Processing of Polymers and Polymer Composites

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Lecture – 03
Thermoplastics and Thermosets

[FL] friends welcome to this lecture 3 on our course on processing of polymers and polymer composites. If you recall we have already discussed the basic properties of engineering materials. Not the properties, the classification of engineering materials. We have also seen the various manufacturing processes in our lecture 2. Lecture 1 was introduction to the course in which we have seen, what all we are going to cover in this course on processing of polymers and polymer composites. I have emphasized the importance of this course as being the course which is not taught at the UG level. So, if you get certification in this course on polymers and polymer composites, you add another dimension to your already developed skills at the UG level.

I agree that in many universities and colleges, these days at post graduate level call courses on nonmetals courses, on polymer composites, and courses on other class of materials which are different from metals, are being offered at the elective level, but at UG level there is no such course available in which we study the polymers and the polymer based composites. And I have experienced this that when we go for interviews and we ask the students that what all materials you can tell us that can be used for engineering applications mostly.

The knowledge is limited to metals and the process is related to metals. Whereas if you see number of other products or other materials are being developed, which are quite different from metals. So, our course is focusing on 1 class of materials; that is polymers, and another advanced form of polymers; that is polymer based composites. So, in the last 2 lectures we just had introductory aspects of different types of engineering materials and processes.

Today we will start our discussion on the basic aspects of polymers, and how they are classified, what are thermosets and thermoplastics, and what are the various types of thermosets and thermoplastics, what are the application areas of thermosets and thermoplastics, and try to see the molecular structure of these materials; why, because the

basic understanding of a polymer is necessary, then only we can try to, we can understand, or we can try to understand the various processes that are used to convert these polymers into the tangible or engineering products. So, polymers are basically the raw material which we will use to convert it into a tangible product. Example can be anything; the toothbrush that you use in the morning may be made up of a polymer material, that plastic bucket that you use to go to the bathroom and take your bath, is made up of a plastic material. So, you have plastics or polymers all around you. Even the switch boards that you use electrical switch boards also are polymers. So, if you see you have polymers all around you. So, we need to understand that, what is this particular type of polymer number 1.

Number 2, we need to understand that how this particular product may have been manufactured. So, these are the 2 important things, with which we are focusing our attention or on which we are focusing our attention. So, our attention as the course is polymers. So, our first attention is on polymers, and then our attention is on polymer composites and on in totality. Our attention is on processing aspects of polymers and polymer composites. So, there can be a course only on polymers, in which we will be discussing the basic concepts of polymers, how they are synthesized, what are the various characteristics, what are the chemical reactions that are done to develop a particular type of a polymer, but our focus is not on the polymers. Our focus is on the processing aspects of polymer. So, we will not be going too much into the depth in context of the polymers, because we have 20 hour of discussion available with us, and we want to learn most important processes that are used for converting the polymers into the tangible products. So, the polymers basically are dealt by the researchers or scientist, the engineers from the chemistry as well as the chemical engineering background.

So, as a mechanical engineer, my job is to take a polymer which has been synthesized, which has been developed, which has been invented by a chemist or a chemical engineer and to develop a process to develop a engineering process, which can convert that polymer into the final product. So, our focus today also will be on the broader picture of the polymers. We may not be going into the detail that how a polymer is synthesized, and we will then see in our subsequent discussion in our subsequent lectures, that how these polymers can be converted into the products. Today also we will try to see, may be in the

next half an hour of discussion that a particular process through which a polymer can be converted into a product

So, let us start our discussion with the discussion on polymers, and the other generic name is plastics.

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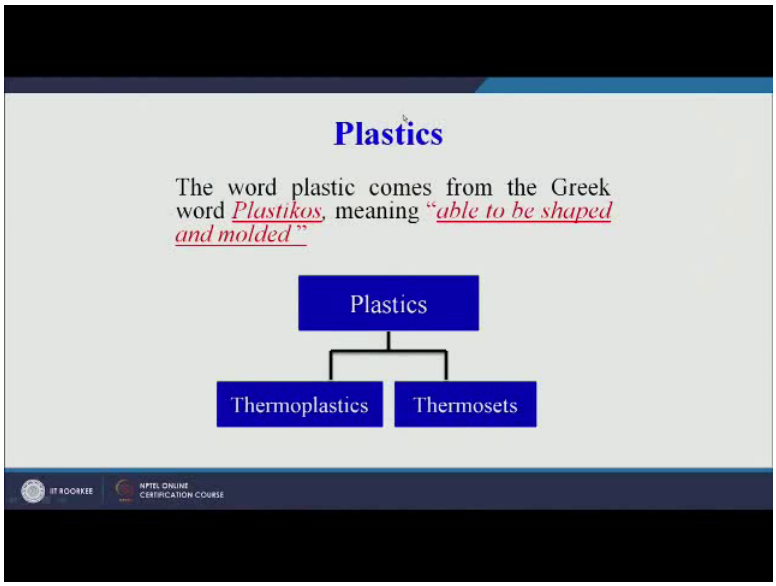

So, on your screen you can see plastics. Let us define them from the very beginning. The word plastic comes from the Greek word plastikos, and plastiko means able to be shaped and molded. So, the title of our course processing of polymers and polymer composites is this. Definition summarizes the title; that is able to be shaped and molded; that is that this is a material which we can give any shape. We can mold it as per our requirement.

So, plastics are materials from their basic definition, those materials which can be shaped or molded, and that is the thing that we want to take and utilize it for converting these novel materials into the tangible products, or to convert this raw materials into the final product. So, plastics broadly are classified as thermoplastics and thermosets. So, first classification may be somebody may ask you a question that how the plastics can be classified. You can very easily answer that; they can be classified as thermosets and thermoplastics. Now let us try to see the difference between the thermoplastics and the thermosets

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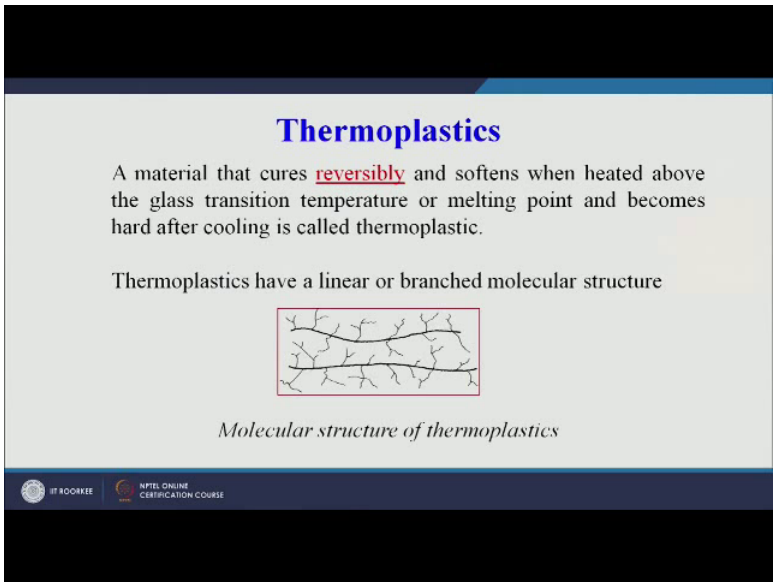

Thermoplastics you can have a definition on your screen; a material that cures reversibly, reversibly is highlighted here, and softens when heated above the glass transition temperature or melting point, as well as becomes hard after cooling is called a thermoplastic. So, very basic fundamental definition; that it cures reversibly. So, reversibly means, that once you give a particular shape to any thermoplastic, if you heat it again, it will again come back to its original perform or shape. So, originally may be it can be in the form of a small block, you heat it, give it a particular shape, again when you will heat it, it will come back to its original form. So, a material that cures reversibly, reversibly means it can it is reversible in nature, the material itself is reversible, it can come back to its original form.

So, its softens when you heat it, and it becomes solid after cooling. So, these are the 2 3 important points related to the thermoplastics. So, thermoplastics, why this type of phenomenon occurs that also we need to understand, when we differentiate between a thermoplastic and a thermoset, we need to understand that why thermoplastics cure reversibly, and why thermosets cure irreversibly that also we need to understand. So, we will try to answer that question also in today's discussion. So, thermoplastics have a linear or branched molecular structure. So, where we can see in your screen, there is a linear structure. This is the molecular structure of a general thermoplastic. We will take some examples of thermoplastics also, and see the monomers that are used as, which polymerized to give us a thermoplastic chain, we will see that. So, this is a general

structure of a thermoplastic, which is linear in nature. Whereas when we will see molecular structure of a thermoset, it will be entirely different from the molecular structure of a thermoplastic. So, once again to summarize this slide, we can just remember 2 or 3 words, that is first word can be.

Thermoplastics cures reversibly, they soften when they are heated and they regain their original shape. So, if or form. So, if we remember these 2 3 sentences or catch words, we can very easily explain the difference between the thermoplastics and the thermosets. now what are the properties of general thermoplastics, there can be exceptions.

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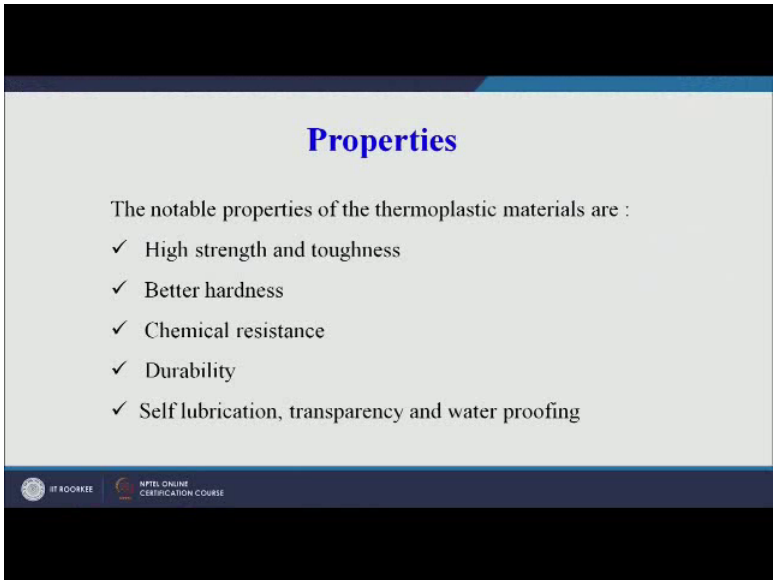

But these are the properties that are generally available in case of thermoplastics. The notable properties of the thermoplastic materials are high strength and toughness, better hardness, chemical resistance, durability, self-lubrication properties, transparency and water proofing. There can be a list there is list is angles, if you name a particular type of a thermoplastic, these properties may vary, but this is comparison of the properties of thermoplastics with the thermosets, because thermosets may be, they may not be having that much high strength as the thermoplastics.

Similarly, toughness of thermoplastics is much better as compare to the thermosets. And therefore, when we will go to the applications of thermoplastics, you will see that these are the properties which give particular application or we can say strength; that is that is these particular properties are helpful for various engineering applications. So, these are

the properties, may be when you will go through this particular discussion, you can have, you can jot down, you can write down that these are the important properties that a thermoplastic material possess. This is the example of a thermoplastic materials, as I have told you that plastics is a very big family, it is a very big family, there are number of materials that fall under the category of plastics. So, here you can see on your screen there are. So, many examples of thermoplastics you can see.

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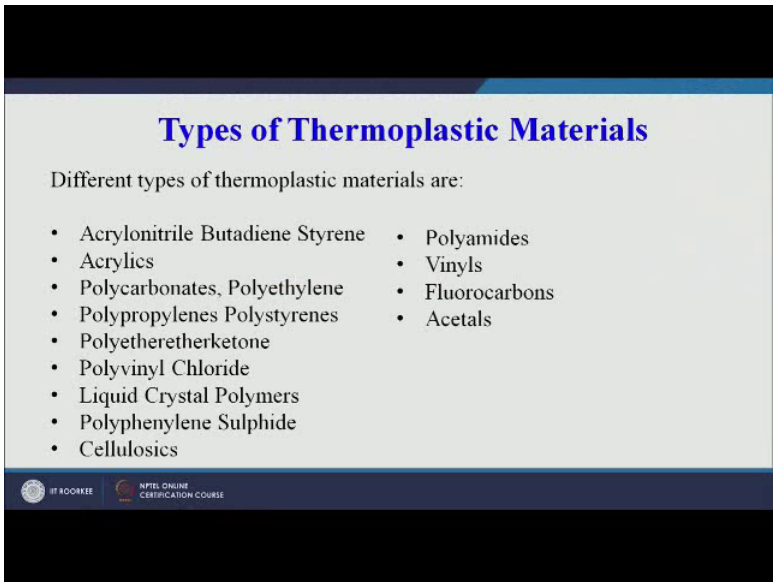

First 1 is usually a in local terminology people will call it as ABS; that is acrylonitrile butadiene styrene, then there are acrylics polycarb, polycarbonates, polyethylene polypropylene, polyvinyl chloride. So, you can see there are different examples of thermoplastics. At IIT Roorkee we are also conducting research in the area of polymers and polymer based composites, and our focus primarily in case of thermoplastics is on polyethylene and polypropylene.

So, we are using different grades of polypropylene and polyethylene, and then we are blending them we are mixing them with fibers to make composites also. So, we will see what are the processes that are used for making of composites or processing of composites, based on polymer as the matrix. So, we will have some research input also during the discussion, but right now in order to have a fundamental understanding, that what are the plastics. Usually if you ask anybody, everybody may be using a pet bottle, a

plastic bottle, usually in general language they call it as a plastic bottle for drinking mineral water, or for having a soft drink.

And if you ask even an engineer that what is the material of this bottle, I can, I am sure I can say this with much confidence that many of the engineers even may not able be to answer that what is the material of that bottle. So, that is the level of understanding that we have in case of non metals, because we do we are not taught non metals at our UG level.

So, that is the importance once again I am emphasizing for this course, and this screen that you are seeing on your, may be monitor these are the examples, there may be other additions also in this examples, but at least I wish that all of you should remember at least 4 to 5 names of thermoplastics that are used, and then you can see what are the various application areas of individual thermo plastics. We will see that what are the imp important application areas, but we are not going to correlate at particular type of a thermoplastic with a particular application area, but the general application areas for thermoplastics we will be observing or we will be seeing.

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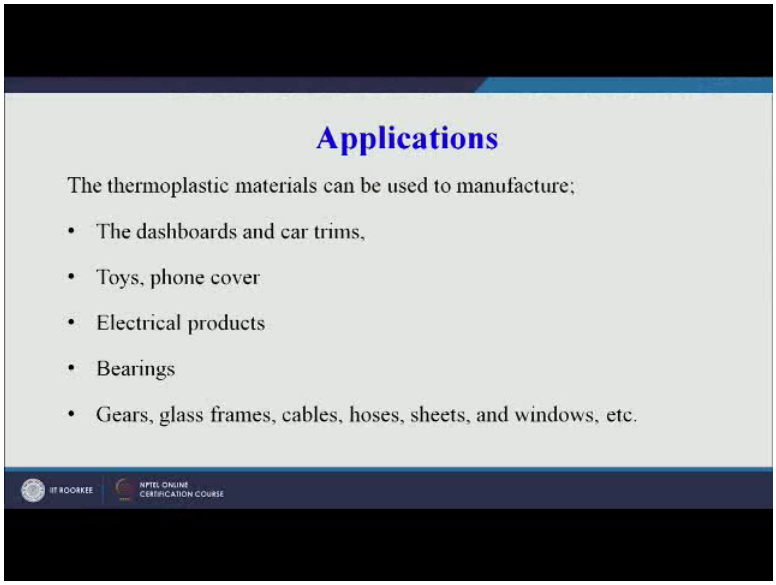

You can see that what are the applications. The thermoplastic materials can be used to manufacture the dashboards and car trims, they can be used for toys, phone cover, we all of us use mobile phones. So, the phone covers can be made by thermoplastics electrical products can be made, then bearings can be made, gears, glass frames, cables, hoses

sheets, and window panes, even the gardeners pipe; that is the simplest example.. Many people use that gardener pipe for watering of plants that plastic pipe usually we call that, that is made by thermoplastics only.

So, there are number of application areas and as I have already highlighted, that the list of thermoplastics and the application areas a table can be made that this par. For example, polyethylene can be used for these applications, polypropylene can be used for this applications, acrylonitrile butadiene styrene can be used for this application. So, that kind of table also you can make, but right now, because we have to finish up our discussion on thermosets and thermoplastics, I may not be able to project that kind of information today, but yes, that can that is a, this type of ready reckoners are already available, in which you can find out easily that this type of thermoplastic material can be used for this specific application, but here you can see the wide spectrum of application that is possible with the thermoplastics.

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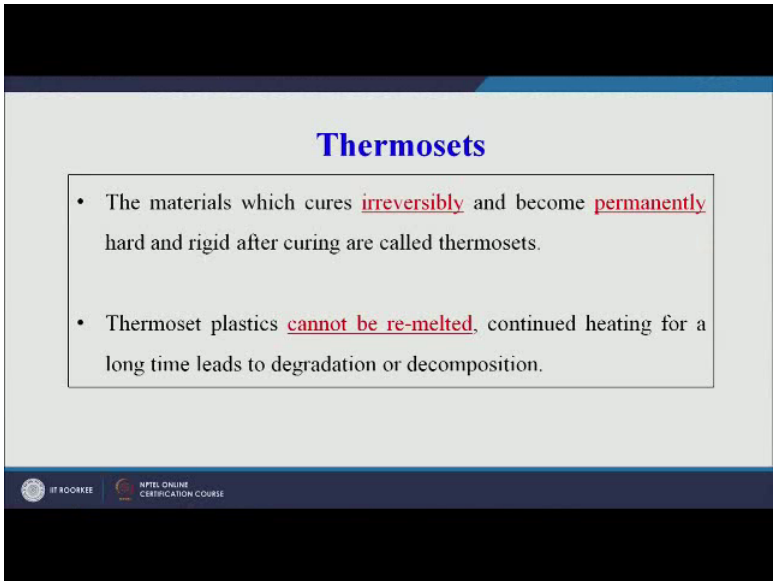

Coming on to thermosets. So, I think we have seen 2 or 3 important points related to thermoplastics, that what are thermoplastics, what is a molecular structure of a thermoplastic linear chain, then we have seen that they cure reversibly, we have seen what are the various types of thermoplastics, and we have also seen that what are the various application areas of the thermoplastics. Now let us see that their contemporary thermosets. What are thermosets? Now the materials which cure irreversibly, and

become permanently hard and rigid after curing are called thermosets. So, may be 1 example can be the normal tube that we use; that is available at the hardware shops, the tubes that we use for joining of 2 plastic parts or joining of 2 wooden part sometime.

So, we bring that tube, and there are two tubes in fact, in that. So, we take out pre determined amount of material, mix it and then we apply it, and leave it for curing may be for 6 hours or 8 hours or 10 hours, and after that it becomes permanently solid. So, if you heat it again, it will not come back to its original form, but it will degrade. So, that is an example of a thermoset material, and epoxy is 1 very good example of a adhesive; that is used for joining of different parts.

So, thermosets, the basic thing that you always have to remember is, that they cure irreversibly, that once you have made them hard, once they have cured, once they have taken a particular shape, it is not possible to change that shape after applying the temperature. So, what is going to happen if you heat them beyond a particular level, they are going to degrade, and sometimes they may char also, sometimes they may be get burnt also. So, thermosets are materials which cures irreversibly. Thermoset plastics cannot be re melted, as I have already emphasized, I am reading what is written on the slide now.

Thermoset plastics cannot be re melted, continued heating for a long time leads to degradation or decomposition. So, that is an important point that I have already highlighted that they cannot be re melted or remolded. Once you have made a particular shape or a particular product, out of a thermoset material or a thermoset plastic, you cannot re melt it, you cannot remold it whereas, in case of thermoplastics that is easily possible. So, that is one important you can say good point with the thermoplastics that they can be re molded, and the first point in their characteristics was they have high strength and toughness, which is another important point, which is giving an slight edge to the thermoplastic applications as compare to the thermoset based applications.

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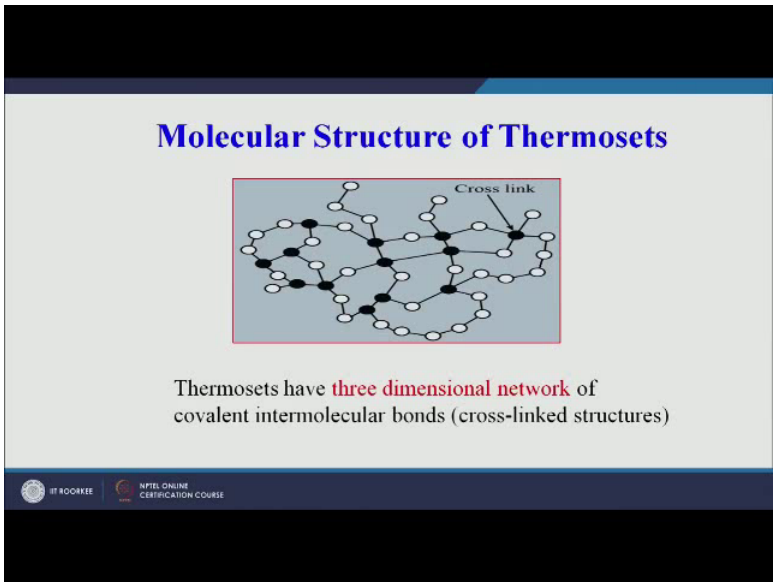

Now, on your screen you can see a molecular structure of thermosets. So, you can here there is a cross linking of the molecular chains. So, here you can see thermosets have 3 dimensional network of covalent intermolecular bond. So, there is no linear structure here, there is a 3 dimensional cross link structure, which do not allow the re melting of these materials. So, the difference between thermosets and thermoplastics is that, in thermoplastics there are linear chains, and they can slide these chains can slide, and therefore, the materials can be remolded or re melted.

Whereas, in case of thermosets you form a very strong bond, there is a 3 dimensional network that is formed, and therefore, the remolding and the re melting is not possible, and therefore, they cure irreversibly. So, this difference should be clear to the learners, to the beginners, who start studying about the polymers, specifically when they want to differentiate between a thermoset and a thermoplastic. We must be able to explain this basic difference, because usually people will say that they can be remolded, which can be remolded thermoplastics.

They cannot be remolded, which one thermoset. So, thermoset cannot be remolded, thermoplastic can be remolded. Next question will be why, and that answer to that why should be known to you at the molecular level, that what is happening what type of molecular structure is there, how the chains are oriented, how the chains are aligned, what type of bonds are present in the thermosets and thermoplastic. Based on that you

can very easily explain that, because of these type of structure thermosets cures irreversibly, because of these type of structure thermoplastics cure reversibly.

So, that thing should be absolutely clear in mind of each and every learner. So, that we can go to next level, and we can learn all the processes, and we can say compression molding, injection molding, exclusion filament, winding pultrusion. We may know may be 50 processes 60 processes, until and unless we are able to explain the difference between a thermoset and a thermoplastic. All that knowledge may be irrelevant. So, the fundamental knowledge, regarding the base materials that we are using for making products, should be absolutely clear to all of us.

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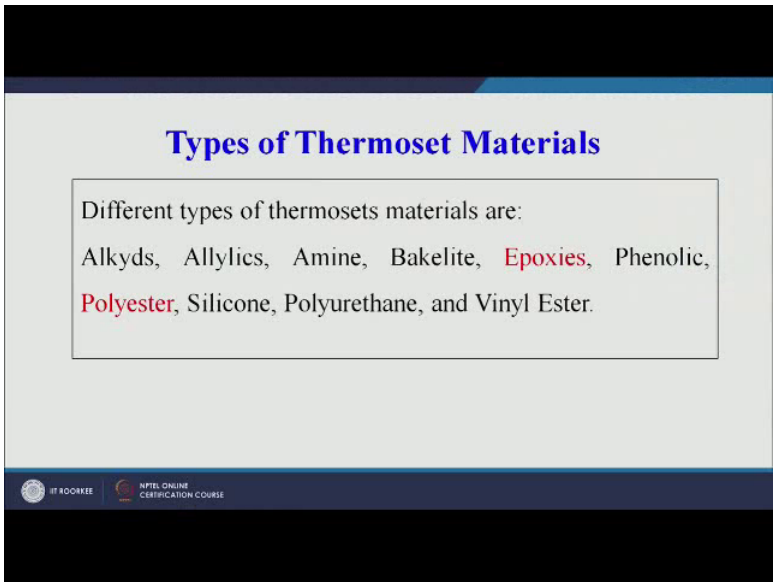

Now, let us see the what are the various types of thermoset materials. So, we can have alkyds, we can have amine, amines epoxy, Bakelite, polyester. On your screen you can see number of examples, there can be other examples also.

Two here you see have been highlighted epoxies and polyester; why, because at IIT Roorkee we have conducted some research. We have made products; we have made composites based on epoxies and polyester as the raw material, as the matrix materials. So, we will be focusing on this aspect also, when we will learn the various processing techniques for these thermoplastics and thermosets. So, few examples are given, Bakelite is another important material which is used for specific application, that we will see may be in the subsequent lectures.

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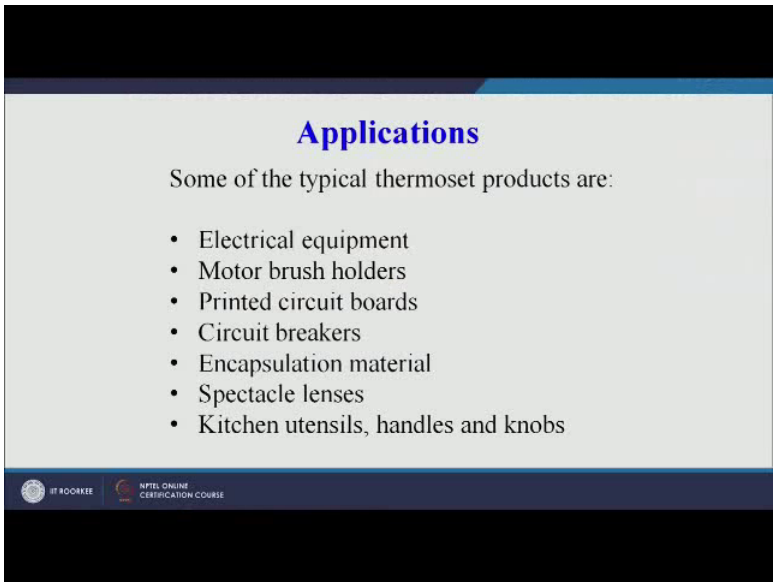

Now, what are the various application areas of the thermosets? We can see electrical equipment. Now you can see electrical equipment both, we can use thermoset also, we can use thermoplastic also. Now depending upon the requirement we will choose which 1 is better for a particular application. Then motor brush holders, printed circuit boards, circuit breakers, encapsulation material, sometimes electrical wires are encapsulated in a plastic, because why, plastics are bad conductor of electricity.

So, for encapsulation purpose many times we use these thermosetting materials, spectacle lenses, kitchen utensils, or number of applications are there for thermosets also, and we have seen that there are number of applications of thermoplastics also. So, we will see, that once we make the products out of these thermosets and thermoplastics, what are the specific applications where they are used. Right now we are having a very general view of the applications, but when we will go to the processing techniques, we will go for the specific application for which a particular process is being used.

Now, to wind up todays discussion, let us see a broad classification or the structure of plastics.

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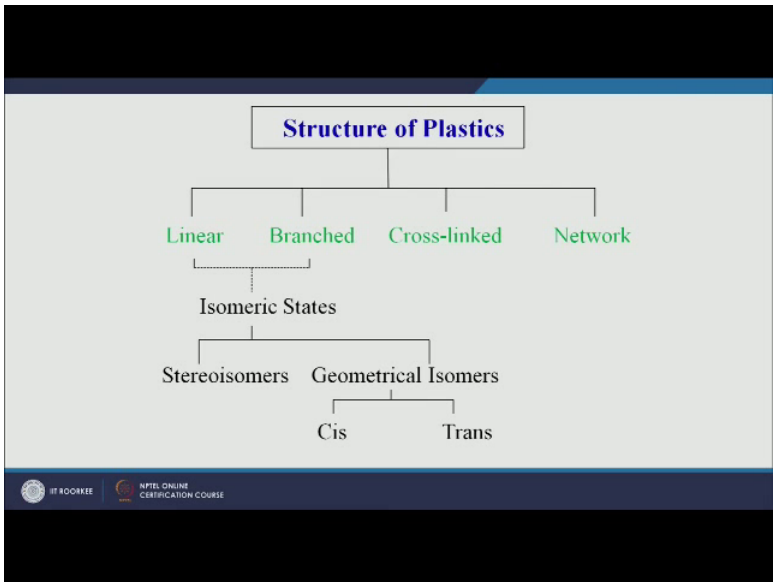

We can see the plastics can be linear, they can have branched structure, they can have a cross link structure, and they can have a network structure. So, these are the, may be the first level of classification linear, branched, cross links or network. So, we will see and then they can exist in various isomeric states also; that is stereoisomers and geometric isomers, and geometrical isomers can further Cis and trans type of isomers, but we will not go to that much depth or that much detail. We will see that how a linear structure would look like, how a branch structure would look like, how a cross link structure would look like, and how a network structure would look like.

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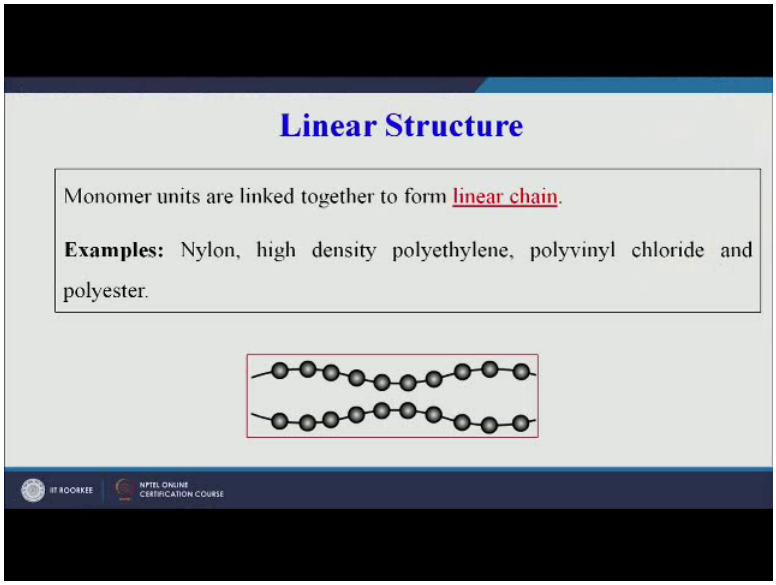

So, on your screen you can see a linear structure, there are two chains here. So, this is one chain, this is another chain. So, monomer units are linked together to form the linear chain

So, this is the chain, and individual monomer units. So, now, we will quickly see that, what are the monomer units for various types of polymers or various types of plastics. Now linear structures do exist in case of nylon, high density polyethylene, polyvinyl chloride and polyester. So, they are linear structure we can see here.

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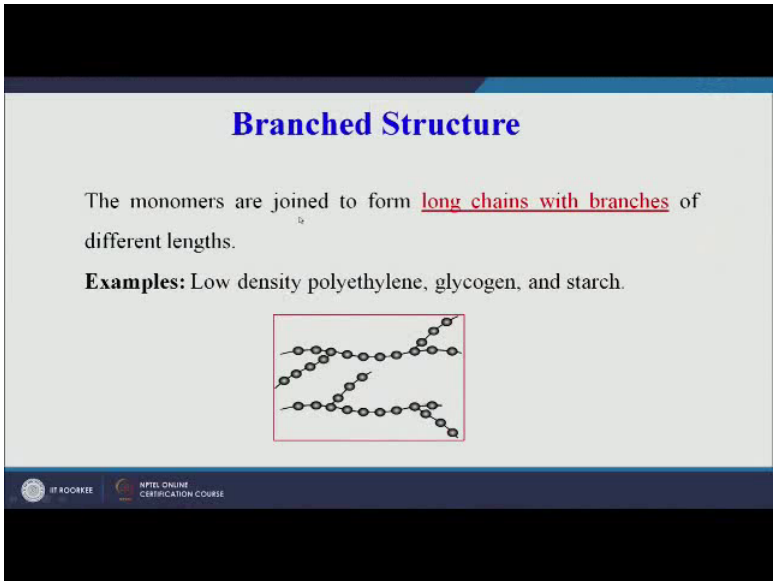

Then there can be branched structure. The monomers are joined to form long chains with branches of different lengths, here we can see there is a branched structure, there is another branch coming out from here, this is linear chain, but then there are different branches also. Such type of arrangement is called the branched structure; examples are also given starch, glycogen, and then polyethylene.

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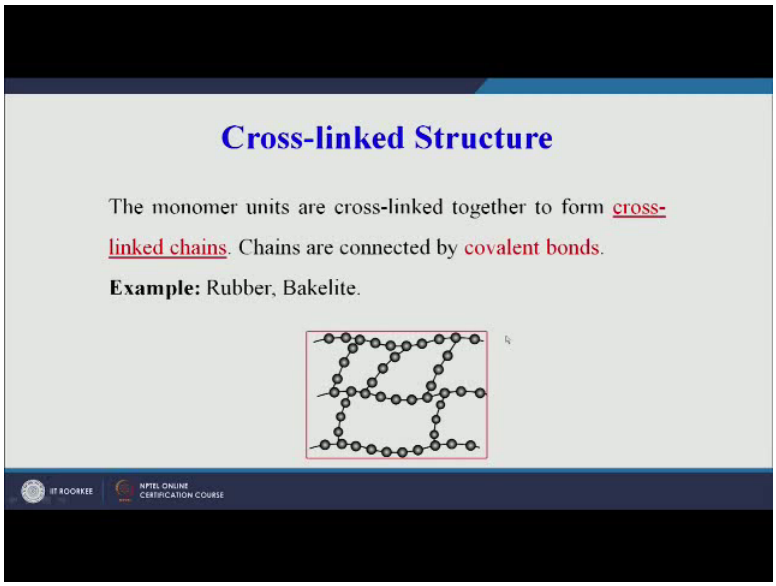

We can have a cross linked structure. The monomer units are cross linked together to form a cross linked chains. Chains are connected by covalent bonds we can see, example is rubber and Bakelite. If you remember Bakelite is an example of a thermoset, and therefore, we can see, say that thermosets have cross linked structure.

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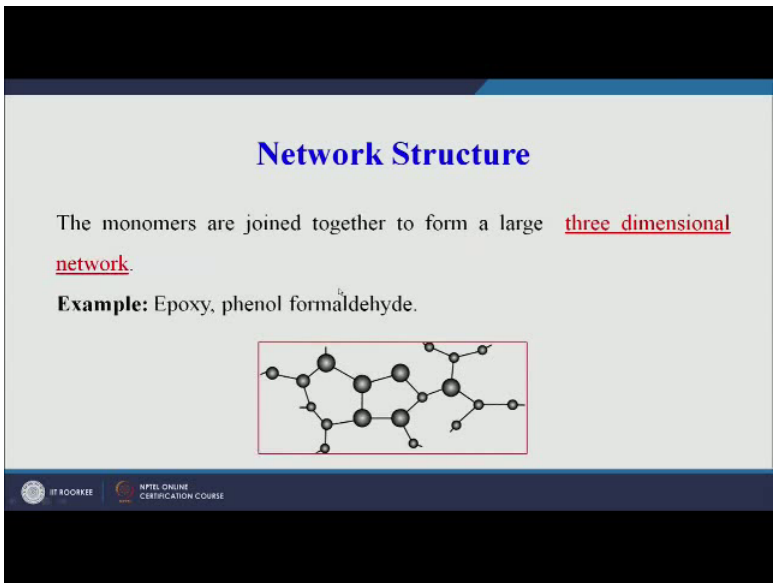

And then there can be a three dimensional network structure we have already seen, epoxy is one example, epoxy is a thermoset. So, epoxy has a three dimensional network, and because of this three dimensional network only, the thermosets cure irreversibly. So,

you cannot remold them, because of the strong three dimensional network that is formed in the chain, or we add the molecular level. So, we will now take, just may be one slide in which we will see that what are the various monomers that polymerized or that cure to make a final product or final polymer. So, plastic monomers where we can see just we can take one example polyethylene.

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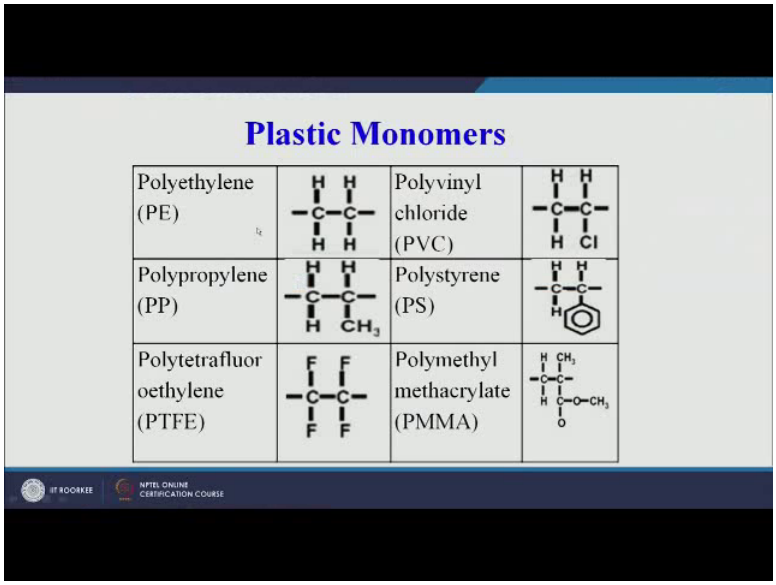

We have this type of a monomeric monomer which will polymerized or cure to make a long chain. Now if it is l it can be a linear chain, it can be a branched chain, it can be a three dimensional network of chains. So, depending upon the curing process, depending upon the fundamental molecular structure available, we will have different types of structures. May be for thermosets we will have a three dimensional network of arrangement or three dimensional network, in case of our thermoplastics, we will have linear chains, where the sliding of chains is possible and we can remold the thermoplastics.

So, here you can see that 6 different types of plastic monomers are given, and these monomers then polymerized to make a polymer. So, with this we come to an end of our very basic, very fundamental discussion on the different types of polymers; that is thermosets and thermoplastic. In our next session, our focus would be to start our discussion on our major part; that is processing aspects of polymers as well as processing aspects of polymer matrix composites or polymer based composites

Thank you.