

A Study of Plastic Extrusion Process and its Defects

Pankaj M.Patil¹, Prof. D.B. Sadaphale²

¹Student of M.E(Machine Design), Mechanical Engineering Department, SSBT COET, Bambhori-Jalgao, Maharashtra, India

²Faculty Member of Mechanical Engineering Department, SSBT COET, Bambhori-Jalgaon, Maharashtra, India

Abstract-Extrusion is by far the most important and probably the oldest transformation and shaping process of thermoplastic polymers. To ensure a quality through extrusion process during manufacturing, it is essential to discover, control, and monitor all quality parameters. Some of the important parameters are state of equipments, working conditions, temperatures, pressures, quality of dies, materials and cooling medium. Instead of the truthful efforts from the manufacturers, still there are number of obstacles in the process which show the way to defects in the product. The purpose of this paper is to properly understanding the extrusion process and focus on the various defects and its impact on product quality.

Keywords-Extrusion Process, Shaping Process, Product Quality, Quality Parameters, Cooling Medium.

I. INTRODUCTION

Plastic processing needs the knowledge of basics of raw materials, additives, process control and finally the product properties required to finish end products. Plastic materials have a useful combination of properties that can be modified for used wide range of applications.

In thermoplastics, processing techniques can be classified into either batch or continuous process. Batch process includes injection moulding and roto-moulding. Extrusion of plastics is a continuous process. However, blow moulding is available both in batch and continuous process. In these days, online continuous thermoforming machines are available along with extrusion process. [9]

Various products manufactured through above mentioned processes are highlighted in the following table.

Classification of plastic products as a type of process

Plastic products	Extrusion	Films and sheets, fibrous and filaments pipes, conduits and profiles, strapping.
	Injection Moulding	Industrial Injection moulding, Household Injection moulding, Thermo ware/Moulded luggage.
	Blow Moulding	Bottles, Containers, Toys and housewares, Air Ducts,panels.
	Roto Moulding	Large circular tanks such as water tanks.

Extrusion process is the most commonly used process in India and accounts for ~60% of total consumption by downstream plastic processing industries. Injection

moulding is the other popular process accounting for ~25% of the consumption. Blow moulding is used for ~5% while Rotomoulding 1% while the rest of the plastic is processed through other processes. [2]

From the above data we can see that ~60 % extrusion process used in the industry but it has been observed that there are lots of problems in extrusion process which lead to defective products. In extrusion products, defects due to processing include, poor understanding of the processing method, use of old machines, be short of trained staff, machine break down. Due to this it become essential the industries have better extrusion process.

II. PLASTIC EXTRUSION PROCESS

Plastic extrusion is a high-volume manufacturing process in which raw plastic is melted and formed into a continuous profile. This process starts by feeding plastic material (pellets, granules, flakes or powders) from a hopper into the barrel of the extruder. The material is gradually melted by the mechanical energy generated by turning screws and by heaters arranged along the barrel. The molten polymer is then forced into a die, which shapes the polymer into a shape that hardens during cooling.[13] There are two basic types of plastic extrusion: screw extrusion and ram extrusion. A ram extruder is an extruder where, instead of extrusion screw, a ram or plunger is used and a plunger goes through a barrel and pushes out the material under pressure. The ram extruder was the earliest extruder to be used in the plastics industry. This typical process is applied for producing profiles, sleeves, rod, block, tubing, lining sheet bars, etc. The ram extrusion process is very effective for specific materials like PTFE which are not extruded successfully using screw extruder because of its low friction. In this process plastic material in powder form is gravity fed into a chamber. In the extrudating chamber the resin powder is heated on sintering temperature. Ultra high molecular weight polyethylene becomes gelatinous as it melts so it can be extruded with this type of processes. A hydraulic ram pushes the resin materials like PTFE, UHMW, etc. from the chamber to the die. The die actually gives the shape of the desired plastic like a rod, tube or a profile shape with the requisite internal or outer diameter. When the material comes out of the die, it moves the length of the conveyor. The profiles can be manufactured endlessly and cut by the continuous extruding of each length. Screw extrusion involves a helical feed screw that turns inside a barrel. This is often called the feed screw or the extruder

screw. The screw is a single shaft with helical flights. Sometimes, when more thorough mixing is needed, two screws are used. The constantly turning screw moves the resin through the heated barrel where it is heated to proper temperature and blended into a homogeneous melt. Extrusion screw design has been improving over the years, with new innovations and ideas. Nowadays, single screws are available that have a secondary flights that improve speed by enabling faster melting. This process of extrusion serves two functions: it heats the plastic material above its melting point and puts the melt under pressure. The molten plastic material can then be forced through an orifice, commonly known as the die. This process is common to all types of extrusion. Most screws have these three zones, Feed zone (also called the solids conveying zone): this zone feeds the resin into the extruder, and the channel depth is usually the same throughout the zone. Melting zone (also called the transition or compression zone): most of the polymer is melted in this section, and the channel depth gets progressively smaller. Metering zone (also called the melt conveying zone): this zone melts the last particles and mixes to a uniform temperature and composition. Like the feed zone, the channel depth is constant throughout this zone. A great advantage of extrusion is that profiles such as pipes can be made to any length. If the material is sufficiently flexible, pipes can be made at long lengths even coiling on a reel. Another advantage is the extrusion of pipes with integrated coupler including rubber seal.

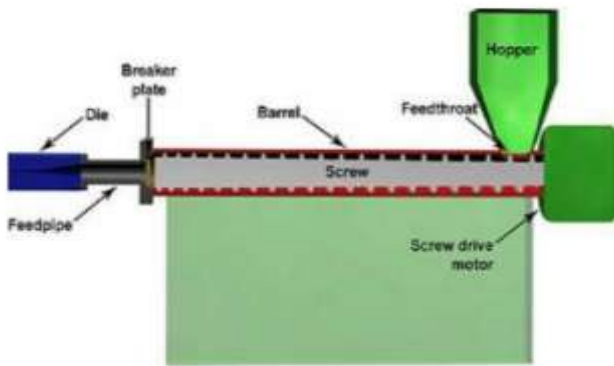


Fig. 1 Plastic Extrusion Process [6]

III. DEFECTS

Defect is any form of deviation of the product's characteristic from the specification set up by the manufacturing process. It can be caused by a single source or the cumulative effect of several factors, which may arise at any stage of the processing. The common failure or defects which are normally occurring in plastic extrusion process are due to three main causes: mould design, material selection, and processing. [1]

Some of the common extrusion defects are Improper operation, Resin Defects, Trapped air, Overheating, Melt

fracture, Moisture absorption, Poor Mixing, Surging, Improper Material Addition, Improper system engineering and installation.[3] Some other defects are Sink, poor or nonuniform gloss, Weld lines, Gels and plate out, Warp.

A. Improper Operation

There is a molecular orientation change, resulting in a variation in the machine direction versus the transverse direction properties. Depending on the orientation change, the properties in the machine direction may increase or decrease, with the corresponding properties in the transverse direction varying in the opposite direction. In other words, if the tensile properties in the machine direction increase, they will decrease in the transverse direction, and vice versa. A potential cause for the change in molecular orientation is the draw ratio has changed between the extruder and the puller. This only occurs with a die with an adjustable gap, where the die lip setting has been changed. As the die lips are opened, a higher draw ratio is required to maintain the final product dimensions. In processes with nonadjustable die lip openings, the product dimensions are changed as the puller speed or the extruder screw speed is changed. With an adjustable die opening, the product thickness exiting the die can be increased or decreased through die adjustments. As the die is opened, the puller speed is adjusted to maintain the product dimensions, causing the product draw ratio to be increased and changing the product orientation. [7]

Gauge variations are defined as thickness nonuniformities in the final product. This changes in product dimensions are due to the no uniform melt temperature that result into polymer viscosity variations and causes of nonuniform melt temperature are poor melt mixing, an unevenly clogged screen pack due to that polymer flows through one part of pack to another.

If take off equipment is not functioning properly, the product slippage can cause thickness variations. Slippage in the puller allows the product dimensions to rise for the reason that the product is not being pulled away from the extruder at the proper rate. The caterpillar or puller pressure has to be adjusted to prevent the product from slipping without causing any distortion or damage to the final product.

1) Remedies

- Verify puller speed correct.
- Verify screw speed is properly set.
- Check extruder temperature and adapter set points.

2) Impact on Product Quality

Uneven wall thickness

B. Resin Defects

Due to resin contamination a chemical reaction in the extruder that may generate gases. It is easily corrected by

properly purging the extruder with a nonreactive resin and by avoiding or removing any contamination from the product prior to feeding it to the extruder.

If moisture induced in the resin is not removed from resin by an atmospheric or vacuum vent it exist the die as steam and causes holes in the product can result. With predried resins still containing a few moisture or moisture that has condensed on the pellet surface, rather than a hole, the moisture can cause surface splay on the extruded part. Splay indicates moisture or gases are there, but their concentration is lower than the critical amount required to blow bubbles in the product.

Due to overheating resin degradation in the extruder or die occurs .It decreases product strength in all directions. It is normally cause by the hot barrel or die temperatures, a wrong screw geometry, long residence time at high temperature.

1) Remedies

- Purge extruder or die.
- Screen the resin material.
- Exact addition of (Percentage of mixing) resin material.
- Increase rpm back pressure for better mixing.

2) Impact On Product Quality

Blow holes formation on the product

C. Trapped Air

Trapped air can be more problematic when starting material is powder compared to pellets. Because powder bulk density is lesser and introduces more air into the extruder. A higher compression ratio screw is used with powders, ensuring that the transition flights are full of melt, preventing air from entering the metering section. Vents and vacuum hoppers will eliminate trapped air and are essential for powders where passages between particles are much smaller. The air cannot escape through this passages and it is carried forward instead

If pelletized material used with long extruder barrel trapped air is not common. Though some old machines have short barrels and even long machines can be pushed so fast that air carried forward in the in the product. Trapped air surface shows bubbles and pits. Such surface will improve if run more slowly if moisture is not problem.

1) Remedies

- Avoid the over-speed of extrusion.
- Increase plastic melt temperature.
- Increase rear barrel temperature.

2) Impact on Product Quality

A trapped surface shows bubbles pits, but little if any dotted lines.

D. Overheating

Overheating may produce degradation of polymer material that is used or make dimensional control and sizing difficult or may limit if takeoff cooling is limited.

It's generally assumed that much of the heat for melting is generated by the barrel. That's true in some instances, but the heat from the barrel has to be conducted from the barrel wall clear through the layer of polymer in the screw channel to do any significant melting. Since polymers are excellent insulators, conducting heat is one of their worst features. In reality, melting occurs in single-screw extruders primarily as a result of shear heating of the polymer. Shear heating is the result of a polymer-filled screw rotating within the barrel. This is a lot easier to understand if you picture the screw as a simple round shaft with no flights turning inside a heated tube filled with a highly viscous material. The amount of shear heating versus the degree of heat conducted from the barrel for melting depends a lot on the gap between the shaft and tube. Generally speaking, the larger the screw, the deeper the channels, and the more important the contribution of shear heating .In the case of smaller screws with shallower channel depths, the transfer of heat into the solid occurs more quickly because there is less distance for the heat to travel through the insulating layer of the polymer itself. In these cases, the transient conductive heating of the solid polymer from the barrel heat can add significantly to the melting or softening temperature suitable for extrusion processing. But that's only if there is enough time available. Except in cases where the screw is very small and turning very slowly, depending on conductive melting severely limits the potential output by waiting for the heat to fully penetrate the solid polymer. The interval of time to conduct full heat transfer increases exponentially with thickness, so that the difference in time to transfer heat through even a small increase in polymer thickness can be surprising. [12]

1) Remedies

- Avoid overheating and make sure that the temperature we heat the polymer is safe and causes no degradation.
- Very accurate temperature control is needed for materials susceptible for degradation.

2) Impact on Product Quality

This create problem in the cooling of product

E. Melt Fracture or sharkskin

In the extrusion of polymer melts, below certain shear rates the emerging extrudates have smooth surface. As the rate increases, small amplitude periodic distortions appear on the surface (sharkskin melt fracture).As rate increases further, the extrudate becomes severely distorted (gross melt fracture). [10]

Melt fracture is supposed to happen in the die entry region where material is being funneled from the melt reservoir into the capillary or die. In a full-scale extruder, this would match up to the point where melt moves into the die parallel portion of the die. Some further complicating effects may occur at the wall of the die. Melt Fracture is not surface phenomenon as with sharkskin in its place it completely goes through the extrudate. The form of the melt fracture distortion varies from one polymer type to another, but it is generally helical in nature. With materials such as polyethylene and polypropylene a distortion like a screw thread may appear, while with polystyrene the extrudate may form a spiral. Other polymer melts may show ripples, or bamboo-like repetitive kinks.

Sharkskin is believed to occur as a result of the melt tearing as it extrudes from the die. This occurs because, within the die, melt close to the wall is moving very slowly (in the case of the layer next to the wall this movement is zero). As the melt emerges, the whole extrudate moves away from the die face at a constant speed so that the outer layers are suddenly stretched and may tear. In the case of sharkskin, the distortion consists of transverse ridges. [8]

1) Remedies

- Lower the shear rate.
- Streamlining the die
- Slowing the extruder rate.
- Reducing the melt viscosity.
- Increasing the die temperature.

2) Impact on Product Quality

This refers to fine ridges or rough surface seen when the melt comes too fast out of narrow die.

F. Moisture Absorption

Many plastic materials absorb moisture. This moisture passes through the extruder and boils when the pressure is relieved at the die lips. A pattern of long bubbles and pits is the result. The maximum percentage of moisture in the granules for the production of good extrudates varies from polymer to polymer but in general should be kept below 0.1 % as measured by water absorption in 24 hours.

Thermoplastic polyester, the nylons and polycarbonate can degrade and weaken if even a very small amount of moisture present when they are melted. So they must be dried in dehumidifying dryers to get moisture turned down to 0.01 % or less.

1) Remedies

- To remove moisture, the material must be pre-dry.
- Vent must be used in the extruder.

2) Impact on Product Quality

The result is a pattern of dotted lines, long bubbles and pits.

G. Poor Mixing

First barrel section or feed zone on the extruder is normally water cooled with no heating present. Cooling is provided to prevent resin or additives from prematurely melting and sticking to the feed throat. Overtime, sticky or premelted material can agglomerate around the feed throat opening causing bridge to block the feed opening. Screw has deep high pitch feed element to provide maximum open area to transport resin away from the feed opening into the extruder. At start up the screw speed is normally run low with significantly reduced feed rate until material exist the die.[7]

Uniform heating around the whole die, transfer pipes and adapters is critical to guarantee uniform melt temperature and viscosity, resulting in consistent polymer flow out of the each die hole if fans or other cooling devices are blowing on one side of the die this can affect melt temperature distribution and affect polymer flow. Melt temperature kept uniform by providing fiberglass or other insulation around the transfer pipes and the die. The die or adapter linking gear pump and die will contain both melt temperature and pressure transducers. A pressure controller is programmed to control gear pump suction pressure by adjusting the extruder rpm. The gear rpm sets the extrusion rate. Finer screen pack too raises the pressure but they keep clogging, pressure is inconsistent. [7]

1) Remedies

- Exact addition of (Percentage of mixing) resin material.
- Check for foreign material.
- Increase rpm back pressure for better mixing.

2) Impact on Product Quality

This problem create the clogging in the extrusion

H. Surging

Surging is the variation in throughput (maximum rate of production at which something can be processed) resulting from a cyclic behavior, with excessive extruder output followed by low extruder output, then excessive output, and so forth.[7] Surging changes dimensions of the extrudate and limits extrudate tolerances in production.[11] It can be easily identified by die pressure, motor load, and product dimensions.

If in the transition section feed or transition temperature is low, the complete polymer mixing may not occur in the transition section, So, unmelted pellets entering the metering zone are difficult to melt and interface with screw mixing section. It interrupts the flow of polymer into the screw. This can be any mechanical device prior to the

screw such as a feeder or the geometry of the flow passage the polymer follows to get to the screw. Also, the polymer bulk-flow characteristics can cause bridging or tunneling that result in erratic flow to the screw. If the motor speed is pulsating, the screw speed is changing, with more and less material being pumped out the extruder as the screw speed changes.

If none of these outside causes are observed, it is probable that the surging originates inside, typically at the beginning of the compression zone, where the solid bed the mass of pellets may be locking and breaking up irregularly. Screw rpm is steady but the ammeter shows variations of $\pm 5\%$ or more. Sometimes this can be cured by increasing the temperature of the feed to promote earlier melting. Raising the rear barrel temperature may help, too. Make big changes, 25-50 °F (14-28 °C), and see what happens. Sometimes raising the barrel Temperature at the beginning of the compression zone will help by getting better sticking of the pellets to the wall there. [3]

1) Remedies

- Replace the screw.
- Installing a gear pump between the extruder and the die.
- Try to running the extruder slower or faster by at least 10%.

2) Impact on Product Quality

Variation in the thickness of the product

I. Improper Material Addition

The Resin materials such as nylon, polyurethane, polyester and polycarbonate and polycarbonate are very hygroscopic, absorbing moisture rapidly from the air. At extrusion temperatures, moisture degrades these materials to lower molecular weight polymers, resulting in poorer property performance. Proper drying to eliminate moisture is critical to obtain the optimum property performance in the final product. Other materials, e.g., acrylics, Ultem polysulfone, Noryl and acrylonitrile butadiene styrene (ABS), also absorb moisture from the air and must be dried prior to processing. Any moisture in the polymer is converted to steam in the extruder and, depending on the quantity present, can cause surface imperfections such as splay, holes in the product, or a foamy product. Some polymers, e.g., nylon, are shipped dry in moisture-proof containers. With proper handling, these resins do not normally require additional drying prior to processing. However, if the seal is broken on the container or the bag is not completely resealed after opening, the product will absorb moisture and have to be dried prior to extrusion. Polyesters are particularly sensitive to moisture and must be dried in dehumidifying dryers, transported with dry air, and blanketed with dry air or nitrogen in the extruder feed hopper. Other problems include contamination with foreign materials such as metal chips, screws, bolts, nuts, cardboard, rodents, and rodent

droppings. Even so-called medical grade plastics are often contaminated. Of course, the contaminate will end up in the melt, so every precaution must be taken to avoid contamination by closing bags, covering hoppers, keeping a clean area around the extruders, and similar measures.[7]

Some of the many problems that can occur during extrusion are traceable to the processed raw material; that is, the raw material is not up to specification. Regardless of any quality assurances by manufacturers of raw materials and countless programs such as ISO 9000, reengineering, and Just In Time (JIT) manufacturing, plastic batches and even bags or boxes within batches have their idiosyncrasies. With all extrusion parameters the same, the tubing or sheet will have a different look, bend, colour, or texture. While this may sound unscientific or preposterous, these problems do occur on the floor. Despite all the computer programs and hardware designed to keep the quality constant, there will be variations.[7]

1) Remedies

- Exact addition of (Percentage of mixing) resin material.
- Check for foreign material.
- Increase rpm back pressure for better mixing.

2) Impact on Product Quality

Material absorb the moisture from the air which can cause bubbles

J. Improper System Engineering And Installation

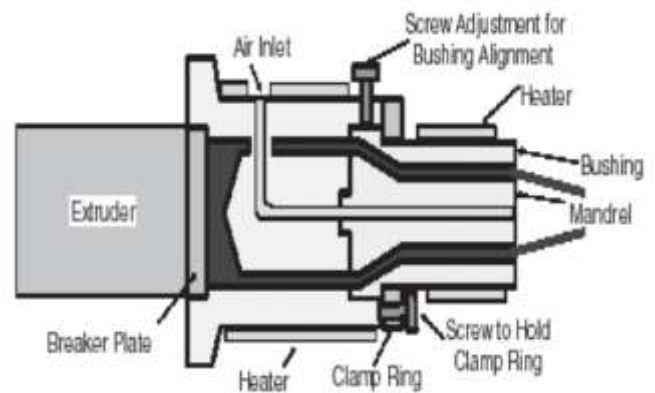


Fig.2 Spider Die [4]

The extrudate enters directly from the extruder through the breaker plate into the die. Large dies require a die stand or cart to support the die weight and prevent distorting the extruder barrel. An adapter may be present between the extruder and the pipe or tubing die, versus the direct connection shown in Figure. The entrance cone distributes the melt uniformly around the mandrel. The mandrel or center section is held in place by spokes radiating out from the

mandrel, called a spider ring with the individual spokes referred to as spider legs. The mandrel centered in the die and bushing centered on mandrel. To make adjustments, the bushing clamping ring loosened and the die adjustments bolts are used. If the bushing improperly centered the pipe or tube concentricity will be incorrect with one side having thicker wall than other side. Through one spider leg there is air inlet tube that supplies air to the centre of the pipe. The air supply is at atmospheric pressure. The die gap area where the melt channel is a constant diameter is called the die land area and it is used to shape the molten polymer into a pipe or tube before exist the die. [7]

Problems can be created by the pull rolls or winder if they are not properly synchronized with the three-roll stack, either generating too much tension or pulling the product across the chill rolls. Potential problem associated with the winder or pull rolls overpowering the three roll stack or chill roll are nonuniform thickness is created in the transverse direction by excessive pulling of the winder or pull rolls, causing the sheet to slip and stick in the roll stack. When the sheet is slipping on the rolls, the resultant product necking is increased, and the product is more likely to be thin on the edges and thicker in the middle than when it is adhering to the three-roll stack and moving with those rolls. In some situations the product is slipping constantly, and lines are formed in the transverse direction by the apparent action of starting and stopping in the nip or chatter as it goes through the nip.[7]

1) Remedies

- Adjust the die setting
- Check for alignment

2) Impact on Product Quality

Centering problems and chatter marks on the product

Some other defects are

K. Sink

Sink is defined as an indentation in the surface opposite a rib or boss. This is generally a problem only in profile extrusion. Sink is caused by shrinkage. Where a flat area intersects with a rib, there is more material present in the cross section. As the material cools, more shrinkage occurs in the thicker section, causing a surface indentation opposite the rib. Indentation is minimized by decreasing the rib width and profile extrusion. Sink is caused by shrinkage by decreasing the rib width and the radius going into the rib. However, a very narrow rib compared to the part's main thickness can lead to warpage due to the rib cooling and shrinking faster versus the rest of the part. [7]

1) Remedies

- Change the part design

2) Impact on product quality

Sink mark.

L. Poor or Nonuniform gloss

Gloss is a measure of the ability of a material to reflect light. It is an optical feature of all materials whether transparent or opaque. When a beam of light strikes a surface, the amount reflected will depend not only on the type of surface finish, and refractive index of the material, but also on the angle of incidence and the angle of viewing of the reflected beam. [8]

Improperly adjusted rolls can lead to poor gloss and rough sheet. To obtain the best gloss, highly polished roll surfaces at high temperature with the correct pressure are required. A guideline for setting roll temperature is to raise the roll temperatures after the process is running until the sheet or film just starts to stick to the roll surface, and then lower the temperature approximately 10°F (5.5°C). The roll surfaces have to be clean with uniform pressure applied across the rolls.[7]

Nonuniform or inconsistent gloss across the sheet can be caused by nonuniform roll temperatures, inconsistent gauge or thickness, volatiles, or high melt temperatures. Inconsistent gauge can originate in the extruder through surging, in the die by improperly setting the die lip opening and/or improperly setting the choker bar, and/or inappropriate roll gap adjustment. Sources for volatiles include resin moisture caused by improper drying, excessive melt temperature leading to polymer or additive degradation, plugged extruder vent preventing gas removal, and a plugged or insufficient vacuum to successfully remove all the volatiles.[7]

1) Remedies

- Set roll temperature high as possible.
- Assure there no extruder surging.
- Check resin for moisture
- Adjust die lips.

2) Impact on product quality

Volatile defects show up as splay or other surface defects.

M. Weld Lines

In polymer processing, weld lines can be formed by joining two different fluid fronts or when a fluid breaks up due to the presence of an obstacle, then rejoins downstream.[4] Dies containing mandrels normally have a spider to center the mandrel in the middle of the die. Polymer flows around each pin or spider arm holding the mandrel in place and then recombines just prior to exiting the die. Contamination or a foreign object such as a wire from the screen pack trapped in the die prior to or in the die lip area can cause a weld line to form in any extruded shape. [7]

2) Remedies

- Raise barrel temperature.
- Remove any foreign material or contaminants from die.
- Increase pressure on molecules forcing them together.

3) Impact on product quality

It generates weld lines in pipe or tubing.

N. Gels and Plate out

Gels are high-molecular-weight polymer particles that do not melt during processing. Gels may soften and elongate as they pass through a screen pack designed to filter or trap contaminants. However, they never really melt. After passing through the screens, they snap back or return to their original shape, forming small, hard particles in the melt. Others define gels as any contamination (dirt, other polymer, cross-linked polymer, and so forth) that passes through the die. In the final part, gels are a speck (may be clear) that forms a defect. In polyethylene, gels are occasionally formed in the process as material hangs up or stagnates in the system. Polyethylene held at processing temperatures over time can cross-link and form high molecular-weight particles that do not melt in the process. If gels are formed in the die, the die needs to be streamlined to prevent stagnation. To remove gels that are already present in the polymer, raise the melt temperature and/or use a finer screen pack to filter them out. [7]

Plate-out or die lip build-up is from low-molecularweight polymer or additives that migrate to the extrudate surface and are deposited on the die lips. Die build-up needs to be chemically analyzed to determine the source. Low-molecular-weight polymer is in the low-end tail on the polymer molecular weight distribution curve. To eliminate plate-out, a different resin can be purchased with a narrower molecular weight band. If the deposits are additives that volatilize and recondense on the die surface, alternative additives can be used or processing conditions changed (lower temperatures) to minimize the deposits. Regardless of the cause, solutions are required to minimize plate-out in order to maximize product yields and process efficiencies. [7]

1) Remedies

For gels-

- Raise melt temperature
- Streamline die to prevent stagnation
- Increase screen pack mesh to filter out.

For plate out

- Lowering the die head temperature.
- Reducing extrusion speed.
- Change the formulation.

2) Impact on product qualities

Due to gels- Defects in extrudate (usually film) that looks like eyes of fish and are the result of small unmelted resin particles.

O. Warpage

Warpage is a type of distortion where the surface of part do not follow intended shape of design.[5] Warpage is caused by the differential or nonuniform shrinkage in the extrudate cross section. This is often referred to as internal stresses in the part resulting from the molecular orientation, molecular relaxation outside the die, or molecular orientation induced in the final product by drawing.[7]

Proper part cooling is critical to produce warpage free parts with the acceptable dimensions and performance. Part warpage is caused by differential shrinkage. To minimize differential shrinkage, the part must be cooled uniformly on all sides. If one side or area of the extrudate solidifies before another, the part will warp, bending toward the side that solidified last. If one side of the extrudate is dragged over an object in the cooling operation, molecular orientation is induced on that side, causing it to shrink differently from the other side, leading to warpage.[7]

Pressure exerted by the puller must be sufficient to prevent product slippage in the puller, but low enough to prevent part distortion or marks on the product surface. Extreme puller pressure can crush the final part, rendering it useless. The puller may be a long distance from the extruder; however, it must be properly aligned with the extruder to prevent the part from being pulled in one direction or another, inducing molecular orientation that may lead to warpage.[7]

Crystalline materials need to be cooled uniformly to generate the same crystallinity and crystal size. If the crystallinity is higher in one section compared to another due to extrudate quenching or cooling differences, the section with higher crystallinity will shrink more. This shrinkage difference induces warpage in the final part.[7]

1) Remedies

- Puller must be properly aligned with the extruder.
- Uniform Melt temperature.

2) Impact on product quality

The part will twist or deform.

IV.CONCLUSION

By studying various papers and books on the extrusion process and its defects it is observed these defects are due to the improper setting of operational parameter. By applying the above remedies it is possible to reduce the losses that occur due to defects in the product.

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