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A Survey of Injection Moulding Process and Techniques

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Abstract: *For many researchers and manufacturer Injection molding is the challenging process to generate the product meeting requirement with minimum cost. Faced with global antagonism in injection molding industry, using the trial and error approach to decide the process parameters for injection molding is no longer good adequate. To ensure high quality and productivity, it is necessary to optimize machining parameters. Various responses of quality of injection moulding process have been studied on the basis of performance parameters and methods. This paper present the survey of injection molding process, techniques and also presents the advantages and disadvantages of injection molding.*

Keywords: *Injection Molding, Non Linear Modeling, Finite Element Method, Blow Molding, ISBM.*

1. Introduction

Injection molding has been a challenging process for many manufacturers and researchers to produce products meeting requirements at the lowest cost. What is more, complexity and parameter manipulation may cause serious quality problems and high manufacturing costs [1].One of the main goals in injection molding is the improvement of quality of molded parts besides the reduction of cycle time, and lower production cost. Solving problems related to quality has a direct effect on the expected profit for injection molding companies. Quality characteristics in injection molding are classified as mechanical properties, dimensions or measurable characteristics, and attributes. In general, some of the main causes of quality problems are material related defects i.e., black specks and splay, process related problems such as filling related defects i.e., flash and short shots, packing and cooling related defects i.e., sink marks and voids, and post mold related defects i.e., warpage, dimensional changes, and weight. Factors that affect the quality of a molded part can be classified into four categories: part design, mold design, machine performance and processing conditions. The part and mold design are assumed as established and fixed. During production, quality characteristics may deviate due to drifting or shifting of processing conditions caused by machine wear, environmental change or operator fatigue [2].

Optimizing process parameter problems is routinely performed in the manufacturing industry, particularly in setting final optimal process parameters. Final optimal process parameter setting is recognized as one of the most important steps in injection molding for improving the quality of molded products. Previously, engineers used trial-and-error processes which depend on the engineers' experience and intuition to determine initial process parameter settings. However, the trial-and-error process is costly and time consuming, thus it is not suitable for complex manufacturing processes. Faced with global competition in injection molding industry, using the trial-and-error approach to determine the process parameters for injection molding is no longer good enough.

The aim of this article is to review the research of the determination of process parameters and mold design injection molding. Research based on various approaches, including Taguchi technique, Artificial Neural Networks (ANN), Fuzzy logic, Case Based Reasoning (CBR), Genetic Algorithms (GA), Finite Element Method (FEM), Non Linear Modeling, Response Surface Methodology, Linear Regression Analysis, Grey Rational Analysis and Principle Component Analysis are discussed..

2. Injection Molding Process

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.[3]
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.[4]

Fig. 1: Injection molding machine

2.1 Advantages and Disadvantages of Injection Molding Machine

Injection moulding is one of the most commonly used methods of producing identical plastic products in high volumes. However, as with every process, it is important to understand the specific design restrictions that must be adhered to in order to facilitate the obvious benefits of successfully producing cost-effective, high-quality parts.

Advantages

1. **Fast production and highly efficient.** Injection moulding can produce an incredible amount of parts per hour. Speed depends on the complexity and size of the mould, anywhere between 15-120 seconds per cycle time.
2. **Low labour costs.** Plastic injection moulding is an automated process whereby a majority of the process is performed by machines and robotics, which a sole operator can control and manage. Automation helps to reduce manufacturing costs, as the overheads are significantly reduced.
3. **Design flexibility.** The moulds themselves are subjected to extremely high pressure. As a result, the plastic within the moulds is pressed harder and allows for a large amount of detail to be imprinted onto the part and for complex or intricate shapes to be manufactured.
4. **High-output production.** Thousands of parts can be produced before the tooling needs to be maintained.
5. **Large material choice.** There is a large selection of polymer resins to choose from. Multiple plastic materials can also be used simultaneously; for example, TPE can be overmoulded onto PP parts.

6. **Low scrap rates.** Injection moulding produces very little post-production scrap relative to traditional manufacturing processes. Any waste plastic typically comes from the sprue and runners. Any unused or waste plastic, however, can be reground and recycled for future use.
7. **Ability to include inserts.** Metal or plastic inserts can be insert moulded.
8. **Good colour control.** Plastic parts can be manufactured in any required colours with the use of masterbatches or compounding.
9. **Product consistency.** Injection Moulding is a repeatable process; in other words, the second part you produce is going to be identical to the first one etc. This is a huge advantage when trying to produce high tolerances and part reliability in high volumes.
10. **Reduced finishing requirements.** There is often very little post-production work required as parts usually have a good finished look upon ejection.
11. **Enhanced Strength.** When plastic injection moulding, it is possible to use fillers in the moulding material. These fillers reduce the density of the plastic whilst it is being moulded, and can help add greater strength to the completed part.

Disadvantages

1. **High tooling costs and long set up lead times.** Up-front costs are high due to the design, testing, and tooling required. There is the initial design and prototyping (probably via CNC or 3D printing), then the design of a prototype mould tool to produce replicas of the part in volume. Lastly, and only after extensive testing during both stages, you can finally injection mould a part.
2. **Part design restrictions.** Plastic parts must be designed with injection moulding consideration and must follow the basic rules of injection moulding, for example:

- Avoid under cuts and sharp edges as much as possible
- Use uniform wall thicknesses to prevent inconsistencies in the cooling process resulting in defects like sink marks.
- Draft angles are encouraged for better de-moulding.

Don't forget, because tools are typically made from steel or aluminium, it can be difficult to make design changes. If you need to add plastic to the part, you can make the tool cavity larger by cutting away steel or aluminium. But in order to take away plastic, you need to decrease the size of the tool cavity by adding aluminium or metal to it. This is extremely difficult and in many cases might mean scrapping the tool (or part of it) and starting over. Also, the weight and size of the part will determine the tool size and necessary press size. The larger the part, the more difficult and expensive it will be.

3) Small runs of parts can be costly. Due to the complexity of tooling, and the necessity to rid the machine of all previous material before the next product can be made, the setup time can be quite lengthy. Therefore small runs of parts have traditionally always been thought of as too expensive to injection mould.

3. Related Work

A lot of research is being carried out to understand and identify the effect of plastic injection moulding process parameters on the quality of the plastic product. Till today many optimization techniques were used to control the plastic injection process parameters.
Harshal P.Kale et al.(2017) studied the effect of melt temperature, injection pressure, packing pressure and cooling time on HDPE material to reduce the shrinkage. In this paper optimal injection moulding condition for minimum shrinkage were determined by the DOE technique of Taguchi methods. The determination of optimal process parameters were based on S/N ratios. [5] Junhui Liu et al.(2017) studied on set of procedures for the optimization of injection moulding process parameters(IMPP), in this study the optical performance and the surface waviness were the two output characteristics of the plastic material. First, the orthogonal experiment was carried out with the Taguchi method, and the results were analyzed by ANOVA to screen out the IMPP having a significant effect on the objectives. Then, the 34 full-factor experiment was conducted on the key IMPP, and the experimental results were used as the training and testing samples.[6] Satadru Kashyap et al.(2015) studied the various optimization techniques for optimization of plastic injection moulding process parameters. The different optimization techniques which were studied by the authors are Taguchi method for design of experiment (DOE), Artificial neural network (ANN), Evolutionary algorithm (EA), Genetic algorithm (GA) and hybrid techniques. From their review the authors had concluded that a complete intelligent technique operable without human interference was yet to be developed. [7] Shih-Chih Nian et al.(2015) studied about the reduction of Warpage .The local mold temperature settings for a

cooling system that can prevent severe warpage in an asymmetric plastic cover for handheld communication devices. Through simulation and experiments conducted in this study, the feasibility of using an effective local mold temperature setting in a cooling system to reduce part Warpage was verified.[8] Julio Rezende et al. (2018) carried out on a Thermoplastic Injection Mould¬ing company, which segment is known for having an intense electrical energy usage given the nature of its production stages. In order to determine the productive and non-productive elec¬trical energy embodied in manufacturing operations and get a better understanding of the production processes, an analysis based on the Machines' time series data streams and some extra information about the processes was made. The outputs result in a better understanding of the machine's electrical consump¬tion, and provide insights regarding potential saving strategies and improvements on the production side such as better sched¬uling, improved production tracking, operator engagement and equipment efficiency.[9] Nik Mizamzul Mehat et al. (2013) analyzed the gear performance with various gating system types, gate locations, and processing parameters via grey-based Taguchi optimization method. With the obtained optimum results in simulation stage, the flow patterns of polymer melt inside the mould during filling, packing, and cooling processes are studied and the plastic gear failures mechanism related to processing parameters are predicted. The output results in the future can be used as guidance in selecting the appropriate materials, improving part and mould design, and predicting the performance of the plastic gear before the real process of the part manufacturing takes place.[10] Peng Zhao et al. (2013) defined the concept of intelligent injection molding as the integral application of these three procedures—sensing, optimization, and control. -is paper reviews recent studies on methods for the detection of relevant physical variables, optimization of process parameters, and control strategies of machine variables in the molding process. Finally, conclusions are drawn to discuss future research directions and technologies, as well as algorithms worthy of being explored and developed.[11]

4. Injection Molding Techniques

Blow Molding

Blow moulding is a technique that was invented thousands of years ago for the production of glass containers, e.g. bottles and jars. The automated blow moulding process as it is known today has seen rapid development during the last century, while at the same time the range of applications and diversity of materials has considerably increased. In spite of the fact that blow moulding has been used for many years, manufacturers still experience difficulties in optimising and controlling the process.[12] In polymer container manufacture three main blow moulding techniques can be distunguished: injection blow moulding, extrusion blow moulding and stretch blow moulding. In injection blow moulding first a polymer preform is formed by injecting a polymer melt into a tube-shaped mould and subsequently it is brought into another mould, where the final container is blown by inflating the perform with air. Injection blow moulding is usually used to manufacture small or wide-mouthed containers. In extrusion blow moulding the polymer melt is extruded in a preform shape before blowing it into the container shape. Extrusion blow moulding can be used for a wide variety of container shapes and has in general a high production rate.

Extrusion Blow Molding

This process usually use commodity materials such as PVC, PS, PP, LDPE, HDPE. The extrusion part of the process is continuous and the rest is cyclic. For continuous parsion blow molding, extrudate is produced continuously which would achieve good melt uniformity. Several molds will be used to process the extrudate. Swift parison removal and control is required for this process. There are three general types of blow molding: extrusion blow molding, injection blow molding, and stretch blow molding. Extrusion blow molding is usually used to make items of weight greater than 12 oz. finish, and to process polymers that conot be extruded. Usual applications include pharmaceutical, cosmetic, single serving liquor bottles that weighs less than 12 oz.[13]

Stretch Blow Molding

Injection stretch–blow moulding (ISBM) is one of the major methods in blow-moulding processes for making hollow polyethylene terephthalate (PET) bottles. In this process, the PET resin is first injected into an axisymmetric U-shaped mould to make structurally amorphous preforms called 'preform'. Then, the preforms are heated in an infrared oven higher than the glass transition temperature. Next, it is stretched simultaneously with a stretch rod and blown up with high-pressure air inside, to create bottles with desired outer shapes.[14]
Stretch-blow molding is a process that allows the forming of hollow parts such as bottles. In a first step a preform is injection molded. This latter is stored and later re-heated above the glass transition temperature of the material, placed into a mold where forming takes place. The forming itself generally results from three stages: the preform is first stretched with a rod (low-blow delay), and

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then inflated by air at low pressure (pre-blow at 0.5 to 0.9 MPa) whilst stretching goes on. Finally, stretching is stopped and pressure is increased up to 40 bars (4 MPa). The two first stages define the so-called low-blow period whereas the last one is the blowing period. The "three-stage" distinction is not always true in industrial context: pre-blow often overlaps with stretching to prevent the touching of the preform with the stretching rod.[15]

Compression Molding

Compression moulding process is done in two steps, preheating and pressurizing. Compression molding is a one of the well known oldest technique used to develop variety of composite products. Because of its ability to develop variety of composite products, the process is versatile. It is a closed die moulding with high pressure application. This process is suitable for small to medium size parts. In industries, different types of moulding machines are used; Semi-automatic and Automatic The hydraulic machine can be used in some applications where there is a requirement of high pressure or high load for manufacturing the components, these high capacity molding machines cannot be installed in small scale industries, because the cost of the high capacity hydraulic molding machine are too expensive for the preparation of small sized composite products and also a skilled operator is required to operate these high capacity hydraulic machine. To overcome these problems it is a need to develop low cost pneumatically operated molding machine. This machine is useful in small scale industries for the production of FRP composites. The initial cost of machine is low and the maintenance cost is minimal. Compression molding machine is used to prepare the FRP composite samples for testing purpose. In this process, the molding material, generally preheated by using heater after filling in a heated mold cavity. The mold is closed with the help of a top force, by using hydraulic cylinder and pressure is applied to force the material into contact with all mold areas. Heat and pressure is maintained until the molding material has cured.[16]

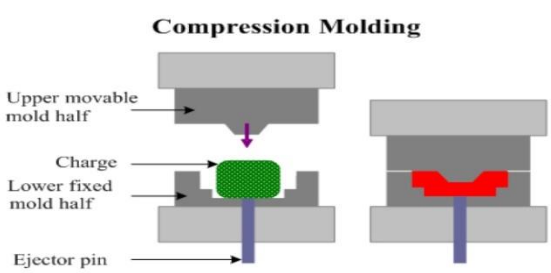

Fig. 2 : Compression Molding Process [17]

Rotational Molding

Rotational moulding, also known as rotocasting or rotomoulding, is a low pressure, high temperature manufacturing method for producing Hollow, one-piece plastic parts. As with most manufacturing methods for plastic parts, rotational moulding evolved from other technologies. The basic principle of forming a coating on the inside surface of a rotating mould dates back for many centuries, but the process did not gain recognition as a moulding method for plastics until the 1940. A British patent issued to Peters in 1855 (before plastics existed) cites a rotational moulding machine containing two-axis rotation through a pair of bevel gears. It refers to the use of a split mould having a vent pipe for gas escape, water for cooling the mould and the use of a fluid or semi-fluid material in the mould to produce a hollow part. Currently rotational moulding is a very competitive alternative to blow moulding, thermoforming and injection moulding for the manufacture of hollow plastic products. This is because it offers designers the opportunity to achieve the economic production of stress-free articles, with uniform wall thickness and potentially complex shapes. Rotational Molding involves a heated hollow mold which is filled with a charge or shot weight of material. It is then slowly rotated (usually around two perpendicular axes) causing the softened material to disperse and stick to the walls of the mold. In order to maintain even thickness throughout the part, the mold continues to rotate at all times during the heating phase and to avoid sagging or deformation also during the cooling phase. The process was applied to plastics in the 1940s but in the early years was little used because it was a slow process restricted to a small number of plastics. Over the past two decades, improvements in process control and developments with plastic powders have resulted in a significant increase in usage.[18]

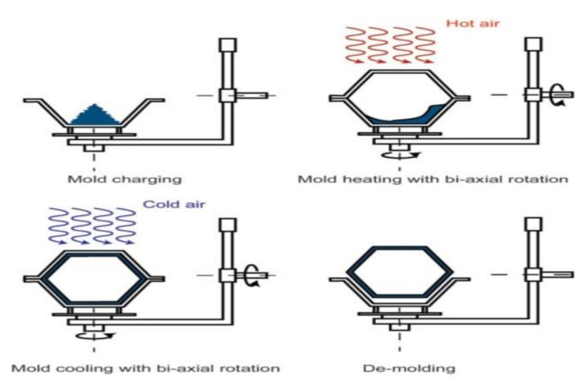

Fig 3 : Rotational Molding Process [18]

Thermofoaming Molding

Thermoforming is used to produce parts for industries such as food, medical, appliance, signage, and automotive. Thermoforming is used in both high and low volume production operations after sheet-fed and roll-fed thermoforming machines have been used. The major advantages of the process are its low initial tooling costs and low equipment costs when compared to other competitive processes such as extrusion, blow molding, and injection molding.[19]

Thermoformed part's quality can be defined by a combination of several parameters. One of these parameters is thickness distribution that affects thermoformed package's gas permeability, which can affect such things as shelf life of the food in the packaging. Thickness distribution has an influence on the package's rigidity too.

Thermoforming machine has four ceramic radiant heater elements that heat 30x30 cm^2 surface areas. The heaters temperature were adjusted to 350°C. After an appropriate waiting time for heating, temperatures were measured on the heated sheet by a thermal imaging cam (Testo). Heating temperature was measured approximately as 150°C. Then the heaters were turned off. Vacuum was applied and the sheet was formed by the aid of a vacuum. Vacuum value was obtained as between 720-730 mmHg from vacuum display. After cooling, the samples were released from the mold.

Gas Assisted Molding

Gas-assisted injection molding (GAIM) is not an innovative technology for manufacturing hollowed plastic parts with the first patent dating from 1978 .However, the establishment as a common molding process has not yet been achieved in the polymer industry. This is a result of some pitfalls in the practical application of the GAIM process due to the inherent gas instability that implies a complex relationship between the parameters which control the gas flow and the quality of the molded parts. Its higher limitation is the understanding of the characteristics of the process, especially with respect to the typical flow phenomenon. [20]

The material flow in both compression moulding and GAIM is a fountain flow. That is the orientation of the polymer and fibre is dictated by the direction of shear flow. In regions near the cold tool walls this orientation will be frozen in, but as more material is forced through the centre onto the cold walls, a familiar 'fountain-like', flow pattern is produced until filling is complete. The thickness of this frozen skin layer is affected by the flow rate, where a high flow rate will produce a thin frozen skin. Hesitation marks occur in thermoplastic processing where a flow front temporarily stops and starts to form a skin of frozen material. This is common in GAIM where the transition from polymer injection to gas injection occurs and was also found in the new process. The most influential processing parameters in the production of a gas cavity in GAIM were found to be the shot size; the gas injection delay time and the polymer melt temperature [21]. How this will translate into the GasComp process however is unknown.

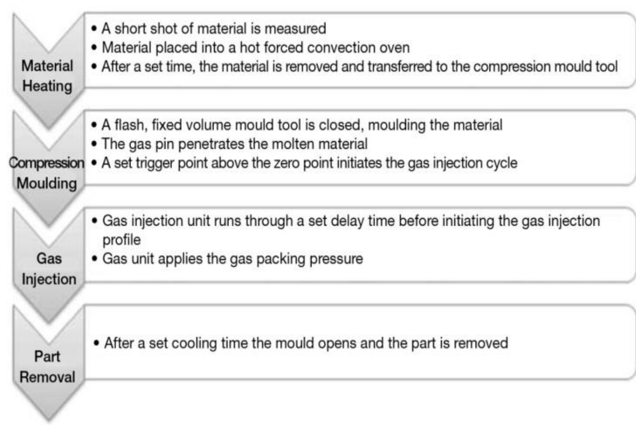

Fig 4: The GasComp process cycle [21]

5. Conclusion

A brief survey of optimization of injection moulding process parameters has revealed that there are so several optimization tools and techniques are available, a lot of work had done by different authors in this area. Because based on this study we know that due to processing parameters many defects occur. So for the production of product control of processing parameters is required. In this we explain different optimization technique of injection molding such as Gas Assisted Molding, Thermofoaming Molding, Rotational Molding, blow molding etc. After studying it is found that the some of them are providing high durability, high stability, strength but some are having dome disadvantages such as Low repeatability, high labour cost, high cycle time etc. So in future work, need to develop such hybrid technique which can improve the performance of machine by reducing labour cost, cycle time and low cost of raw material.

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