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A Review on Parameter Optimization of Injection Moulding for Polypropylene Tooth Brush using Taguchi Method

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Abstract – *Plastic Injection Molding has been a very challenging process for many manufacturers and researchers to produce a products meeting all the expectations of the customer at low cost and in minimum time. Injection moulding is used at large scale in India for Polymeric fabrication process of thermoplastic materials, which finds applications in many industrial as well as household consumer products. The old concept of using the trial and error approach to determine the desired process parameters for injection molding machine is no longer hold good enough because the complexity of product design and global competition in injection moulding industry. Now-a-day's plastic is widely used polymer due to its high production rate, low cost and capability to produce complex parts with high precision. It is much difficult to set optimal process parameter levels in order to meet customer requirements and expectations regarding productivity, quality and performance of the product at a competitive price. The objective of this paper is to provide an insight of literatures about recent research in optimization aspects for determining optimum process parameters of plastic injection molding.*

Key Words: Injection Moulding, Optimization, Taguchi Method, Polypropylene, Quality

1. INTRODUCTION

Injection Moulding is an important manufacturing process used in the case of processing of polymers. It is a very popular process due to its high production rate. Injection molding is generally suited for manufacturing large quantities of mass produced plastic parts of complex shapes and sizes. Optimizing the process parameters of the injection molding process is critical to enhance productivity and quality of the product. For process optimization, parameters must operate at optimum levels for acceptable performance and in order to reduce the defects. In this process, the part is produced by injecting hot melt of plastic into a cold empty cavity of desired shape called mold. The raw material in granular form is fed into the machine by means of a hopper, which pre-heats the material and remove the moisture from the raw material granular. Through the hopper raw material is fed into the barrel. The material is then heated into the barrel with the help of heaters and maintained at required temperatures at a different zone. After this process, the molten polymer is injected into the mold at required pressure from the nozzle. Finally, it is held for given time to cool down and then with the help of ejector pin, the part is ejected when the mold opens. The mold is normally made up of Steel or Aluminium depending upon the type of application.

2. LITERATURE REVIEW

A number 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 lot of optimization techniques were used to control the plastic injection process parameters which effects the moulding processes. Some of the prior research articles are as under:

Gurjeet Singh et. al. [1], the aim of the authors of this article is to minimize the warpage defect by controlling the process parameter. The process parameters which were studied by the authors namely melt temperature, mould temperature, packing pressure, packing time and cooling time. They used Taguchi approach to find out optimal parameter setting. From the result it was concluded that the ability of this approach to predict Sink depth for various combination of processing variables with in design space.

T. Mohan Kumar et. al. [2], studied the effect of various injection moulding process parameters on the volumetric shrinkage and fill time of a Polypropylene chair bottom cap part. In this paper the authors investigated the most significant

parameter causing high volumetric shrinkage and optimised the process parameters through Taguchi L9 orthogonal array design and analysis of variance (ANOVA) method. Four process parameters were considered in this research: injection pressure, cooling time, melt temperature and mold temperature. They found that the injection pressure, melt temperature were most significant factors for volumetric shrinkage. Like that for fill time melt temperature and injection pressure were most critical factors for product.

Dr. Hari Vasudevan et. al. [3], in this Paper the authors presented the application of Taguchi Method on the process parameters of Injection Moulding of Polybutylene Terephthalate (PBT). The effect of process parameters, such as Injection Pressure, Injection Time, Cooling Time, Suckback Pressure, Zone 1 Temperature & Zone 2 Temperature (Barrel Temperatures) on Dark Spots and Short Shots (defects) were investigated using the Orthogonal Array L16 of Taguchi Method for 6 factors at 2 levels each with the response being percent defectives. They showed that Injection Pressure, Injection Time & Zone 1 Temperature had a major effect on the response and they also confirmed from their investigation, the rejection rate reduced from 11.33% to 5.84%.

Sreedharan J and A. K Jeevanantham [4], in this study the authors tried to optimize the molding process parameters in order to reduce the molding defects like shrinkage by using Taguchi's experimental design and the analysis of variance methods. The process parameters considered by the authors namely melt temperature, packing pressure, Injection Pressure and cooling time. From the observation using S/N ratio it was revealed that the Melt temperature plays a major role in shrinkage reduction on the moulded part.

T Kiatcharoenpol et. al. [5], attempted to study process parameters of Plastic injection molding and optimize the process parameters to improve quality characteristic of work-piece. Taguchi's orthogonal array (L_{16}) was applied to conduct experiments. The two responses obtained from the experiment are volume shrinkage and total displacement. They concluded that there are three statistically major factors out of seven factors or process parameters (Filling time, Melt temperature, Maximum injection pressure, Mold temperature, packing time, Maximum packing pressure and Cooling time). The three significant factors are Melt temperature, packing time and Cooling time.

Ramkumar Ramakrishnan et. al. [6], in this research article the authors studied the effect of various injection molding process parameters on the volumetric shrinkage of a acetal polymer gear part, identifying the most significant parameter causing high volumetric shrinkage. Here the Taguchi orthogonal array design and analysis of variance (ANOVA) method were used to optimize the process parameters. The process parameters selected by the authors in this study were Melt temperature (^{0}C), Mold temperature (^{0}C), Packing pressure (MPa), Packing time (sec) and Cooling time (sec). It was observed that the melt temperature does influence the volumetric shrinkage followed by the packing pressure.

Sokkalingam Rajalingam et. al. [7], studied the process parameters setting to minimize shrinkage defect for plastic cell phone housing made by poly carbonate material. In their study they used Response surface methods (RMS) to identify most significant parameters. They considered mold temperature, injection pressure and screw rotation speed. Authors found from their observation that the shrinkage defect can be reduced with the optimal setting obtained by RMS.

J.A.M. Agnelli et. al. [8], presented optimization of injection molding process parameters for sisa-glass fibre hybrid biocomposite by using Taguchi method. The six process parameters namely melt temperature, mould temperature, injection pressure, holding pressure, holding time and cooling time were included by the authors. Taguchi orthogonal array L_{18} was applied to run the experiments, and analysis of variance was then used to identify the significant process factors. On their analysis, they consider that the injection pressure had a significant influence on the shrinkage.

Harshal P. Kale et. al. [9], in this paper the authors had studied the effects of plastic injection moulding process parameters and optimise the parameters to reduce shrinkage. Here the Taguchi's and analysis of variance (ANOVA) were used to optimize the process parameters for High Density Polyethylene (HDPE) Material. The selected process parameters in this study were Melting temperature, Injection Pressure, Packing Pressure and cooling Time. The result showed that melt temperature is the most significant parameter.

Anand Kr Dwiwedi et. al. [10], in the study of processing parameters on injection moulding process they consider injection pressure, Processing temperature, cooling time and injection speed as a process parameter which affect the

strength of material polypropylene(PP). They found that Processing Temperature significantly affect the tensile strength of material.

Y. P. Tidke et. al. [11], the aim of the authors of this paper was to review the research of the practical use of Taguchi method in the optimization of processing parameters for injection moulding with various approaches including Signal to noise ratio. On their review, they consider the most affecting factors is the melting temperature, packing time and packing Pressure which effect the quality of the product. They suggest that gate location, cooling time and direction of polish, these are factors which effect the warpage of the plastic material.

Yi-qi Wang et. al. [12], presented Taguchi optimization method to find the optimal plastic Injection Moulding process parameters for improving compression strength. The authors consider number of gates, gate size, resin temperature, molding temperature, switch over by volume filled, switch over injection pressure and curing time factor effect on compression strength for manufacturing a brake booster valve body. From the results it was concluded that the molding temperature plays a vital role for improving compression strength.

Mohd. Muktar Alam et. al. [13], in their work they find optimal injection moulding condition in order to reduce shrinkage. The material namely Polypropylene was considered to perform various observation. They applied the DOE technique of Taguchi method by optimizing the plastic injection moulding process parameters like Melt temperature, Injection Pressure, Packing Pressure and Packing time. The authors concluded that the packing pressure was the most effective factor for reducing the shrinkage of the material.

Sajjan Kumar Lal et. al. [14], in this paper the authors made an attempt to investigate the effects of plastic injection moulding process parameters on shrinkage of Low Density Polyethylene (LDPE) material. They used Taguchi approach to find out optimal parameter setting and to reduce shrinkage. The process parameters were considered in this research: melting temperature, injection pressure, refilling pressure and cooling time. From the result the cooling time found most influential parameter followed by refilling pressure and injection pressure was found to be the least effective factor.

Wu-Lin Chen et. al. [15], to find the optimal combinations of process parameters for a digital camera thin cover. In this work, warpage, shrinkage and volumetric shrinkages of plastic parts were usually considered as their quality indices. Moldflow and Solid works are used to simulate the injection molding process and to create the part's geometry, respectively. Taguchi's orthogonal array L_{27} is applied to perform the experiments, and analysis of variance is then used to obtain the significant process factors out of nine parameters namely injection time, cooling time, injection pressure, packing time, packing pressure, cooling temperature, mold open time, mold temperature and melt temperature.

Kalpit Jain et. al. [16], in this article the authors reviewed the practical use of Taguchi method in the optimization of processing parameters for injection moulding. After reviewing the articles on optimization of plastic injection moulding process parameters for plastic material, the author found that the orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio are utilized to find the optimal levels and effect of process parameters are determined by many researchers on shrinkage & warpage.

Sanjay N. Lahoti et. al. [17], has done study to determine the optimal process parameter settings which influences productivity, quality, and cost of production in the plastic injection molding (PIM) industry. The experimentation will be done for three different thermoplastic materials with at least two varieties in each. They develop a methodology to manufacture defects free parts by controlling the initial process parameters settings. The parameters were considered in this work: melt temperature, injection pressure, packing pressure, packing time, cooling temperature, injection velocity, injection time, cooling time, etc.

Ng Chin Fei et. al. [18], in an attempt to review the research in the optimization of processing parameters for injection moulding the methodology was taken as taguchi method. The Taguchi robust parameter design has been widely used to solve various single response process parameter designs. However, the authors found that there is no single technique that appears to be superior in solving different types of problem.

Dragan Kusic et. al. [19], in the study of processing parameters on injection moulding process they consider six parameters namely Melt temperature, injection speed, packing time, Injection pressure, packing pressure and Cooling time which effect post-moulding shrinkage and warping of parts. They did their analysis on polyethylene filled with calcium carbonate. Here an optical 3D scanner was used by the authors to scan each test specimen for accuracy. They showed that the packing pressure has significant factor which affect most.

Rishi Pareek et. al. [20], in this paper the authors considered the tea plate of plastic product to define suitable parameters in producing plastic product. On their analysis, they consider the tensile strength by taking process parameters injection pressure, melting temperature, cooling time and Polycarbonate as a material. They obtained an optimum value or the best value of injection pressure, melting temperature and cooling time by using Taguchi and ANOVA.

M.G. Rathi et. al. [21], did investigation on the effects of Back Pressure, Mould Closing Speed, Mould Pressure and injection pressure on the quality Characteristic of Chlorinated Poly Vinyl Chloride (CPVC) material. In this experimental work the authors find the optimum level of factors by DOE technique of Taguchi and the analysis of variance methods. Form the ANOVA results the authors found that the mould closing speed had significant effect on quality characteristic.

3. RESULT AND SUMMARY

From the literature review it is found that many researchers did study on optimization of the process parameters for plastic injection molding with different plastic materials by using various technique and some of them are listed below:

S.No.	Title of paper	Published year	Parameters studied	Material	Responses
1.	Effect of Injection Moulding Process Parameter on Warpage of using Taguchi Method	2019	Melt Temperature Injection Pressure Packing Pressure Cooling Time Packing Time	Polypropylene	warpage
2.	Optimization of process parameter in injection moulding using Taguchi Method	2019	Injection Pressure Cooling Time Melt Temperature Mold Temperature	Polypropylene	volumetric shrinkage and fill time
3.	Optimization of Injection Moulding Process Parameters for Manufacturing Plastic Components (PBT) Using Taguchi Method (TM)	2019	Injection Pressure Suckback Pressure Injection Time Cooling Time, Barrel temperatures	Polybutylene Terephthalate (PBT)	Dark Spots and Short Shots
4.	Analysis Of Shrinkages in ABS Injection Moulding Parts for Automobile Applications	2018	Melt Temperature Injection Pressure Packing Pressure Cooling Time	Acrylonitrile Butadiene Styrene (ABS)	shrinkage
5.	Minimization of Shrinkage in Injection Molding Process of Acetal Polymer Gear Using Taguchi DOE Optimization and ANOVA Method	2017	Melt Temperature Mold Temperature Packing Time Packing Pressure Cooling Time	Acetal [Delrin 500P]	volumetric shrinkage

6.	Optimization of injection molding process parameters for a plastic cell phone housing Component	2016	Mold Temperature Injection Pressure Screw Rotation Speed	Polycarbonate (PC)	Shrinkage
7.	Optimization of Injection Molding Process Parameter for Reducing Shrinkage by Using High Density Polyethylene (HDPE) Material	2015	Melting Temperature, Injection Pressure Packing Pressure Cooling Time	Acrylonitrile Butadiene Styrene (ABS)	Shrinkage
8.	Practical application of Taguchi method for optimization of process parameters in Injection Molding Machine for PP material	2015	Injection Pressure, Processing Temperature, Cooling Time Injection Speed	Polypropylene (PP)	Tensile Strength
9.	Optimization of Plastic Injection Molding process parameters for manufacturing a Brake booster valve body	2014	Number of Gates, Gate Size, Resin Temperature, Molding Temperature, Switch Over by Volume Filled, Switch Over Injection Pressure, Curing Time	Phenolic molding compound (CY3915 30G)	Shrinkage
10.	Reducing Shrinkage in Plastic Injection Moulding using Taguchi Method in Tata Magic Head Light	2013	Melt Temperature Injection Pressure Packing Pressure Packing Time	Polypropylene (PP)	Shrinkage
11.	Optimization of Injection Moulding Process using Taguchi and ANOVA	2013	Injection Pressure, Melting Temperature, Cooling Time	Polycarbonate (PC)	Tensile Strength

4. CONCLUSION

Plastic injection moulding is very important process in manufacturing of products. There are number of plastic products that manufactured by injection moulding. So the settings of various processing parameters of the injection moulding process to minimize defects is challenging task that costs time, effort and money. This paper presents a review of research article in the optimization of processing parameters for injection moulding. Here a lot of work had done by many authors in this area. From the study we found that a systematic methodology exploring the relationship between parameters and identifying the optimal process settings is proposed in the optimization of processing parameters is the Taguchi method. Taguchi method is robust design techniques widely used in industries as it can improve the processing quality, reduce the number of experiments, minimize the processing variation and increase the quality stability. However, it is realized that there is no single technique that appears to be superior in solving different types of problem. Advancements are to be expected by integrating the practical use of the Taguchi method into other optimization approaches to enhance the efficiency of the optimization process.

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