Processing of Polymers and Polymer Composites

Dr. Inderdeep Singh
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture – 04
Processing of Polymers

[FL] friends. So, welcome to this lesson 4 or lecture 4 or discussion session 4 on our course on polymers and polymer based composites. Again and again I am seeing polymers and polymer based composites rather our topic is processing of polymers and polymer based composites and in fourth session we are entering into the exact we can say topic that is processing of polymers and polymer composites.

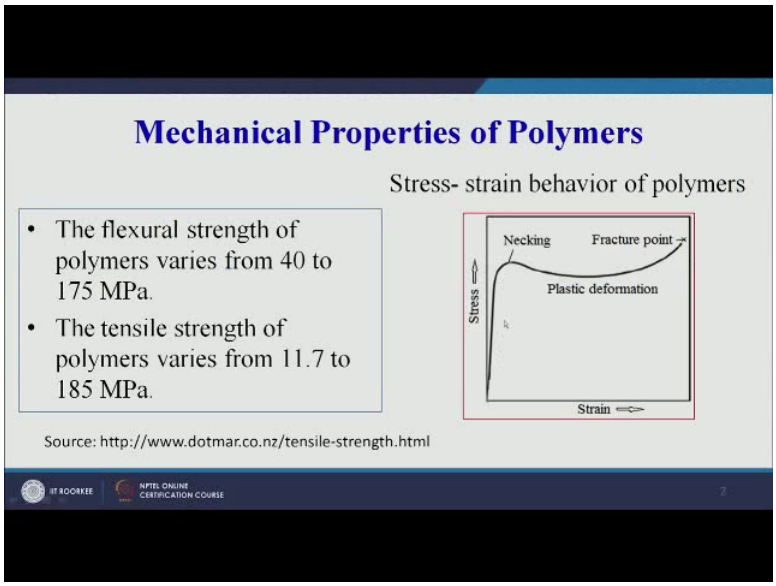
In session 4 also our first discussion will be related to the mechanical properties or mechanical behavior of polymers because that is going to dictate the processing techniques that we are going to use for making products from the polymers. So, if you remember in our last three sessions what we have covered just briefly in 3-4 sentences I will revise in session 1 we have seen the introduction to the course, what are the various weekly assignments or weekly discussion sessions. The broad we can say picture of the course in second lecture we have seen which what are the various engineering materials what are the various manufacturing processes or manufacturing techniques.

In session three we have covered the basic difference very fundamental difference between thermoplastics and thermosets. And we have seen that what are the various application areas, what are the specific characteristics of thermoplastics and thermosets. And we have seen what are the various monomeric a chain monomers that are polymerized to make the polymers. So, we have seen polyethylene, polypropylene and what are the monomer unit and how this monomer unit then polymerizes to make a long chain polymer. We have also seen that the polymers do exist in various type of structures or molecular structures they where they can have a linear structure where the monomers are arranged linearly, they can have a bronze structure, they can have a three dimensional network structure as well as they can have a branched type of structure, so linear branched network. So, three types or cross linked sorry the third one is cross link and fourth one is networks type of structure. So, different types of structures exist and because of this type of arrangements their properties are also entirely different and

because of these type of structures their mechanical behaviour is also different. So, today we will start our discussion with the mechanical properties of the polymers and finally, we will try to understand one process that is the most primitive, most simplistic, most of you can say easy process for processing of polymers.

So, let us start our discussion with a fundamental discussion on the behaviour of the, mechanical behaviour of the composites.

(Refer Slide Time: 03:21)



So, here we can see the stress strain behaviour on your screen you can see the stress strain behaviour of a polymer. Now, as an assignment I wish that all of you have studied metals or may have studied metals and may have seen the stress strain behaviour of mild steel or stress strain behaviour of any metal. Now, you can compare that stress strain behaviour with the stress strain behaviour of a polymer.

So, here you can see after the necking there is a long zone of plastic deformation and then there is a fracture point and must I tell you that this behaviour may be observed in case of thermoplastic type of polymer. In case of thermoset the properties will or this behaviour will entirely change. So, within the polymer family also the stress strain behaviour will keep on changing depending upon the grade of the polymer, depending upon the type of the polymer, depending upon the molecular arrangement inside the polymer the stress strain behaviour will change. But this behaviour is one typical behaviour that you are seeing on your screen where there will be a large zone of plastic

deformation. So, it will take lot of strain before it finally, fills and the fracture point is shown here.

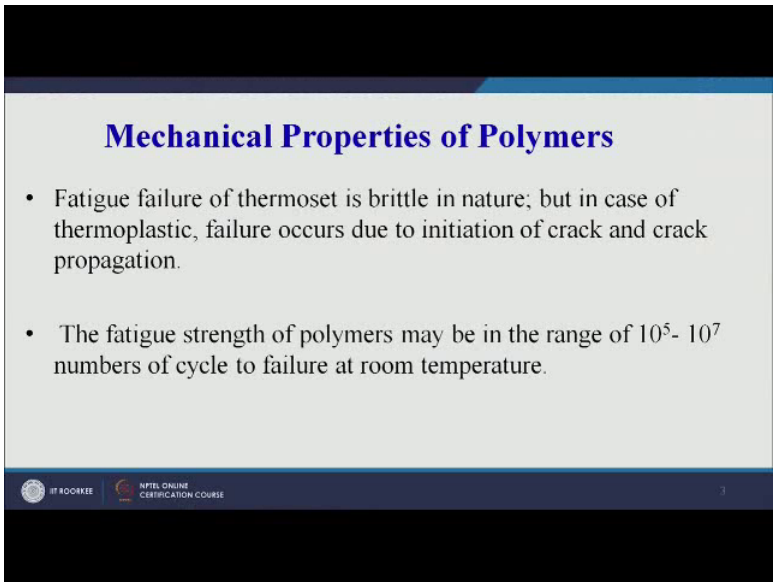
Once you do the tensile testing and the flexural testing of the polymers or the polymer specimen you will get certain values. So, a flexural strength of the polymers may vary from 40 to 175 megapascal. So, you can see the important point that I want to highlight here is that the polymers is a very big family. So, the range that you can see on your screen 45,40 megapascal to 175 megapascal the difference is to the order of 4, 40 into 4 - 160. So, there is a lot of range that is available and why this range is possible because of the difference in the materials. So, you have different properties for thermosets you have different properties for thermoplastics. So, flexural strength you can see the variation 40 megapascal to 175 megapascal and this can be even bigger maybe we have taken this from one particular source, you may have a some other source where this range can be even wider.

Similarly, the tensile strength of polymers varies from as low as 11.7 megapascal to as high as 185 megapascal. So, you can see the range of tensile strength that is possible. So, therefore, it is important to understand that the mechanical properties are different, the chemical nature of the different types of polymers is different and therefore, the processing techniques required for different types of polymers are different. Because of the difference in the properties, because of the chemical nature of the different types of polymers or variation in the chemical nature of different types of polymers the techniques that we employ for converting these polymers into the products vary and they vary significantly. For thermoplastics we may use different techniques, for thermosets we will be using different techniques.

So, we will see that what are the techniques that are used for processing of thermoplastics, what are the techniques that we use for processing of thermosets and why these techniques are different, what are the basic fundamentals of these techniques or the process mechanisms, then we will try to understand that how these techniques can be employed means working principle and finally, we will see what are the application areas. And prior to the application areas I forgot to mention we will see that what are the operating conditions what are the control parameters that we can control in order to avoid that defects or the problems that may occur during the processing what are the control parameters that we have for different processes.

So, two or three slides today our focus is on the mechanical behaviour of the polymers. So, you can see the wide range of flexural strength the wide range of tensile strength the difference in the stress strain behavior of the various types of polymers and because of these differences the processes are also different.

(Refer Slide Time: 07:56)



Again you can see the fatigue failure of thermoset is brittle in nature, but in case of thermoplastic failure occurs due to initiation of crack and crack propagation.

So, here also we can see that because of the difference in the chemical structure or the chemical nature of the two types two broad types of polymer their fatigue failure is also different. So, in case of thermoplastics crack propagation generation of a crack and propagation of the crack then may lead to a catastrophic failure at a later stage. In case of thermoset there is a brittle failure, so it a crack maybe there immediately catastrophic failure will take place your crack propagation and other things will be very very rapid and maybe the product made of thermoset may break down into two part using the brittle nature or may be because of the brittle nature of the thermoset.

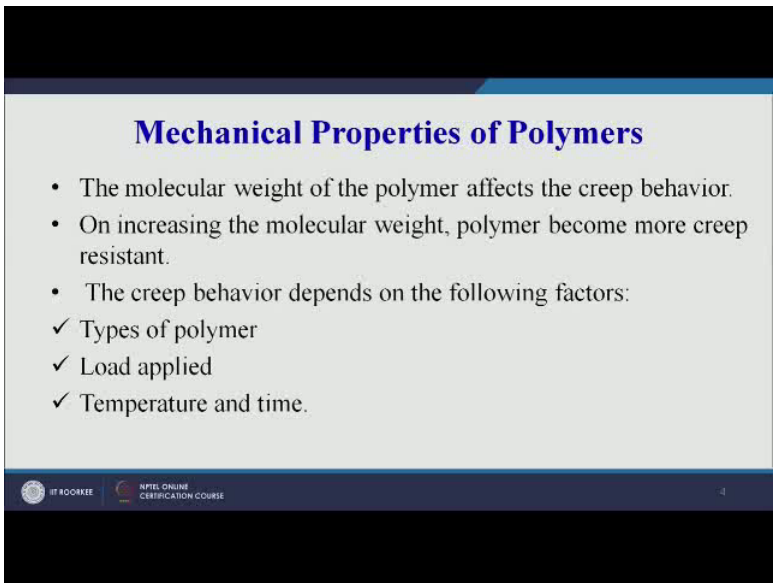
So, another thing that you can remember is the thermosets usually have brittle nature and thermoplastics have a kind of a the tile nature in which if you stretch them under tensile load the thermoplastic, you will definitely see stretching or the necking and then finding the plastic deformation and finally, the failure. If you go back to the previous slide this stress strain curve I can say with confidence that represents a thermoplastic material

because after necking there is a lot of plastic deformation that is taking place before the final fracture point.

So, this nature is at the tile nature and usually the thermoplastics will process or sorry not possess the tile nature. So, we can see the fatigue strength of polymers may be in the range of 10 to the power 5 to 10 to the power 7 number of cycles to failure at room temperature and if we increase the temperature beyond the room temperature these number of cycles may change that depends upon the conditions under which we are doing the testing. But we can see that there is lot of difference in the properties and that difference in the properties definitely guide us that we should choose a appropriate process for making a composite or for making a polymer product because the properties are different not only the chemical, but also the mechanical properties. So, different types of polymers are different and we should be very very careful while selecting processing route or a processing technique or a manufacturing process for a particular type of a polymer.

So, the mechanical properties of polymer I think I will try to wind up this discussion on the chemical and the mechanical nature of polymers and we will start discussing the various processes which are used for processing of polymers and polymer based composites.

(Refer Slide Time: 10:50)



So, maybe this may be the last slide before we jump to one of the processes for processing of polymers. The molecular weight of the polymer affects the creep behavior. So, we have seen tensile strength lot of variation flexural strength again lot of variation. Fatigue strength also may be number of cycles vary.

So, finally, the creep behavior also is very very important in case of polymers especially. So, molecular weight of the polymer affects the creep behavior. So, you can see the molecular weights of all the polymers that we have seen in the previous class. I have given a long list of materials which fall under the thermoplastics category and we have also seen a long list of materials that fall under the thermoset category and the molecular weights for different types of these thermosets and thermoplastics will vary and when the molecular weight will vary the creep behavior will also vary.

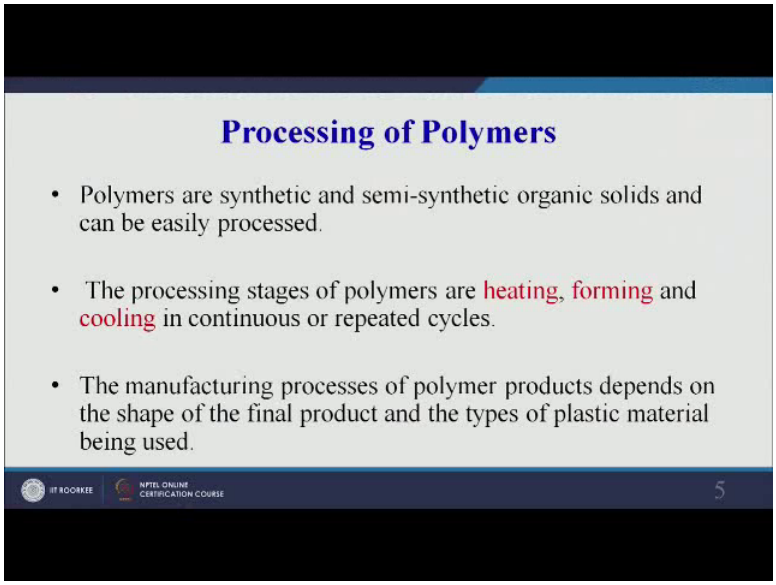
So, the molecular weight of the polymer affects the creep behavior on increasing the molecular weight polymer becomes more creep resistance, so may be high molecular weight polymers will be more creep resistant. So, a creep behavior depends upon the following factor the type of the polymer as I have already told, the type of polymer the load applied and the temperature and time for which we are applying the load. So, we have seen that the molecular structure or the molecular weight of the polymer is affecting the creep behavior. The chemical nature of the polymer is affecting its mechanical behavior. So, we have seen that the mechanical behavior also there is a lot of variation. So, the important point to highlight here is that polymers is a very large family, they differ in chemical nature, they differ in the mechanical properties, they differ in their characterization techniques also therefore, we need to understand the various processes that can be used for processing of polymers.

Once we understand the processing of polymers it becomes easier for us to understand the processing of polymer based composites, why because in processing of composites our fundamental thing remains the same that we have to mold we have to heat the polymer, we have to mold it in a desired shape and then we have to allow it to cool to take the desired form or desired shape.

So, the three steps are very very common in processing of polymers and the processing of polymer based composites that is heating molding or given shape and cooling. So, three steps are common. So, if you are able to highlight the importance of these three

steps for polymers we will be easily able to highlight or understand that these three steps are also used for processing of polymer based composites.

(Refer Slide Time: 13:42)



Now, coming on to the processing of polymers as I was already discussing in the previous slide also polymers are synthetic and semi synthetic organic solids and can be easily processed. If you remember in our previous session we have seen the basic definition of plasticos plastic word comes from plasticos which means that they are easy to mold and shape.

So, we can again we are referring to the same definition plastics are easily molded therefore, we see all around us number of plastic parts why because it is very easy to mold them how we can mold them it is given in the next point. So, they are easily processed number one. The processing stages of polymers are as I have already told heating, forming and cooling in continuous or repeated cycles. So, as is clear from the slide it is not very difficult to process the polymers, it is very easy. You have a raw material you have to heat it first stage how to heat it is another thing you can have a screw and a barrel type of arrangement in which you can heat it using electrical heaters, you can heat the polymers using microwave energy you can heat the polymers using laser energy. So, one thing is heating somehow you have to heat the polymer.

Second stage is forming, forming means you have to give a desired shape to the polymer. Now, for example, I want to make this mouse on your screen I think this will be visible I

want to make this first stage will be I have to heat the polymer. So, that it can flow into the mold that is available for making this mouse. The shape is exact duplicate of this mouse first I have to heat my polymer then I have to bring that polymer into this mold which is the exact duplicate of this shape and once this is there it will give it a form, form means it will give it a desired shape and finally, I have to allow that polymer to cool in that controlled mold. So, that it becomes solid and my product is ready. So, these are the three important stages in case of processing of polymers.

Now, let us draw an analogy with processing of metals also we use a process called casting what do we do in casting I think everybody has studied casting. So, what do we do in casting we have different types of furnaces, we may have a cupola furnace, we may have a reverberatory type of furnace may be have a simple hearth. So, first thing is first thing first is we take a metal scrap we melt that metal it comes into the molten form then we make a mold, the mold can be a permanent mold may be a metallic mold or it can be a temporary mold maybe a sand mold. We pour that molten metal into that mold and we allow that metal to solidify we allow that metal to cool.

And once it has solidified we break the mold in case of sand molding or we open the permanent mold and we get our product. So, the fundamental things remains same as we do casting in metals similarly we can do casting or molding in polymers also first thing is we will heat the polymer we will change its viscosity we will allow it to fill our mold the mold will be the exact replica of our final product and finally, we will we will allow it to solidify we will allow it to cool down we will open our mold and we will get our solidified product. So, the basic fundamental thing remains same and therefore, this processing of polymers or plastics is not a very difficult task.

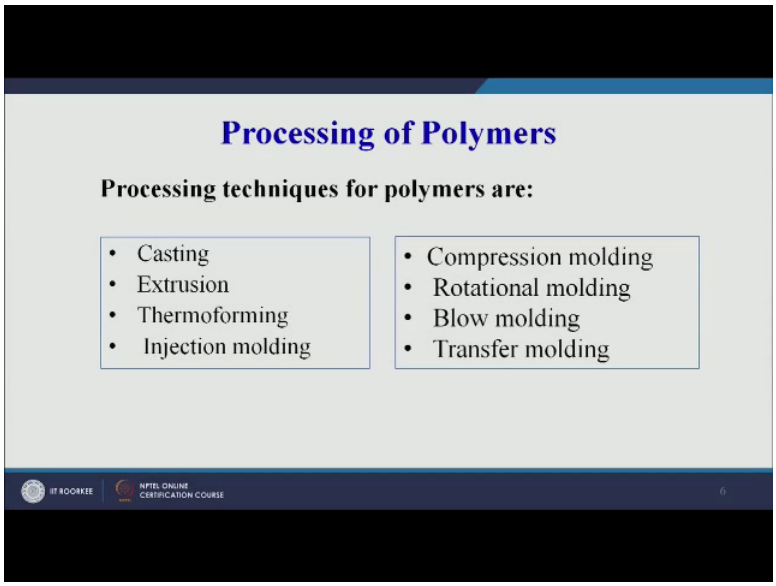
Now, depending upon the requirement we may have different types of processes, if we want to make a plastic bottle the process will be different, if we want to make a wooden sorry a polymer handle or a plastic handle the process will be different, if we want to make a handle of a toothbrush the process will be different, if we want to make a specific shape that has to be used in a toy for children the process will be different. But depending upon our final requirement we will use a different process, but the fundamental thing will remains same that is heating forming and finally, cooling. So, these three steps will always remain same.

And we will see when we will discuss a particular process we will see let us see. Now, here heating is happening after heating we are giving a shape and finally, when it has solidified it has cooled we are taking it out. So, three stages will be common in almost all processes that we will see for processing of polymers. So, here we can see these three stages which have been highlighted also the manufacturing processes of polymer products depends on the shape of the final product and the types of the plastic material being used.

Now, in my previous this thing discussion I have already highlighted that depending upon the final shape of the product the process will change I have already given. So, many example a plastic bottle a plastic handle, a component of a toy. Now, as the shape is changing as the application is changing our process will change that is first criteria. Second is depending upon the material as I have already highlighted in the previous session that thermosets and thermoplastics are two entirely different types of polymers and depending upon their characteristics we will have different processes for both of them for thermoplastics we may have different process for thermosets we may have a different process – yes, there may be some processes which are commonly used for both they can be used for thermoplastic also they can be used for thermoset also.

So, broad classification of the processes for polymers can be based on the type of end product that we want to make and based on the type of raw material that we are using. So, the raw material can be thermoplastic or a thermosetting polymer.

(Refer Slide Time: 20:26)



Now, we can see the processing techniques for polymers on your screen we have so many maybe there are eight processes on your screen, but these are not the only 8 processes that are used for processing of polymers. In different books, different text Google on internet you may find many other processes which are used for processing of polymers. But these are we can say commercially available standard processes that every engineer or every learner should know, therefore, we have put these 8 processes together and we will try to understand some of these processes in our subsequent lectures and try to understand what is the basic working principle of this process.

So, many of these processes you may have already heard their names for example, casting, casting is similar to the casting that we do in case of metals, then there is extrusion process extrusion also is done for metals if you remember extrusion process for metals we have different types of extrusion forward extrusion, backward extrusion, impact extrusion, hydraulic extrusion.

So, exclusion process is common both for metals also will do it similarly for polymers also we do the extrusion process we will try to understand it with the help of a diagram. Then thermo forming process injection molding process, these days injection molding is also being done for metals they call it MIM process compression molding rotational molding, blow molding, transfer molding and there can be other processes number of

other processes which can be used. But these are some of the standard processes that are used.

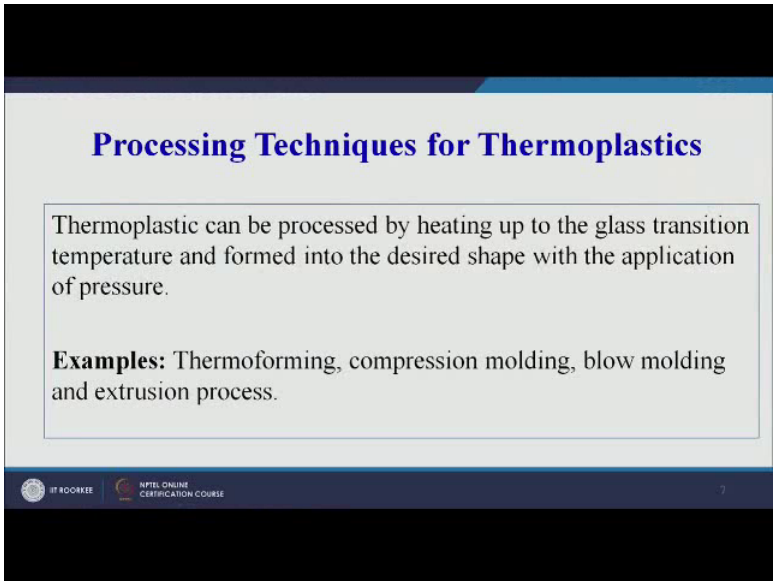
Now, these processes can further be classified into processes that are only used for thermosets and the processes that are only used for thermoplastics and the processes which can be used both for thermosets and thermoplastics they can also be further classified based on the type of end product that you are going to make. For example, in injection molding process you will get discrete products number of discrete products in a repeated cyclic manner. So, maybe you may have 60 products in a minute or you may have maybe 60 is maybe on the higher side maybe the injection molding cycle depending upon the cycle we may get maybe 10 products, 6 products, 5 product depending upon the shape the complexity and the holding time number of parameters are there, but we can get discrete products.

For example, the surgical syringes the plastic syringes that the doctors usually use to impart an injection or to apply an injection surgical syringes maybe 100 syringes we can make an hour or maybe depending upon the size and the complexity. So, discrete products number of products you can make in terms of number. The volume can be expressed in terms of numbers at 100 parts per hour, 200 parts per hour, 500 parts per hour that can be the production rate in case of injection molding, whereas in case of extrusion it can be length why because it is a continuous process continuously you will produce the products. For example, the gardeners hosepipe the pipe that we used for watering of plants or giving water to the grass gardeners use that horse pipe or the gardeners pipe usually we call it. So, it is length maybe 500 meters per hour maybe a larger number, but we 200 meters, 300 meters, 500 meters, 1000 meters. So, it is continuous. So, depending upon the requirement if it is a continuous long axis symmetric product may be where you go for extrusion. If it is discrete small size number of product small size products we may go for injection molding.

So, the processes can further are developed because we have different applications of polymers. So, we will see some of these processes in our future or in our further discussion and try to understand that what is the basic principle of the process what is the basic working principle, what are the governing parameters control parameters of that process, what type of products we can make with these processes and what are the

limitations of a particular process. So, all that will be covered when we go into the intricacies of each and every process.

(Refer Slide Time: 24:51)

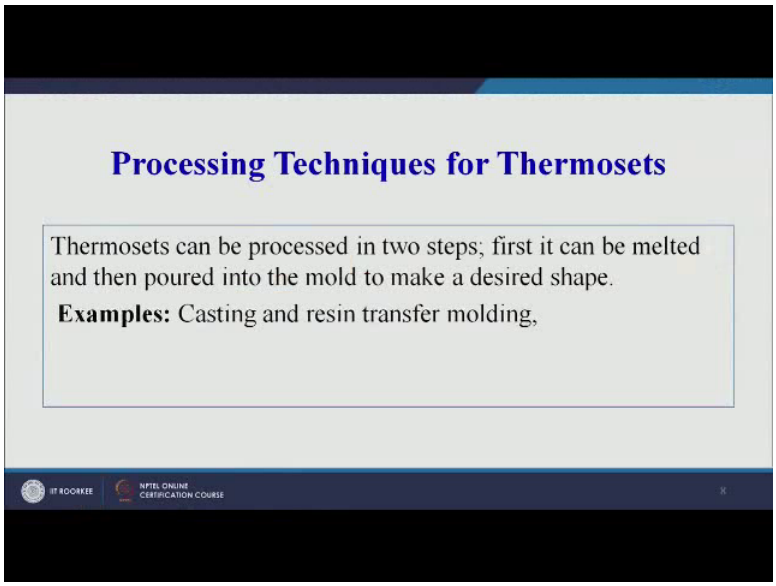


Now, we are again going into processing techniques for thermoplastics because as I have told you different types of materials will have different types of processes. Thermoplastics can be processed by heating up to the glass transition temperature and formed into the desired shape with the application of pressure.

So, here again the in catch words are coming the important words are coming heating is one important word, formed or forming is another important word and the third additional control parameter is coming that is pressure. So, in case of thermoplastics what we are going to do we are going to heat the raw material we are going to put it into the mold of the die and give it the desired shape and many times we may apply pressure also. So, that we consolidate our final product.

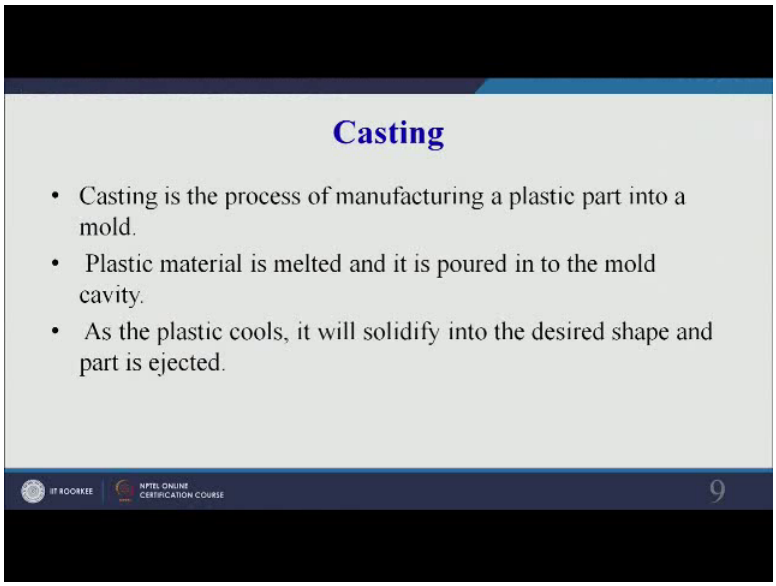
So, the basic fundamental principle remains same that is heating forming and finally, applying the pressure and the last part is allowing it to cool and solidify finally, we get our product the examples that are processes that are specifically used for thermoplastics are thermo forming compression molding can also be used for thermosets, blow molding and extrusion. So, these are the processes maybe injection molding is also many times used for thermoplastic materials maybe not mentioned on the slide.

(Refer Slide Time: 26:23)



So, there are number of processes which can be used for processing of thermoplastics. Processing techniques for thermosets, thermosets can be processed in two stages first it can be melted and then poured into the mold to make a desired shape or to get the desired shape casting and resin transfer molding. So, basically our thermoset is available most of the times in the gel form. So, we can change its viscosity by adding the hardener and the other additives and finally, we can pour it into the desired mold. Mold will be the exact replica of the final product that we want and allow it to solidify allow it to cool and after maybe the predefined time period we will get the final product when it has when the thermoset has cured it has become solid we can take out the product.

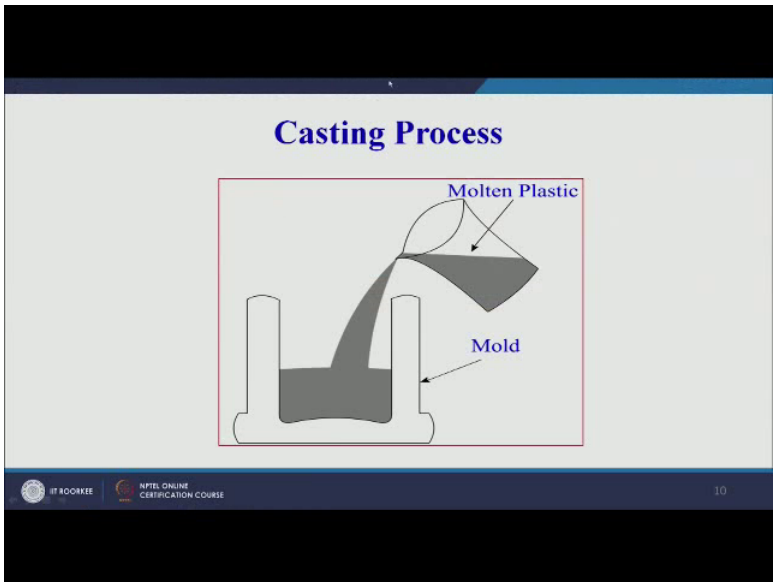
(Refer Slide Time: 27:10)



Now, quickly we will try to understand the process of casting because casting is similar to that we do for metals and that is the basic principle remains same. Only difference being in case of casting of metals we use metal scrap as the raw material in case of polymer we will use a polymer as the raw material. So, casting is the process of manufacturing a plastic part into the mold plastic material is melted and it is poured into the mold cavity.

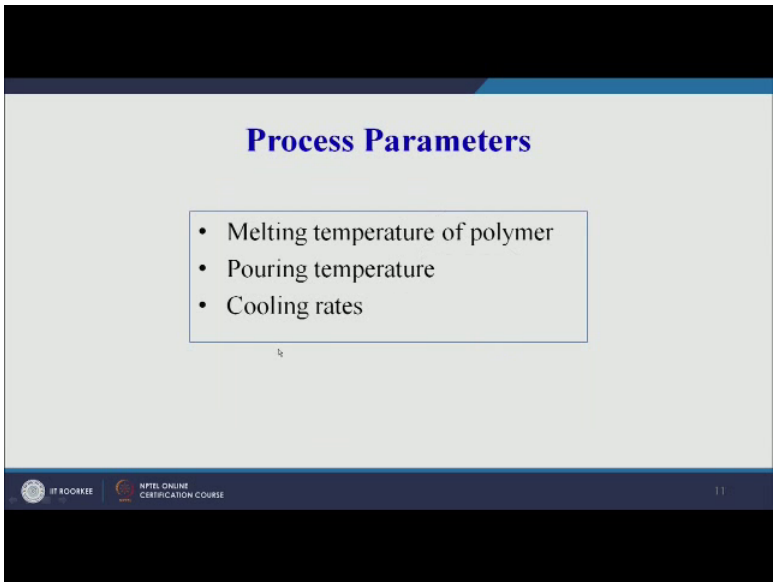
So, here the word melted is slightly ambiguous because if the thermoset is available in the gel form we will directly use that and pour that into our mold cavity with the hardener and allow it to solidified after solidification it will take that desired shape. As the plastic cools it will solidify into the desired shape and the part is taken out from the mold.

(Refer Slide Time: 28:00)



Very simple diagram molten plastic is or may be it can be a plastic in the gel form thermoset specifically is poured into the mold and we can see it will take the shape as per the shape of the mold when it will solidify.

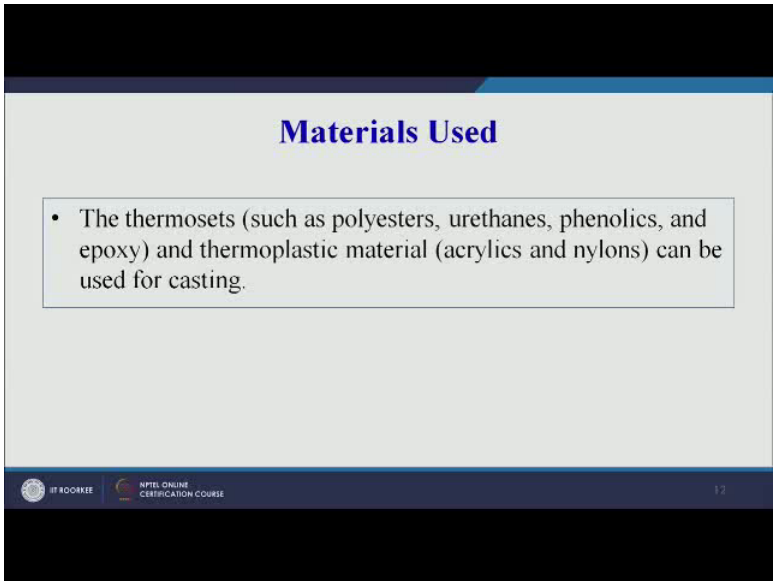
(Refer Slide Time: 28:15)



So, what are the parameters that we can control? We can control the temperature of the polymer when we are pouring it the pouring temperature and the cooling rates we can control we can just encapsulate or we can cover this mold and allow and put it sometimes in a oven also in order to accelerate the curing process or depending upon the

requirement we can control the cooling rate we can control the pouring temperature and we will get our desired product after the predefined time.

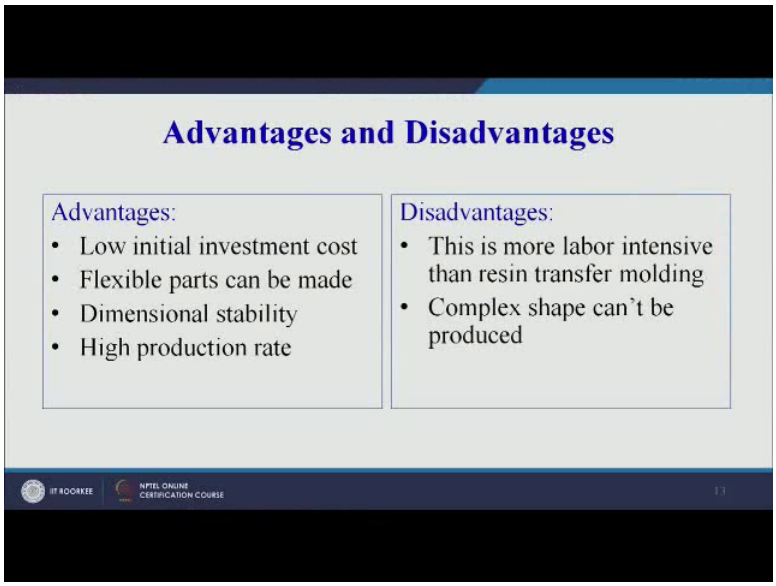
(Refer Slide Time: 28:49)



Now, what are the types of materials that can be used for casting process? The thermosets are majorly used for the such type of process. So, thermosets such as polyester urethanes phenolics and epoxy can be used in some (Refer Time: 29:02) and thermoplastic materials like acrylics and nylon can be used for casting. So, the process is very very simple you have to have your raw material and a mold and depending upon the shape of the mold you will get your final product and the important thing, the three important steps are common to casting also first one is a heating, second one is forming and third one is cooling. So, all these three steps are also happening in the casting process.

And as I have told you that these three steps will be common in almost all processes that we will be seeing for the processing of polymers. So, here we can see that all three steps have happened first one was the heating, second one is the giving shape that is forming and third one is the cooling. Now, what type of we can say advantages and disadvantages we can get.

(Refer Slide Time: 29:52)

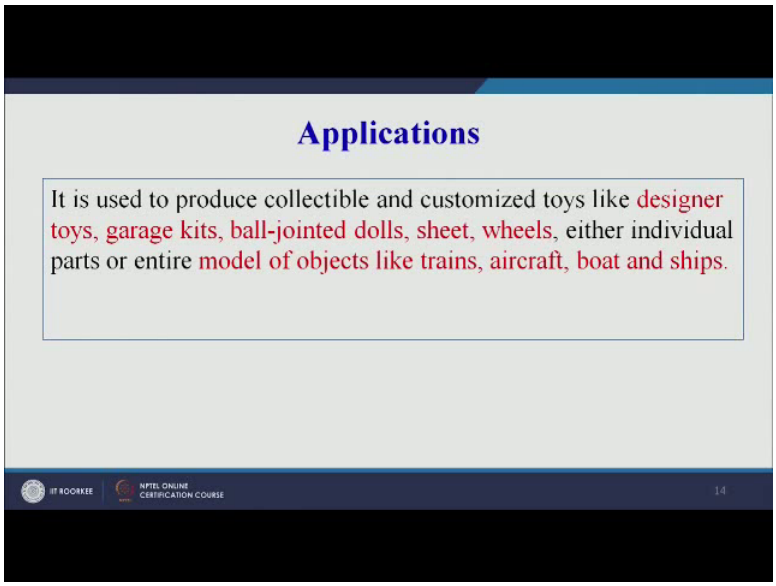


Now, you can see not much sophisticated instrumentation tools or fixtures are required we simply require a mold which is the exact replica of our final product.

So, low initial investment cost, flexible parts can be made dimensional stability will be the exactly depending upon the type of mold and high production rate. So, we can make number of products continuously.

Disadvantages it is a manual process because we are not using any machines, complex shapes because the heated plastic has to flow in the mold cavity. So, if the shape is very very complex we are not applying any external pressure to force this plastic or the polymer into the mold cavity. So, it may not on its own flow into the mold cavity and therefore, the complexity of shape is one major limitation in case of the casting process.

(Refer Slide Time: 30:50)



And finally, we can see what are the application areas. So, it is used to produce collectible and customized toys, leg designer toys, may be the toys is one major application garage kits ball joined dolls, sheets, wheels either individual parts or entire models of object like trains aircraft boats and ships. So, depending upon the mold we can use these raw materials as well as given in the previous slides and give shape to the polymer. And one of the most primitive and most of the applications that you see are not very high end applications and as the process has no machine control so is used for low and a non structural or we can say twice and very simple products can be made using this process of casting.

In our subsequent lectures or subsequent discussion we will definitely focus on some automated manufacturing processes for polymers and which can make products which are high end products, which can be used for aircraft industry, which can be used for marine industry, but this process is the very simple process and is used for making household items or very simple products out of polymers. In our subsequent sessions we will focus on other processing techniques such as extrusion, injection molding and blue molding which are very very you can say commercial processes which are very very important processes and are being widely used for processing of plastic parts.

Thank you.