Review on Optimization of Injection Molding Process Parameter for Reducing Shrinkage of High Density Polyethylene (HDPE) material

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Abstract: ***Injection molding is the most widely used polymeric fabrication process. It evolved from metal die casting, however, unlike molten metal; polymer melts have a high viscosity and cannot simply be poured into a mold. Instead a large force must be used to inject the polymer into the hollow mold cavity. More melt must also be packed into the mold during solidification to avoid shrinkage in the mold. The injection molding process is primarily a sequential operation that results in the transformation of plastic pellets into a molded part. Identical parts are produced through a cyclic process involving the melting of a pellet or powder resin followed by the injection of the polymer melt into the hollow mold cavity under high pressure. . In this paper review on optimal injection molding condition for minimum shrinkage were determined by the DOE technique of Taguchi methods. The various observation has been taken for material namely HDPE. The determination of optimal process parameters were based on S/N ratios.***

Keywords: Injection molding, Taguchi method, shrinkage, H.D.P.E.

1. Introduction

This is the most common method of producing parts made of plastic. The process includes the injection or forcing of heated molten plastic into a mold which is in the form of the part to be made. Upon cooling and solidification, the part is ejected and the process continues. The injection molding process is capable of producing an infinite variety of part designs containing an equally infinite variety of details such as threads, springs, and hinges, and all in a single molding operation. A plastic is defined as any natural or synthetic polymer that has a high molecular weight. There are two types of plastics, thermoplastics and thermoset. Thermosets will undergo a chemical reaction when heated and once formed cannot be resoftened. The thermoplastics, once cooled, can be ground up and reheated repeatedly. Thus, the thermoplastics are used primarily in injection molding.

There are four major elements that influence the process. They are:
• The molder
• The material
• The injection machine
• The mold

Of these four, the injection machine and the mold are the most varied and mechanically diverse. Most injection machines have three platens. Newer models use just two platens and may be electrically operated as opposed to the traditional hydraulic models. They can range in size from table top models to some the size of a small house. Most function horizontally, but there are vertical models in use. All injection machines are built around an injection system and a clamping system. Injection molding is a process of forming an article by forcing molten plastic material under pressure into a mould where it is cooled, solidified and subsequently released by opening the two halves of the mould. Injection molding is used for the formation of intricate plastic parts with excellent dimensional accuracy. A large number of items associated with our daily life are produced by way of injection molding. Typical product categories include house wares, toys, automotive parts, furniture, rigid packaging items, appliances and medical disposable syringes.

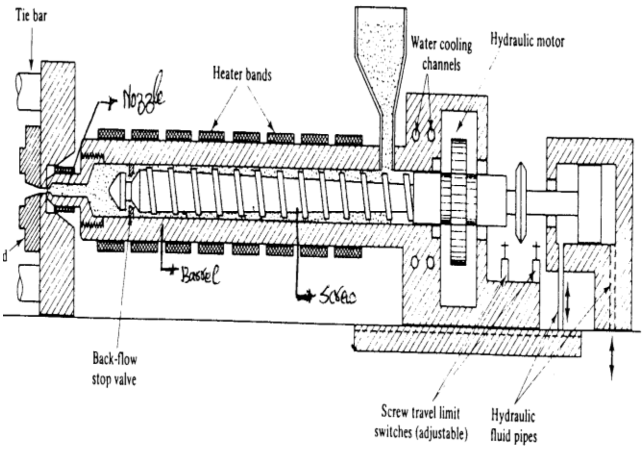

Figure 1: Injection molding machine set up

1.1. Advantages of Injection Molding

- Accuracy in weight of articles
- Choice of desired surface finish and colors
- Choice of ultimate strength of articles
- Faster production and lower rejection rates
- Faster start-up and shut down procedures
- Minimum wastage
- Stability of processing parameters
- Versatility in processing different raw materials

- Option in article sizes by changing the mould.
- Minimum post molding operations

2. Injection Molding Cycle

A typical sequence of Injection molding cycle is as follows:

Starting with an empty cylinder, raw material from the feed hopper falls onto the rear flights of the screw which conveys material to the front of the cylinder. During its passage along the cylinder it is plasticized to a fluid state with the help of external heaters on the barrel. Some material may escape through the nozzle but the back pressure is generally sufficient to push the screw back in the cylinder and to provide a reservoir of fluid plastic in the front of the cylinder for injection. The mould closes and the cylinder moves forward on its carriage until the nozzle is in contact with the entrance of the mould. The screw is moved forward by the hydraulic cylinder and the injection takes place. After a short interval (the holding time), the screw rotates, creating some pressure in the barrel, which forces it back against low pressure in the hydraulic cylinder, until the limit switch operates, stopping the rotation. This plasticize material ready for the next shot. The mould opens, the article is ejected and the mould closes again ready for the next shot.

3. Cycle of Operations

The injection system mechanism may be of the reciprocating screw type or, less frequently, the two-stage screw type. Also included is a hopper, a heated injection barrel encasing the screw, a hydraulic motor, and an injection cylinder. The system's function is to heat the thermoplastic to the proper viscosity and inject it into the mold. As the resin enters the injection barrel, it is moved forward by the rotation of the screw. As this movement occurs, the resin is melted by frictional heat and supplementary heating of the barrel encasing the screw. The screw has three distinct zones which further processes the resin prior to actual injection. Mould release spray is sometimes used to remove the articles from the mould. Due to contours, ribs and undercuts, the article may get struck up in the mould.

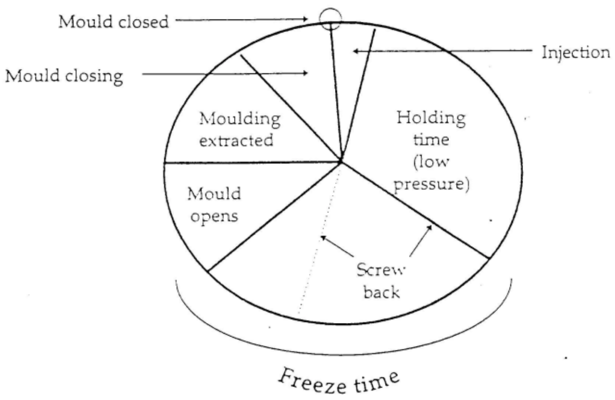

Figure 2: Cycle of Operations

3.1Cause and Effect Diagram

The main causes of defect in injection molding can be because of mold design, process parameters, machine, operator or material .The details are shown in fish bone diagram.

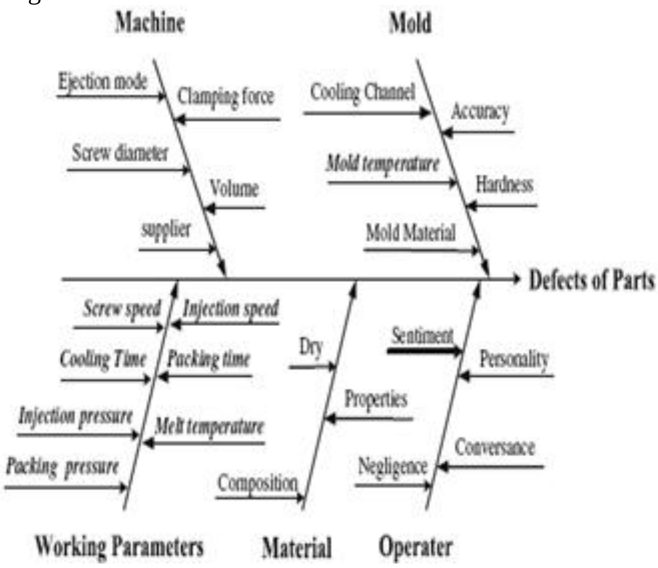

Figure 3: Cause and Effect Diagram

3.2 Materials

HDPE is the natural color polymer with Good process ability, very good mechanical properties.HDPE is designed to make injection molded product like industry handling, pallets and luggage shells.

Table 1: The general property of HDPE material

S. No	property	unit	value
1	Density	g/cc	0.96
2	Melt flow index	g/10 min	8.0
3	Tensile strength	Mpa	25
4	Elongation at yield	%	11
5	Elongation at break	%	800
6	Flexural strength	Mpa	30

4. System Development

There are several researchers that have studied the effects of injection molding process parameters on the shrinkage of moldings [5, 8]. Since many process parameters affect the shrinkage, parameter optimization and experimental design are needed to produce high quality products. Some researchers have been conducted on optimizing shrinkage in plastic injection moldings. In thin-shelled plastic component production, Oktem et al. [9] used the Taguchi method to reduce warpage problems that were related to a variation in the process-parameters dependent on the shrinkage. They improved the warpage and the shrinkage by determining the optimal packing time, packing pressure, injection time and cooling time. The packing pressure and the packing time were found to be the most important parameters. Vaatainen et al. [10] investigated the effect of the injection molding parameters on the visual quality of the moldings using the Taguchi method. They focused on the shrinkage with three more quality characteristics: weight, weld lines and sink marks. They were able to optimize many quality characteristics with very few experiments, which could lead to cost savings. Shen et al. [11] studied the effects of the process parameters on the shrinkage by utilizing a combination of the CAE and the Taguchi technique. Chang and Faison [12] studied the shrinkage behavior and optimization of PS, HDPE and ABS parts by using the Taguchi and ANOVA methods. They stated that the mold and melt temperatures along with the holding pressure and the holding time were the most significant factors affecting the shrinkage behavior of the three Materials studied. Liao et al. [13] determined the optimal process conditions for a thin-walled injection molding, for cellular phone covers, by the Taguchi method. Based on the results of the analysis of variables and the F-test, packing pressure was found to be the most important parameter affecting the shrinkage and the warpage. However, various industries have employed the Taguchi method over the years to improve products or manufacturing processes. It is a powerful and effective method to solve challenging quality problems. Actually, the design of experiments (DOE) method has been used quite successfully in several industrial applications like in optimizing manufacturing processes or designing electrical/ mechanical components [14, 15].

In this work, the effects of the process parameters on the shrinkage of injection molded high density polyethylene determined by the Taguchi and ANOVA methods. Signal-to-noise ratio was used to obtain the optimal set of process parameters. Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provides much-reduced variance for the experiment with optimum setting of process control parameters. Thus the integration of design of experiments (DOE) with parametric optimization of process to obtain desired results is achieved in the Taguchi method. [2] Classical experimental design methods are time consuming. Many experiments must be performed when the number of control factors is high. Taguchi methods use a special design of orthogonal arrays to study the entire factor space with only a small number of experiments. [3] The Taguchi method attempts to optimize a process or product design and is based upon three stages, as follows:

1. Concept Design or System Design
2. Parameter Design
3. Tolerance Design

The concept design is considered to be the first phase of the design strategy. This phase gathers the technical knowledge and experiences to help the designer to select the most suitable one for the intended product. In parameter design, the best setting of the control factors is determined. This is perhaps the important step, as it does not affect the unit manufacturing cost of the product. The third step is performed only after completion of the parameter design step and is exercised when further improvements are required for the optimized design. This phase focuses on the trade-off between quality and cost. However, designers in this stage consider only tightening tolerances, upgrading material standards and components, if any, having a significant impact on quality through parameter design experiments. [8] The Taguchi method uses the signal-to-noise (S/N) ratio instead of the average to convert the trial result data into a value for the characteristic in the optimum setting analysis. The S/N ratio reflects both the average and the variation of the quality characteristic. [3] The standard S/N ratios generally used are as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio. [2] Taguchi technique [13] recommends using orthogonal array experiments.

Taguchi method uses signal-to-noise (S/N) ratio which reflects both the average and the variation of the quality characteristics. It is a measure of performance aimed at developing products and processes insensitive to noise factors.

4.1. Types of S/N ratio

<u>Larger- the- better</u>: S/N = -10 log 10(1/n Σ 1/yi2)
Where, i=1 to n, n = no. of replications applied to the problems where maximization of quality characteristics of interest is needed.

<u>Smaller- the- better</u>: S/N = -10 log 10(1/n Σ yi2)
It is used where minimization of the characteristics is intended

<u>Nominal-the-best</u>: S/N = -10 log 10 [μ2 / σ2]

4.2. Shrinkage Measurement

It is the difference between the size of mould cavity and size of finished part divided by size of the mould.
S = (Dm-Dp) / Dm X 100
Here, Dm is mould dimension,
D_p is part dimension and S is the shrinkage.

5. Conclusion

A review of literature on optimization techniques has revealed that there are, in particular, successful industrial applications of design of experiment-based approaches for optimal settings of process variables. Taguchi methods are robust design techniques widely used in industries for making the product/process insensitive to any uncontrollable factors such as environmental variables. Taguchi approach has potential for savings in experimental time and cost on product or process development and quality improvement. There is general agreement that off-line experiments during product or process design stage are of great value. Reducing quality loss by designing the products and processes to be insensitive to variation in noise variables is a novel concept to statisticians and quality engineers. Taguchi and ANOVA methods were used to investigate the effects of melt temperature, injection pressure, packing pressure, packing time and cooling time on the shrinkage of the HDPE material.

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