Processing of Polymers and Polymer Composites

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

Lecture - 05
Thermoforming Processes

[FL] friends. Now, we are at lecture 5 or module number 5 in our course on Processing of Polymers and Polymer based Composites. If you remember in the previous lectures or in the previous part of our discussion we have seen that processing of polymer composites as well as processing of polymers is an important aspect which all engineers must know. We are emphasized on the importance of polymers in our day to day life and we have seen that in the UG curriculum these topics are not covered in detail.

Therefore we saw that what are the different types of polymers, how to classify the polymers and then what are the important properties of the polymers we have already covered that discussion part. We started with the major focus of our course that is processing of polymers and polymer composites in which we have seen casting as one of the important process and one of the most simplest process for giving shape to the polymers. If you remember there are three major steps three major points that have to be taken into account. So, the first one that we have seen is heating. So, first we have to heat up the polymer we have to supply it heat we have to change the viscosity we have to manipulate the viscosity of the polymer so that it can flow freely and it can fill the mold cavity easily.

So, the first part is heating the polymer the second part is molding or forming in which we give the desired shape to the polymer. So, first step first step is heat second step is form f o r m. So, we are going to deform we are going to change the shape of the polymer or we are going to give the desired shape to the polymer in the mold cavity.

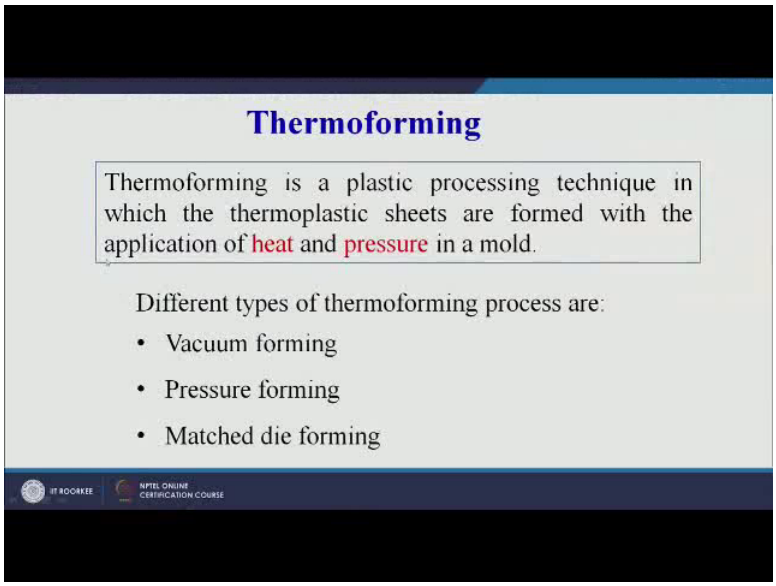
Now, we can have different types of molds we can have different types of dies in which we will inject we will force we will allow the polymer to flow and then it will take the shape of the mold cavity. So, again coming on to the first two important points point number 1 is heat, point number 2 is form and point number 3 is cool. We will allow the mold to cool so that the polymer that we have injected that we have forced that we have

allowed to flow in the mold cavity solidifies and takes the shape of the die takes the shape of the mold so that we get our final product.

So, all the processes that we are going to cover in our topic on processing of polymer these three will be the main steps may be heating followed by forming followed by cooling. So, these are the three major steps that we are going to follow. So, continuing our discussion we are going to cover today an important process for making sheet type of components or making the components which are not very thick which are thin components thin walled sections and we will deform them to give them the desired shape. So, we will see what are the various applications of thermoforming process, what are the advantages of thermoforming process, what are the limitations of thermoforming process as well as you will see that how thermoforming process is different like what are the different types of thermoforming process.

So, let us first start our discussion with the types of thermoforming process and later on we will come to the advantages limitations as well as application areas for the thermoforming process. So, let us start our discussion. Now, let us see what is thermoforming process.

(Refer Slide Time: 04:15)



On your screen you can see, thermoforming is a plastic processing technique, so it is a polymer processing technique in which the thermoplastic sheets are formed with the application of heat and pressure in a mold. So, here whatever I have discussed in the

introductory part of today's session heat is again coming into picture, mold is again coming into picture and additional thing that we are supplying here is the pressure. Now, pressure can be in the form of mechanical pressure it can be in the form of pneumatic or air pressure it can be pressure can be applied even with vacuum and based on the method with by which we are applying the pressure we classify the thermoforming processes into different types.

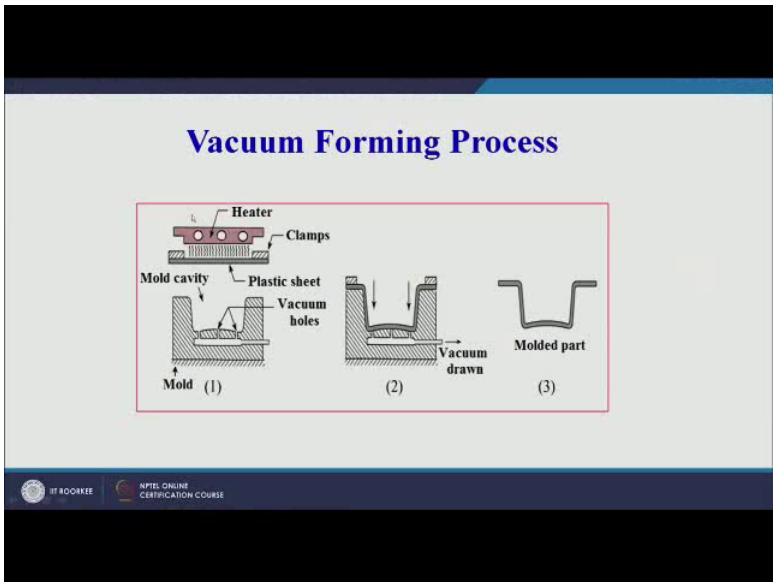
We can have vacuum thermoforming we can have pressure thermoforming we can have matched die which is a mechanical type of thermoforming process. So, each one of these we will try to understand with the help of a specific schematic diagram. So, first of all we need to understand that this is used for thermoplastic sheets. So, again I am emphasizing that thermoforming is never used for very thick sections it will be used for thin sheets only. So, first is the limitation on the raw material that this is used for thin sheets number one, number two heat is applied number three pressure is applied and number four the mold is used to deform the sheet into the desired shape.

So, the basic definition once again I am reading for you thermoforming is a plastic processing technique in which the thermoplastic sheets are formed with the application of heat and pressure in a mold. Another point that you should remember here is that this is thermoplastic sheets. So, if you remember we have classifies the polymers or plastics into two broad categories that is thermosets and thermoplastics.

So, thermoforming process is specifically applicable to thermoplastics whereas, in some special cases may be the process may be modified slightly to be suitable for thermo sets also, but majority of the cases thermoplastic will be the raw material for the thermoforming process. The different types of thermoforming process as you can see on your screen is vacuum forming, pressure forming and matched die forming.

So, we will try to understand the basic working principle of each one of these classification of the thermoforming process.

(Refer Slide Time: 06:54)



To start with on your screen you can see we have a basic diagram of a vacuum forming process, in vacuum forming process let me first read out what is there on your screen there is a heating arrangement, there are clamps there is a raw material thermoplastic sheet this gray color sheet on your screen you can follow the cursor this is the raw material which we want to deform. Then you have a mold cavity this hatched portion is representing the mold cavity and then there are vacuum holes through which we will apply the vacuum.

So, we have mold, we have a heating arrangement, we have clamps to hold the plastic sheet or the thermoplastic sheet and we have a mechanism for applying the vacuum. So, here you can see once this sheet is heated the mold is closed that this particular clamps come here and the sheet occupies this position on your screen you can see. And finally, when we apply the vacuum through this vacuum hole the sheet is pulled down to conform to the shape of the mold.

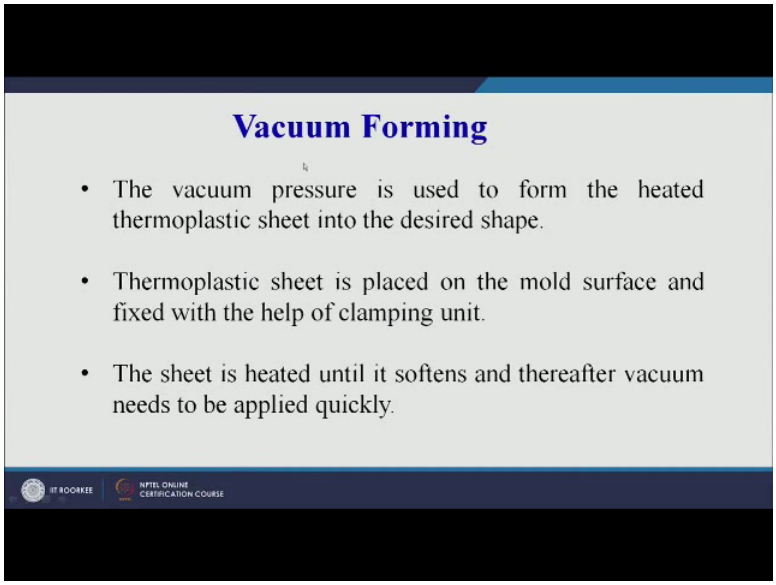
Now, whatever will be the shape of the mold the sheet will conform to the shape of the mold why because of the pull exercised by the vacuum. In the bottom we are a vacuum. So, vacuum will pull the sheet down and it will conform to the shape of the mold. So, I think it is a very simple process. Now, we are not going to go into that details that how much vacuum is required what can we typically thickness of the sheet. We are currently focusing on the basic working principle of the vacuum forming process, we should know

that this is this process is used for thin sheets the raw material of the sheets is thermoplastic and we have to apply a vacuum. So, that the sheet conforms to the shape of the mold is that much we can remember we will never forget the vacuum thermoforming process or the vacuum forming process that falls under the category of thermoforming.

Now, on your screen you can see as in the part two or the step two of the process the sheet is conforming to the shape of the mold after the vacuum has been drawn out or there after the vacuum has been applied and this is the final molded part that we can produce using the vacuum forming process.

Now, whatever I have explained let us try to systematize it let us try to study it step by step so that you remember the basic working principle of the vacuum forming process.

(Refer Slide Time: 09:33)



On your screen you can have a look at the various stages steps or the basic working principle of the vacuum forming process. The vacuum pressure is used to form the heated thermoplastic sheet into the desired shape. Thermoplastic sheet is placed on the mold surface and fixed with the help of a clamping unit in the diagram we have seen there are two top clamps and then there is a plastic sheet the clamping unit is used to clamp the sheet on top of the mold surface

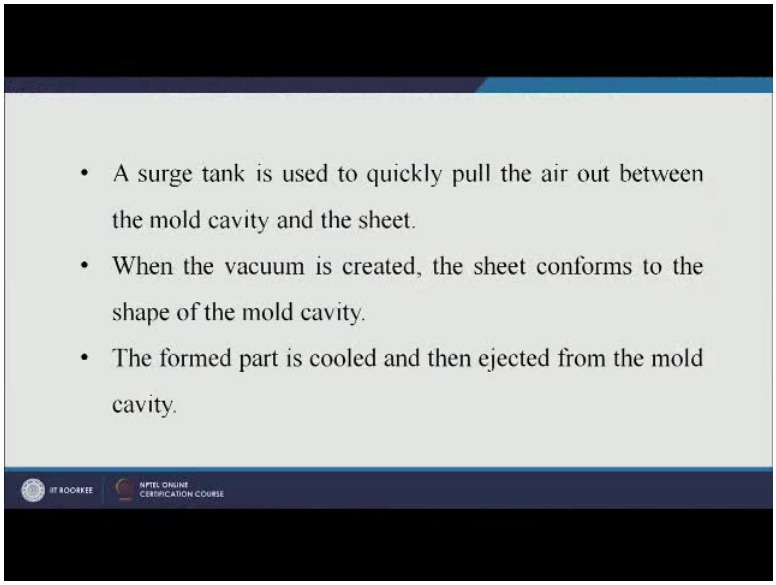
Then thermoplastic sheet is placed on the mold surface and fixed with the health of a clamping unit I have already explained. The sheet is heated until it softens. Now, I have

already told in most of the polymer processing techniques heat is a major source that we have to supply. So, the sheet will be heated until it softens. Why do we need to soften the sheet? Because we need to deform the sheet in the next stage, if we soften the sheet it will be easy for us to deform it as per our requirement that is given in the design of the mold. Our requirement is already present in the form of the mold because the mold is the exact replica of the product that we want to make. So, as per our requirement means the sheet if the sheet is soft it will deform easily into the mold it will conform to the mold shape that is our requirement that is the product that we want to make.

So, the sheet is heated until it softens and thereafter first we have to ensure that the sheet has to soften then only we will apply the vacuum therefore, the requirement of vacuum will also be depend will also be depending on the thickness of the sheet, it will also depend upon the state of the sheet. If it is not soft suppose it is very hard, so the vacuum has to be applied accordingly. So, first what we will do we will soften the sheet so that the requirement of vacuum is also optimized.

So, the sheet is heated until it softens and thereafter vacuuming needs to be applied quickly. So, as the sheet is soft we will apply the vacuum the sheet will be pulled down as per the shape of the mold. So, that we have already seen with the help of a diagram.

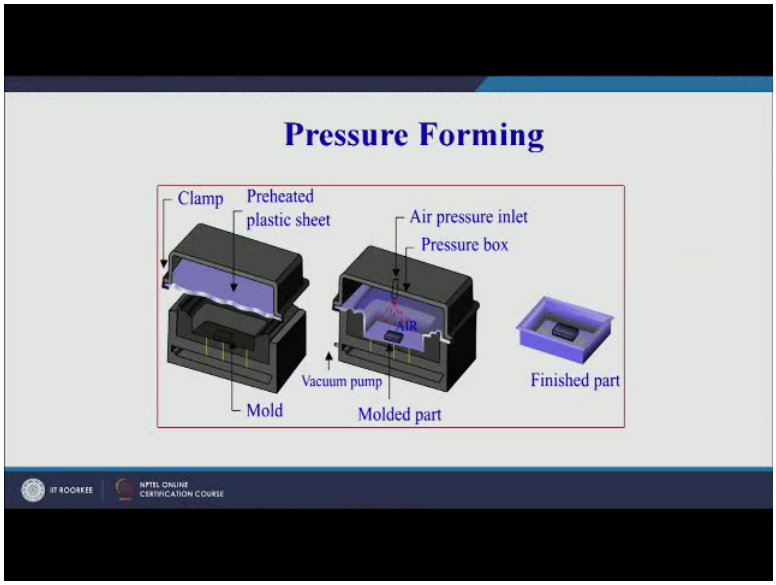
(Refer Slide Time: 11:48)



A surge tank is used to quickly pull the air out between the mold cavity and the sheet that is a method of applying the vacuum, then when the vacuum is created the sheet conforms

to the shape of the mold cavity that I have already explained the formed part is cooled and then ejected from the mold cavity. So, the third step now, cooling. So, three step process heating, forming and cooling. Finally, when once the part has cooled or once the mold has cooled of part or thermoformed part is taken out and that is our final product. At the later stage we may require some kind of trimming we may require some kind of finishing before we can use that part, but we will get our final product as up as our final outcome of this vacuum thermoforming process. So, this is a first classification of thermoforming process which is based on vacuum the pressure is applied in terms of vacuum.

(Refer Slide Time: 12:49)



The second process that we want to cover today is pressure forming. So, here again on your screen we see a diagram in the diagram we can see there is a clamp the clamp will fix the two parts of the mold. So, there is the upper mold path and there is a lower mold part. On the screen you can see this sky blue color sheet is a preheated plastic sheet. So, in this case what we will do we will have a preheated plastic sheet. In previous case if you remember in case of vacuum thermoforming we were having a heating arrangement. So, the sheet was being heated in the setup itself, but here we need to have a preheated sheet. So, we have a preheated plastic sheet and we have two part mold that we will close and apply the pressure on this preheated sheet. So, that it conforms to the shape of the mold and we get our final product.

So, here you can see the two part mold then there is a clamping unit which will clamp the two parts of the mold together and then the air pressure inlet is there through which we will supply the pressurized air to apply pressure on this sheet so that the sheet conforms to the shape of the mold. So, you can see this is the molded part here the sectioned view is we shown here we see the final part how the final part of the final product would look like.

So, the difference between the two that is a vacuum forming process as well as the pressure forming process is the mechanism of applying the pressure or the mechanism of forcing the sheet against the mold. So, in case of vacuum we apply vacuum. So, that the sheet is pulled as per the mold cavity or as per the design of the mold cavity. So, we will form the sheet based on vacuum. In case of pressure forming we are pushing the sheet if you see with the diagram this is a sheet, this is a sheet we are pushing it down how with the application of air pressure.

So, we will up we are applying air pressure to force the hot or the heated sheet of the preheated sheet against the walls of the mold so that the sheet conforms to the walls of the mold and takes the shape of the mold that is the exact replica of our final product. So, mold is designed as per the requirement as per our final product, so we are forcing the sheet with the help of air pressure against the walls of the mold so that we get our desired product

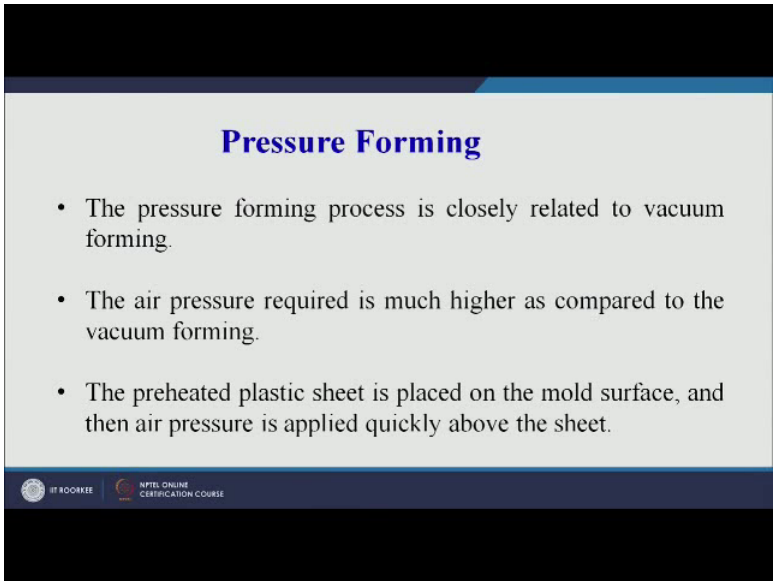
So, here you can see the final product or the finished product is shown on your screen this is a final product. So, this is a basic working principle of the pressure forming process. Now, here if you see if we have to control the process we need to see that what can be the thickness of the sheet, what is the amount of pressure that is required and for how long the pressure is required, how much time is a sheet will take to form to the wall or the conform to the shape of the mold. So, all are the all these are control parameters that we need to take into account when we are working with the pressure forming process.

We will get different types of defect we may get non uniform thickness of the sheet once the product is ready that may be because of non uniform application of pressure on the sheet. So, there can be number of defects that can arise due to non optimal or due to wrong selection of the process parameter such as the application of air application of air

pressure, the holding time, that is the cooling time, then the time for which you are applying the pressure all these are important parameters that have to be taken into account in order to make a successful product that is shown on your screen.

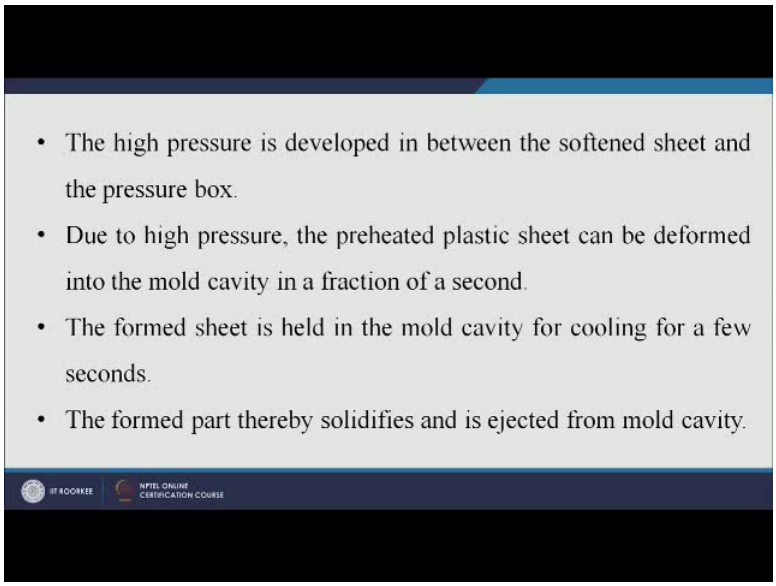
So, we have seen two types of thermoforming processes one is vacuum forming another one is pressure forming. Now, let us try to understand the third type of process that is the mechanical forming, but prior to going to the mechanical forming process. Let us first just revise what we have covered in pressure forming. I have tried to explain with the help of a diagram, but whatever I have said we have summarized it in 6 or 7 points. So, I will quickly read this point and then we will move on to the mechanical forming process that falls under the category of thermoforming processes.

(Refer Slide Time: 17:10)



So, the in case of pressure forming the pressure forming process is closely related to vacuum forming I have already explained the difference between the two. The air pressure required is much higher as compared to the vacuum forming. The preheated plastic sheet is placed on the mold surface and then the air pressure is applied quickly above the sheet.

(Refer Slide Time: 17:28)



The high pressure is developed in between the softened sheet and the pressure box due to high pressure the preheated plastic sheet can be deformed into the mold cavity in a fraction of a second, so it does not take much time. The formed sheet is held in the mold cavity for cooling for a few seconds the sec formed part there by solidified gets solidified or solidifies and is ejected from the mold cavity.

So, these are important steps or the sequence of operations that are carried or carried out in order to successfully deform a preheated plastic sheet into a tangible product. So, we have seen two broad variants of a thermoforming process let us now see the third variant of a thermal of the thermoforming process that is a mashed die forming.

In matched die forming process you can see let us first see the diagram properly we have a preheated plastic sheet. So, in this case also we will have a preheated plastic sheet you can see the sheet here again the sky blue color sheet. Then there is a clamping unit there is a core plug. Now, poor plug is different from the first two processes in case of vacuum forming we had a heating arrangement on top of the sheet.

In case of pressure forming we had a pressure box on top of the sheet. Now, in case of matched die forming we have a core plug on top of the sheet. Now, this core plug is used to apply mechanical pressure on the sheet so that the sheet deforms as per the mold cavity. So, here we have were core plug here preheated plastic sheet clamping unit then there is air escape because once you are forcing the sheet against the mold wall, the air

has to be released whatever air is present inside the mold and then we have a mold which is the final shape that we want to produce.

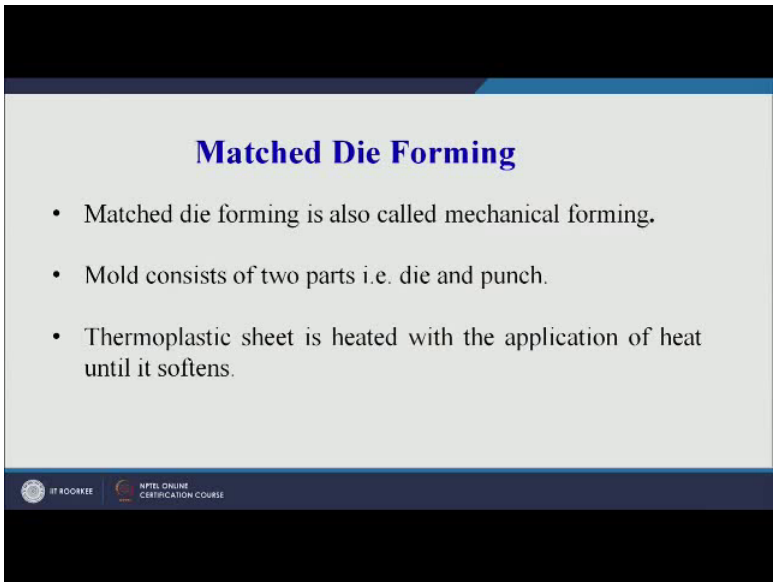
So, here we can see the mechanical pressure is applied, the core plug is used to push the sheet or the thermoplastic sheet against the walls of the mold. So, there the sheet conforms to the shape of the mold cavity and we get our final product. So, here you can see this is the final product that has been formed that is the finished part. So, this is a closed mold or core, core plug has come down and the gap between the core plug and the mold is filled by the thermoplastic sheet.

So, here we can see the three types of processes and the basic principle remains the same, the important three steps remains the same that first we have to heat whether it can be within the setup also or we can have a preheated sheet. So, first thing is we have to heat the sheet. Second is we have to deform it apply the pressure the deformation is happening or the forming of that thermoplastic sheet is happening because of the pressure in this case. Now, pressure can be applied by different means as we have seen and finally, we will allow the sheet to cool so that finally, our final product is ready. So, the three major steps of any polymer processing technique are again being repeated in case of thermoforming process also. So, the classifications we have seen.

Now, let us go through the advantages limitations, application areas of the thermoforming process. Before going to the thermoforming application areas let us first quickly have a look at the various steps involved in a matched die forming process. I have tried to explain the matched die forming process with the help of a diagram.

Now, let us see that how or what are the various steps involved in the matched die type of thermoforming process.

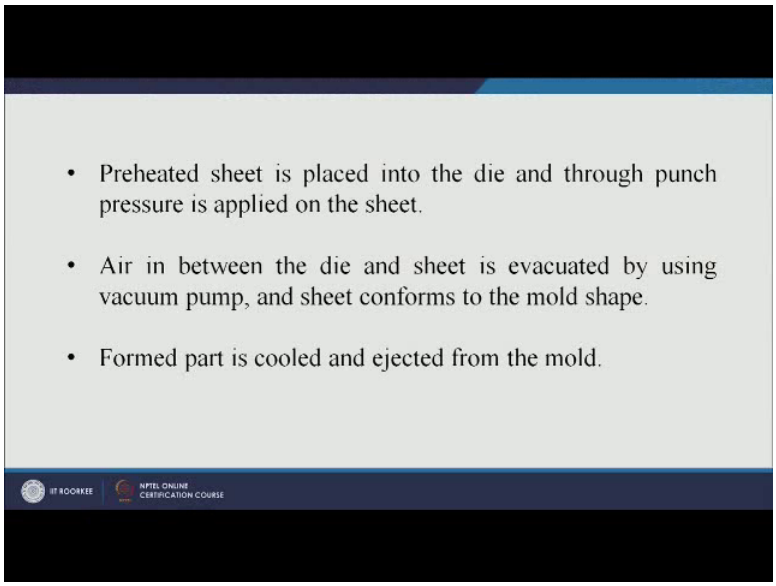
(Refer Slide Time: 21:14)



Matched die thermoforming or matched die forming is also called mechanical forming. Now, why mechanical because in pressure forming the pressure is applied by a jet of air, in vacuum forming the pressure is applied by a vacuum in case of matched die forming or mechanical forming the pressure is applied mechanically by the core plug on the thermoplastic sheet. Mold consists of two parts die and a punch. So, the core plug in this case acts as a punch and it forces the sheet against the mold or against the mold walls.

Thermoplastic sheet is heated with the application of heat until it softens as in the diagram it was given heat is a prerequisite for thermoforming and the sheet can be pre heated in a different setup and then can be brought to the molding setup or within the setup also we can have a heating arrangement where we can heat the sheet until it softens and then deform it by the application of pressure.

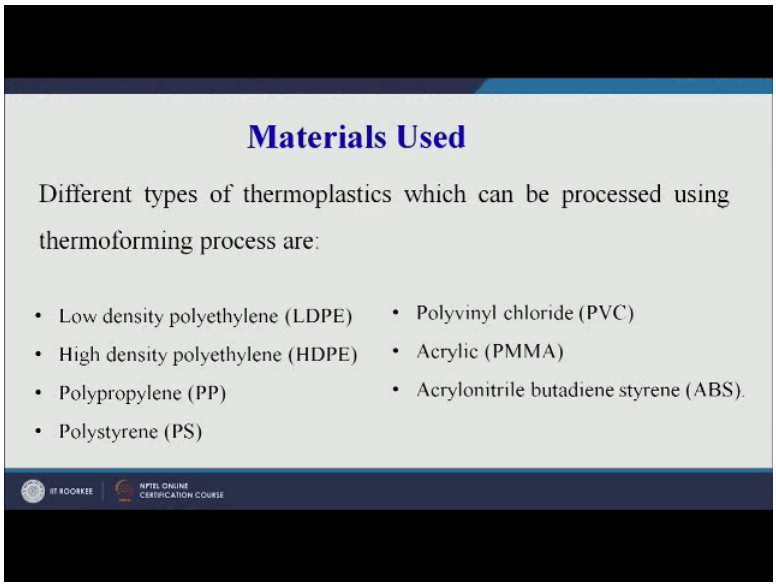
(Refer Slide Time: 22:12)



Preheated sheet is placed into the die and through punch pressure is applied onto the sheet. Air in between the die and the sheet is evacuated by using vacuum pump and sheet conforms to the mold cavity. Formed part is cooled and ejected from the mold.

So, in many cases we there can be combination of processes also that maybe if it is slightly thicker sheet we may apply pressure from both side, we can apply vacuum also we can apply mechanical pressure also, but the basic principle will remain same; thermoforming, thermo forming heat and forming. So, the basic principle of the process remains same. Now, let us see what are the different types of materials used.

(Refer Slide Time: 23:00)



On your screen you can see different types of thermoplastics which can be processed using thermoforming process are low density polyethylene LDPE, high density polyethylene, polypropylene, polystyrene, polyvinyl chloride, acrylic, acrylonitrile butadiene styrene.

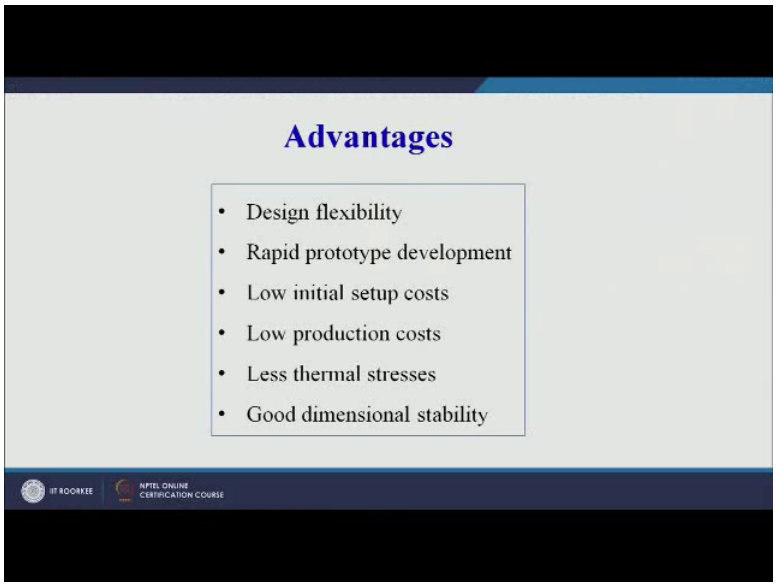
So, I just read the things for you so that even if it is not clear on screen you can just remember two or three or four names of thermoplastics which can be easily processed by the thermoforming process. But the major constraint is on a thickness of the sheet that we are thermoforming. If we use a very thick sheet it will become difficult to deform it with the application of pressure and we may not get uniform thickness of the final product that we are trying to make. So, it is important that thickness of sheet is optimally selected. So, that we are able to deform it successfully.

So, material you can see lot of choices are available you can have HDPE, you can have LDPE, you can have PP. So, different types of raw material can be there, but important point is that this particular process is limited to may be sheet form of products only. So, we may not be able to make three dimensional very complicated products using thermoforming process so that is one limitation of the thermoforming process, but we will see what are very important advantages and limitations in our subsequent slides.

First let us try to understand what are the advantages. I think if you have been attentive and you have been able to infer or you have been able to understand what has been

discussed today the process is not very complicated the process is simple therefore, it has got lot of advantages also. First thing is design flexibility, we can change the mold the process whole product will change as per the mold cavity we will get our product therefore, there is lot of design flexibility in this process.

(Refer Slide Time: 25:02)

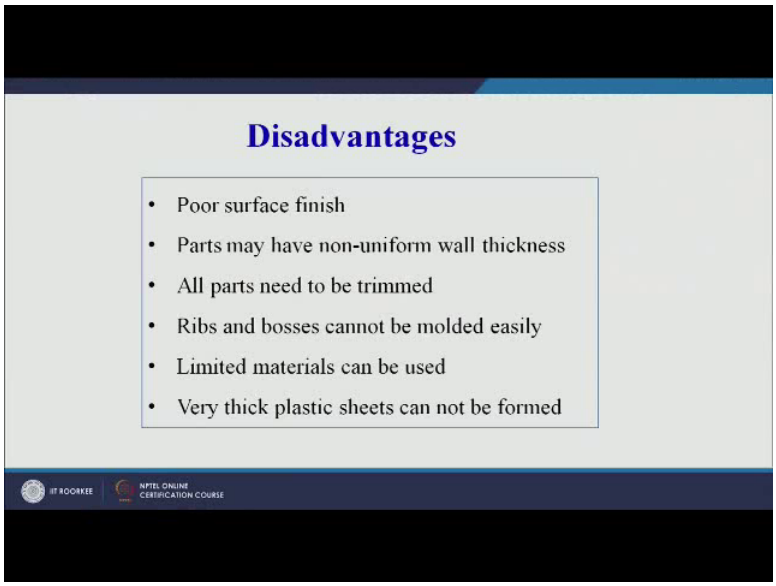


Then rapid prototype development which means that very quickly we can make a prototype or maybe a product only the raw material required is a sheet or thermoplastic sheet quickly we can apply the pressure and the product is ready it is not a time consuming process.

Setup costs are also not too high especially if you see the mechanical forming process or mechanical based thermoforming that is matched die type of forming process only thing you require is that two part mold cavity - one will act as a punch or a core plug, another one will be the mold cavity you need bring your thermo preheated thermoplastic sheet inside close the mold it will take the shape of the final product. So, the cost involvement is also not that high, the low initial setup costs are there.

Then production costs are also not very high thermal stresses are less and dimensional stability is good, if the design is not very complicated. If the design is very very very very complicated than the dimensional stability may not be that good. So, apart from all these advantages there are certain disadvantages also.

(Refer Slide Time: 26:18)



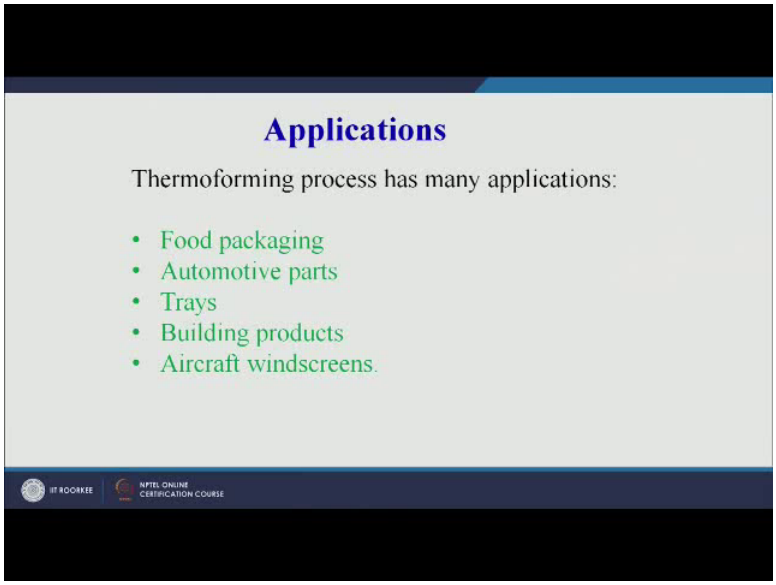
Now, what are these disadvantages first is sometimes we may not get very good surface finish. So, it may the process may lead to poor surface finish which is one disadvantage. Parts may have non-uniform wall thickness, if you remember during the course of today's discussion I think two times already I have mentioned that this process one limitation is that the thickness is non uniform. Many times the product that we get if we do not close the mold if you remember in all the setups there was a clamping unit the importance of clamping unit is that the mold should close appropriately so that there is no shift of the mold even a slightest shift in the two parts of the mold will lead to maybe non uniform wall thickness.

So, another important limitation is that all parts need to be trimmed because always there will be some flash or some part of a thermoplastic coming out our left which is not a part of the product. So, we have to cut or trim that part, so that we only get the desired shape that we are looking at. Ribs and bosses cannot be molded easily yes that is true because one problem already we have seen non uniform wall thickness and if on top of that even if we have the ribs and bosses also inside the design or inside the mold cavity then it becomes difficult to control the process. So, ribs and bosses cannot be molded easily.

Limited materials can be used within polymers also the process is majorly focused on thermo plastics. So, thermo sets cannot be molded easily using the thermoforming process very thick plastic sheets cannot be found which I have already explained that it is

difficult to deform. The thin plastic sheets use of thick plastic sheets sorry very thick plastic sheets difficult to deform using the standard methods that we have seen today that is vacuum based forming or pressure forming or matched die forming, if the thickness is reasonable then only we are able to deform it using these standard methods of thermoforming.

(Refer Slide Time: 28:37)



Now, what are the various application areas? So, see in the process is simple easy to operate not very costly. So, because of these advantages the number of industries are making use of this process. Now, what are these application areas? Food packaging is one, automotive parts, trays, building products, aircraft wing screens and there can be numerous other products that are made by the thermoforming process. We have tried to compile from internet two or three images that give us a glimpse of the products that can be made by the thermoforming process.

(Refer Slide Time: 19:00)

On your screen you can see food packaging parts all of us may have used maybe this can be strawberry box, we have used this box number of time this type of disposable cups also have been used, disposable boxes can easily be made using the thermoforming process even these glasses can be made. So, you can see you need to only have a thermoplastic sheet and a mold conforming to the shape of the product and you can deform it by applying heat as well as pressure. On the right hand side right hand side of the diagram automotive interiors you can see these are the parts that can be easily made by the thermoforming process. So, here we have FMCG or may be household equipment or household products, here we have industrial scale products.

So that means, that thermoforming has got a wide range of applicability it can be used for household products also it can be used for industrial scale products also. So, it is always you can say better to have information about all these processes which are used for making products that we see in our day to day life. Now, I believe that if you look at a particular product which is made out of a polymer very easily you will be able to tell that this may have been made by using the thermoforming process. May be you may not be able to tell that which type of thermoforming process may have been used to make this product that is whether it is matched die thermoforming or it is pressure thermoforming or it is the vacuum thermoforming, but at least you will be able to tell that this product may have been made using a thermoforming process.

So, with this we come to the end of this session on thermoforming and we will continue our discussion on the different processes and the other processes that are used for forming or manufacturing or processing of polymers. Once our discussion is over on processing of polymers we will move to the next module that is the processing of polymer based composites.

Thank you.