Review on injection molding process for tensile strength of plastic components using optimization techniques

BELAL AHMAD [1], DR. MANISH GANGIL[2]

M.Tech.Scholar[1], Professor[2]

belalahmad0137@gmail.com, rkdfbhojpal@gmail.com
Department of Mechanical Engineering, RKDF, University Bhopal, (M.P.) India.

* Corresponding Author: Belal Ahmad

Abstract:

Over the years, injection molding has been a premier manufacturing technique in the production of intricate polymer components. Its molding efficiency rests on the shoulders of multiple process and machine parameters, which dictate the final product quality in terms of multiple output responses. It is imperative to state that a precise optimization of various input parameters is paramount for achieving the desired quality indices. In this article, a review of different techniques employed till date for optimizing various injection molding parameters is presented along with their advantages and limitations. It is found in the review that a complete intelligent technique operable without human interference is yet to be developed.

Keywords: Injection Modelling, Process Parameter, Optimization Technique, Review

1. Overview

The manufacturer generally takes into account some aspects of the manufacture of high-quality plastic products. The products must meet the customer's specifications, the energy consumption and the cost of production must be minimized, the plastic product receives the mechanical properties that gained by the product during the processing are dependent on the parameters, can be regulated to make the product defect free.

1.2 Background of research

The injection molding process is the most versatile process for the manufacturing of complex plastic products and also more demanding because it can efficiently process the complex geometry of the products. However, injection molding operations can sometimes challenge the mold designer to design a mold that produces low-defect products because plastics are easily usable without such type of defects Warpage, shrinkage, weld lines, and air traps **[1]**. Also, Molding materials having different thermal properties that affect the mechanical properties of plastic parts during the injection molding process. Materials like steel, aluminum, etc. can be used for making the mold, but the aluminum mold has advantages in terms of weight, heat transfer and low production costs **[2]**. The design of plastic molds is not only an essential process in the commonly used manufacturing process but also essential to control parameters to make defect-free products. The molding process of the hot injection material is allowed to freeze inside the mold. The solidified product of the net shape is thrown out of the mold when it is opened. Although this process is simple, due to many processing variables, predicting the quality of the final part is a complex phenomenon **[3]**. As a result, the process of improvement and testing in the study parameters to optimize the injection molding process that can be implemented in the process. The need for a process of optimization is necessary for a broad sense. The manufacturing process of plastic parts presents discrepancies due to misinformation and lack of knowledge.

The main requirement is to check and to prevent the risks associated with the production of plastic products during the processing itself. The variation of the injection molding process should be such that the correct position of the response is within the range to be diagnosed then the empirically based predictive model approach is the most suitable solution for the injection molding process. For such type problems experimenter designed through different approaches like full factorial design, fractional factorial design, response surface method, Taguchi approach, etc. Out of which Taguchi approach design is performed due to its less no of experiments, which leads to reduce the time, the cost associated with it.

1.2 Process variables of an injection molding machine

The basic process can be classified such as speed, pressure, time, temperature and stroke. The relationship amongst is interactive in nature because out of which many has combine effect on the process. For example, this relationship can be demonstrated, on increasing the hydraulic back pressure, the linear shrinkage speed (during recovery) of the screw causes a screw recovery time, melting temperature and/or symmetry. Due to the increase in melt temperature, changes in mold filling, injection pressure, mold temperature, product temperature, and temperature changes in the product dimensions. As a result, three other main variables are collectively affected by the increase of a pressure variable (e.g. hydraulic backpressure). The Table1.1 presents the typical process parameters that must be monitored and/or controlled at each cycle. To help you identify the variable causing the static stability caused by the primary interference, you can divide it into two types: controllable and Consequential.

Table 1.1: Process variables of the Injection molding process

Pressures	Temperature	Times	Speeds	Strokes
Holding	Melt	Ejection	Injection	Melt cushion
Injection	Mold surface	Mold close	Screw	Screw stroke
Hyd. back	Barrel	Mold open	Mold close	Mold open

Ejection	Component	Cooling	Mold open	Change over
Mold safety	Material	Cycle	Screw return	Position
Nozzle	Environment	Screw recovery	Ejection	Decompress.
Oil	Oil	Hold press.		

2. LITERATURE REVIEW

The non-gradient-based optimization technique does not require an objective function, f (x); it can be isolated because the algorithms do not use derivatives off (x). Examples of non-gradient-based optimization techniques are adaptive simulated annealing, Hooke-Jeeves direct search, and genetic algorithm. These optimization techniques are meant to reach a globally optimal, but a large number of function evaluations are required. Example genetic algorithm is a well-known non-gradient based optimization technique, which is a stochastic search or optimization algorithm which imitates Darwin's biological theory of evolution **[4]**. The gradient-based technique defines search directions by the gradient of the function at the current point. Example there are many kinds of gradient-based optimization techniques such as generalized reduced gradient, conjugate gradient, method of feasible directions, mix integer optimization, sequential linear programming, sequential quadratic programming, and Davidson–Fletcher–Powell. Gradient-based techniques, in general, allow for rapid convergence, but if the number of variables increases, it may be necessary to run them for long hours **[5].** Gradient-based techniques can also be a risk of local extremes for high nonlinear optimization problems. Hybrid optimization technique uses a combination of gradient-based and gradient-based technique to reduce the loss of single optimization technique problems. However, optimization methods based on simulation can divided into two categories of methods:

(1) Direct optimization methods
(2) Meta model-based optimization methods

Direct optimization methods cannot define the relation between input and output variables. Such as Gradient-Based Optimization Techniques, Non-Gradient Based Optimization Techniques, and Hybridization-Based Optimization Techniques. Meta model and hybrid model based optimization can detect optimal space by selecting a suitable model which establishes the connection between input and output variables **[6]**. It is necessary to see the online and offline quality control of the injection molding process; the process can be controlled by the control of process parameters by the online artificial intelligence optimization methods and offline methods for cost minimization. Thus the objective is to improve the manufacturing process and quality of a product. For this, various researchers study of adaptation methods by considering the response as a dimensional defect, mechanical properties and cycle times of the process of construction by injection molding. In this section, the researcher's research has been classified, based on the methods and reaction behavior of the study process.

2.1 Study based on Response surface method

Examine the Warpage as the response by considering melt temperature, packing pressure, cooling time, coolant temperature as process parameters with the help of rotatable central composite design response surface method. In their analysis, they find that cooling temperature is the most effective factor, which affects the dimensional defect warpage **[1].**

Investigate shrinkage and cycle time as response with the help of melt temperature, packing pressure with the help of Center composite design and Latin Hypercube design of response surface method. In their analysis, they find that melt temperature contribute significantly in cycle time and shrinkage **[2].**

2.2 Study based on different hybridization methods

Inspect Warpage and clamp force as the combined response by considering melt temperature, mold temperature, packing pressure, packing time, cooling time as process parameters with the help of Back propagation and Genetic algorithm method. In their research, they find that as packing pressure increases, the Warpage gets reduced and the clamping force needs more to keep the material in the mold **[3].**

Evaluate the shrinkage defect with the help of melt temperature, packing pressure, packing time, cooling time as process parameters with the help of Taguchi's method coupled with GRA. The melt temperature in their study is the most effective processing parameter **[4].** Surveyed on the product weight as response with the help of injection velocity, injection time, packing pressure as process parameters. In their studies, they find that packing pressure is a critical contributing factor to the increase in product weight **[5].**

Examine the effect of Warpage as response with the help of melt temperature, mold temperature, injection velocity on the Polycarbonate plastic material by Artificial neural network and particle swarm optimization methods. In the study, they find that the melt temperature contributes a lot to the Warpage **[6].**

Explore study Warpage as response with the help of melt temperature, mold temperature, injection time, packing time, packing pressure by Kriging surrogate model combining the design of experiment methods. In the study, they find that the melt temperature is an effective factor for the warping of plastic products **[7].**

Evaluate warpage as response with the help of melt temperature, injection pressure, packing pressure as process parameters by Taguchi's method coupled with desirability function. Melt temperature and filling/packing pressure found in both simulations and experiments, with the most critical factors being detected **[8].**

To fulfill this identified gap, the research statement, problem statement, and objective have been finalized. From the literature review, few of them have been work on the polypropylene plastic materials with advance optimization hybridization techniques.

3. Terms used in an experiment

In the scientific investigation there are various stages. It starts for the trial experiments, collection of data, conduction of experiments, analyzing the data by different methods as described in Fig.3.1 and the different terms had been used in experimental data are discussed as:

1. Treatments: Treatment is the various procedures that are compared for various responses.
2. Experimental units: Experimental units are the things from which applied to the treatment.
3. Responses: Responses are the results measured after applying treatment in a pilot experiment. The response measures what happened in the experiment.
4. Randomization: Randomization is a known use, explaining the potential mechanisms for assigning treatment to units.
5. Experimental Error: The experimental error is the random difference in all the experimental results. Different experimental units will give different responses to the same treatment, and it is often true that repeated trials of the same treatment will have different responses in different tests. The experimental error does not refer to misuse or to leave test.
6. Unit of measurement: The units of measurement (or units of response) are real objects on which the response is measured.
7. Blinding: Blindness occurs when response respondents do not know which unit has been treated. Control: There are different uses of control in design. First, an experiment is controlled by experimental units. Secondly, a control treatment is a "standard" treatment used as a basis or basis of comparison for other treatments. This control treatment can be a commonly used treatment or zero treatment (no treatment).

8. Alleviation: Alleviation is zero processing that is used when a treatment has an effect on the implementation of any treatment
9. Parameters: Parameters combine to make a treatment.
10. Confounding: Confounding is called when the effect of a parameter cannot be separated from another parameter.

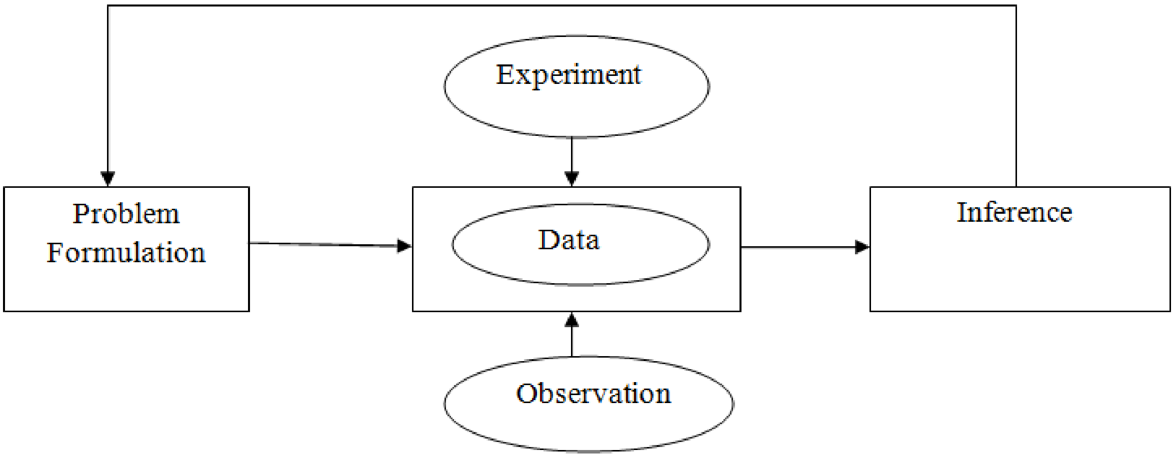

Fig. 3.1 Critical stages of Statistical input in scientific investigations

3.1 Taguchi's Method

One of the largest engineering's of 20th-century achievements is Taguchi's comprehensive quality system. This method focuses on the useful application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shops floor quality Engineering. Upstream methods use small-scale experiments to reduce variability efficiently and to maintain cost-effective and robust designs for mass production and marketplace. Shop-floor technology provides cost-based real-time methods for quality monitoring and maintenance. A quality method is applied to the front, it has many advantages over improvements, and the more it reduces the cost and time. Taguchi's philosophy is based on the following three elementary and original concepts:

(1) The quality of the product is designed and not inspected in it.
(2) Quality is best achieved by reducing the deviation of the objective. The product or process must be designed to be immune to uncontrollable environmental variables.
(3) Quality cost should be measured as the work of deviation from the standard and the damage should be measured system-wide.

To achieve the desired product quality by design, Dr. Taguchi recommends the three-phase process.

(1) System design

(2) Parameter design

(3) Tolerance design

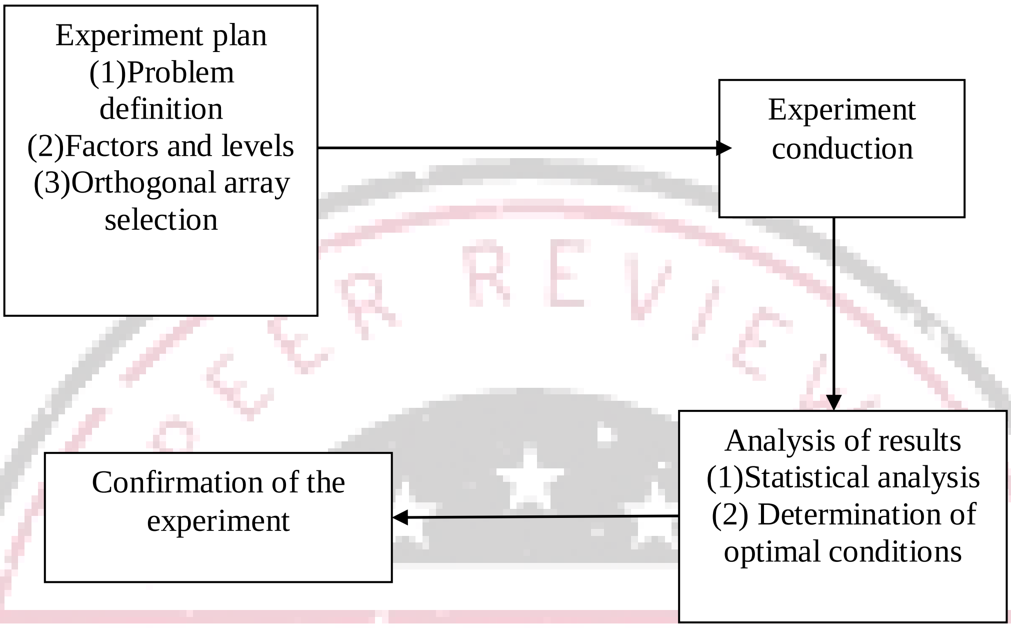

Fig.3.2 Steps of Taguchi Methodology for Single objective optimization

3.2 Experimental Design Strategy

Taguchi has recommended an Orthogonal array (OA) to plan the experiments. These 'OA' are generalized Greco-Latin squares. To design an experiment, select the most appropriate OA and assign the parameters of interest and interactions to the appropriate columns. Using linear graphs and triangular tables suggested by Taguchi simplifies the assignment of parameters. The matrix forces all experimenters to design almost identical experiments. The results of the experiments are analyzed to achieve one or more of the following objectives in the Taguchi method.

(1) Establish the best or optimum combination process parameters for a product or process.

(2) Estimate the contribution of individual parameters and interactions.

(3) Estimate the response in optimal conditions.

3.3 Loss Function

The heart of Taguchi method is his definition of the nebulous and elusive term "quality" as the characteristic that avoids a loss to the society from the time the product is shipped **(Braker [1986])**. The loss is measured in terms of monetary units and it is related to the quantifiable product attribute. The Taguchi defines quality loss through its "loss function". It unites financial losses with functional specification through a Taylor series expansion coming from the quadratic relationship. The quadratic function takes the form of a parabola. The Taguchi defines the loss function is proportional to the deviation from the nominal quality characteristic. Following quadrilateral form as a useful experimental work:

$$L(y) = k(y - m)^2 \quad (3.1)$$

Where

L= Loss in monetary units

m = value at which the characteristics should be set

y = actual value of the characteristic

k = constant depending on the magnitude of the characteristic and the monetary unit involved

The loss is a continuous function and there is no sudden move in the case of traditional (round post) approach (Fig. 3.3b). This result of the continuous loss function indicates this point that creating a product within the specification limits does not mean that the product is of good quality.

(a)

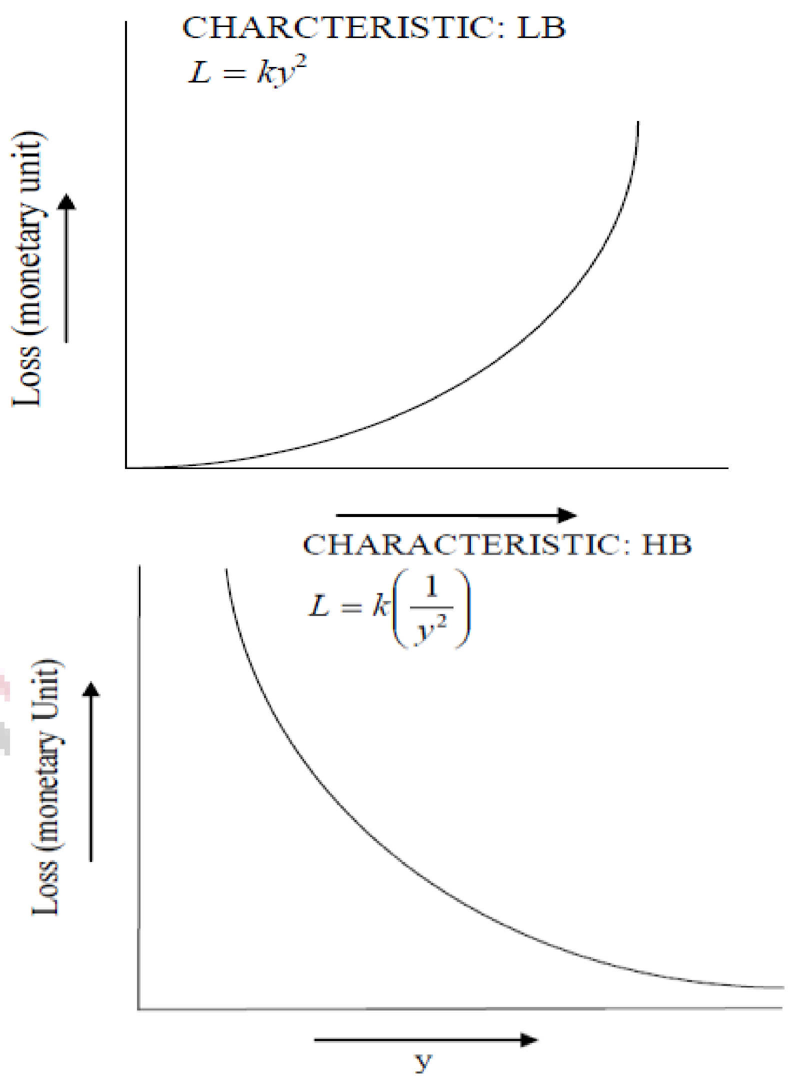

Fig. 3.3 (a, b) The Taguchi Loss-Function for LB and HB Characteristics (Barker[1990])

A high value of S/N means that signal to noise is much higher than the random effects of noise factors. The highest S/N compliant process operation always gives optimum quality with minimum variation.

The S / N ratio aggregates multiple repetitions (requires at least two data points) in one value. For calculation of S / N ratios, the equation is "Small is better (LB)" and larger is better (HB) and "Nominal is best (NB)" characteristics are as follows:

1. Larger the Better:

$$(\frac{S}{N})_{HB} = -10\log(MSD_{HB}) \tag{3.2}$$

Where $MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}(\frac{1}{y_j^2})$

2. Smaller the Better:

$$(\frac{S}{N})_{LB} = -10\log(MSD_{HB}) \tag{3.3}$$

Where $MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}(y_j^2)$

3. Nominal the Best

$$(\frac{S}{N})_{NB} = -10\log(MSD_{HB}) \tag{3.4}$$

Where $MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}(y_j - y_0)^2$

R=Number of repetitions

CONCLUSIONS

This study investigated the influence of process parameters, namely injection pressure, injection temperature, mould temperature, holding pressure, injection speed, powder loading, holding time, cooling time, solvent debinding temperature, thermal debinding temperature, isothermal holding time, sintering temperature, heating rate, sintering time and cooling rate on tensile strength, yield strength, impact toughness, hardness and density.

The conclusions drawn from this research are as follows:

When the injection molding process parameters are controlled whereas the process parameters for debinding and sintering stages are kept constant: The injection pressure, mould temperature, holding pressure, injection speed and powder loading are the significant factors during injection molding stage, which influence the tensile strength of the parts produced by PIM process. Whereas the injection temperature, holding time, cooling time are insignificant factors. These factors fail to achieve 95% confidence level and are considered to be error factors.

References

1. Gangil, Manish, and M. K. Pradhan. "Modeling and optimization of electrical discharge machining process using RSM: a review." *Materials Today: Proceedings* 4.2 (2017): 1752-1761.
2. Gangil, Manish, M. K. Pradhan, and Rajesh Purohit. "Review on modelling and optimization of electrical discharge machining process using modern techniques." *Materials Today: Proceedings* 4.2 (2017): 2048-2057.
3. Gangil, Manish, and M. K. Pradhan. "Optimization the machining parameters by using VIKOR Method during EDM process of Titanium alloy." *Materials Today: Proceedings* 5.2 (2018): 7486-7495.
4. Pradhan, M. K., Manish Gangil, and Prabhat Ranjan Kumar. "Application of MCDM for Optimization of EDM of LM6 Silicon Carbide Boron Carbide Hybrid Composite." *In6th International and 27th All India Manufacturing, Technology, Design and Research conference (AIMTDR 2016)*. 2016.
5. Gangil, Manish, and M. K. Pradhan. "Electrical discharge machining of (Ti–6Al–4V) using RSM." *6th International and 27th All India Manufacturing, Technology, Design and Research conference (AIMTDR 2016)*. 2016..
6. Gangil, Manish, and M. K. Pradhan. "Optimization of machining parameters of EDM for performance characteristics using RSM and GRA." *J. Mech. Eng. Biomech* 2.4 (2018): 27-33.
7. Basak P.K and Gangil Manish "CNC Machine-A Boon For Engineering Industries For Performing Innovative Machining Of Cylindrical And Prismatic Parts" Industrial Engineering Journal (ISSN-0970-2555), 2021
8. Basak P.K and Gangil Manish "FEA Designing of Propeller Shaft and Stress Analysis" Research Journal of Engineering Technology and Medical Sciences (ISSN: 2582-6212), Volume 04, Issue 01, March-2021.
9. Singh Ajit and Gangil Manish "Taguchi Optimization of Process Parameters on the Hardness and Impact Energy of Aluminum Alloy" Research Journal of Engineering Technology and Medical Sciences (ISSN: 2582-6212), Volume 03, Issue 02, June 2020.
10. kumar Manish Ram Prasad and Gangil Manish "Material Removal Rate Optimization During Production of Implants" Research Journal of Engineering Technology and Medical Sciences (ISSN: 2582-6212), Volume 03, Issue 02, June 2020.