Manufacturing of Composites
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Lecture - 02
Matrices

Welcome friends we will go on to lecture 2. So, lecture 1 we had a very basic introduction on composites, different types of composites. So, today our prime focus will be towards matrices. So, in today's lecture we will see matrices, are the characteristics of matrices, functions of matrices, different types of matrices and here we are more focused towards polymer matrix composite.

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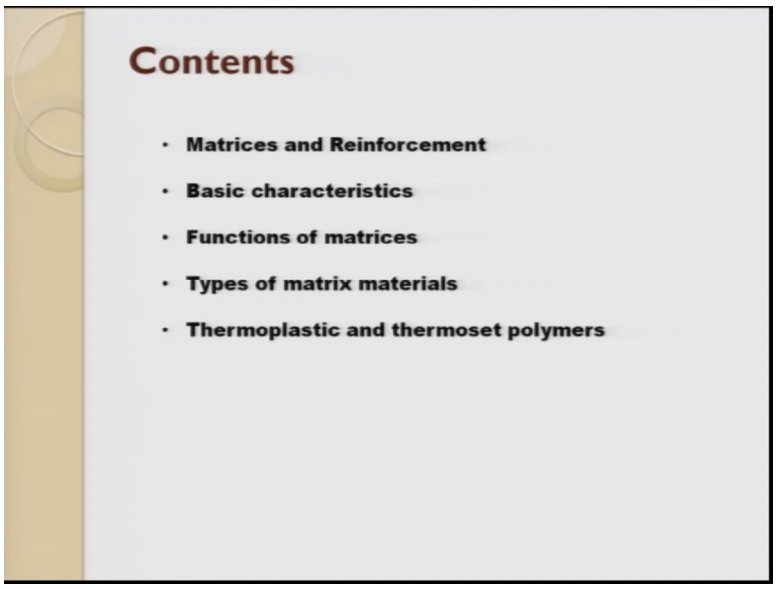

So, we will see different types of matrices that is thermoplastic matrix and thermo set polymer matrix composites.

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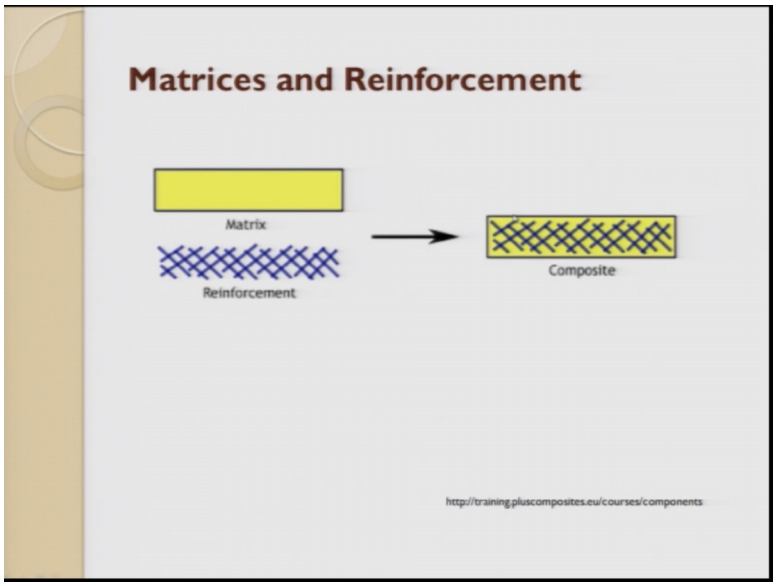

Rewind or recap of last class, you have to make a composite you need 2 or more ingredients, the most predominant ingredient will be matrix it would be called as matrix and the reinforcing agent will be those which gives strength to the composites.

So, matrix can be of any type: it can be made out of polymer, it can be made out of metal or it can be ceramic, the reinforcement like discussed last class it can be continuous it can be discontinuous it can be particular type. So, depending upon these 2 combinations we would always try to have a cenergitic output as a composite material.

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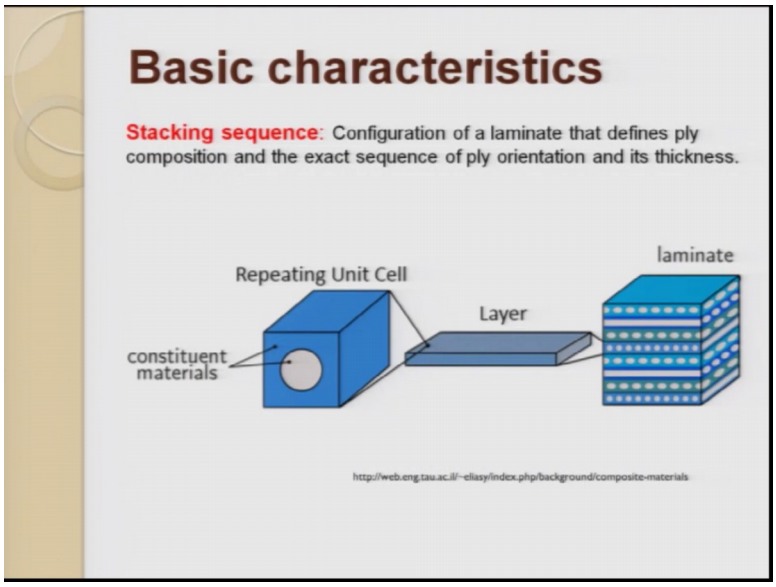

So, if I try to go little bit about composites for example, if you want to make a thick or if you want to make a part where in is it as all 3 dimensions. So, if you look at it, this is what is a composite? So, the composite can be made out of bulk as 1 and they can have 3 dimensional reinforcement or they can be stack of several 2 d several layers, to form a 3 d composite when it is a several layers stacked it is called as a laminate and one layer is called as a laminate.

So, in a laminate we will have a reinforcing agent and we will have a matrix. So, that is nothing but a layer. So, in a layer what you will have? You will have reinforcement as well as matrix. So, if you look at it further go in backwards it this polymer, the polymer is nothing but repeated unit cycle of polymers is reinforced with reinforcing agent and several of them stack together forms a composite and you can see there are circles, but smaller circles and larger circles. So, this shows very clearly that you can keep changing the orientations of the layer to get the required output. So, that laying of different layers is called as stacking sequence.

The configuration of a laminate that defines by ply composition and the exact sequence of ply orientation and it is thickness is called as a stacking sequence.

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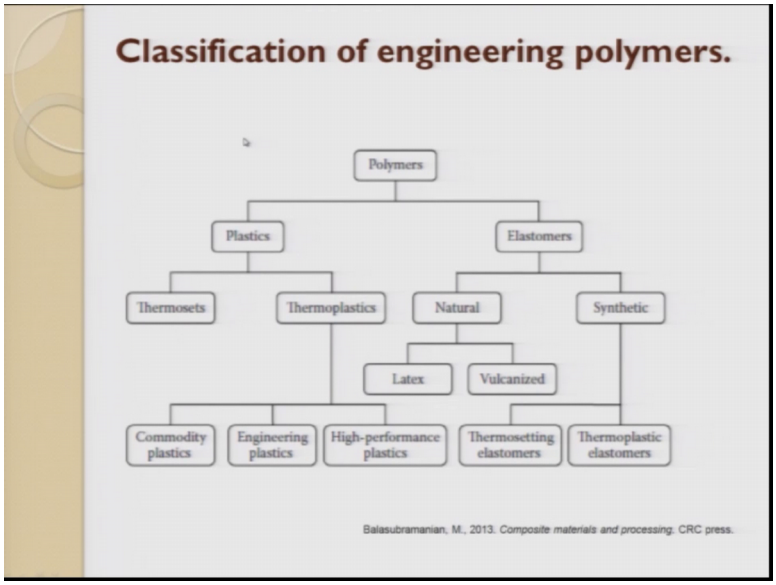

So, when you would discuss about matrices and I told very clearly that we are more focused towards polymer matrix composite. So, polymer can be classified into 2, one is called as plastics and the other one is called as elastomers and plastics can be further

classified into thermo set and thermo plastic composite. Very crude differences it is non-recyclable and this is recyclable. Thermoplastic can be further classified into commodity plastics engineering plastics and high performance plastics.

Commodity plastics are plastics where in which there as not much of load component and it is predominately used for house hold applications or for some entertainment. For example, making a closure for machine tool can is called as commodity plastic; where in which it does not take any load, it is a secondary structure. The next one is a engineering plastics where in which it has high strain and it also we has taken to a place or it was service condition rather is temperature in involved. High performance plastics are for endurance cycles all these things we can look at these types of plastics; when you go to elastomers the difference between thermoplastic and elastomer is the ductility.

So, here it can go up to1000 percent depending upon the combination, playing with the properties, elastomer can go up to 1000 percent ductility. So, you can have this is classified into one is called as natural, the other one is called as synthetic. Since there is lot of components coming out of elastomers today, people are more and more moving towards synthetic elastomers, natural elastomers again there are 2 classification one is latex the other one is vulcanized. When you talk about synthetic again you can divide into 2 which is called as thermo sets elastomers and thermoplastic elastomers going further.

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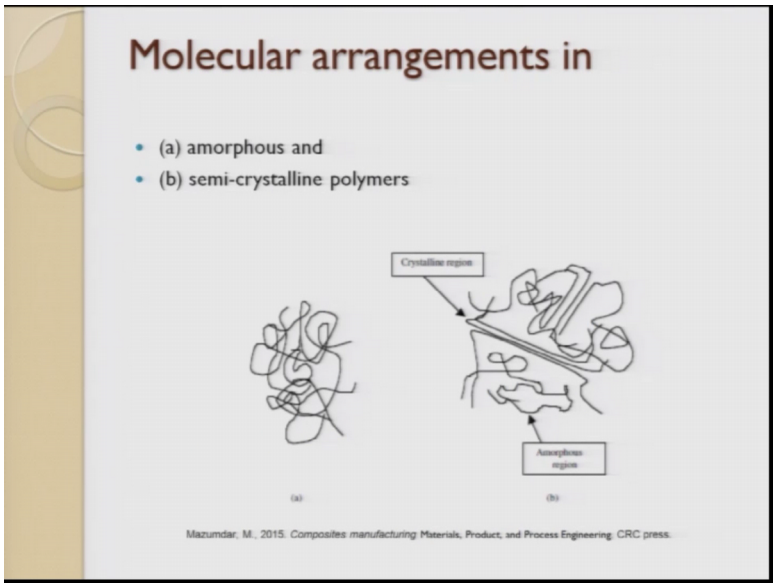

When you try to see the molecular arrangement of inside of polymer, it can be like this people called this as Kinkini structure.

Where in which it is like a coil the spaghetti you can keep pulling one thread and it stretches itself. So, these are called as amorphous structure. Amorphous polymers are those polymers where in which it is not arranged in a uniform or a periodic pattern and it helps in mobility of the chain. So, these are amorphous polymer and there is some other where is another classification called a semi crystal and polymer where in which there is some zone where in which a fixed at arrangement pattern received and in some places there is a randomness. Is there crystalline polymer; no 100 percent crystalline polymers are not available or it cannot be made.

If the polymers can be of 2 classifications it can be amorphous or it can be semi crystalline polymers, depending upon the amorphous their properties like transparent transmission properties all these things changes. So, before getting into understanding the thermoplastic and thermo set matrices, let us first try to understand what is the function of a matrix? Let me go back to this figure which we discussed earlier. So, in this figure you see that it takes a broad base and in that broad base this reinforcing is pushed inside.

So, what can be the function of a matrix? So, the first thing is it helps in holding the matrix, second thing is it helps in protecting the matrix, the third thing is it can try it helps in distributing the load on the reinforcement. The last thing is if you want to selectively make the reinforcement to take the load, that work also matrix can do. This is what it is. So, now let us go ahead and see the functions whatever I have said and whatever we would guess is written here.

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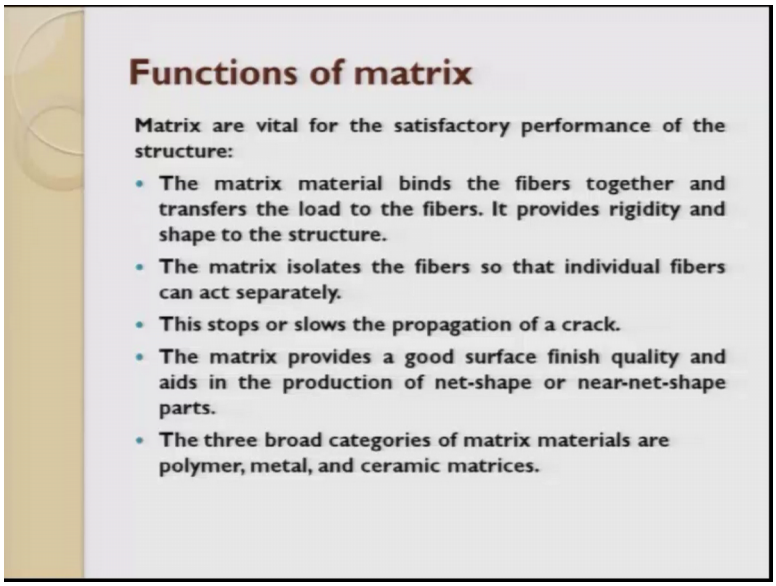

First thing is the matrix material binds the fiber together and makes were the load is uniformly transferred across the fiber.

It provides shape and rigidity, if you have only reinforcement we cannot make a product. So, in order to make a product we try to use matrix and a reinforcing agent. So, it provides rigidity and it provides shape to the structure, second thing as I told earlier if you want to selectively make the fibers to take the load, that is possible by properly making the matrix and the matrix is allowed to isolate also fibers. So, that you can make sure those things take over. Second thing is it tries to protect from the service environment or I can put it this way suppose if there is a crack which is keep growing and the matrix make sure that if diverges a crack and so that the energy is dissipated the cracks progression gets pro long and the service life enhances.

So, it is one of the major property or a major function of a matrix to make sure that it is makes the crack growth slower, then it gives you a good surface finish as I told you earlier it also helps in making near net ship flow.

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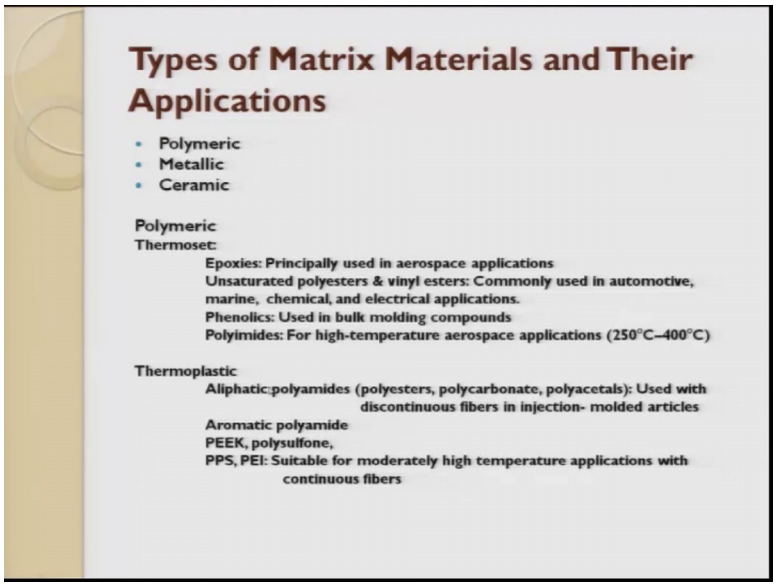

When you talk about matrices 3 types I have already discussed, now let us get into different examples of thermo set polymer and thermoplastic polymer. So, under thermo set you have epoxies, which principally is used in aerospace industry, marine industry a transportation industry everywhere it is exhaustively used.

So, this helps in towards manufacturing then you have unsaturated polyester and vinyl ester, there commonly used in automotive marine and chemical and electrical appliance. You are phenolics resin which is used for bulk molding components; that means, to say thick components you have polyimides which to for high temperature aerospace application which can vary from 250 degree Celsius to 400, that is what is a typical temperature we are working on.

It is not that thermo sets or all there is room temperature slightly higher temperature is also played around. When you talk about thermo plastic, the different examples are different aliphatic groups where in value which aliphatic polyimides you have polyesters, polycarbonate, polyaccetal. Polycarbonates are exhaustively used in rapid manufacturing; that means, to say in f d m process we use polycarbonate as a one of the wires for processing it. So, polycarbonates these are predominantly used for where used for injection molding process where in which you will not have continuous fibers, when we talk about manufacturing you will talk about what happens with continuous fibers and what happens with discontinuous fibers.

So, kindly make a note here that, aliphatic polyamides polyester, polycarbonates and polyacetate are used to for discontinuous fiber reinforcement to injection molding process. You also have aromatic polyamides, you have PEEK, polysulfone and then you also have PPS, PEI all these things are used for high temperature applications.

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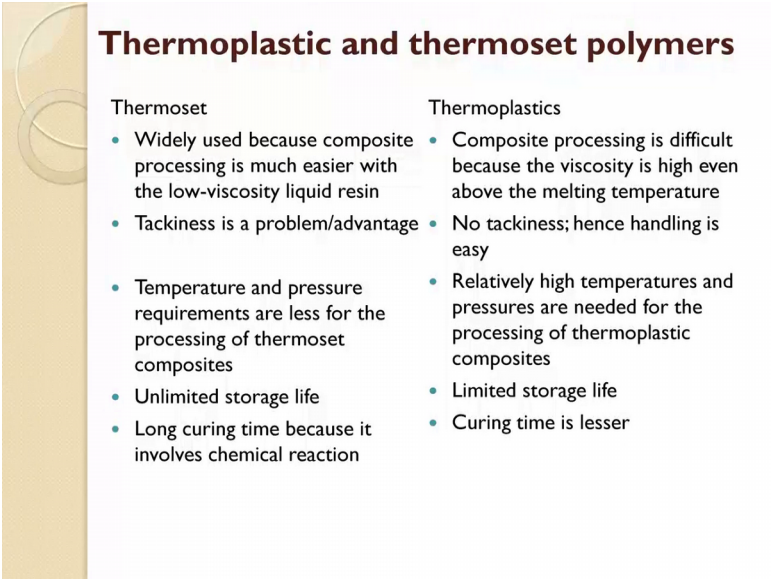

Now, let us see the difference between thermoset and thermoplast, as you all know thermoset non-recyclable thermoplast recyclable biggest difference.

The next difference, when you are trying to process it is always easy to use thermoset because it does not have very high viscosity. So, if it can exist in liquid form it can exist in solid which we can quickly convert into a liquid form. So, the viscosity is not very high. So, if the viscosity is not very high then it can quickly flow around I confined path or flow around the reinforcement to make a product. Whereas, thermoplastic is concerned at when you try to take it to a high temperature it becomes viscous, this viscosity is very high you always mean a pressure as a one more reading parameter to make sure it flows through the confined path or around the reinforcement. So, the temperature and pressure requirements are very less as for as thermoset is concerned, but in thermoplastic these pressures and temperatures required are very high.

Thermoset has unlimited storage life or self life; that means, to say you buy a rushing it has a validities for 2 years whereas, a thermoplast liquid form is very difficult when you

are trying to make composites solid to liquid; that means, to say high viscous liquid it does not have a larger storage life.

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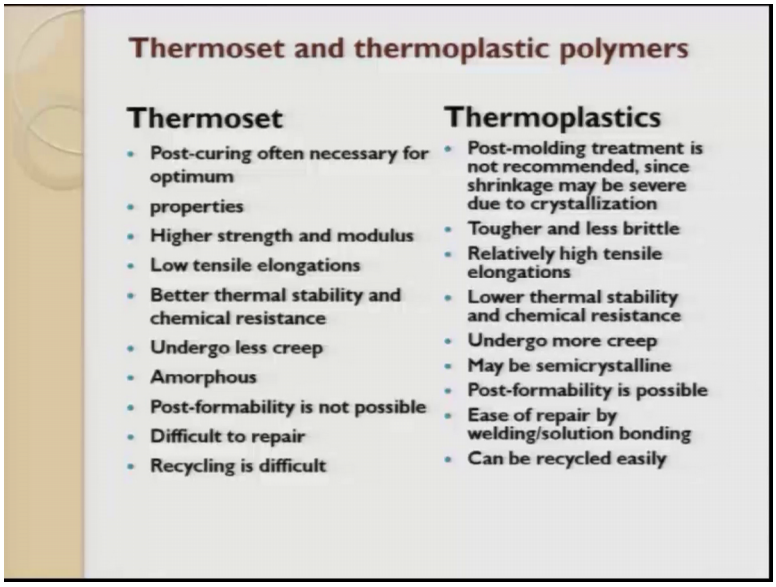

The post curing one thing you should understand the polymer, when you make a polymer matrix composite 100 percent setting never happens, the setting happens up to 95to 96 percent and over a period of time. All this cross linking are happened and small changes happen within the polymer and it becomes 100 percent cure after all longer period of time as for as thermoset is concerned.

We do not need to use the post curing often necessary for optimizing. So, here and as for as thermoplastic is concerned post mold treatment is not recommended. So, here you try to get then full part, near net part I as in 1 shot, but the biggest problem is in thermoplastic the shrinkage as are very high. So, you have to make sure in your mould design it so this property is at taken care. So, it has a very high strengths to modulus thermoset the roughness and very less brittleness is there, it has low tensile elongation it has relatively high tensile elongation, when you talk about thermal stability and chemical resistance thermo set is good as compared to that of thermoplast. So, it has very low creep resistance, it has very high creep resistance, it predominantly it is amorphous it is semi crystalline nature.

The post formability is not possible as for as thermoset is concerned because it is not recyclable so here it is still doable. So, it is very difficult to repair here it you can do

some amount of repair because it is recyclable. So, the recycle is difficult and the recycle is very easy as for as thermo plastic is concerned.

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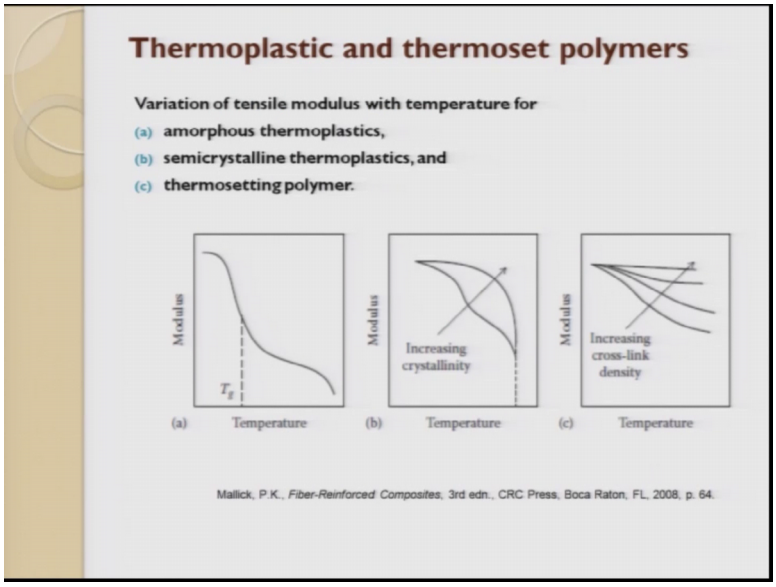

So, here are some of the various properties which we have compared. So, you can see here the first one is modulus with respect to temperature. So, here since it is a polymer it does not have a exact point of transition from solid to liquid, it gets into a zone and then it gets converted into a liquid form.

So, this is called a glass transition temperature. So, you can see that the modulus falls drastically down after the mod glass transition temperature. So, the crystallinity you remember we discussed about amorphous and crystalline moment, you start increasing the crystallinity of the polymer, you can see the reason enhancement in the modulus; that means, to say semi crystalline material will have higher properties at higher temperatures also. So, here you can see that modulus increases with respect to temperature, here by changing the cross linking; that means, to say I said when I increase the cross linking density; that means, to say number of cross links present in a unit area.

If I can keep on increasing then you can see the modulus reminds almost constant for wearing temperature. So, here in which in this line, we have seen the variation of tensile modulus with respect to temperature. Why I am talking about temperature because temperature is one major parameter, which is used while processing polymer composites. So, that is why we are trying to put here.

So, this shows an amorphous thermoplastic, this shows semi crystalline thermoplastic and this shows a thermoset of a polymer. So, this graph clearly says that the in the involvement or the influence of modulus on temperature is clearly shown here. So, crystalline it is very important and the glass transition temperature is also very important, we after record the glass transition temperature for a polymer such that, this data is used for while processing a polymer matrix composites.

So, here we can see depending upon the loading rate as stress versus strain curve loading rate see for example, you take a small rubber band which is made out of an elastomer material, you pull it a very high strain rates it fractures; if you slowly pull it the strain rates are very slow you can keep elongating it for a longer time. So, this is what we are trying to show in this graph, this property is very important.

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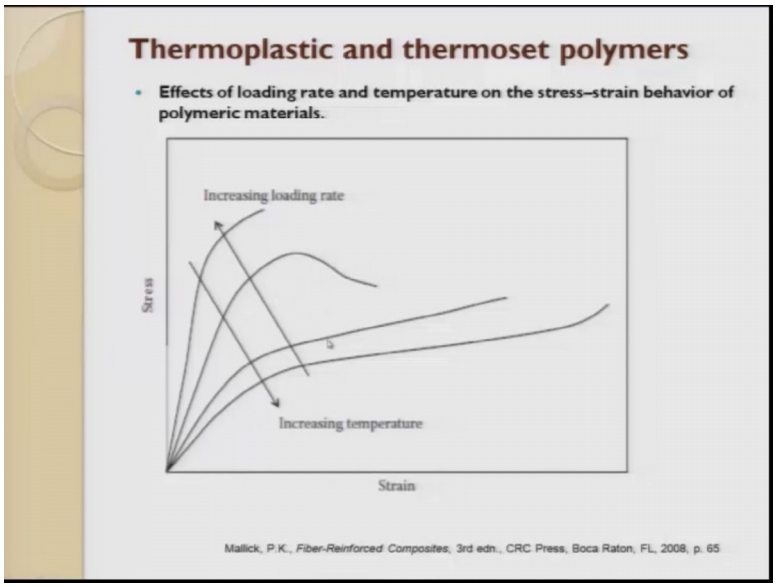

Because, this property tries to decide how the load gets distributed in the composite and what should be done. So, you take here this is stress this is strain. So, stress versus strain graph, so here let us take the influence of loading rate, if the loading rate pattern increases; that means, to say at higher loading rate the ductility falls down drastically.

The e enhances drastically the Young's modulus, as when as the temperature goes higher and higher the polymer gets soft and so because of this soft mean, the strain rates the strain is going for a longer time as compared to that of the stress, this graph clearly says if you want to process a polymer matrix composite or if you want to process a

thermoplastic material, you should take it to a higher temperature such that you bring in ductility., Moment ductility is brought end the shape to which it is manufactures can be achieved easily.

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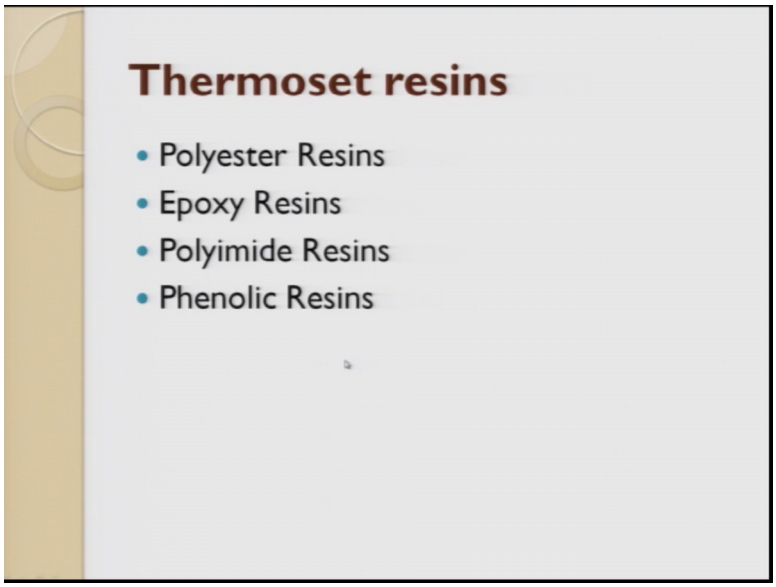

So, now let us see the different polymers, the different sets of the different thermoset resins and then we will see some of the properties. So, that you are understand which one to choose for what application.

So, under thermoset resin we have polyester resin, we have epoxy resin, we have polyimide resin, and we have phenolic resin.

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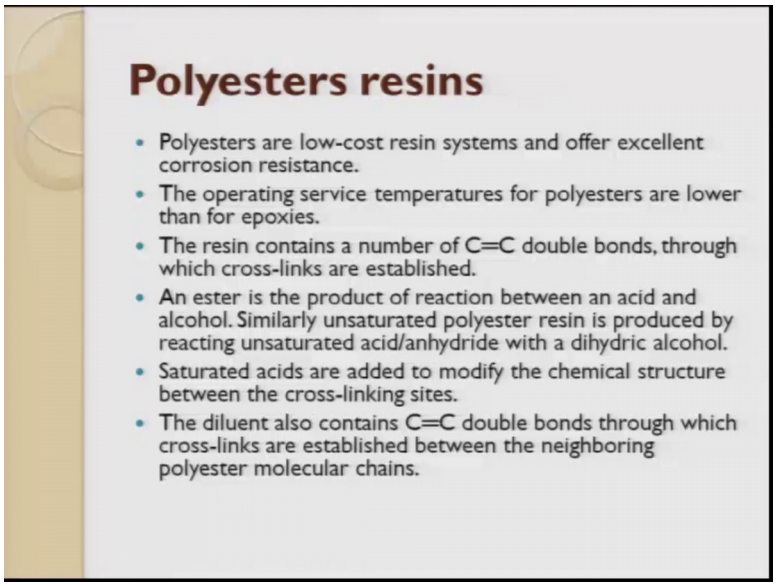

The most common resin is polyester resin because it is very inexpensive or it is very economical, polyester are low cost resin systems and have often excellent corrosion resistance. These composites are used thermoset composites are used for making bridges, making containers where in which water is carried or some acid is carried. So, they always make through polyester resin because of it is economic nature and it is always available in a liquid form. So, liquid is easy to give a shape. So, the operating service temperatures for these polyesters are very low as compared to that of the epoxy, room temperature itself you can make this composition. The resin contains a number of C double bond, when you talk about a polymer it is only c and h because all other bonds.

So, it is C double bonds are there through which the cross linking are established. So, what is cross linking? Suppose let is assume you have a chain a polymer chain and then you have another polymer chain. So, between these 2 chain let have you have secondary bonds, these secondary bonds if they try to lock all these bonds then what happens the mobility of this chain is not available.

So, moment the mobility is not available then the polymer becomes stiff; that means, to say it is cured cross linked and it is cured. So, the strength of the polymer in enhances. So, the resin contains a number of c double bonds through which cross linking are established, moment cross linking established it is cured plus the strength property enhances and yester polyester.

So, yester is a product reaction between an acid and an alcohol, similarly unsaturated polyester resin is produced by reacting unsaturated acid slash anhydride with a dihydric alcohol, this is how the polyesters are made. The saturate acids are added to modify the chemical structure between there cross linking sites, the diluents also contains c double bond through which the cross linking are established between the neighboring polyester molecular chain, thereby making it stronger. So, this is how polyester is for manufactured and this is our manufactured polymer is cross linked and the strength enhances.

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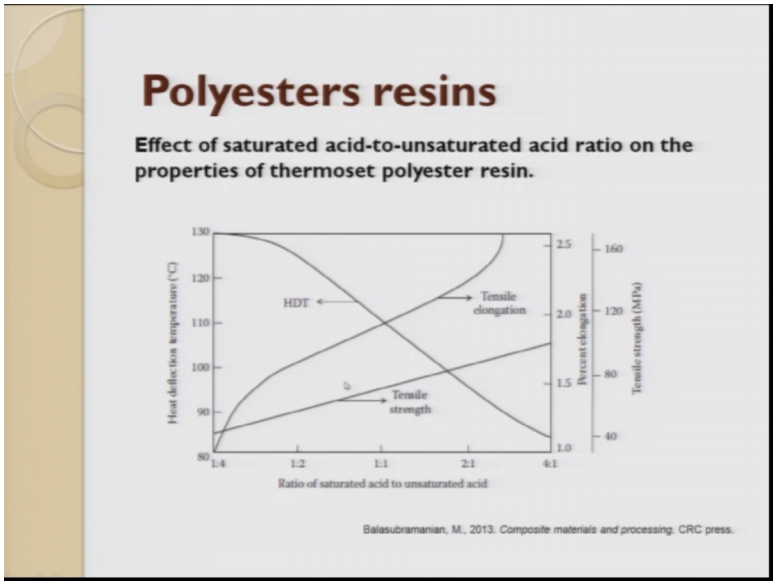

So, if you look at this graph it clearly says the effect of saturated acid to unsaturated acid ratio, on the properties of thermoset polyester resin.

So, you can see this is the heat deflection temperature curve with respect to the ratio this unsaturation and saturation acid, tries to talk about the cross linking density. So, you can see that as the ratio increases the tensile strength increases, the tensile elongation increases you can see that this is percentage of deflection and this is tensile strength.

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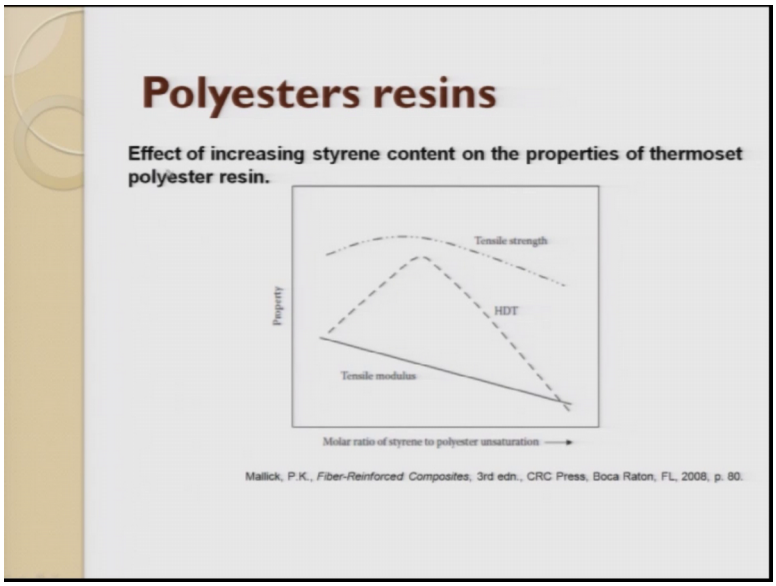

So, polyester resin the effect of increasing styrene content on the properties of the thermoset polyester resin, you can see that the molar ratio of styrene to polyester unsaturation. You can see what happens to the HDT curve and the tensile properties and tensile modulus.

You can just to compared with the previous graph here, the graph or does it behave with respect to saturation and un saturation here with respect to styrene content and the polyester unsaturation. Next let us move onto epoxy resin epoxy resin is the next most commonly used thermoset resin. So, epoxy is very versatile resin system it allows for a broad range of properties and processing capabilities.

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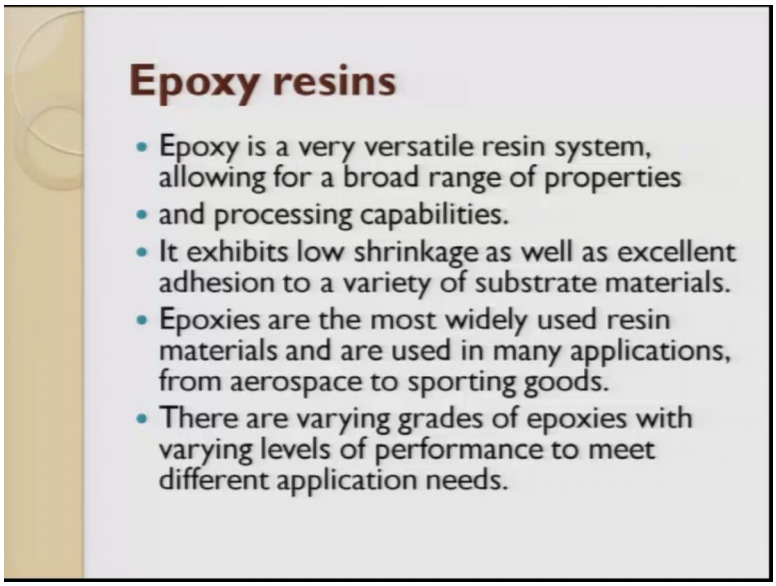

It exhibits very low shrinkage, low shrinkages very important because in a liquid form when you try to use a resin and when the resin gets cured; that means, to say when it is completely liquid is converted in to solid, the shrinkage if it is very less than the shape whatever you want you can easily get it done, if there is a shrinkage than this can be happening 3 dimensionally and it is little difficult to control the output.

But as for as the epoxy seems the shrinkage is very low it gives excellent adhesion with various substrate and it will gives very high strength, epoxy are most widely used in resin matrix and is used in many application from aerospace to sports, there are varying grades of epoxies with varying level of performance to meet different applications; the epoxy just by tweaking the small percentage or just by changing amorphousness to semi crystallinity. So, you try to get new properties.

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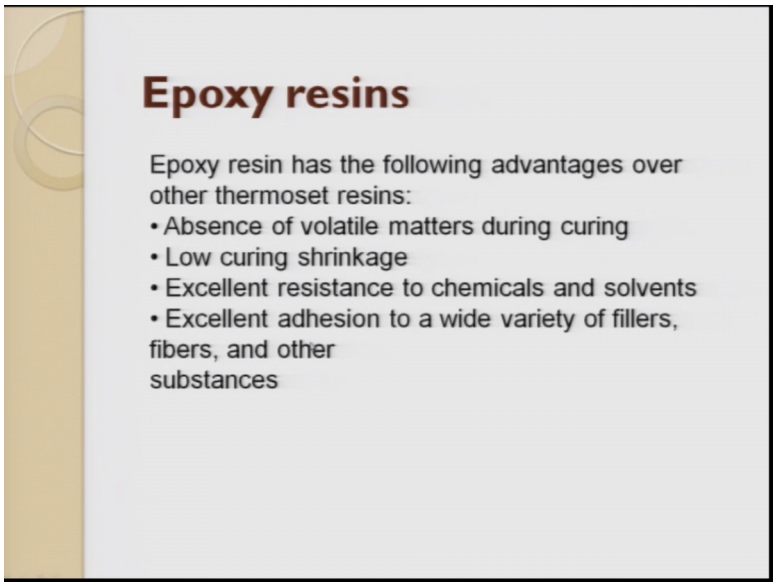

The epoxy resin has the advantage over all other thermoset resins these are the. So, it is the volatile matters during curing is one of the biggest thing, it has low curing shrinkage it has excellent resistances to chemical and solvent, it has excellent adhesion to wide variety of fillers fibers and substrate.

So, it is very important property if you do not have a good wet ability property then matrix and resin will not get lot and you will really not be able to enjoy the advantages of composite material and the enjoyment of the composite material comes, if you have a proper link or proper bonding between the polymer and the reinforcing agent epoxy gives that in a big way. So, that is why epoxy resins are exhaustively used under thermoset category for various polymer matrix manufacturing. Next let is move to polyamide resins the polyamide resins work on slightly higher temperatures.

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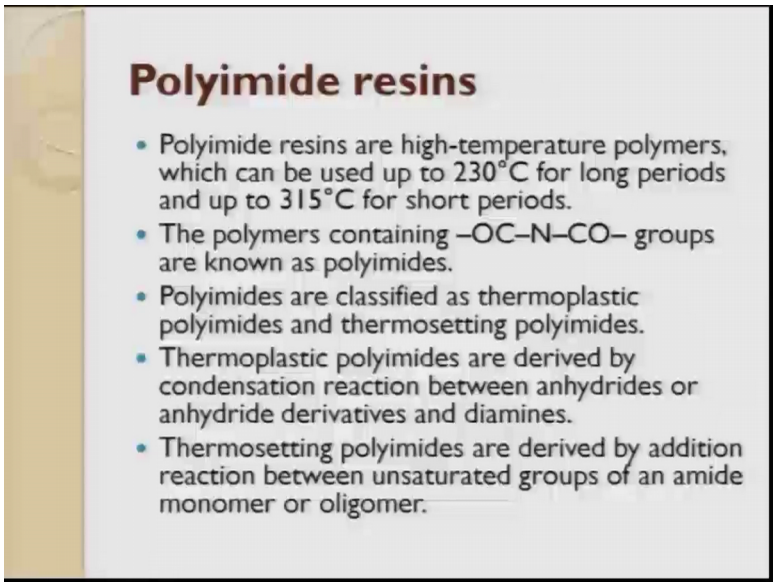

So, where the temperatures, where the polymer requires high service conditions; so we always go for polyamide resins or high temperature polymers, which can be used up to 230 degree Celsius for a longer period of time and it can also work up to 315 for a shorter period of time.

The polymer contains OC slash N slash CO group which are polyimides. Polyimides are classified as thermoplastic polyimides and thermosetting polyimides, the thermoplastic polyimides are derived from condensation reaction between anhydride or anhydride derivatives and diamines. Thermosetting polyimides are derived by addition reaction between unsaturated group of an amide monomer or oligomer. So, this you should have this in mind polyimide can exist in thermoplastic form as well as in thermosetting form. one is done by condensation, one is done by addition. So, in the last class previous lecture we discussed about what is a addition reaction and what is a condensation reaction.

So, please keep that in mind polyimide high temperature application and it can existing thermoplastic polyimide as well as thermoset polyimide. Next is a phenolic resin phenolic met FAA and jar requirement for low smoke and toxicity. So, this smoke contents which gets evolved or the toxicity which is getting evolved, as far as phenolic resin was very less. So, FAA is an agency they are used for aircraft interior because you

should understand in an aircraft internally; if there is a or by accident if there is a smoke getting evolved, if there is lot of smoke it chokes the passage.

So, they try to use phenolic resin because it does not generate smoke, it is stow bins galley walls as well as other commercial markets that required low cost flame resistant and low smoke products we always go for phenolic resin. Phenolic products have finding wider application at high temperature assistants electric property wherever it is required, wear resistance and good chemical resistance, we always use phenolic resins for making bulk products bulk components.

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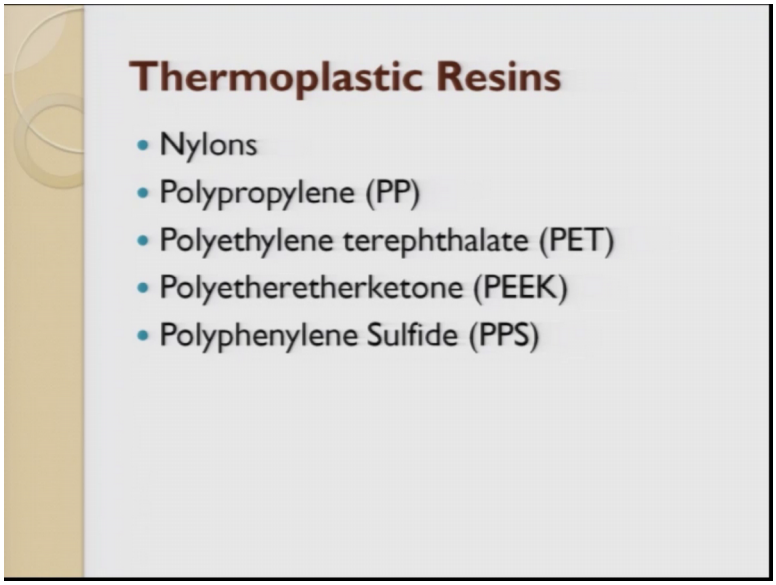

Now, let us go to thermoplastic so if you want to consolidate in thermoset, thermoset is non-recyclable it will have predominantly it exists in a liquid form at room temperature.

So, it tries to help us in giving shape to the composite very easily, but it is non-recyclable. Till now the people have been exhaustively used in lot of thermoset matrix polymer composite for various applications, now because of it is non recyclability thermoplastics are getting pushed very hard by aerospace industry, automobile industry and marine industry for various applications, but what are the issues related with thermoplastic, thermoplastic means you need to have it exist predominately it exist in solid form.

So, in order to convert into the liquid form you need to apply very high temperature and for pushing this, when you try to track it to a high temperature; that means, to a see around the glass transition temperature it is viscous in nature, with this viscous it if you want to make a composite it is difficult. So, we always pressure along with this temperature to get a composite term. So, that is what the restriction of thermoplastic, but the major advantages it is recyclable.

So, with this let us get into thermoplastic resin, thermoplastic resin what we will cover is nylons, polypropylene, polyethylene terephthalate PET which is used for exhaustively used for making water bottles which is called as pet bottles. So, there may at a speak polyetheretherketone, when it is polyphenylene sulfide at PPS these are some of the most commonly used thermoplastic resins.

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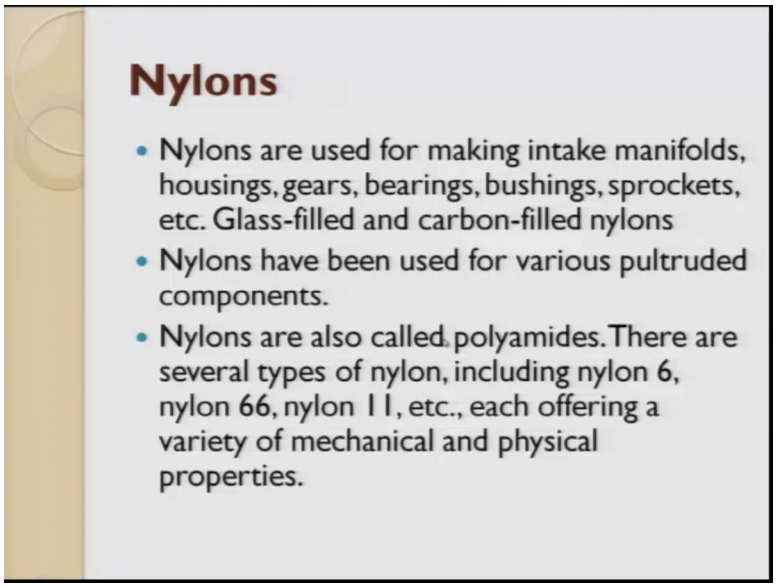

So, nylon are exhaustively used in the intake manifold, it is used as gears in the printers, we used nylon gears where in which it has low friction it is used as bearing material, bushing, sprockets etc are made as for as thermoplastic is concerned, you cannot use long and continuous fibers for making composites, we always used short fibers. So, it is easy to mix thermoplastic nylon with glass fillings and directly you can try to use injection molding process to make a component out. Nylons are exhaustively used for making pultrotion components, nylons are also called as polyamides.

There are several types of nylons including nylon 6, nylon 66, nylon 11 etc each offering a variety of mechanical physical properties.

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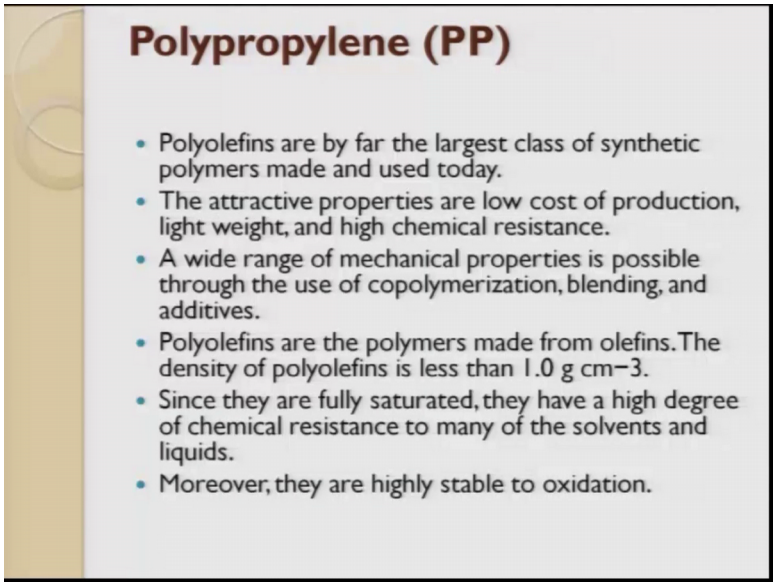

The next most common is polypropylene. So, it is polyolefin are used by far the largest class of synthetic polymers made and used today, the attractive properties are it is low cost of production light weighted high chemical resistance, a wide range of mechanical properties, as possible just by doing copolymerization blending and additives; that means, to say you keep adding ingredients such the properties of the thermoplast can be changed to meet out your requirements, the densities are as less as 1 gram per centimeter cube.

So, if you talk about steel it is 7.8, if you talk about aluminum it is not about 3 to 4 kg per meter square. So, so here if you see it is not about 1so it is very light weight. So, it can be used for several applications, where in which it is a moving body; For example, car you can use it and exhaustively today polyethylene thermoplastic composites are used for lot of composite parts in automobiles. So, it has also high stability towards oxidation, which tries to use this property for several applications.

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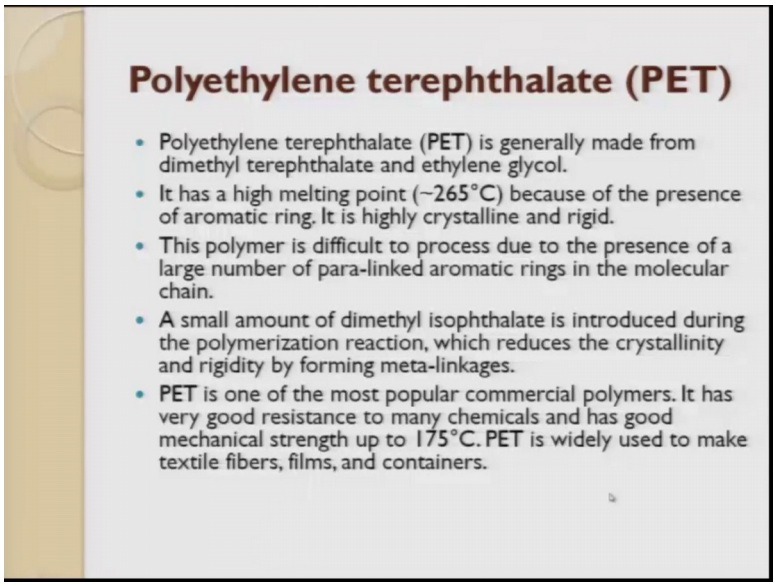

Next one is pet is polyethylene terephthalate is generally made out of dimethyl terephthalate and ethylene glycol. So, these 2 mix together to form PET as a melting point of 265 because of it is presence of aromatic ring, it is also highly crystalline and rigid in nature.

So, this can be used for high strength applications, this polymer is difficult to process due to the presence of large number of Para linked aromatic rings in the molecular chain. So, processing it is slightly difficult because you need to have high temperature and pressure, a small amount of dimethyl is introduced during the polymerization reaction, which reduces the crystallinity and rigidity by forming Meta linkage. So, what are you trying to do you are trying to play with the properties, this is one of the most popular commercial polymer. It has very good chemical resistance to mechanical strength up to 175 degree Celsius; it is not at room temperature at high temperature.

So, this is what PET is also exhaustively used in process industry, especially food processing industry.

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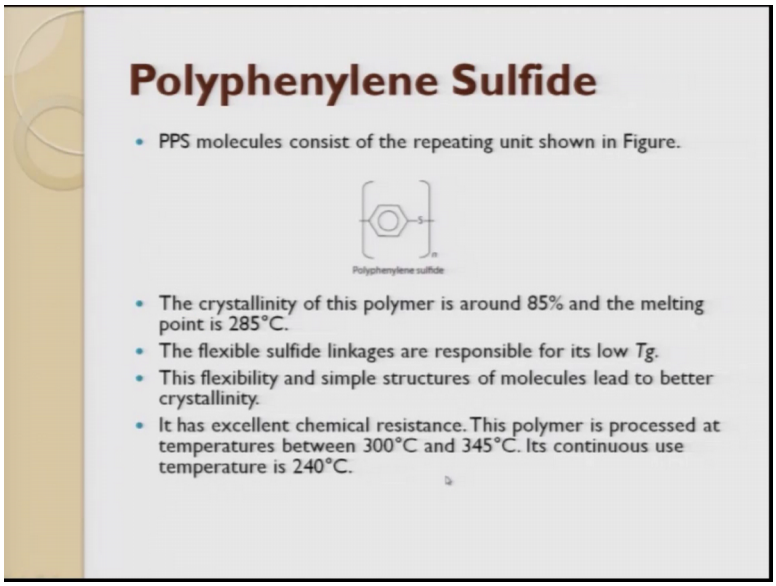

Next is polyphenylene sulfide, so PPS molecule consist of a repetition unit of this figure this is the unit cell, the crystallinity of this polymer is around about 85 percent and the melting point is around about 285 degree Celsius. The flexible sulfide linkages are responsible to lower that glass transits and temperature. Why is glass transits and temperature important because it is very clear this is the temperature where you have to take the polymer and afterwards you process it to give a required shape and size, the flexibility and the simple structure of the molecules you needs to a better crystallinity. It has a excellent chemical resistance and it can work up to 345 degree Celsius.

So, you look at it all the polymers what we have seen each one it is works very good at room temperature slightly higher, it is much higher 175 then it can go up to 300 degree Celsius. We have just listed it according to the temperature with it can be processed and which it can work.

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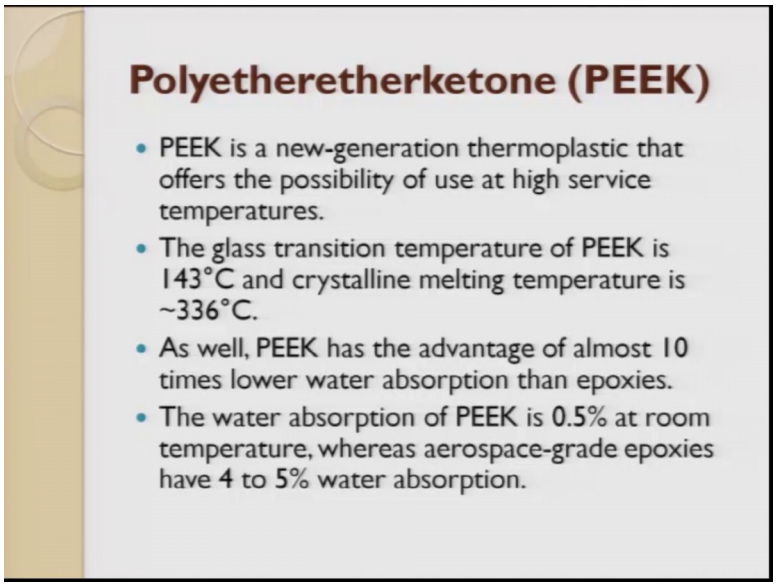

PEEK is a new generation thermoplastic that offers possible of using of high service temperature condition, the glass transition has 143 the crystalline melting temperature is about 336, it has the advantage of almost 10 times more, 10 times lower water absorption than epoxies polymer. So, it can be used for several marine applications PEEK is exhaustively used because it does not observed water, what happens if it absorbs water there is a property called as hygroscopic, water gets absorbed and the polymer gets swollen. So, this is a very common feature in polymer matrix composites, if at all there is a defect then or a crack it through this crack if water enters inside it is to swell the polymer.

So, that kind of defects will not happen with respect to PEEK, the water absorption of PEEK is around about 0.5 at room temperature whereas, aerospace grade epoxies have 4 to 5 percentage of water absorption. So, look at it the epoxy is a thermoset absorbs and it expands, but whereas PEEK has absorption of 0.5 percent and again you should be now mentally weakly, it is not 1 property you take choose and peek a polymer you always look for multiple properties depending upon your requirement. You have to keep start using it for example, in aerospace we will look at water absorption less, we look at smokeless, we should look at lightweight, we should look at slightly higher temperature, so all these properties or thought off thought off and then you choose a polymer for it.

So, with this we will try to come to a end of the second lecture, the second lecture was predominantly focused on matrices and in matrix me first so, what are the functions of a matrix, then we saw different types of polymer matrix one is thermoplast thermoset. Again in thermoset some classifications of thermoset polymer matrix and some thermoplast polymer matrix composite and sure by this you will try to have a small fell that polymers can be classified. And they are classified according to the recyclability and how do we choose which property for making a composite or a product.

So, we will end this lecture with a small assignment, again this assignment is a home assignment you do not have to submit it to me, you can choose any one thermoplastic product it need not be a composite choose one thermoset product polymer and then what you do is you list down all the properties and you really listed down you write the relative properties; that means, to say lighter heavier stronger weaker ductile brittle just write like that. So, when you start write listing down all the properties keeping 2 polymers in your hand, then you try to understand the properties in a big way.

So, with this we will try to come to an end for the lecture 2. We will meet in lecture 3 where in which we talk about reinforcements.

Thank you very much.