Lecture 32 - Injection Moulding-02

Hello friends, welcome to the Injection Moulding Part 2 under the edges of Polymer Proximity. Now, here you can see what different aspects we have covered in the previous segment. We discussed the historical background of the injection molding machine and then gave a brief idea about the process of injection molding. Then we discussed the different types of injection molding machines. Apart from this, we discussed the advantages and disadvantages associated with the various injection molding machines because it always attributed to the different parts like different parameters like pressure, temperature, speed of the barrels all those things we discussed all these things. Then we discussed the breaking down of the injection molding cycle because of the continuous operation it is quite essential to know about this breaking down operation.

Then we discussed the injection molding tooling and we have already discussed the different terms related to the injection molding like L/D ratio, compression ratio, back pressure, injection speed, and cushioning all those things we discussed. Now in this particular chapter, we are going to discuss the different types of materials being used for the injection moulding process. Now you see in the previous chapters we discussed the different types of polymeric systems, polymers, synthesis, and classification of the polymers moreover in the last segment we discussed the product quality or the type of injection molding or a type of mold it all depends on the material which you are using in that particular aspect. Suppose we need to prepare a bucket of polypropylene then based on that particular thing what should be its melting temperature, what should be its density, and what is the impact of the temperature on the polypropylene?

So all these things are quite essential before we set the parameters for the injection moulding machine. Now this particular information is extremely important. So based on this, we have decided to cover the topic of the material that can be used in the injection molding machine. So basically in a broad spectrum, we can divide these materials into thermoplastic, thermoset, and polymers and we will discuss the material processing fundamentals like crystalline, amorphous, semi-crystalline behavior, and the molecular weight and its distribution, viscosity, density, some of the things we have already covered in the first segment. Then viscoelastic behavior, Newtonian, non-Newtonian, the effect of temperature on the polymeric behavior, orientation, so all these things because the temperature plays a very crucial role because the ultimate aim is to get the final product in the desired form but if you are not maintaining all these parameters then it may get, we may get the deformed part or we may get the product which is not as per our specification or as per desired.

So let us discuss the first segment which is materials, various materials can be used for injection molding. There, broadly we can divide these materials into two segments, thermoplastic and thermosets. Like in thermoplastic, you can use HDPE, high-density polyethylene, low-density polyethylene, DPE, polypropylene, polystyrene, polyamide, polyethylene, tetramethylene, PET, polyvinyl chloride and thermosets, different types of epoxies, melamine, phenolics, polyurethane, unsaturated polyester. So all these things can be injection molded. Then there are certain thermoplastic elastomers like polyolefin blends, polyolefin alloys, styrene, polyamides, polyesters, polyether esters, polythene, polyester urethanes, polyester urethanes, polyether urethanes, all these things can be used in the injection molding process.

Now here you see that when we discuss the material used for the moulding, again we can subdivide the things into three different segments, crystalline, semi-crystalline, amorphous, and filler. Now here you see different types of thermoplastic materials with different properties and different kinds of processes being used to get the useful product. Like polystyrene, it has a low cost moderate heat distortion, good dimensional stability, good stiffness, and impact strength. Now here the process can be used like injection molding or continuous laminating. Similarly, nylon, has a high heat distortion, low water absorption, low elongation, good impact strength, and good tensile and flexural strength and it can be injection molded or sometimes doe molding, doe molding we will discuss in a separate segment and rotational molding.

Then polycarbonate is a very common commutated plastic. This has self-extinguishing, high dielectric strength, and high mechanical properties and it can be injection molded. Then styrene acrylonitrile, has good solvent resistance, good long-term strength, and good appearance, it can be injection molded. Acrylics, they are having very good gloss, weather resistance properties, optical clarity, color, the excellent electrical properties, they can also be injection moulded. Apart from this, this can be vacuum forming, compression molding can be carried out with the acrylics as well as continuous laminating.

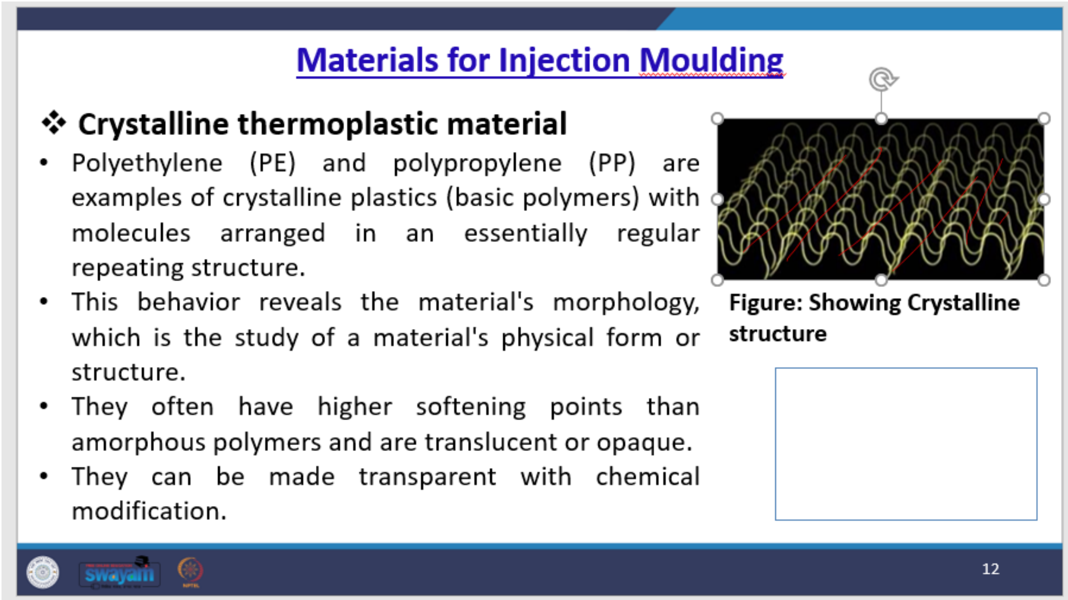
We will discuss all these segments in due course of time. Then vinyl, they are excellent weather ability, superior electrical properties, excellent moisture, and chemical resistance, and self-extinguishing and this can also be injection molded. Then acetals, have very high tensile strength and stiffness, dimensional stability, and high chemical and abrasion resistance, this can also be injection molded. The purpose of this particular property is that once you require the specific properties, you must have a material of your choice. Like, suppose you need the simplest material, versatile and economical, widely used by the family of resins, you must choose polyesters and they are because they also have good electrical properties, good chemical resistance, and specialty, especially to the acids, etc.

So they have a very good resistance attitude towards these types of attacks and this can also be injection moulded. Apart from this various other processes can be used to get the desired product like compression molding, filament winding, hand layup, matte molding, and pressure bag molding, all these things can be carried out. Then epoxies, they are having excellent mechanical properties and these are the thermosets and the dimensional stability is again very good. The chemical resistance they possess has good chemical resistance, low water absorption, low shrinkage properties, and a good abrasion resistance. So if you are looking for the material that is quite essential for this one, then definitely the epoxies are the better choice also you can go for compression molding, filament winding, hand layup, continuous pultrusion, encapsulation, all those things can be carried out.

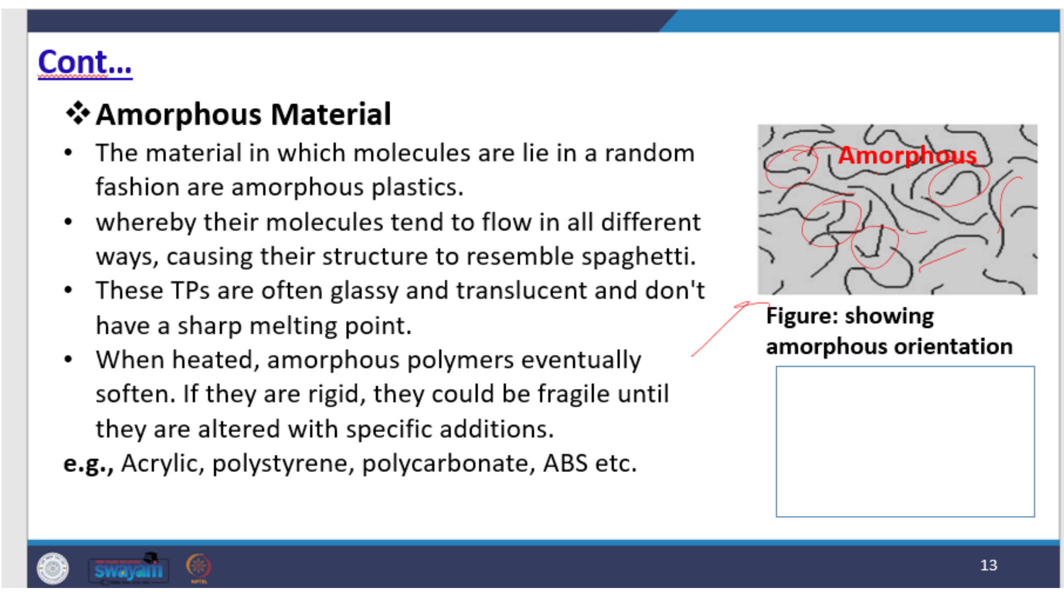
So when we are discussing the other thermosets, now the phenolics again are having a good choice, they have good acid resistance, good electrical properties, high heat resistance and they can be compression molded, they can have the continuous laminating all those things. Then silicones, they are having the highest heat resistance and low water absorption and they possess excellent dielectric properties with high arc resistance. So this can also be injection molded and encapsulation can be carried out to get the desired product. Melamine is a very common thermoset, they are having good heat resistance, and high impact strength, apart from this the daily phthalates, they are also having good electrical insulation and low water absorption. Both of these things can be compression molded so that we can get the desired product, all the switches and other things can be compression molded.

Now let us have a brief outlook on the different types of thermoplastics, the crystalline or amorphous. They usually soften during the processing and harden after cooling into the products that can be repeatedly softened by reheating with the crystalline or amorphous morphology. So based on the molecular structure. During the heating cycle, care must be taken to avoid any kind of degradation or decomposition. Otherwise, you cannot recycle and they cannot acquire this original chemical property once you are recycling them.

So you have to be very careful about this one. Now some thermoplastic experiences, there are no changes or essentially no substantial property changes unless otherwise you are not promoting the degradation or decomposition. Some of them though might have substantial alteration because of the impact of heat. Now crystalline thermoplastic materials, polyethylene, and polypropylene are examples of crystalline plastics, the basic polymer with molecules arranged in an essentially regular repeating structure like seen in this particular figure. Now this behaviour reveals the material's morphology which is the study of the material's physical form or structure.



Now they often have higher softening points than amorphous polymers and they are translucent or opaque. Now they can be made transparent with chemical modification. Now let us talk about amorphous materials. Now the material in which the molecules are lies randomly, they are amorphous plastics. Now whereby these molecules tend to flow in different ways.



This may cause their structure to resemble spaghetti. Now they are often glassy, translucent, and do not have a sharp melting point because you see the variety of the chains we discussed in the very first chapter. When heated amorphous polymers eventually soften and if they are rigid they could have been fragile, they could be fragile until they are altered with the specific addition. For example acrylic, polystyrene, polycarbonate, ABS, etc. Now the figure shows the amorphous orientation.

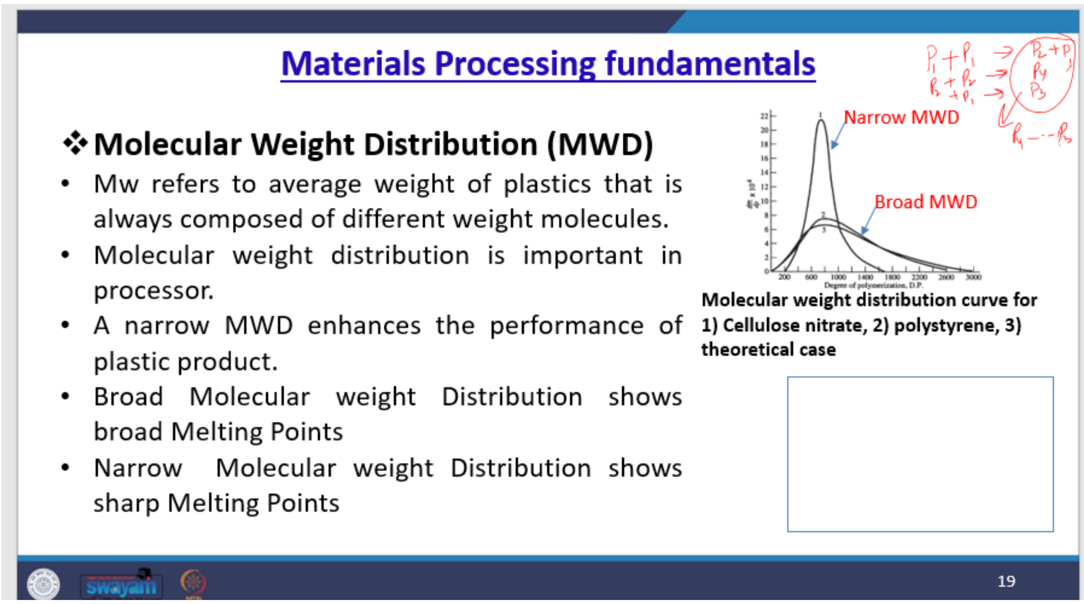
You see the different types of orientation here. Now in the molecules those who fall in the crystalline and amorphous pattern, you can see over here. The crystalline normally has up to 80 percent crystalline structure and the rest is amorphous. I am talking about the thermoplastic. Now there is a difference between there is a couple of differences between the crystalline and amorphous material.

The crystalline plastic requires more precise control during fabrication, processing and which is more challenging although it is controllable it is challengeable. They have a high melting point and they tend to shrink and deform more than amorphous plastic. Now when melting or solidifying during the processing amorphous polymers only experience they experience minor volumetric change in comparison to the crystalline kind. So when hot melt is cooled to solidify the polymers that typically crystallize are not properly quenched which results from the amorphous or partially amorphous solid state that often has the inferior characteristics. Because there is a regular during the melting state there is a regular motion of the polymeric chain.

So if they are properly quenched then this molecular motion the chain motion is seized and then you may have proper characteristics but if it is not being properly quenched then some of the chains are also in the amorphous region and then or they are partially amorphous solid state then you may have some inferior characteristics. Let us talk about the molecular structure, property, and the process. Now three molecular structures or properties affect the processing performance. Flow condition we are more concerned about the flow condition. These affect the product performance like strength, dimension stability, etc.

One is the mass or density, next is the molecular weight, and then the molecular weight distribution though we have discussed some of the things let us have a brief outlook about this mass or density. The density has a direct effect on the properties such as stiffness and permeability to gas or a liquid and a change in the density may also affect some of the mechanical properties. Then the molecular weight, the molecular weight is the sum of atomic weights of all repeating units or all atoms in the molecule which has polymerized having many different chain lengths. So the molecular weight of the plastic influences its properties. In the first week, we discussed the effect of molecular weight on the various properties including the glass transition temperature, etc.

Now an increase in the molecular weight properties increases the abrasion resistance, brittleness, chemical resistance, elongation, hardness, melt viscosity, tensile strength, modulus toughness, and yield strength. Decrease occurs in the adhesion, melt index, and solubility. Now molecular weight distribution, we discussed the three different types of molecular weight distribution patterns, number average, weight average, and viscosity average molecular weight in the first week. This molecular weight refers to the average weight of plastics that are always composed of different-weight molecules. Now we have already discussed why polymers they are having the molecular weight distribution because, at any point in time, you cannot precisely say that polymer mass has this much of the chain and every chain has a unique molecular weight so that you can multiply the molecular weight of the particular chain into the number of the chain so that you can get the molecular weight of the polymer but it is not easy.



The reason is that you are first suppose you are having this P1 monomer. Now this P1 monomer in a reaction mass may combine with the P1 to give you P2. Now here the reaction mass may have the P1 and P2 at the outset. Now this P2 may react with P2 or it may react with P1.

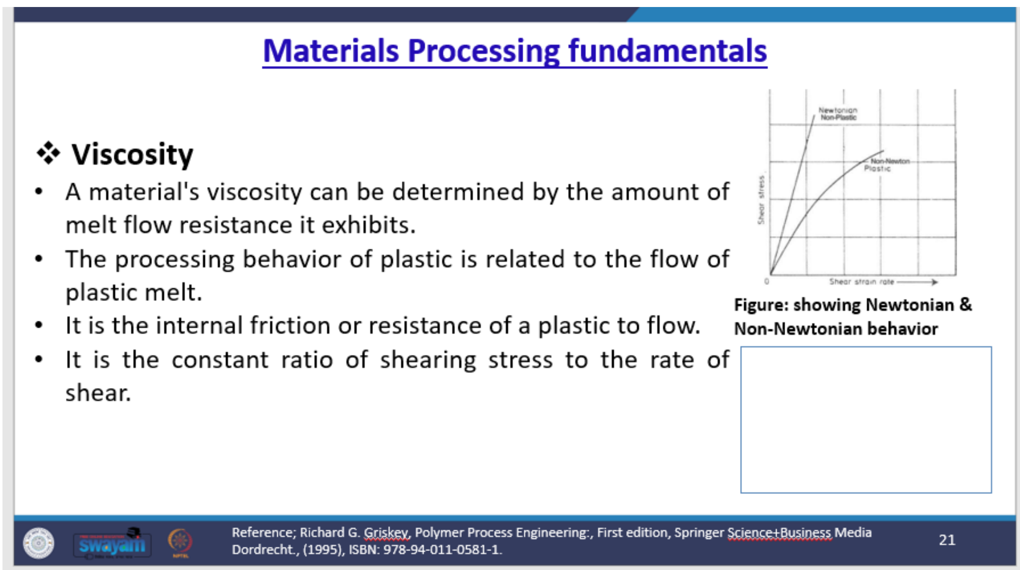
$$P_1 + P_1 \rightarrow P_2$$

$$P_2 + P_2 \rightarrow P_3$$

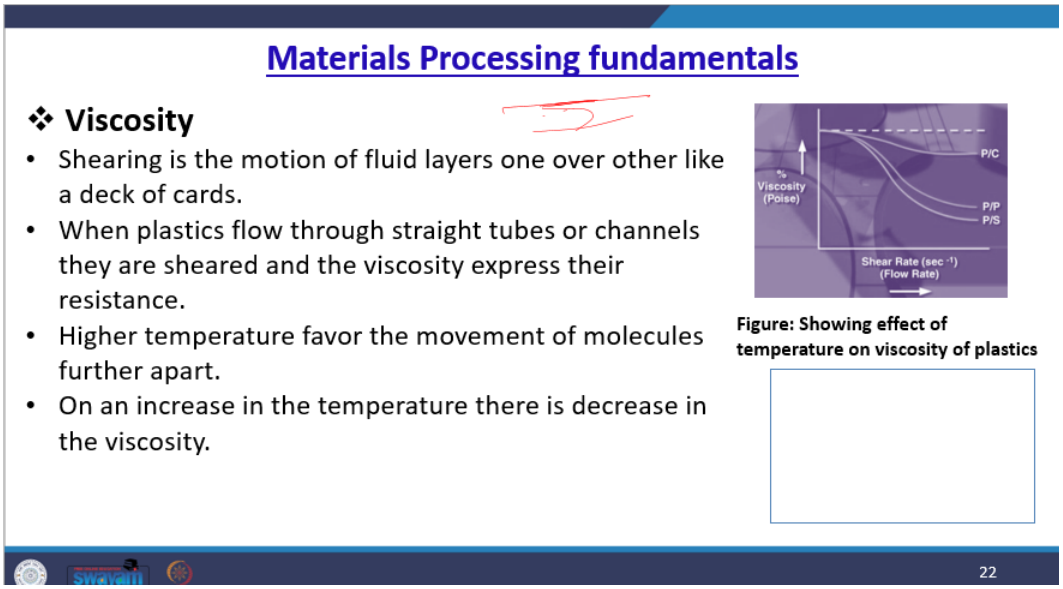
$$P_1 + P_2 \rightarrow P_4 \quad \ldots$$

So it gives the P4 and a P3. So the reaction mass may have P1, P2, P4, and P3 which means that P4 they have 4 repeating units, P3 may have 3 repeating units, and P2 they have 2 repeating units. Similarly, if we go on further polymerization then the system may become more and more complex up to P4 to Pn and that is why the chain length is not fixed and that is why we have the molecular weight distribution right from P1 to Pn. So this molecular weight distribution is an important process. A narrow molecular weight enhances the performance of the plastic product because definitely, you will have a more and more useful polymer. So a broad molecular weight distribution shows a broad melting point and a narrow molecular weight distribution shows a sharp melting point.

So wide molecular weight distribution permits the easier processing and the processing and property characteristics of plastics they are partly a function of molecular weight distribution that may vary widely even among the plastics of identical composition, density, average molecular weight, and melt index. So all these things are essential for the proper processability of a polymer. Now a method for usually determining the distribution of molecular weight we have already discussed fractionation, sedimentation, gel permeation, chromatography, and rapid estimate all these things because you know that the determination of molecular weight distribution is essential for them to assess the polymer being processable or not. So you need to carry out this particular analysis before you go for the processing. The viscosity, this material viscosity can be determined by the amount of a melt flow resistance it exhibits.

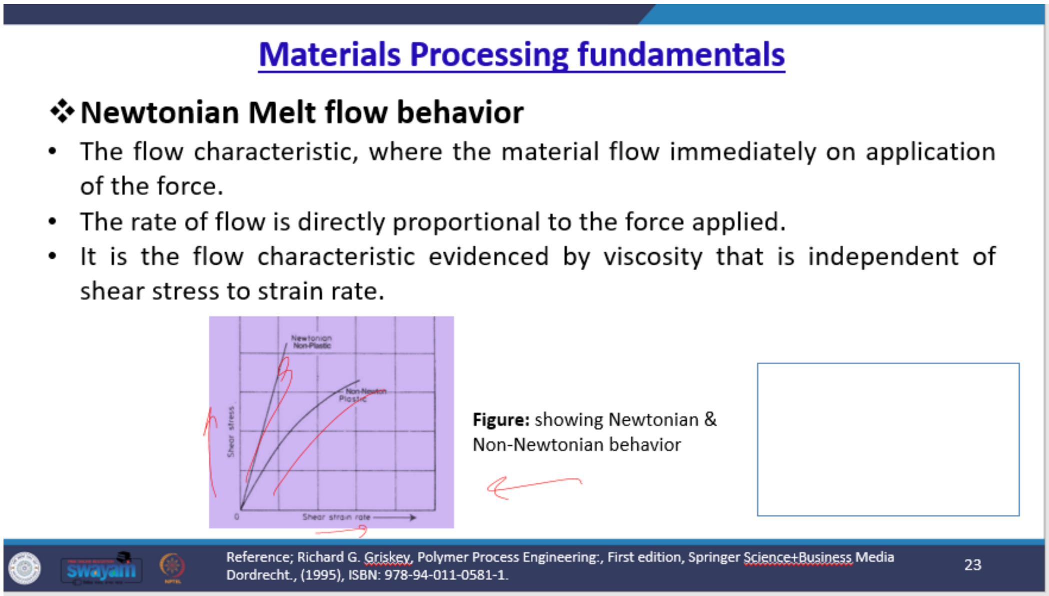


There are so many methods available as of date to find out the viscosity. Now the processing behavior of plastic is related to the flow of plastic melt as we see we saw in the first segment of this injection molding because the processing because if the viscosity is too high then energy consumption and deformation may take place but if the viscosity is too low then either the product may not have such kind of the properties which is required or it may in a flow of behavior so proper pressure cannot be applied in the injection molding machine. So the proper viscosity is essential. Now if the internal, if it is the internal friction or resistance of plastic to flow it is a constant ratio of the shearing stress to the rate of shear. Now shearing is the motion of a fluid layer one over another like a deck of cards.

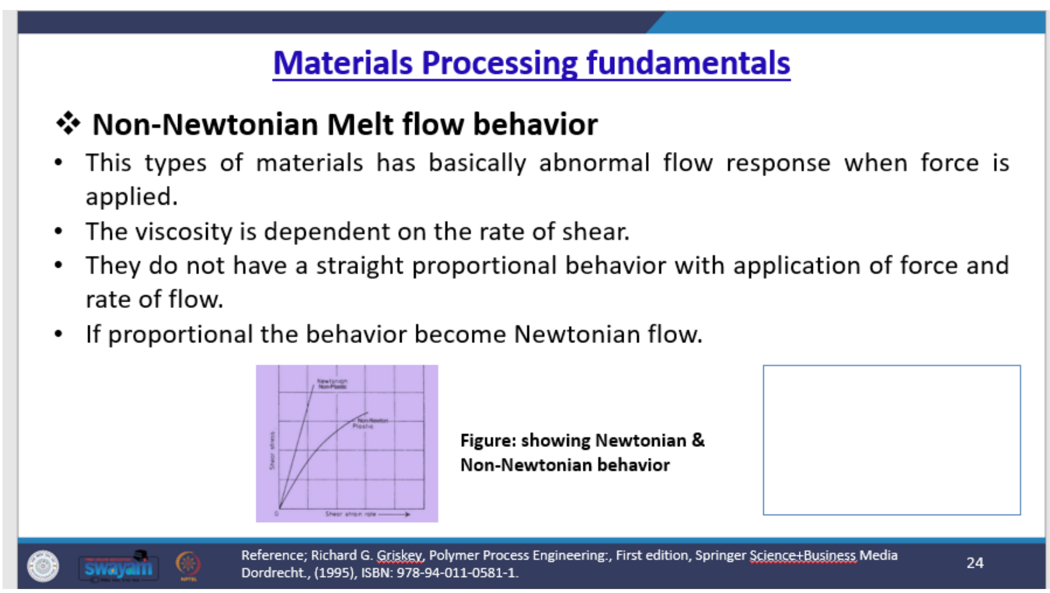


So like if you are moving then these surfaces are resistance impart the resistance. So suppose I am moving this then the lower part of the surface tends to go into the opposite direction. So it is just like whatever pressure you applied for moving a deck of cards. So when plastic flows through the straight tubes or a channel the sheared and viscosity express their resistance. So if it is in the tube then this is the stagnant layer and movement is like this.

The higher temperature favors the movement of molecules further apart because in that case, the viscosity is very low. On the increase of the temperature there is a decrease in the viscosity so it favours the thing but simultaneously must have an optimum viscosity otherwise it may create a problem with the period. Let us talk about Newtonian melt flow behavior. The flow characteristics where the material flows immediately on application of the force the rate of flow is directly proportional to the force applied. Now it is the flow characteristics evidenced by the viscosity and that is independent of shear stress or strain.



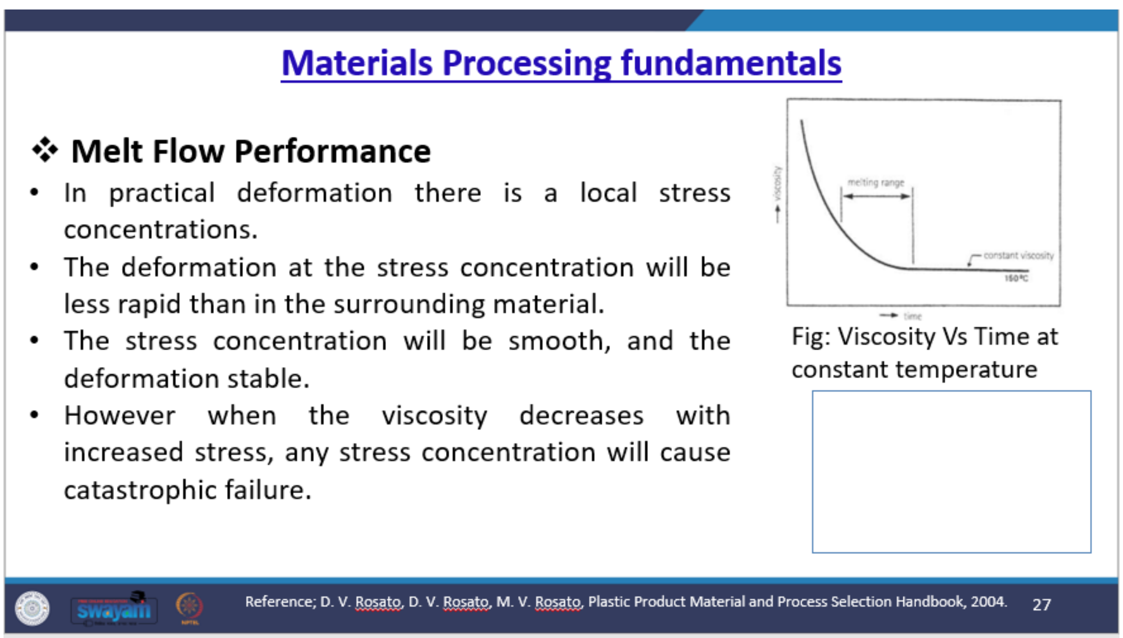
Now here you see the Newtonian and non-Newtonian behavior. This is the shear stress rate and shear stress. Now this is the non-Newtonian plastic and this is the Newtonian the non-plastic. Now this type of material has abnormal non-Newtonian melt flow behaviour. This type of material has an abnormal flow response where force is applied.



Now viscosity is dependent on the rate of a shear and they do not have a straight proportional behaviour with the application of force and a rate of flow. Now if proportional the behavior becomes the Newtonian flow. The melting temperature is very crucial as in the previous segment we see that the melting temperature is you can say the triggering point of a smooth operation of any injection molding machine. Now this is also known as the melting point and is usually represented as TEM which the plastic liquefies on heating or solidifies on cooling. So the proper information of this melting point is quite essential.

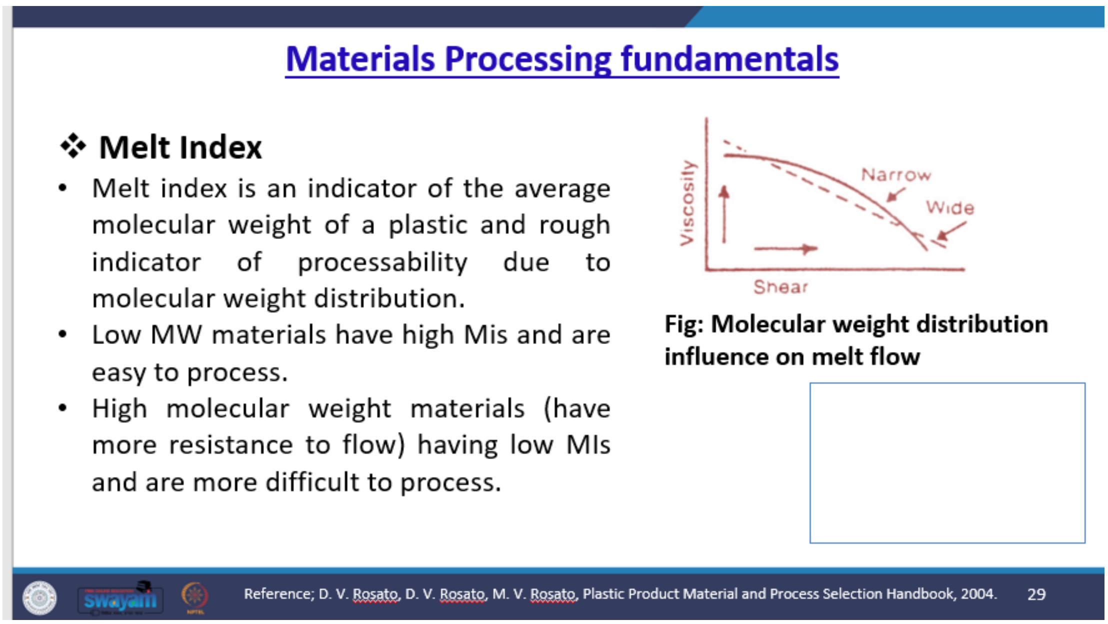
Now it depends upon the processing pressure and time heat, particularly during slow temperature changes for relatively thick mass. So when the melting temperature is too low the melt viscosity is high so more power is required to process the plastic. That means the economy is on the lower side. Sometimes degradation can also occur if the viscosity is too high because of the frictional heat being generated when the material is being processed. So the amorphous crystalline regions can be determined or identified by the peaks of the differential scanning calorimeter through the thermal analysis test.

The melt flow rate is used to detect the degradation of the fabricated product where the comparison as an example they are made of the melt flow rate of pellets to the MFR of the product. Now the melt flow rate has a reciprocal relationship to melt viscosity and melt flow rate is inversely proportional to the molecular weight. So that is why molecular weight is again very important to determine. Melt flow performance is again very important. Now in practical deformation, there is a local stress concentration.

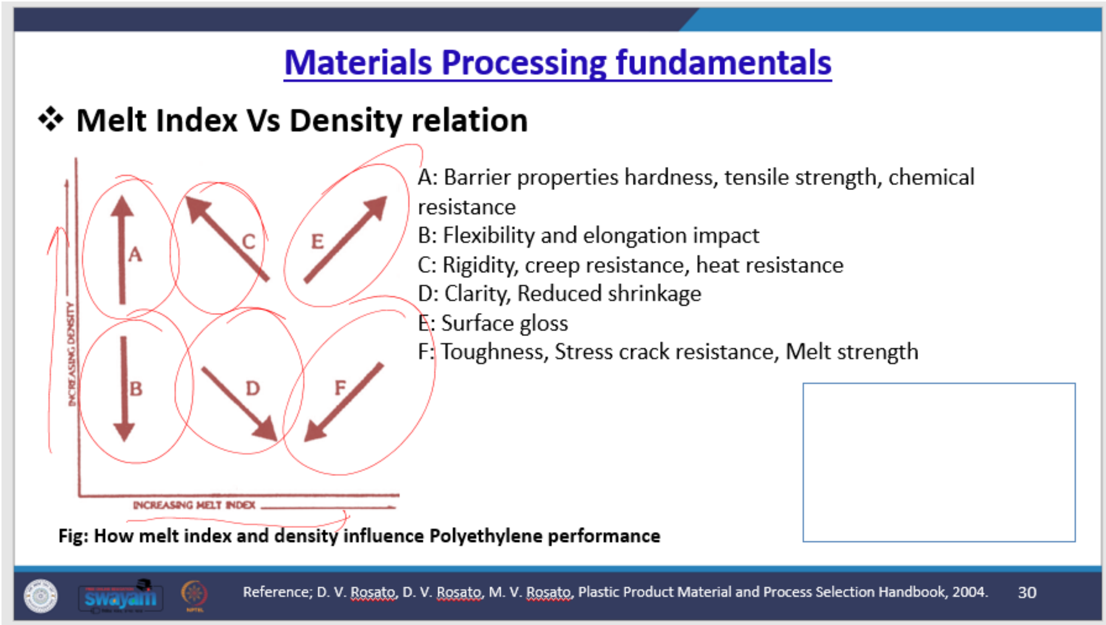


The deformation at the stress concentration will be less rapid than in the surrounding material. So the stress concentration will be smooth and the deformation stable. So when the viscosity decreases with the increased stress any stress concentration will cause catastrophic failure. Sometimes we need to discuss the melt flow defects. The melt flow defect plays a very important role in many processes as they affect the appearance of the product.

The effects can be identified and corrected it is a routine process and these flow analyses can be related to the other process and even complex flow injection molding. Melt index, the melt index is an indicator of the average molecular weight of a plastic and rough indicator of the processability due to the molecular weight distribution as we have discussed in the previous lectures. Low molecular weight materials have a high melt index and are easy to process. High molecular weight materials because of their bulky character have more resistance to flow have low melt index and are more difficult to process. So whenever you go for this type of melt index on step then molecular weight distribution you need to draw a plot for the molecular weight distribution influence on melt flow with the help of viscosity versus shear.

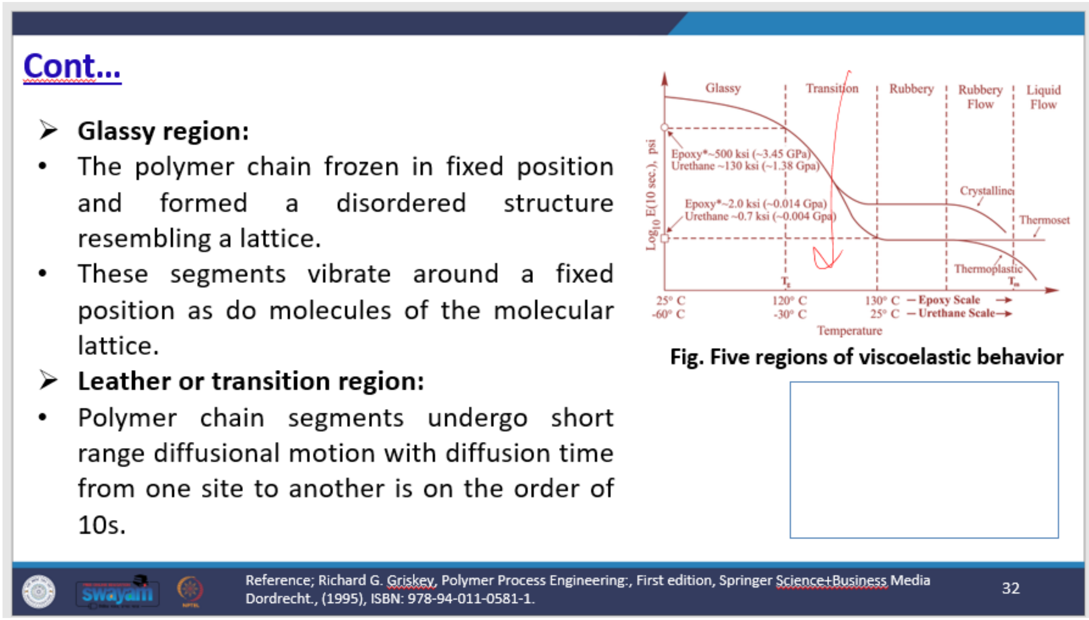


Melt index versus density relation. Now here you see that we have plotted a graph for increasing melt index and decreasing density for the different indices like barrier properties, hardness, tensile strength, and resistance. So at a fixed melt index if you increase the viscosity then it will go up. Then the flexibility and elongation impact, rigidity, creep resistance, heat resistance, clarity, surface gloss and toughness, stress crack resistance, melt resistance. So all these things are very important and you see when it gives you an idea of how melt index and density influence the polyethylene performance.

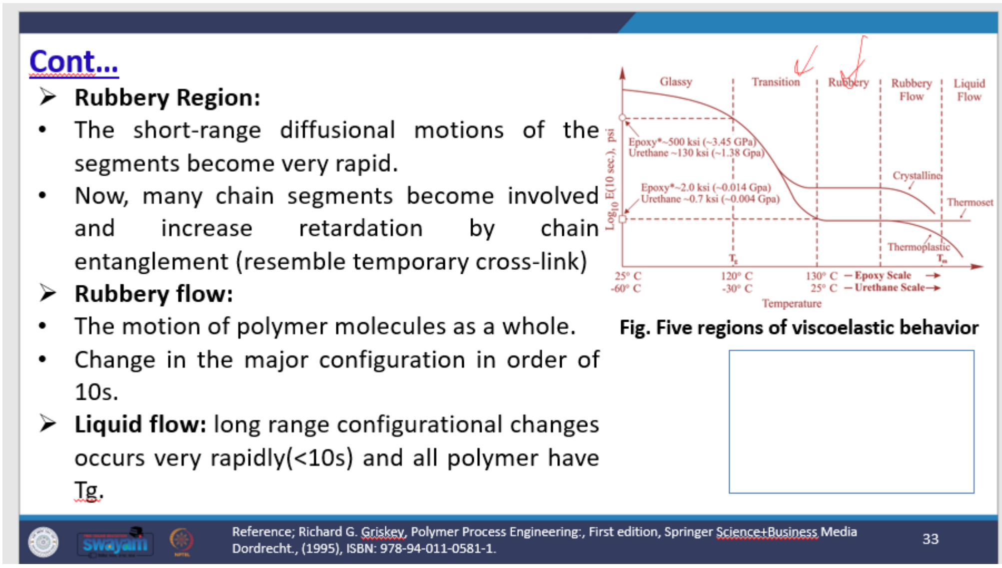


So for every polymer, you may have such kind of a plot. Now let us discuss the effect of temperature on polymer structure. Now temperature can influence the behavior of polymers, and change in phase from solid to molten state which is desirable in the case of injection molding. Now such changes involve melting point and the transition that results in a change in state or phase they are classified as transition. The second form of transition can take place in the polymer-like second order, this shows the type of polymeric behavior. It gives a relation of the logarithm of mechanical modulus for polymer as a function of temperature.

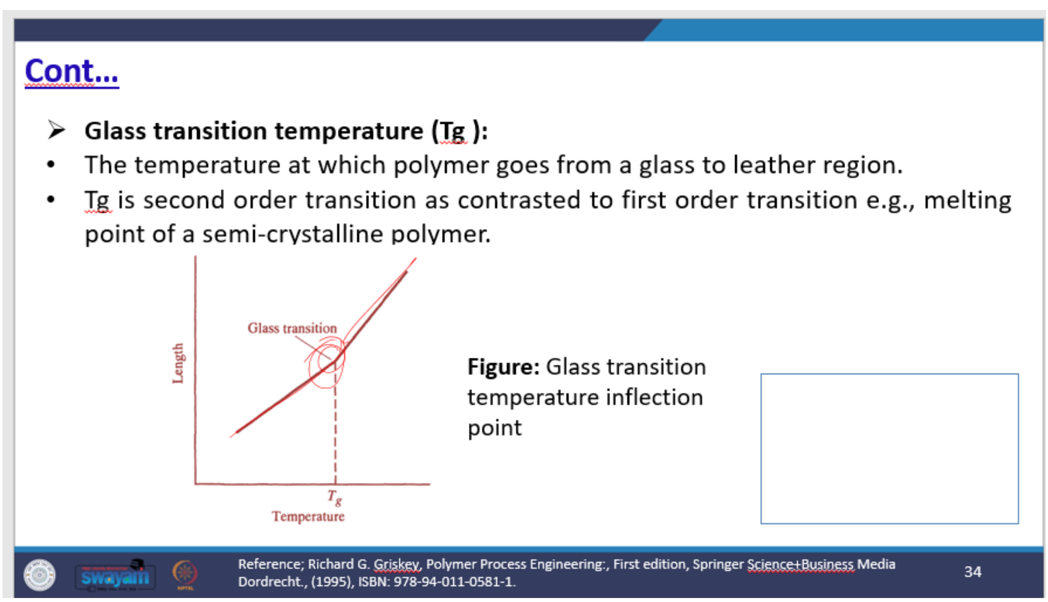
Now as on heating if you keep on heating the polymer goes from the glass to leather to rubber to ultimately liquid flow. So when you are heating initially all the polymer chains are entangled position. So upon heating the shear is coming out and the polymer chains try to get unentangled so that they start melting and that is the glass transition temperature then leather to rubber and all those then the liquid flow. The glassy region of the polymer chain froze in a fixed position and formed disordered structures like discussed in that entangled position and resembled a lattice. These segments vibrate along the fixed position to add molecules to the molecular lattice.



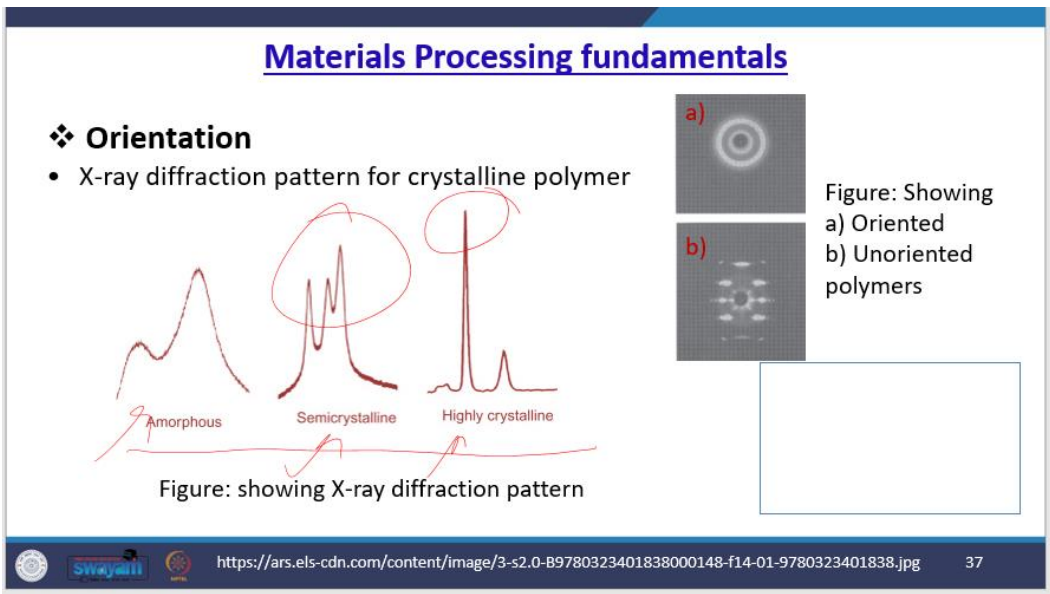
Now the leather and leather or transition region of the polymer chains like here you see the polymer chain segments undergo short range diffusional motion with the diffusion time from one side to another in the order of say 10. Now rubbery region the short diffusional motion of the segment becomes very rapid and now many chain segments become involved and increase the retardation by the chain entanglement and resemble the temporary cross-linked. The rubbery flow is the motion of the polymer molecules as a whole this changes in the major configuration and this is what you see at the start of the flow. The liquid flow is the long-range configurational changes that occur very rapidly and all polymers have a glass transition temperature. The glass transition temperature we have already discussed in the first week is the temperature at which the polymer goes from glass to leather region when it starts just to start the flow.



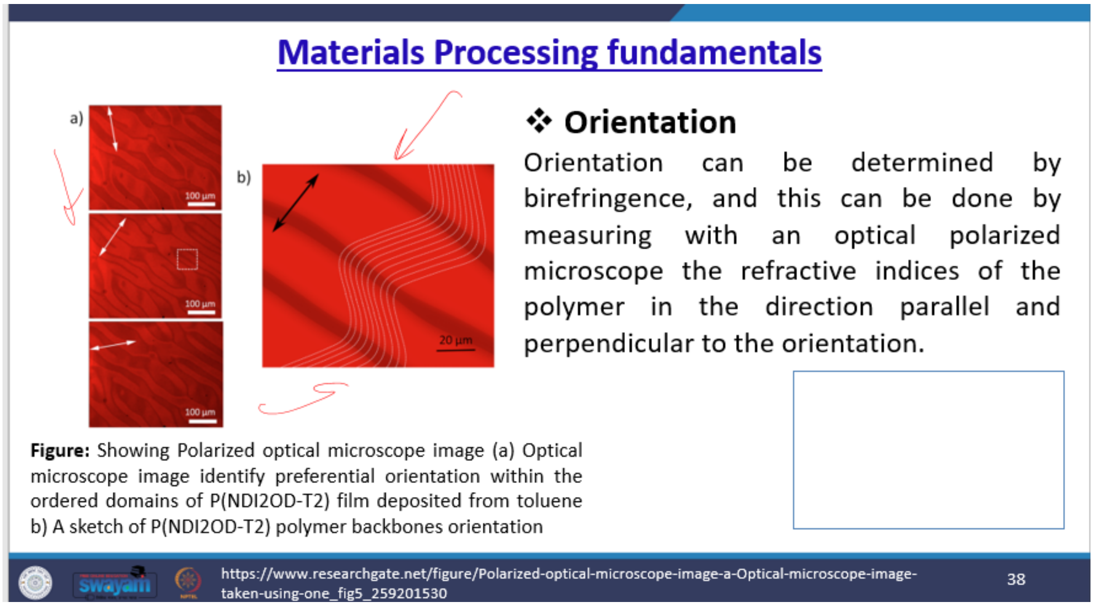
Now glass transition is the second order transition in contrast to the first order transition that is a melting point of semi-crystalline polymer. Now here you see that this is the glass transition temperature when this is a triggering point. Orientation The orientation represents the alignment of the polymer molecules. So for crystalline structure, the orientation can and does occur in the amorphous material. When mechanical stress the amorphous polymer molecules or the crystalline this will be oriented.



It is possible for orientation to bring about the crystallization and this occurs when the crystalline polymer has melted into an amorphous state. So there are 3 principal methods for measuring the orientation in polymer one is the XRD or X-ray diffraction pattern for crystalline polymer. The orientation and refringence measuring the optical polarized microscope and by the sonic modulus. The orientation is usually carried out with the X-ray XRD X-ray diffraction pattern you see different types of XRD patterns like amorphous, semi-crystalline, and highly crystalline. Now this orientation can be determined by the B-refringence and this can be done by measuring with the optical polarized microscope the refractive indices of the polymer in the direction parallel and perpendicular to the orientation.



Now here you see that the polarized optical microscope image for different reasons like optical microscope image identifying the preferential orientation in the order of domain film deposited from toluene and this is the sketch of a polymer backbone orientation. So the sonic modulus is the third one to determine the orientation and this is done by transmitting a sound wave through the polymer sample. So the temperature and the sonic molecule give you which type of plot it is and by this way, you can assess whether it is oriented or nonoriented. Now here you see the sonic velocity of 3 polymer films plotted against the orientation of the PET film and then the polypropylene and the polyethylene you see the different types of orientation concerning the angle and you can determine the nature of the polymers. So in this particular segment, we discussed all the different materials because in the first segment of injection molding, we discussed that the product quality, and product form all depend upon what different kinds of materials you are using and what is affinity with others and how this particular thing is processable into the different machine.



So we had a brief outlook about the different types of thermoplastic thermoset material what different kinds of things you can form and what kind of different processes you need to adopt. For your convenience, we enlisted references you can use as per your requirements. Thank you very much.