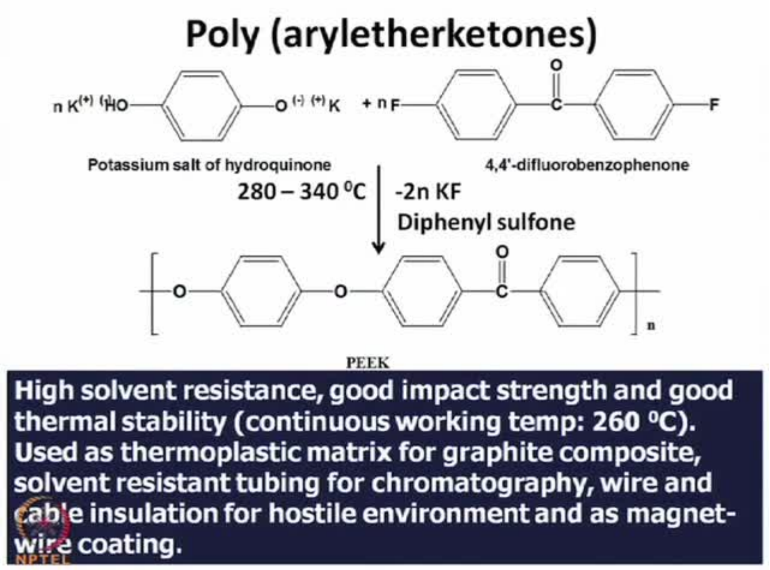

Poly (aryletherketones)

High solvent resistance, good impact strength and good thermal stability (continuous working temp: 260 °C). Used as thermoplastic matrix for graphite composite, solvent resistant tubing for chromatography, wire and cable insulation for hostile environment and as magnet-wire coating.

Poly arylethertketones is another class of polymer, this poly aryletherketone is made from Potassium salt of hydroquinone, this is the Potassium salt of hydroquinone. That is reacted with four four difluorobenzophenone and it forms a tic polyether etherketone. This polyethyle ethyl linkage is there, ketone is there having aromatic groups this polyether etherketone. So, is high solvent resistance, good impact strength and good thermal stability and shows a continuous working temperature, used temperature 260 degree Celsius, used as thermoplastic matrix for graphite composite, solvent resistant tubing for chromatography wire and cable insulation for hostile environment and as magnetic wire coating.

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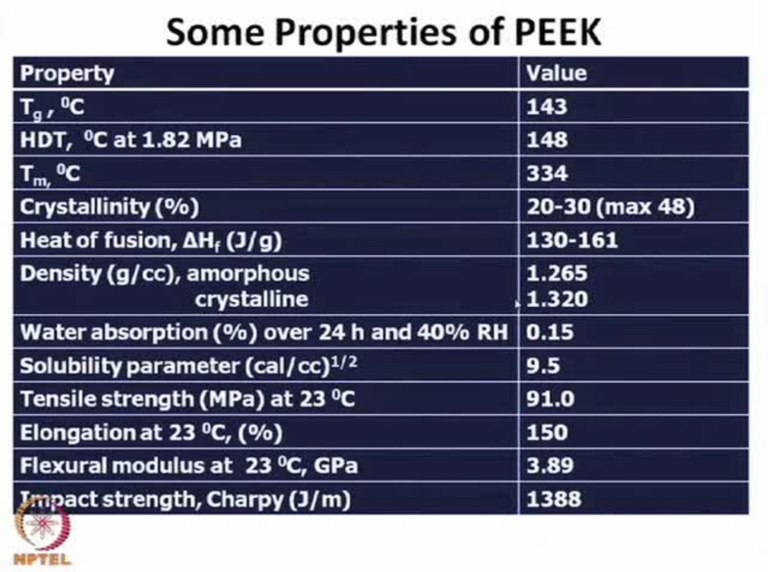

Some Properties of PEEK

Property	Value
T_g, ^0C	143
HDT, ^0C at 1.82 MPa	148
T_m, ^0C	334
Crystallinity (%)	20-30 (max 48)
Heat of fusion, ΔH_f (J/g)	130-161
Density (g/cc), amorphous crystalline	1.265 1.320
Water absorption (%) over 24 h and 40% RH	0.15
Solubility parameter $(cal/cc)^{1/2}$	9.5
Tensile strength (MPa) at 23 ^0C	91.0
Elongation at 23 ^0C, (%)	150
Flexural modulus at 23 ^0C, GPa	3.89
Impact strength, Charpy (J/m)	1388

Some properties of PEEK are listed in this table. Glass transition temperature is quite high, 143 degree, heat deflection temperature 148 and water absorption is quite low almost almost negligible 0.15 percent at 40 percent humidity. Solubility parameter is high, tensile strength 91 megapascal, elongation at break at 23 (( )) to 150 megapascal is quite high, flexural modulus is also high 3.89 gigapascal, impact strength is 1388 joules per meter.

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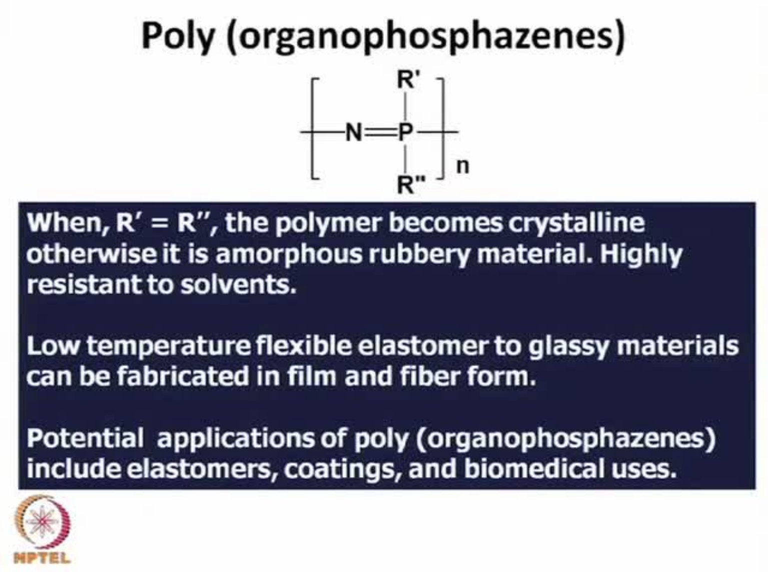

Poly (organophosphazenes)

$$\left[-N{=}\overset{R'}{\underset{R''}{P}}- \right]_n$$

When, R′ = R″, the polymer becomes crystalline otherwise it is amorphous rubbery material. Highly resistant to solvents.

Low temperature flexible elastomer to glassy materials can be fabricated in film and fiber form.

Potential applications of poly (organophosphazenes) include elastomers, coatings, and biomedical uses.

Poly organophosphazenes is a polyphosphazene polymer is a formula and is a low temperature flexible elastomer to glassy materials can be fabricated in film and fiber form. Potential applications include poly elastomers coatings and biomedical uses.

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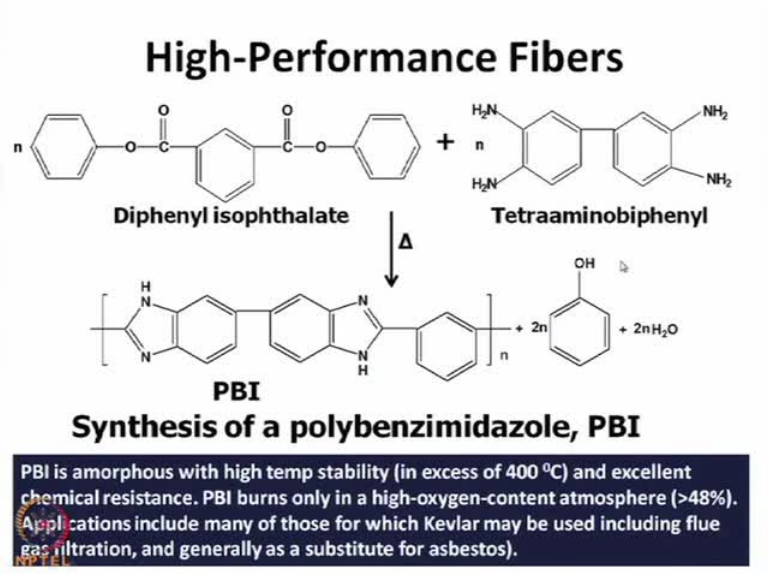

High-Performance Fibers

Synthesis of a polybenzimidazole, PBI

PBI is amorphous with high temp stability (in excess of 400 ^{0}C) and excellent chemical resistance. PBI burns only in a high-oxygen-content atmosphere (>48%). Applications include many of those for which Kevlar may be used including flue gas filtration, and generally as a substitute for asbestos).

High performance fibers are made from this diphenyl isophthalate tetraaminobiphenyl. This is actually polybenzimidazole; polybenzimidazole, this polybenzimidazole is amorphous with high temperature stability in excess of 400 degree celsius and excellent chemical resistance. This polyimide polybenzimidazole burns only in a high oxygen content atmosphere containing 48 percent, maximum 48 percent oxygen. Applications include many of those, for which kevlar may be used, that means in place of kevlar this can polymers can also be used including flue gas filtration of chemical industries and generally as a substitute for asbestos.

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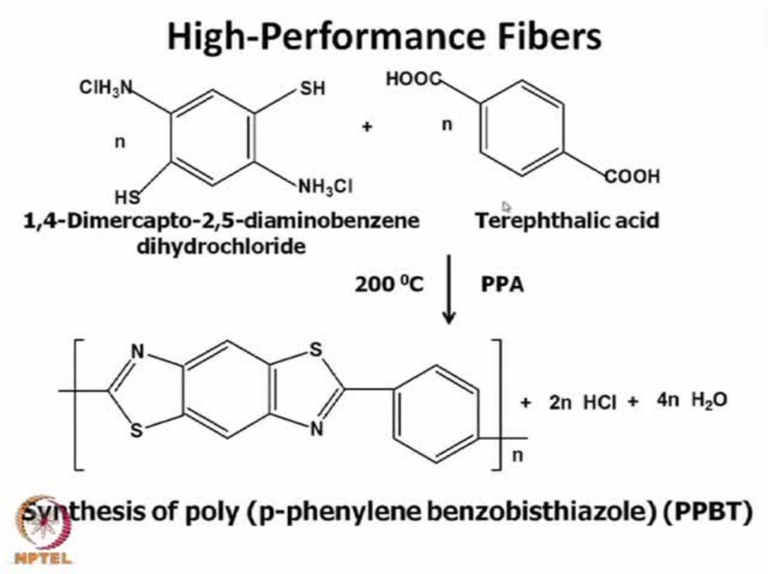

High-Performance Fibers

Synthesis of poly (p-phenylene benzobisthiazole) (PPBT)

High performance fiber, other high performance fiber say, this polyphenylene benzobisthiazole poly bisthiazole this is thiazole thiazole thiazole is bisthiazole poly phenylene benzobisthiazole.

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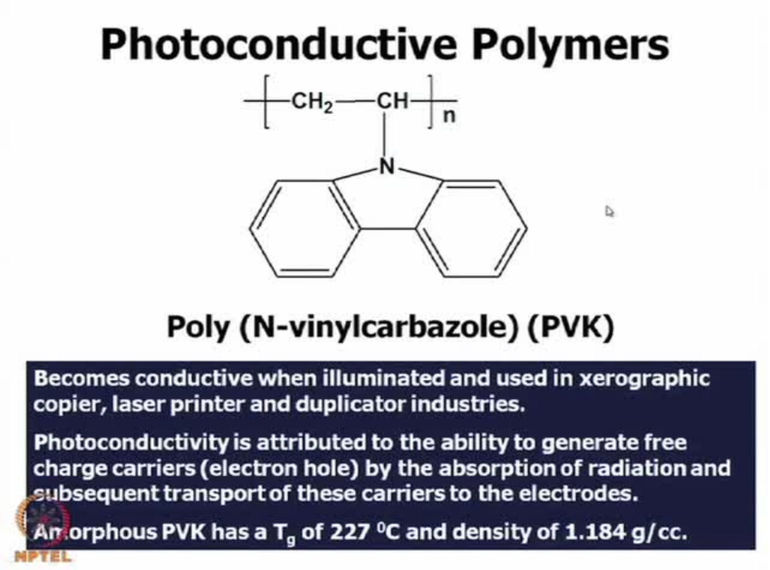

Photoconductive Polymers

Poly (N-vinylcarbazole) (PVK)

Becomes conductive when illuminated and used in xerographic copier, laser printer and duplicator industries.

Photoconductivity is attributed to the ability to generate free charge carriers (electron hole) by the absorption of radiation and subsequent transport of these carriers to the electrodes.

Amorphous PVK has a T_g of 227 ^{0}C and density of 1.184 g/cc.

Photoconductive polymer is poly N-vinylcarbazole photoconductive polymer, this becomes conductive when illuminated and used in xerographic. When illuminated means, when it is exposed to light, it becomes conducting in nature, electrically conducting in nature, and that is used in xerographic copier, laser printer and duplicator industries. This photoconductivity is attributed to the ability to generate free charge carriers or electron holes by the absorption of radiation, electromagnetic radiation and subsequent transport of these carriers to the electrodes. Amorphous polyvinyl, carbazole has a glass transition of (( )) high glass transition 227 degree Celsius and density is 1.184 grams per cc.

Thank you very much.