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Plastic Injection Molding Process and Its Aspects for Quality: A Review

Rizwan Mohd Khan[1] and Gaurav Acharya[2]

[1]Department of Mechanical Engineering, Poornima College of Engineering, Jaipur, India
[2]Department of Mechanical Engineering, Suresh Gyan Vihar University, jaipur, India
rizwan.khan@poornima.org

ABSTRACT

Due to environment of competition, industries are into heavy pressure to produce products at a rapid rate. This led to evolve new technologies and production processes. Plastic injection molding process is one of the production technique used to produce plastic products at a rapid rate with minimum defects, but it is a complex process in terms of product, process parameters, and production set-up etc. A small change in the environment of process can affect the quality of the product. In the past two decades researchers have worked on injection molding process and optimized different aspects of injection molding process such as mold design, process parameters, machines set up, product design and shape etc. This review work is done to identify the most critical aspects of the injection molding process and to identify the factors which requires consideration at the time of production to produce objects with minimum defects.

Key words: Defects, Optimization, Plastic, Process, Quality

INTRODUCTION

In the past few decades, plastics became the most dominant engineering material for human being. In daily life, many plastic products were used by people [1]. The most common methods of processing plastics to manufacture plastic parts include Extrusion, Injection molding, Plastic injection molding process, Blow molding, Casting, etc. Among these, perhaps injection molding is the most significant for local industry – almost all manufacturing companies use parts that are injection molded, whether they make toys, home-appliances, electronics or electrical parts, watches, computers, etc [2].

In Plastic Injection molding process, plastic products are produced by forcing the resins made of plastic materials by application of high pressure into a mould where it is cooled, allowed to solidify and after that taken out from the mould by opening cop and drag part of the mold. Articles having complicated shapes and geometries with great dimensional accuracy can be easily produced by the plastic injection molding process [3]. Plastic injection molding machine consist of three units namely Clamping Unit, the Injection Unit, and the Drive Unit. The functions of the clamping unit are to hold the mold, close and open during the operation. The fixed and moving plates, the tie bars and the mechanism for opening, closing and clamping are the parts of the clamping unit. The injection unit or plasticizing unit melts the polymer resins and injects it into the mold. The drive unit provides power to the plasticizing unit and clamping unit. The Basic requirement to produce article by plastic injection molding process is the preparation of mold, runner system, gate location and sprue design and selection cooling channels and location of the cooling channels [4].

Injection moulding process can be performed in four steps
Step-1: The process starts with selection of the product which is going to be produced and selection of suitable of plastic resin which fits in characteristics of the product such as tensile strength, compressive strength, stiffness etc.
Step-2: Preparation of mold, runner, gate and process parameters.
Step-3: Injecting the melt resin into the cavity and allowing it to solidify.
Step-4: Taking out the final product from the mold.

Plastic injection molding process is used to produce products with high quality, good dimensional accuracy and dimensional stability but many defects may occur during the process or after the completion of the process in the products. There are several types of defects like shrinkage, warpage, voids, weld-lines etc. which usually occurs in plastic products. Ultimately this will affect the reputation of the industry. Defects in the products can be occurred at any step of the procedure. Industry persons and researchers have tried to minimize these defects by optimization of any of the feature like mold, plastic resin; parameters of the process.

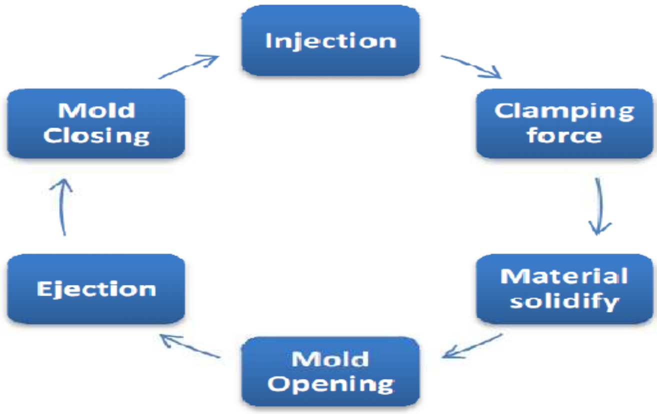

Fig: 1 Plastic injection molding cycle [4] [1]

Objective of Study

Objective of the present study is to summarize the past research work done on the plastic injection molding process and to provide a platform to the researchers for future work. For this purpose the literature review is classified according to the four steps which are carried out at the time of production. Table given below will give describe the step as the name "Task" and possible reasons of defects in that steps which are in spotlight of the researchers.

Table -1 Step, Work and Reason of Defects

S. No.	Step	Work	Reason of Defects
1	1	Selection of the product and selection of suitable of plastic resin	• Product attributes-thickness, corners, undercuts etc. • Resin Attributes- • Viscosity, surface tension, density, thermal conductivity etc.
2	2	Selection of mold, runner, gate and process parameters	• Mold material, thermal conductivity of mold, • Runner type (cold/hot), shape, size • Gate cross-section, location and • Process parameters
3	3	Injecting the melt resin	• Resin properties, • Process parameters, • Machine Specifications
4	4	Taking out the final product	• Cooling Channel type, location, shape

LITERATURE REVIEW

Considering above four steps carried out in the production of plastic products, the table has been prepared to enlighten that which factor or feature most consistently considered by the researchers. For the literature review purpose, following previous research work have been considered and discussed in the literature review.

Sortino *et al* [5] compared conventional injection moulding machine with ICM and VIM. They verified the dimensional correctness of the micro structured prism geometries and appropriate ranges of process parameters for each injection moulding machine through MoldFlow CAE software simulations. Azaman *et al* [6] used Autodesk mold flow insight to simulate the products having thin walled geometry. They found that the volumetric shrinkage and warpage in thin walled products are greatly affected by the packing pressure. They designed a meshing model of the thin walled object and varied the parameters such as mold temperature, cooling time, injection time, packing pressure but they found that the mold packing pressure was more important than the cooling time on the volumetric shrinkage of the thin-walled part. According to Selvaraj *et al* [7] with proper selection of the controllable parameters and cooling system, defects like flash mark or flow line can be reduced in cam bush made up of nylon 66. They designed and modelled a cam bush in PROe 5 wildfire and fabricated all the tools like core plate, cavity plate, ejector rod, ejector plate of injection moulding machine. They concluded that no blow hole deficiency occurred throughout the production of Nylon 66 cam bush baffle type cooling channel is provided in the moulding tool. Jauregui-Becker *et al* [8] used a simulation approach to evaluate the performance of the cooling channel in injection moulding process and they optimized of product quality, and process parameters designs through simulation. They concluded that automated design generation and simulation software shows potential results for simple and prevalently planar geometries (i.e. square box), and it is still difficult for three dimensional part (i.e. cylindrical part). Ozcelik *et al* [9] used finite element analysis approach and Autodesk Moldflow insight to investigate and simulate the effects of weld lines on the mechanical properties of the plastic products. They found that weld lines greatly affect the impact strength of the plastic products. They compared plastic products having weld lines and without weld lines with respect to impact strength and tensile strength by varying packing pressure and melt temperature. The impact strength of the plastic products show significant changes with packing pressure and melt temperature as compared to tensile strength. Sin *et al* [10] investigated the injection moulding process ability of polyvinyl alcohol (PVOH) blending with starch as ecological polymer multifarious. They simulated the object through Moldflow software. The Moldflow simulation results revealed that PPV55 requires an elevated injection pressure than PPV46 and in the intervening time, the simulation results also showed that the volumetric shrinkage of PPV55 is higher than PPV46. Both PPV46 and PPV55 have need of at least 20 s holding time to achieve stable production.

Kovacs [11] proposed a mathematical model to investigate the effect of cooling on warpage and shrinkage at the corners of the mold cavity and they also used Autodesk Moldflow Insight 2011 injection molding simulation software to run the cooling analysis on the model. They predicted that warpage can be minimized by keeping the temperature of mold surface as uniform as it can be possible and their simulation results showed that an extended cooling is required at the corners before ejection of the article. Khor *et al* [12] investigated meso-scale injection molding process both numerically and experimentally. They also utilized FLUENT 6.3 software for the simulation. They predicted the effect of viscosity and shear rate on mold cavity with respect to the melt temperature. They observed that higher melt temperature can minimize the effect of viscosity and the higher shear rate can be achieved with high temperature. They plotted the effect on viscosity and shear rate with respect to the temperature. They also prepared flow profiles for the polymer resins both experimentally and by simulation. Hassan *et al* [13] developed a numerical model to investigate the effect cooling system on shrinkage rate of polystyrene. They illustrated that the location of the cooling channels has an enormous effect on end product temperature and the shrinkage rate distribution throughout the product. They show that when the cooling channels come within reach of the product, the cooling amplifies. From the analysis of the model it is found that the cooling channels position which performs greater cooling process not necessary achieves optimum shrinkage rate distribution throughout the product, and the system layout must be optimized to achieve the both goals. Hassan *et al* [14] illustrated a numerical approach which shows the effect of cooling system design on solidification of polymer during the moulding process and heat transport by the polymer. Through numerical model they found that for the equal cross-sectional area and coolant flow rate of the cooling channels, rectangular cross section cooling channel requires minimum time to completely solidify the plastic product. In addition to this, they also pointed out that when the cooling channels come close to the artefact surface, the cooling effectiveness increases. Rahman *et al* [15] used Moldflow software for the plastic Injection molding simulation analysis of natural fibre composite window frame. They investigated packing, cooling, flowing and cost of the process. They found that hollow design window frame desirable to be made-up than solid design of window frame due to the lower part thickness of the hollow design but hollow design had undergone warpage during cooling. Due to difficulty of removing heat of solidification from the molten polymer compare to thin wall regions. They also found that that unbalance cooling caused excessive shrinkage problem to occur. Besides that, hollow design intrinsically required small amount of materials to fabricate. Thus, hollow window frame has low material and operation cost.

Song *et al* [16] used numerical simulation and orthogonal experiment method to analyze different process parameters which affect the quality of the thin walled plastic products. The complexity in molding ultra-thin wall parts lies in the fact that the ratio of frozen layer thickness to part thickness during filling will significantly raise with the diminish in part thickness. From the result, they found that thickness of the object is greatly affected by the injection rate and metering size. Kwak *et al* [17] used the 3D Timon v.6.11 CAE software to carry out simulation on plastic injection moulding process. The objective of their study is to minimize the porosity and thickness drop defects in the optical lenses. Thickness reduction was measured by the neural network method and it was found that as holding time increased, the thickness reduction decreased. Porosity increases proportionately to the volumetric distortion in the product. Galantucci [18] used finite element analysis to optimize the filling conditions of the plastic injection moulding process. They also used Taguchi and response surface Statistical approaches to support FE analyses. They proposed that the location of the gate for filling of the mould cavity is very significant effects on warpage and plastic resin orientation and all cavities must be completely filled at the same time, as it can reduce weld line shrinkage and air traps in moulded part. In addition, the best gate location can minimize the problem of over-packing sticking, flashing, excessive cycle time and part weight. Tolga Bozdana [19] developed expert system software to determine the optimum parameters for a given job by means of material and machine databases. They first categorized the plastic injection moulding parameters as injection unit parameters, clamping unit parameters and other parameters of the machine after that they developed a system consist of three module, first module select the most suitable plastic injection moulding machine and second module select the most suitable plastic resin as per selected PIMM machine and third select the optimum no. of cavities for the given product in a single operation.

Table -2 Summary of Literature Review

Ref. No	Year	Problem	Problem associated to	Step No.
5	2014	Comparison of injection molding technologies	Product geometry	Step-1
6	2013	Shrinkages and warpage	Product Thickness	Step-1
7	2013	Design and fabrication of cooling channel and submarine gate	Cooling channel and Gate	Step- 2 & 4
8	2013	Performance evaluation of design of cooling system	Cooling channel	Step-3 & 4
9	2012	Effects of geometry and parameters on weld line	Product geometry and Process parameters	Step-1 & 2
10	2012	Analysis of polyvinyl alcohol–starch	Plastic Resin and Process parameters	Step-1 & 3
11	2011	Effect of cooling on warpage at the corners	Product geometry	Step-1
12	2010	Effect of viscosity, shear rate	Plastic resin behaviour	Step-1
13	2010	Effect of cooling system on the shrinkage	Cooling channel	Step-3 & 4
14	2010	Effect of cooling system	Cooling channel, Process parameters	Step-3 & 4
15	2009	Determination of Process parameters for thin-shell plastic parts	Product geometry and Process parameters	Step-1 & 3
16	2008	Analysis of fibre composite window frame	Product geometry, Process parameters and cooling channel	Step-1, 3 & 4
17	2007	Effects of parameters on Ultra-thin wall plastic parts	Process parameters and Product geometry	Step-1 & 3
18	2005	Surface profile of optic lens	Plastic resin properties and product geometry	Step-1 & 2
19	2003	Evaluation of filling conditions	Process parameters	Step-3
20	2002	Determination of parameters	Process parameters and Machine set up	Step-3

RESULT AND DISCUSSION

Through literature review we may conclude that most of the researches have been done on the process parameters and product geometry. It is easy to control the defects through selection of proper geometry and parameters. Process parameters can be modified at any stage of the process while other factors like mold design and material have certain limitations of cost and time, whereas the application of cooling channel can improve the quality of the product but it increase the cycle time and cost.

Although plastic injection molding process is complex one but the product can be produced with fewer defects by controlling the process environment. Through literature review it has been found that process parameters plays important role in the process. The other factors like mold/product shape, size, and geometry and machine set-up, post process factors were not so much important as process parameters.

CONCLUSION

Due to limitation, only few references are given which shows the area of interest of the researchers. Optimization of this process in terms of material part is limited due to dependency of material on the application of the product. It is easy to optimize the process through selection appropriate process parameters and modifying them.

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