ROOT CAUSE ANALYSIS OF EXTRUSION PROCESS DEFECTS IN PVC PIPE MANUFACTURING

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Abstract: PVC plastic manufacturing industry produces reasonable amount of waste during production with major contribution of Scrap generated during the manufacturing of plastic products and waste due to defects in manufacturing process. Pipe extrusion process has different defects such as voids, gels and specks etc. This study is conducted to identify different product defects during extrusion process of PVC pipes and to develop systematic approach for effective trouble shooting of major root causes of most frequently occurring defects identified by Pareto analysis. This study will be helpful for increasing the life of PVC pipes and to reduce waste during the manufacturing process.

Index Terms: **Plastic, Extrusion, Pareto analysis and Root cause analysis.**

INTRODUCTION

Extrusion is a high volume manufacturing process. The plastic material is melted with the application of heat and extruded through die into a desired shape. A cylindrical rotating screw is placed inside the barrel which forces out molten plastic material through a die. The extruded material takes shape according to the cross-section of die. The schematic of extrusion process is shown in figure 1.

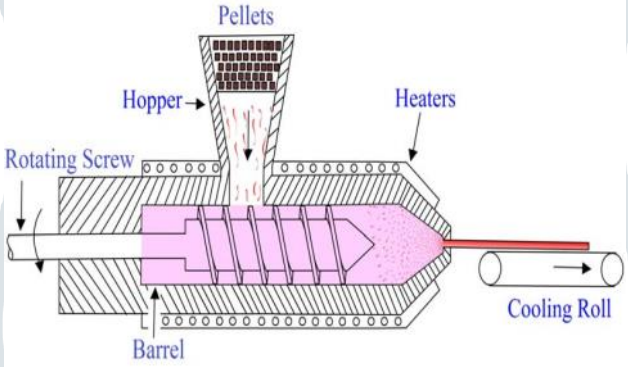

Figure 1: Extrusion Process

In this process, plastic material in the form of pellets or granules is gravity fed from a top mounted hopper into the barrel. Additives such as colorants and ultraviolet inhibitors (liquid or pellet form) can be mixed in the hopper. The plastic material enters through the feed throat and comes into contact with the rotating screw. The rotating screw pushes the plastic beads forward into the barrel. The barrel is heated using the heating elements up to the melting temperature of the plastic. The heating elements are used in such ways that gradually increase the temperature of the barrel from the rear to the front. There are three possible zones in a rotating screw i.e. feed zone, melting zone, and metering zone. In the feed zone, the plastic beads melt gradually as they are pushed through the barrel. The plastic material is completely melted in the melting zone. A thermostat is used to maintain the inside temperature of the barrel. The overheating of plastics should be minimized which may cause degradation in the material properties. A cooling fan or water cooling system is used to maintain the temperature of the barrel during the process. At the front of the barrel, the molten plastic leaves the screw and travels through a screen pack to remove any contaminants in the molten plastic. The screens are reinforced by a breaker plate. The breaker plate assembly also serves to create back pressure in the barrel. The back pressure gives uniform melting and proper mixing of the molten plastic material into the barrel. After passing through the breaker plate, molten plastic enters into die. The die gives the desired shape of plastic product. An uneven flow of molten plastic would produce unwanted stresses in the plastic product. These stresses can cause warping after solidification of molten plastic. Plastics are very good thermal insulators and therefore it is very difficult to cool them quickly. The plastic product is cooled by pulling through a set of cooling rolls.

The study carried out literature survey of other works related to the pipe extrusion process and its defects. Few prominent works are acknowledged here, Gadekar et. al [1] used Taguchi approach to find optimum process parameters for extrusion of High density Polyethylene to manufacture pipe of 14 mm diameter. A L9 orthogonal array, signal-to-noise ratio and analysis of variance (ANOVA) are applied to study performance characteristics of process parameters Javier Vera Sorroche et.al [2] characterize the thermal dynamics of the extrusion process by using in-process monitoring techniques. Novel thermocouple grid sensors have been used to measure melt temperature fields within flowing polymer melts at the entrance to an extruder die in conjunction with infra-red thermometers and real-time quantification of energy consumption. Chris Rauwendaal [3] described the basic prerequisites for efficient trouble shooting and discussed logical step-by-step approaches to solving various extrusion problems. It was not possible to visually observe what goes on inside the extruder; only the material going into the extruder and material coming out of the extrusion die is observable. Narasimha & Rejikumar [4] developed a systematic approach to find the root causes for the occurrence of defects and wastes in plastic extrusion process to manufacture HDPE Ø 50 mm pipes. Particularly defects such as surface roughness and scratch, bulging, sink marks, uneven wall thickness, dimensional variation,

centering problem, tears and marks were identified. Process parameters including vacuum pressure, temperature, take-off speed, screw speed of the extrusion process and raw material properties were recognized as root causes of occurrences of the defects. The complexity of extrusion process and the enormous amount of process parameters involved make it difficult to keep the process under control [5]. Ware E. concluded that the extrusion of molten plastic on the wire and other metal shapes requires very close control on temperature to ensure consistent product quality at maximum production rate [6]. The mainly the plastic pipe extrusion process depends on the parameters such as take-off speed, temperatures, vacuum pressure and relative speed of auxiliary. The common defects which are normally occurring in plastic extrusion process are due to three main regions like the problem in mold design, improper material selection, and wrong processing [7]. Cirak and Kozan Presented knowledge based and neural network approaches to wire coating for polymer extrusıon [8]. The dependency of extrusion process parameters viz. barrel heating zones' temperatures and screw speed on coating thickness of wire coating extrusion processes was investigated using ANN. In the determination of the process parameters for plastic extrusion, ANN and GA are emerging as the new approaches. A trained neural network system can quickly provide a set of extrusion parameters according to the results of the predicted quality of extruded parts [9]. Prabhat Kumar Mahto proposes that the Plastic extrusion process uses first order transfer function. The four control techniques are traditionally PI, PID and two intelligent controller FUZZY and ANFIS. The tuning synchronizes the controller to the controlled variable and make the process to work at its desired operating condition [10].

DEFECTS IDENTIFICATION AND ANALYSIS

Defects in extrusion process:

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 are part and mold design, material selection, and processing. In many cases, the failures occur during the processing and these failures cause some defects that can be found in extruded parts.

a. Voids:

Voids are rather common problem in extrusion. It is caused by air being dragged in with particulate material from the feed hopper. Under normal conditions, the compression of the solid particulate material in the feed section will force the air out of the solid bed. However, under some circumstances the air cannot escape back to the feed hopper and travels with the polymer until it exits from the die. As the air pockets exit from the extruder, the sudden exposure to a much lower ambient pressure may cause the compressed air bubbles to burst in an explosive manner. However, even without the bursting of the air bubbles, the extrudate is generally rendered unacceptable because of the air inclusion. It should be noted that bubbles in the extrudate are not only a sign of air entrapment, but it may also be an indication of moisture, surface agents, volatile species in the polymer itself, or degradation.

b. Gels:

Gels are generally defined as small, more or less round defects in extruded pro- ducts, especially film or thin walled tubing. Some people define gels as any particle in an extruder plastic product that has visual properties different from the rest of the product. This includes discolored specks, contamination, cross-linked polymer droplets, etc. Gels can be defined as small spherical droplets or specks with a distinct boundary that can be observed by simple visual inspection. The material making up the gel particle is basically the same as the polymer of the surrounding film. Therefore, a gel particle is different from contamination. In many cases the gel particle has no discoloration.

c. Specks:

Discoloured specks are a common problem in extrusion. This problem is similar to another common defect, which is the problem of gels. Like gels, discoloured specks are formed not only in extrusion and molding at the processor but also in polymerization at the resin producer (P-speck) and a speck also formed in extrusion (E-speck).

d. Shark skin:

Shark skin manifests itself as a regular ridged surface distortion, with the ridges running perpendicular to the extrusion direction. A less severe form of shark skin is the occurrence of maintenance of the surface, where the glossy surface cannot be maintained. Shark skin is generally thought to be formed in the die land or at the exit. It is dependent primarily on the temperature and the linear extrusion speed.

e. Longitudinal Streaks:

Die lip build-up or Die drool is a common phenomenon in the extrusion process; it is a condition where material accumulates right at the die exit which causes longitudinal streaks on outer surface of the pipe. It typically results from incompatible components in the compound, even though it can also happen in non-compounded plastics. Die drool can be caused by gas or moisture in the molten plastic, degradation, or poor dispersion of fillers or additives.

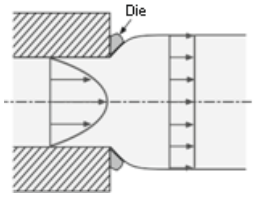

Figure 2: Die Drool

f. Weld Lines:

Lines in the extruded product can result from weld lines. These form when the polymer melt is split and recombined in the die or even before the die. Weld lines are also called knit lines; they can form in tubing and pipe dies where a mandrel is held in place by spider supports. The polymer melt is split at the start of the spider leg and flows together again behind (downstream) the spider support. Because of the limited mobility of long polymer molecules, it takes a certain amount of time for the molecules to re-entangle. This re-entanglement process is also called a "healing" process. Longer molecules take longer to re-entangle. As a result, high molecular weight (high viscosity) polymers are more susceptible to weld lines than low molecular weight (low viscosity)

polymers.

If the residence time is longer than the healing time, the weld line will disappear inside the die and not cause a problem in the extruded product. However, if the residence time is shorter than the healing time, the weld line will not disappear inside the die and the weld line will cause a problem in the extruded product. The weld line problem can be reduced or eliminated by increasing the residence time in the die or reducing the healing time of the polymer melt.

Data collection and Analysis

Check sheets are used to collect the data about occurrence of defects. Data collection can often become an unstructured and messy exercise. A check sheet is a table or a form used to systematically register data as it is collected. The main purpose of a check sheet is to ensure that all data is registered correctly. Main application of check sheet includes registering on daily basis how often different defects occur during extrusion process.

Image 1: Machine Setup

Steps in Data collection:

Following steps were taken for collecting the data through check sheets.

1. Defects to be recorded are clearly defined.
2. All defects are listed down and discussed with person who will be recording the data.
3. Time period of 1 month is selected for data recording.
4. Check sheet is designed to be used during data recording, allocating space for recording each defect.

Table 1: Defects occurred during extrusion

Sr. No.	Types of defects	Total number of defects
1	Voids	42
2	Gels	12
3	Shark skin	21
4	Longitudinal Streaks	23
5	Weld lines	11
6	Dimensional Variations	17
Total		126

Data Analysis:

The Pareto principle states that most effects, often 80 percentage, are the result of a small number of causes, often only 20 percentage. A healthy approach to root cause analysis is therefore to attack these 20 percentage, often labelled “the vital few. The main purpose of the Pareto chart is to display graphically this skewed distribution. The chart shows the frequency of occurrences of defects during extrusion process. In root cause analysis, the Pareto chart can be used to obtain a clearer picture of number of occurrences of defects and it also helps in setting a preference as to which defects need to be focused. Graph obtained after Pareto analysis exhibits that voids are the major defects resulting in production of inferior quality pipes.

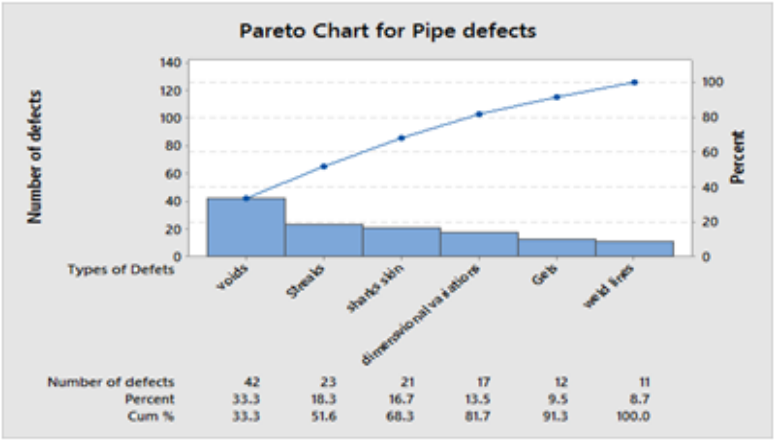

Figure .3: Pareto Chart for pipe defects

ROOT CAUSE ANALYSIS

Tools for root cause analysis:

Cause and effect diagram is used to find out the root cause of defects. Cause and effect diagram is a diagram that analyzes relationships between a problem and its causes. It combines aspects of brainstorming with systematic analysis to create a powerful technique. The tool is also known as an Ishikawa diagram, named for its inventor. In the larger framework of root cause analysis, this tool's main purpose is to understand what causes a defect. It can be used to:

1) Generate and group defect causes.
2) Systematically evaluate the causes and determine which are most likely to be root causes.

Steps in preparing cause and effect diagram:

Following steps are followed to prepare cause and effect diagram.

1) All probable causes are brainstormed.
2) These probable causes are listed in the order they are generated.
3) The causes are then grouped into main categories
4) The problem being analyzed is drawn on right-hand side of the chart, at the end of a large arrow.
5) Main groups of probable causes are drawn as branches to the arrow and for each branch; all possible causes are written on the fishbone chart.

Cause and effect diagram:

With literature survey, brainstorming and expertise of company employee, air entrapment is considered as root cause of air entrapment.

Remedial Action:

There are a number of possible solutions to air entrapment. The first approach should be to change the temperature in the solids conveying zone to achieve a more positive compacting of the solid bed. Often, a temperature increase of the first barrel section reduces the air entrapment; however, in some cases, a lower temperature causes an improvement. In any case, the temperatures in the solids conveying zone are important parameters in the air entrapment process. It should be realized that both the barrel and screw temperatures are important. Thus, if a screw temperature adjustment capability is available, it should definitely be used to reduce the air entrapment problem.

The next step is an increase in the die head pressure to alter the pressure profile along the extruder and to achieve a more rapid compacting of the solid bed. The die head pressure can be increased by simply adding screens in front of the breaker plate. Another possible solution is to starve feed the extruder; however, this may reduce extruder output and requires additional hardware, i. e., an accurate feeding device. The aforementioned recommended solutions can be implemented rather easily. However, if these measures do not solve the problem, more drastic steps have to be taken. One possibility that needs to be explored is a change in particle size or shape. If this is a reasonable option, it will most likely solve the problem. A rather safe solution is to utilize a vacuum feed hopper system; however, these systems are rather complex and expensive. Another possible solution is to use a grooved barrel section.

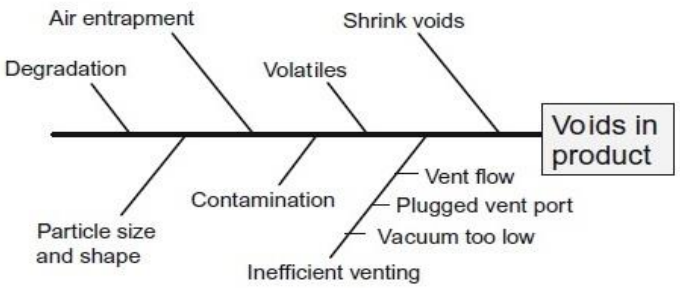

Figure 4: Cause and effects diagram

Pressure development in a grooved barrel section is much more rapid than in a smooth barrel. Thus, a grooved barrel section causes a rapid compacting of the solid bed and, therefore, less chance of air entrapment. Instead of grooving the barrel, one can opt for reducing the friction on the screw, which would have a similar effect. Air entrapment is also often successfully eliminated by vented extrusion using a multi-stage extruder screw. Increasing the compression ratio of the screw is also likely to reduce air entrapment. It should be noted that bubbles in the extrudate are not only a sign of air entrapment, but it may also be an indication of moisture, surface agents, volatile species in the polymer itself, or degradation.

CONCLUSION

Extrusion is a high volume processing method in which plastic material is melted with the application of heat and extruded through die into desired shape. A cylindrical rotating screw is placed inside the barrel which forces out molten metal plastic material through a die. Significant parameters affecting the quality of products includes take off speed, temperature of transition and metering zone. Also, extruder screw geometry and screw rotation speed were found to have significant effect on process energy.

In company where study is carried out, voids are most occurring defect among other defects like gel, specks, shark skin etc. Root cause analysis carried out through Fishbone diagram tool exhibits probable causes wherein air entrapment is concluded as a root cause. Stepwise approach was developed and suggested to avoid the occurrence of air entrapment. This study paves the way for research work to study the effect of process parameters like air pressure and screw geometry on quality of products manufactured by using PVC material.

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