Processing of Polymers and Polymer Composites

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

Lecture – 06
Extrusion – I

[FL] friends, welcome to this lecture 6 in our course on Processing of Polymers and Polymer Composites. If you remember in the last sessions we have discussed the basic properties of the polymers, we have also started our discussion on the various processing techniques for polymers. We have already covered two processes that is casting as well as thermoforming. In casting we have seen that it is a most simplistic process and we can use both thermo sets and thermoplastics majorly used for thermo sets and we can give shape to the polymer using a mould cavity for a metallic mould. In case of thermoforming if you remember it is used majorly for thermoplastic sheets very thin sheets and we can give desired shape to these sheets with the help of three types of pressure.

We have seen vacuum thermoforming we have seen pressure thermoforming and we have seen matched die type of thermoforming process. So, if you see that we have already try to understand two important processes that are used for polymers and in both the processes plus in the processes that we are going to cover in our subsequent lecture you will try you will understand that there are three components again I am emphasizing that heating, forming and cooling that are common. So, that we are going to see today also. If you see the topic that we are going to cover today it is extrusion the extrusion is a most widely used process for processing of polymers and we will see that how the plastics are processed using extrusion, what is the process, what are the various parts of extrusion machine we will try to understand that what are important control parameters, what are the different types of products that can be made and then we can always understand the things better if we have a video which represents the process.

So, today we will see a very small video which will give a complete description of the whole process that whole process operates and finally, makes a product out of a plastic. So, let us start our discussion on extrusion and we will cover whatever I have listed down in the beginning of the session that all these things will be covered in today's session

So, let us start our discussion.

(Refer Slide Time: 02:49)

On the screen you can see there are different types of products with different colors are processed for plastics. So, if you see yellow color blue color and first let us start first I want to grab your attention towards the products that are made then we will go to the technical aspects of the products.

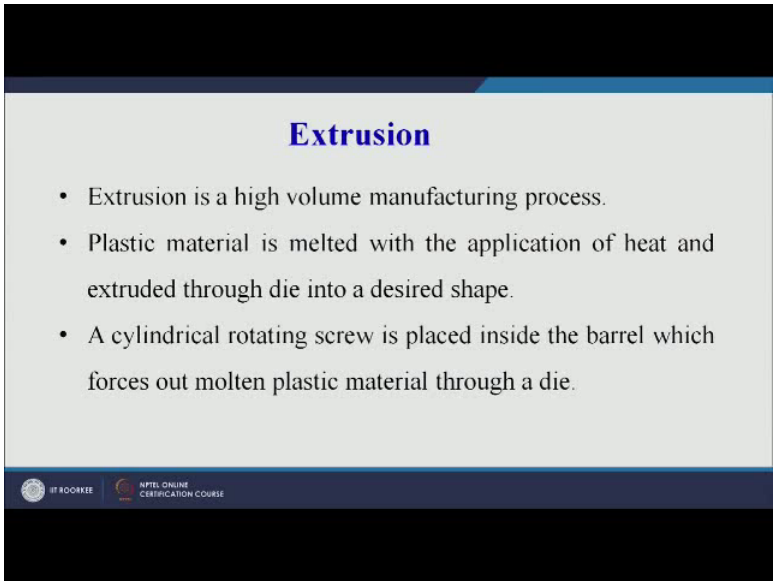
If you see different colors products can be made that is one versatility of the process that it is not color specific any color can be made, so if you can appreciate that then you can see the shapes which is a technical parameter. So, if you see the shapes there are circular cross sections, there are maybe different types of cross sections square cross sections are there oval type of cross section is there then we can see a special design a honeycomb type of cross section is there. So, depending upon the cross section we can make use of the extrusion process and we can make a product. So, on this side also the other view of these products you can see there is the angle section here, there a solid cylindrical cross section, the solid cylinder has been made there is a rectangular type of cross section and there is a complicated cross section also.

So, extrusion process is a versatile process and everything depends upon the die or the heart of the extrusion machine that is the die. Now, depending upon the product we have to design the die and the die will give us that desired shape the things as I have already told we have to heat the plastic material. Once it is hot it will be pushed through the die

depending upon the shape of the die it will take the desired shape finally, the product that is coming out of the die we will cool that product and finally, our product will be ready. And depending upon the length that we require we will cut the product into desired cross sections or not the desired cross section the desired length across the cross section. So, that we get the product in the video it will be very very clear. So, you can see the different types of products that we can make using the extrusion process.

Just to explain you the importance of those process I can just share with you that the gardeners pipe that we use in for watering the plants or sometimes for washing over cars also the plastic pipe that we use that is made by the extrusion process so that you can appreciate relate to that process that what is extrusion. So, let us start our discussion with the extrusion process extrusion is a high volume manufacturing process. So, you can see it is a continuous process.

(Refer Slide Time: 05:25)



Once you feed your raw material which is available in the form of pellets. So, these pellets will be melted and then they will be forced through the die and continuously the production can be there.

So, you see you have long gardeners pipe or long hauls pipes. So, that means, that they have been produced through a continuous process of manufacturing. So, extrusion is a high volume continuous manufacturing process plastic material is melted with the application of heat and extruded through the die into the desired shape. I have already

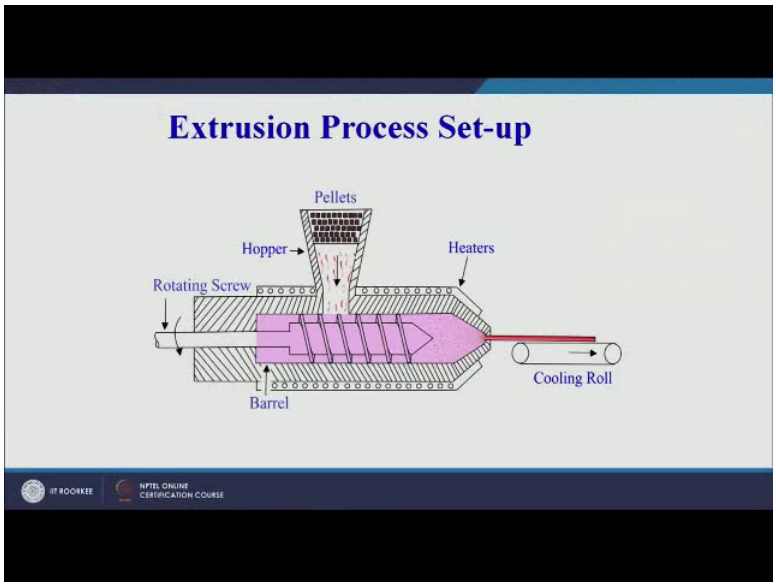
emphasized this point that heat for your heat your deformation in the form of a die and finally, the cooling are the basic principle or the basic steps involved in the extrusion process. A cylindrical rotating screw is placed inside the barrel which forces out molten plastic material through the die.

Now, something has to be there which will push from material through the die, so that work that is pushing the material through the die in achieved by the barrel. You can try to understand this with the help of a surgical syringe. In the syringe what is done first you pull the medicine inside the syringe and then you apply the pressure and inject the medicine into the human body or into the animal's body. So, the same principle you can correlate that medicine with the plastic and you have a plastic inside a barrel you have to push it. So, that it comes out. So, die in this case can be the needle through which the medicine comes out

So, that is the principle, but here that piston cylinder arrangement in place of the piston cylinder arrangement many a times we use a screw and barrel arrangement through which we have the plastic we push that plastic with the help of a screw and it is forced through the die into the mould cavity. In this case it will not be a mould cavity it will be a die. So, we will push the molten plastic through the die and that will be the exact replica of the final product that we want to make.

Now, as I have shown in the previous slide different types of products can be made on your screen you can see. So, these products the shape of this product will depend upon you can very easily. Now, answer this question the shape of this product will depend upon the shape of your die. Now, if it is a circular die you will get a circular product if you have a square die you will get a square product. Now, depending upon the shape of the die you will get to your product. So, this is the these are the three basic steps that is heating of the plastic, pushing of the plastic through the die and cooling of the product when it comes out of the die.

(Refer Slide Time: 08:16)



On your screen now, you can see a very simplistic representation of the extrusion process. There can be so many other components in the extrusion machine, but we are trying to understand the very basic mechanism of the extrusion process. So, if you here you can see there are for any process there are three things there those are important - first is the raw material, second is the process mechanism and third is the product. So, here let us start from the raw material.

So, raw material in case of a extrusion process are the pallets. On your screen we have this setup these are black portion particles are the pellets. So, usually we are get for thermoplastics we get spherical pellets and those pellets act as the raw material for the process this these pallets move through this hopper into the barrel this is a barrel portion I am highlighting that barrel portion.

So, that is the barrel and there we have this rotating screw the rotating screw has also a specific design that we will cover towards the end of today's session. So, there is a screw there is a barrel there are pallets that are coming down. Now, pallets are solid spherical particles. Now, we have to melt them and for melting we require heat and for heating we require heaters. So, on your screen you can see all around the periphery of the barrel we have heating arrangement these square dots these squares sorry these circular dots represent the heaters. So, these are the coils or the heating coils, these circular coils here also represent the heaters. So, here heaters all around the barrel. So, this these heaters

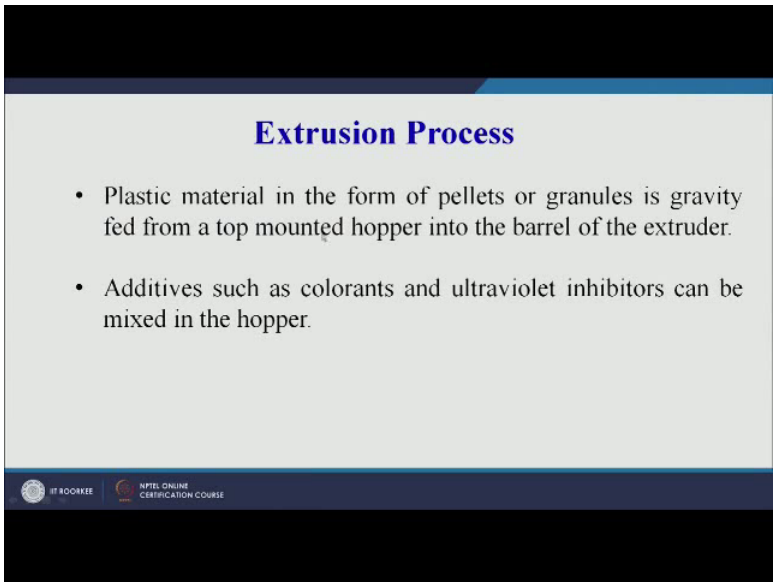
will heat the polymer pallets and will melt them and once you melt them next stages you have to push them through the die and then your product will be formed.

So, here we have the die arrangement this is the place where we will have the die and then this red color portion is the final product that is coming out. Now, this product is rolling on a cooling rule roll and we can have we will see in our subsequent slides when we will try to study step by step that how the process operates we will see that the cooling can be water cooling it can be air cooling, but right. Now, with the help of this diagram we are trying to understand the how the extrusion process works in case of plastics. All of you may have studied extrusion of metals. So, there are different variants of extrusion of metals, but here in case of plastics there is slight modification as compared to how the raw material is fed into the machine how the product comes out from the setup all these are the different things as compared to the extrusion of metals.

So, here you can see once again I am repeating just maybe three or four sentences we have polymer pallets thermoplastic pallets here these pallets are fed into the barrel there is a rotating screw inside the barrel, the barrel is heated with the help of heaters all around the periphery of the barrel the rotating screw rotates and it pushes the molten plastic through the die therefore, on to the cooling roll and your final product comes out from the die. So, that is the basic working principle of the extrusion process.

Now, let us read whatever I have said so that we are able to remember that what is extrusion process actually.

(Refer Slide Time: 11:56)



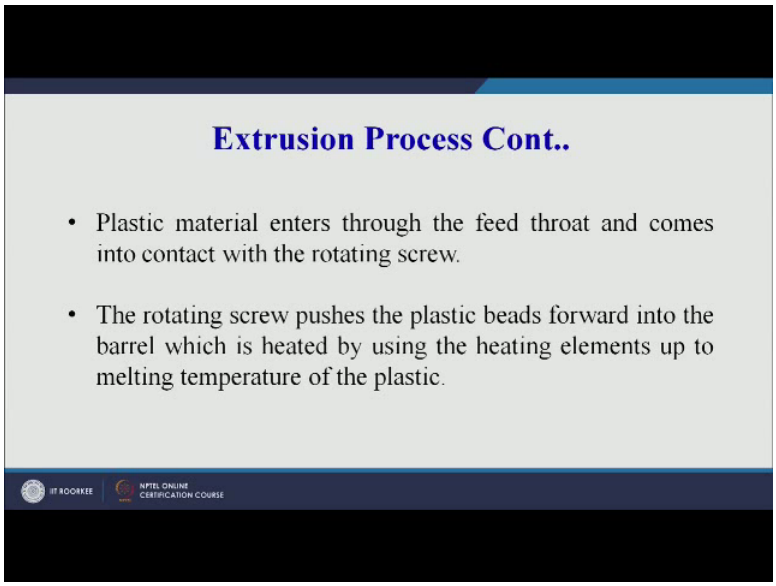
The plastic material in the form of pellets or granules is gravity fed from a top mounted hopper into the barrel of the extruder. I have already explained the raw material is in a hopper it is gravity fed means it comes down by its own weight.

Additives such as colorants and ultraviolet inhibiters can be mixed in the hopper. Now, this is important. You have seen so many different colors of products were there in the very first slide there was yellow color, green color, black color. So, with these coloring agents we have to add in the hopper we have to prepare a batch of the raw material which will have the pallets, other additives sometimes fire retardants may also be added at the raw material mixing stage only. So, here coloring agent will be added.

Similarly, ultraviolet inhibiters can be mixed in the hopper. Now, ultra violate inhibitor many a time we see decoloration of the plastic products takes place if suppose the bucket lies in the sunlight every day and for months altogether for years altogether the decoloration takes place.

So, we can add some inhibitors which inhibits the decoloration of the plastic parts.All those things raw materials can be added in the hopper.

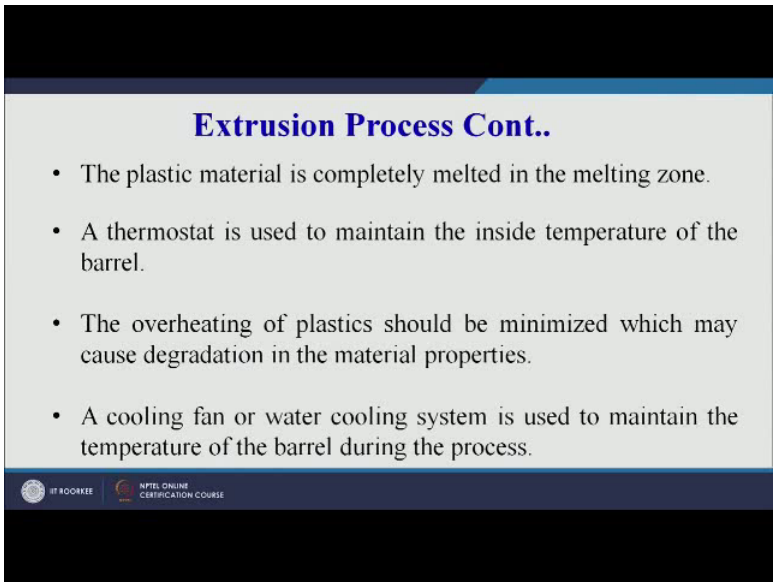
(Refer Slide Time: 13:12)



Plastic materials enters through the feed throat and comes into contact with the rotating screw. Now, feed throat is at the end of the hopper. So, you have a hopper there is a feed throat at the end and through that the raw material in the form of pellets and other additives adds and enters into the barrel. So, rotating screw pushes the plastic beads or plastic pellets forward into the barrel which is heated by using the heating elements up to the melting temperature of the plastic. So, we will melt the plastic because of the heating arrangement that we have provided around the barrel.

So, once the plastic is in the molten state it will start to flow and then we will push this molten plastic with the help of a reporting screw through the die. So, the next stage is the plastic material is completely melted in the melting zone. So, we will see that design of the screw and there are three zones specifically for specific task that we will see later. So, the plastic material completely melts in the melting zone.

(Refer Slide Time: 14:11)

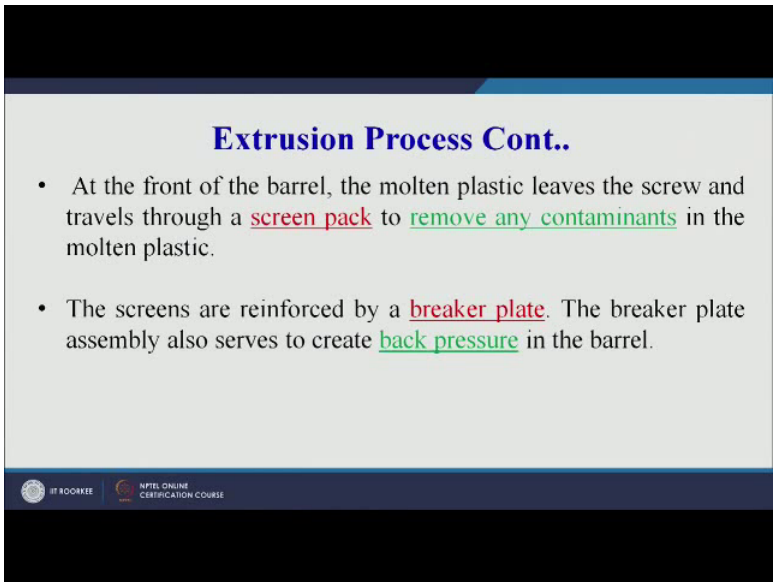


The thermo strategy used to maintain the inside temperature of the barrel because we need to maintain that temperature by the time we push our molten plastic through the die. The overheating of plastics must be minimized which may cause degradation of the material properties. Now, we have to see that how much temperature we should give to that plastic overheating of the plastic is also not is also not advisable why, because it will degrade the properties of the product that we are making. So, we have to be judicious in the choice of the temperature that we are going to give to the heating elements so that we are able to control the properties of the final product. So, the overheating the plastics has to be avoided we should always keep this thing in mind.

A cooling fan or a water cooling system is used to maintain the temperature of the barrel during the process. So, this is an another important point that we need to maintain the temperature in the barrel for that we have heating elements in order to avoid the overheating view of the cooling arrangement that is a fan or a cooling system is provided.

Now, there are other arrangements as I have told you the diagram that was shown is a very simplistic way to explain that how extrusion process actually works. But there are other arrangements also for specific tasks. So, we have seen that over for avoiding the overheating we have to provide that cooling system similarly at the front of the barrel.

(Refer Slide Time: 15:39)



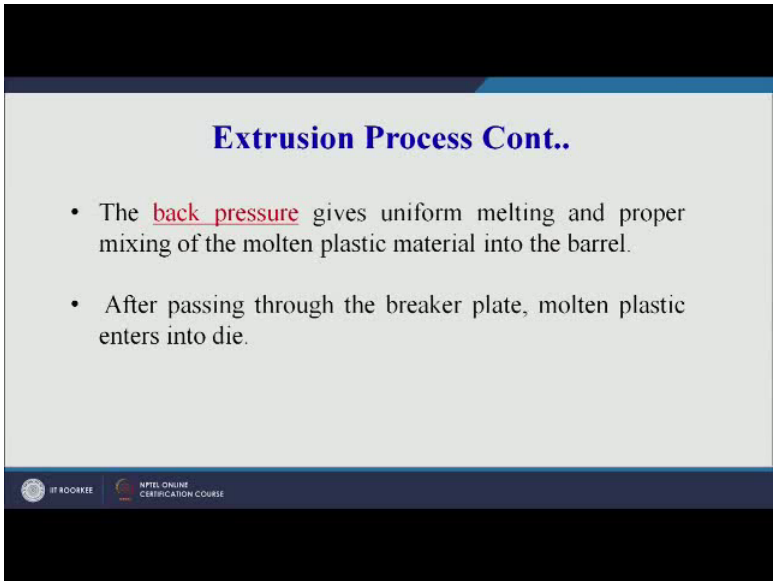
The moulting molten plastic leaves the screw and travels through a screen pack. Now, what is the roll of this screen pack? It the roll of screen pack is to remove any contaminants in the molten plastic. Many a times we are using the plastic pellets there may be some undue particles or non wanted particles all mixed with the pellets that may travel through the barrel through the screw they may be fed through the die. So, we need to check that these particles they may be sometimes causing harm to the die also. As I have told you die is the most complicated part of the whole system and the shape size surface finish of the product depends upon the die.

So, if your die wears out very fast that is the most costly component in the whole setup. So, therefore, we do not want any additional or any undue particle going into that die that has to be avoided. And for avoiding that we can put a screen pack which will only allow the plastic to go through into the die and will arrest all other particles which are not required or unwanted particles or unwanted impurities. So, the roll of the screen pack is to remove any contaminants in the molten plastic the screens are reinforced by a breaker plate. Now, what does the rule of the breaker plate? The breaker plate assembly also serves to create back pressure in the barrel. Now, back pressure why brack pressure is required? There are two three terms that have come up on this screen.

One is screen pack that is to avoid the flow of the undue or unwanted particles or impurities with the molten plastic it will arrest those. Secondly, the breaker plate. Now,

breaker plate will apply also help us in applying the back pressure. Now, what is back pressure we will see why back pressure is required.

(Refer Slide Time: 17:31)



The back pressure gives uniform melting and proper mixing of the molten plastic in the barrel. So, that that pressure has to be maintained so that we are able to properly mix the plastic the all the pallets melt and proper mixing as we as I have already told that we may be adding some additional we can see additives in the hopper. So, proper mixing is one of the purposes of the barrel. Then it is supported by the back pressure as well as the uniform mixing is one thing and uniform melting is the other thing.

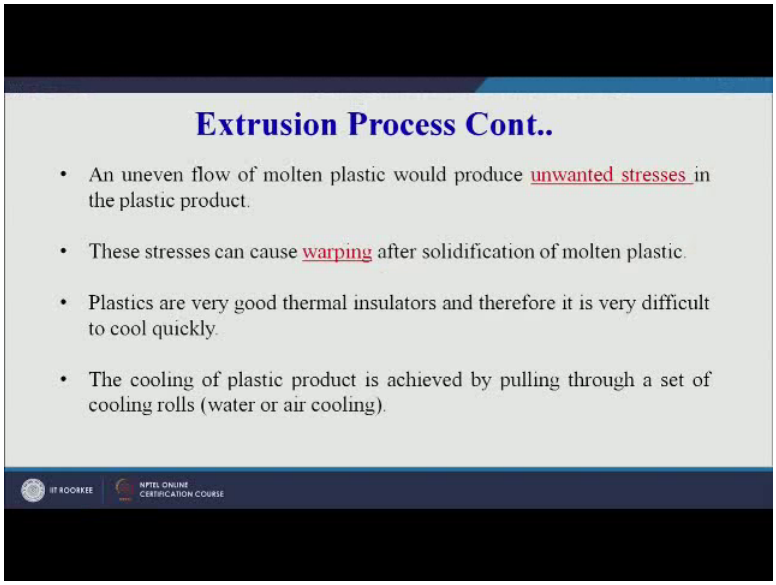
So, both are m mixing and melting. So, back pressure helps us to achieve these two ms, the two ms are mixing and melting uniform melting and proper mixing after passing through the breaker plate the molten plastic enters in to the die. Now, die is we can say is one stage, die is one stage before that what has happened the molten sorry the polymer pellets or the plastic pellets have travelled from the hopper through the we can see thought they have entered into the barrel then there is a rotating screw, there is a heating arrangement the heating arrangement is heat providing heat to this plastic, raw material the material is getting melted, this melted material is pushed forward with the help of a rotating screw and this screw also results in the mixing and melting of the raw material there is a screen pack which avoids the undue or the unwanted particles to move through move along with the plastic and then there is a breaker plate which provides the back

pressure which ensures the proper mixing and proper melting of the polymer pallets. So, this thing has already happened.

Now, the material is entering into the die and once the material enters into the die it will take the shape. So, as per our principles of processing of polymers three things are very very important. First thing is heating we have to heat the raw material that has already happened till. Now, second is forming that is giving shape to the raw material. So, now, the die will help us in the second step that is giving shape to the raw material and third part is cooling. So, cooling we will see later.

Now, we have finished level stage one that is melting mixing the raw material. Now, the raw material is ready to be deformed into the desired shape and that will be achieved by the help of a die. Now, the after passing it with a breaker plate the molten plastic enters into the die.

(Refer Slide Time: 20:16)



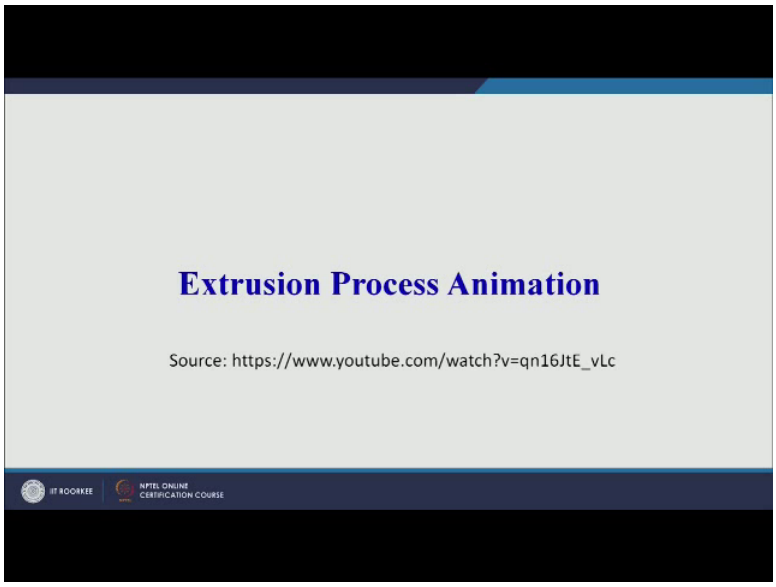
Now, an uneven flow of the molten plastic would produce unwanted stresses in the plastic product. So, we have to ensure a uniform flow or a even flow of the molten plastic through the die. Why? Because otherwise unwanted stresses will develop and unwanted stresses will cause warping after the solidification of the product. So, this uniform flow of the molten plastic has to be ensured. Now, plastics are very good thermal insulators they are not good conductors of heat and electricity and therefore, it is

very difficult to cool them quickly. So, the cooling of the plastic product is achieved by pulling through a set of cooling rolls.

As we have seen in our diagram that the we can always supply water cooling or air cooling for making those gardeners pipe or hose pipes the product when it comes out from the die it is fed through the water very adequate length of this water column or a water chamber through which the product is passed and when it comes out of the water chamber or water channel it is solidified and it is in the final shape or it is in the useful shape or useful heat become the useful product. So, cooling can be achieved through water also cooling can be achieved through air also. Through three steps now have been completed heating, melting of that plastic deforming in the die and finally, cooling whether it is air cooling or it is water cooling and on the way there are two three things that we have to ensure that no undue particles travel with the molten plastic there is adequate mixing of the plastic and additives that we have added, there is a uniform flow of the plastic through the die as well as after it comes out of the die that has to be ensured.

Now, we will try to see a very simple simulation or animation. Number of such animations are available on general platforms general video platforms one such platform is YouTube, on YouTube number of such animations are available as open source we have given the shows also, www dot youtube dot com and this video is available.

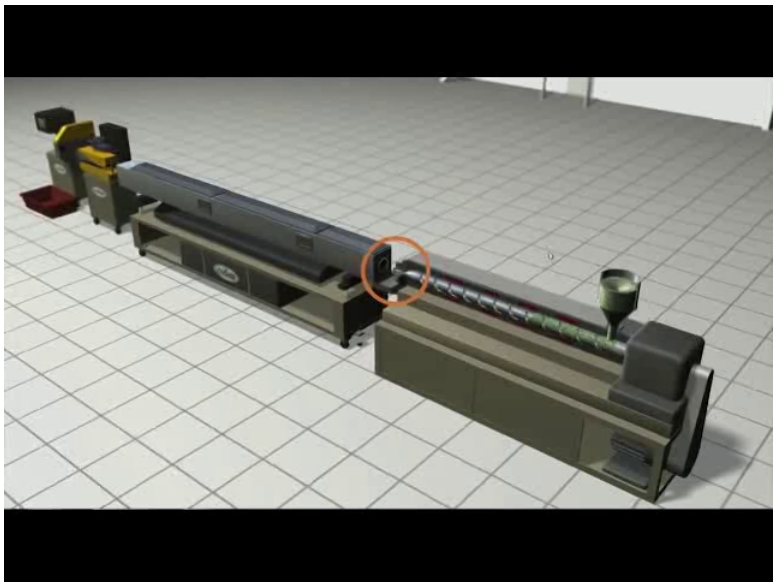
(Refer Slide Time: 22:18)



So, you can see there are other videos also available for better understanding you can look at these videos, but here we can try to understand how the process actually works on your screen you can see this video now, the video is going to start.

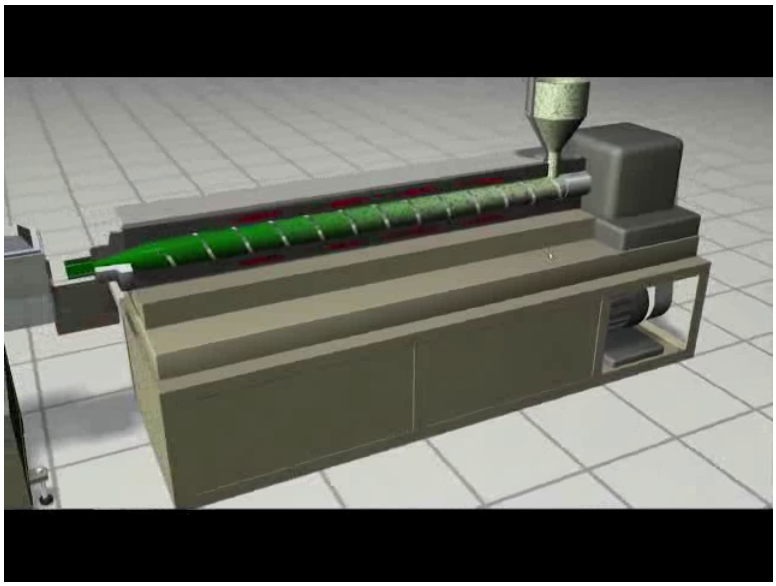
(Refer Slide Time: 22:47)

(Refer Slide Time: 22:51)

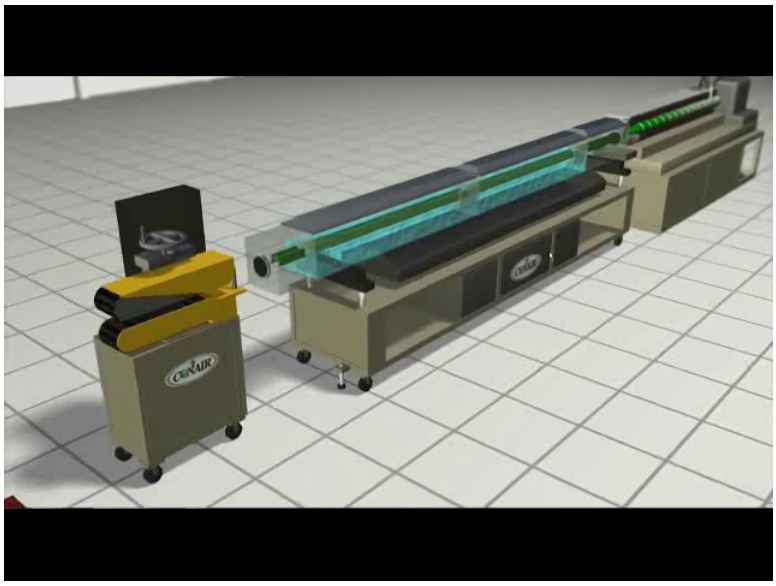


And here also the it is mentioned the extrusion process is a continuous process here you can see the barrel is rotating, the material is entering through the feed throat there is a hopper and you can see there is a coloring agent also, plastics pallets also and the barrel is feeding it then it goes into a water column chamber it is getting cooled.

(Refer Slide Time: 23:03)

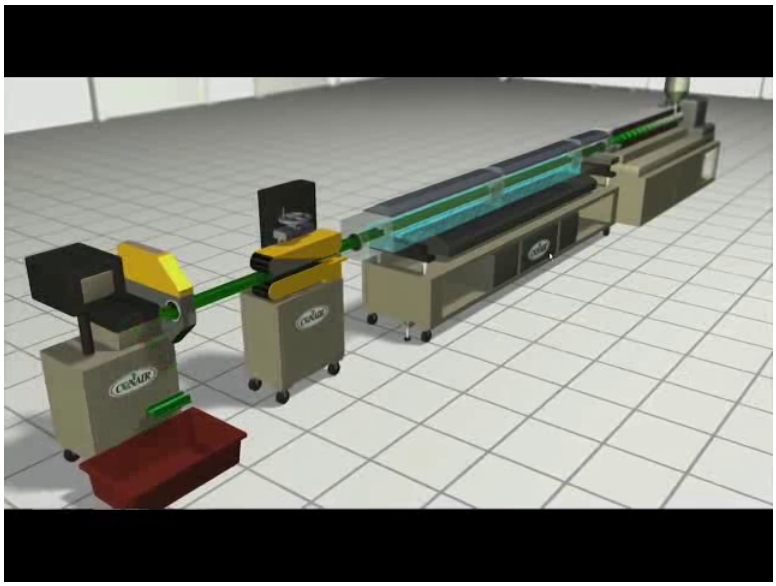


(Refer Slide Time: 23:12)



And finally, the desired length they have a cooling rolls then it is cut as per the desired length you can see. The products are falling down.

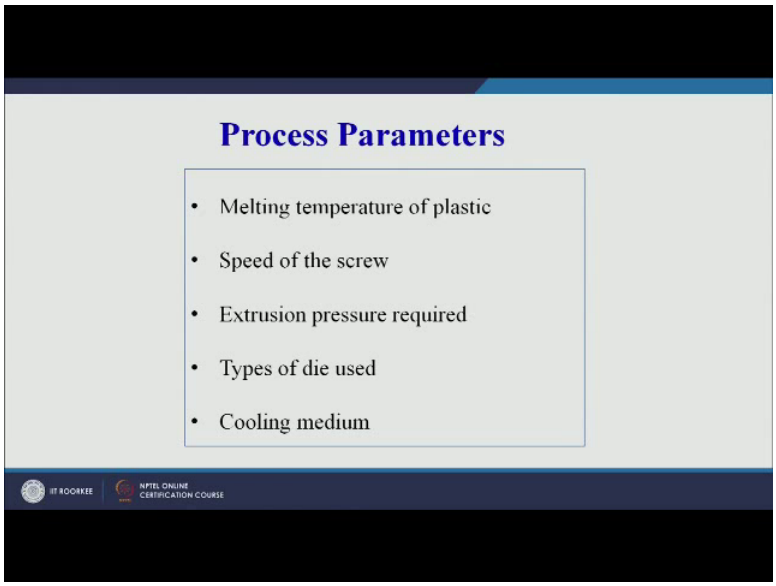
(Refer Slide Time: 23:16)



So, this is you can see you can try to understand you can try to understand that how fast is the process, how continuous is the process, how time saving is the process continuously we have to feed the raw material in the hopper and once the hopper is full of material the material is automatically by gravity go through the barrel as the rotating screw we will rotate and there are heating arrangement the molten plastic will be heated sorry the plastic will be heated and then it will melt and once it melts it will travel through the die and it will take the desired shape it will travel through the water column or a water chamber it will cool down and finally, it will be cut as for the desired length. So, the process I think is clear to each one of you if you have seen this video.

Now, what are the parameters? As engineers we need to design the whole process we have to see that what parameters we need to control and there are different types of polymers that can be processed by extrusion process. So, depending upon the type of the polymer, depending upon the shape of the product, depending upon the complexity of the shape of the product we will see that what parameters we can control in order to make a good quality product. Now, on your screen you can see that we have different types of parameters that we can control.

(Refer Slide Time: 24:41)

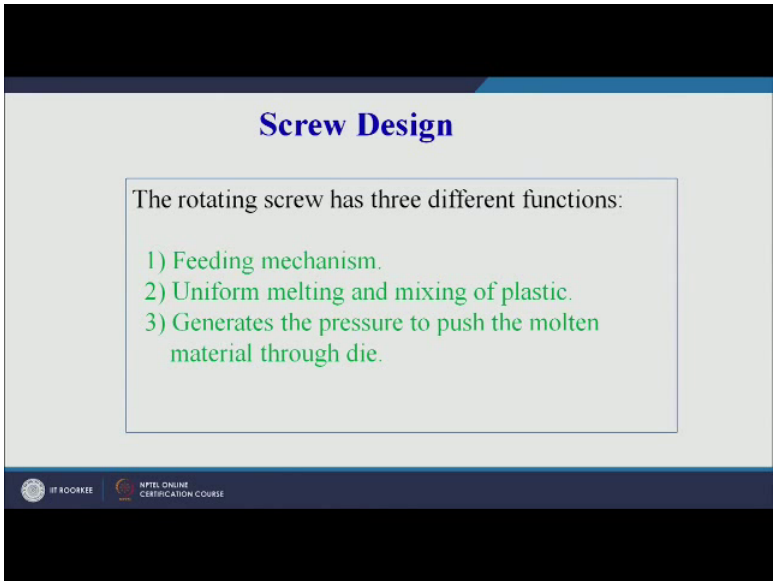


First parameter that we can control is the melting temperature of a plastic we have to see that how at heating arrangement we should use what should be the temperature that we should generate. So, that the plastic melts and it flows by the rotating screw. Second is a speed of the screw you can see in this video the screw was rotating at a particular rpm, it can be increased also, it can be decreased also. So, that will depend upon the viscosity of the molten plastic and depending upon that we will decide that what at what speed the screw should rotate so that it melts the plastic also as well as it forces the plastic also through the die.

Similarly, we can see that extrusion pressure that is required that we also depend on the rpm of the screw similarly the types of the used there are number of types of dyes which can be used which is beyond the scope of our this session, but we can see that the type of die that we select is also equally important. Similarly cooling medium we have to see depending upon the type of plastic that we are using. Now, cooling medium can be water, it can be air, it can be a jet of water. So, depending upon it can be a column of water can be chamber of water depending upon the requirement we have to choose that what kind of cooling medium we have to employ so that we get a good quality product there are no defects in the product that we have to ensure. So, these are the process parameters that an engineer has to keep in mind in order to design the process for a particular product.

Now, let us this is a last part of our today's session that is the screw design. Now, we see that we are the major part of our process or setup is the screw as well as the die. Now, these are the two important elements. Now, die design is belong the scope, but for extrusion process we can just have a look at the screw that what type of screw is used for extrusion process. So, that rotating screw has three important functions.

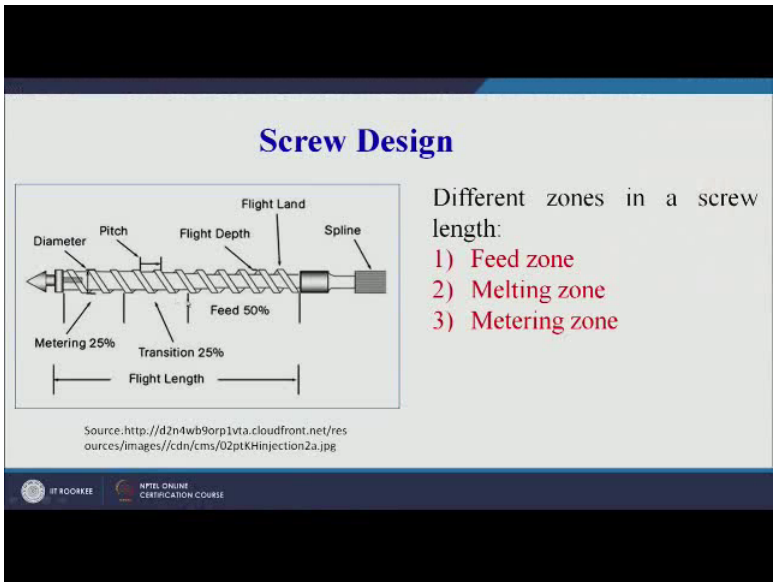
(Refer Slide Time: 26:57)



First is feeding mechanism, if you see that if you remember the diagram that we have seen today through the hopper the polymer pallets are coming down. Now, these polymer pallets enter the barrel and then the screw rotates. So, first is the feeding mechanism that is a screw is helping us in the feeding mechanism. Second is uniform melting and mixing of the plastic, third is it generates the pressure to push the molten material through the die.

So, feeding mixing melting and then pressurizing that it generates the pressure to put the molten material through the die or push the molten material through the die. So, these are three major functions of the rotating screw that is used in the extrusion process. Here you can see on the screen different zones in a screw length. So, this is the typical screw that is used for the extrusion machine there is a spline, then there is a flight land major part is these three zones.

(Refer Slide Time: 27:51)



So, there is a feed zone 50 percent of the screw length may be a usually is for feeding purpose then transition that we can say it is a melting zone and finally, the metering zone. So, basically different zones in a screw length are feed zone, melting zone and the metering zone.

So, the this screw has to achieve three basic functions that is it has to feed, it has to ensure the mixing and melting, it has to ensure the third part that is pressurizing the molten plastic into the die. Therefore, there are three zones basically feed zone, melting zone and the metering zone to ensure that we get a good quality product.

With this we come to the end of today's session. We have discussed today the fundamental process mechanism of extrusion process, we have tried to understand it with the help of a video also, we have seen that what are the various operating parameters that we need to control in order to make a good quality product. And in our subsequent session we will further see that what are the various types of extrusion process is or what are the process variants of extrusion. Today we have only understood the very fundamental process that is extrusion. We will see that how the process has been modified in order to suit specific requirements for processing of plastics.

Thank you.