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Optimization of Process Parameters of Injection Moldings for Plastic Pallets Manufacturing Industry

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ABSTRACT

Plastics have been heavily used in industries like automobile, manufacturing, electrical and electronics industry all over the world. Injection molding is one of the ways to process plastics polymers. However, one of the difficulties they have to face is to set the optimal parameter for the injection molding process. Incorrect parameter selection can lead to parts defects such as warpage, shrinkage, sink marks, weld marks and so on. In this study, the optimal process parameter of injection molding for manufacturing of plastic pallets which is used for warehousing was determined by the orthogonal array of Taguchi's L9 which has 3 factors and 3 levels for each factor, experimental design, and Regression Analysis. The three main parameters such as Mold temperature, holding pressure and charging speed were choosen to study their effect on the Compressive strength. S/N ratios were utilized for determining the optimal set of parameters. According to the results, 230 °C of mold temperature, 98 RPM of charging speed, 25 MPa of Holding pressure make the products in the shape and proportion of the product satisfactory. Statically the most significant parameters were found to be as mold temperature and Charging speed for the Polypropylene moldings, respectively. Holding pressure had the least effect on the compressive strength of PP material. After the degree of significance of the studied process parameters was determined, the linear Regression model was generated and was shown to be an effective predictive tool for Compressive strength.

INTRODUCTION

Injection molding is a very simple an easy manufacturing process where the material is fed into the machine hopper and injected thru injection screw or barrel into the mold and finally, the part will be produced. Industrialist used a different type of material in injection molding to produce their product like metals, glasses, elastomers, confections and some polymers. The most common material among Molders is Thermoplastic and thermosetting polymers. The material is preheated in the hopper to reduce the moisture of the material and then fed into a heating barrel. The barrel is fixed with several numbers of heaters with different temperature settings. Each zone plays its role accordingly. The material is mixed and forced into the mold cavity where its flow and hardens according to its cavity. The mold is used to designed by mold maker or toolmaker from metal, steel or aluminium and precision machined to form the required design of mold. Injection molding is very common among plastic makers from the smallest containers to entire body of cars. The mold must be carefully designed to facilitate the molding process. The possibility of defects in injection molding actually depends on the design consideration and also process parameter. Even though the design of the mold is properly done, the defects on the product are still used to happen due to incorrect parameter input on the machine. Even in this high-tech era, it is difficult for the technician to set process parameters for their plastic moldings production. Numerous injection plastic product manufacturers would rather undergo trial and error at the beginning of manufacturing a new product. Suitable mold design is required for a new product and it plays a significant role in achieving a high-quality product with stylish appearance and good mechanical properties [1]. These trials and errors are utilized to optimize processing conditions with lower warpage, shrinkage, residual stress, unbalances, air traps, weld lines, etc.; however, these trials and errors usually increase the final cost and are time-consuming. This will lead to a loss of competitiveness in the long-run basis.

Researches have been done by the academician in this optimization for injection molding previously. Huang and Tai [2] used the experimental design of Taguchi method to examine the influential processing parameters over warpage in thin-walled parts produced by plastic injection molding. They have selected five input parameters like mold temperature, melting temperature, packing time, packing pressure and injection time to study. They have reached a conclusion that packing pressure was found the most important factor that affects the warpage for the thin-walled part. Altan [3] used Taguchi method to minimize shrinkage of plastic using Polypropylene and polyethylene injected parts. The studies successfully minimized shrinkage by 0.937% and 1.224% shrinkage In Polypropylene (PP) and Polystyrene (PS) by using a neural network (NN). The generated neural network model in terms of the most effective process parameters on the shrinkage gave a good approximation as compared with the optimal experimental results with errors of 8.6% (PP) and 0.48% (PS). The time a machine takes to produce one product is one of the important criteria that all the industrialist gives concern and Neeraj Singh C [4] successfully reduced the time taken to produce DVD product in injection molding manufacturing process by optimizing the process parameter in the injection molding machine. He proved that by utilizing the distance traveled and the speed of the mold, the DVD manufacturing cycle time be reduced to the desired level. Moreover, He also highlighted that the cooling time and holding time in injection molding machine are an important parameter to reduce the cycle time. Alireza Akbarzadeh and Mohammad Sadeghi [5] related the input parameter and the output product quality of the process using analysis of variance (ANOVA). They studied four parameters which is packing time, packing pressure, melting temperature and injection time and proved that packing pressure is the most important parameter that needs to be considered and injection pressure is the least important parameter for Polypropylene material. Vaatainen et al. [6] also used Taguchi method to identify the effect of the injection molding parameters on the visual quality of moldings. The quality problem that they focused on is weight, weld line and sink marks and they were able to optimize many parameters with a less practical test in industry, which actually save time manpower and also cost. Mohd. Muktar Alam and Deepak Kumar [7] also spend their time on studying the optimal condition on parameters process for minimum shrinkage by utilizing the design of experiment technique of Taguchi methods. Like others, this researcher also mentioned that the packing pressure is the most effective factor for PP and followed by packing time, injection pressure and melt temperature. Gang XU and Fangbao deng [8] presented in their study a prediction system for a plastic injection molding process which is called an innovative neural network. The particle swarm optimization algorithm (PSO) is analyzed and an adaptive parameter-adjusting PSO algorithm based on velocity information (APSO-VI) is put forward. From the practical test, it can be claimed that the APSO-VINN can better predict the product quality (volume shrinkage and weight) and liked can be used for other industrial use.

In industrial societies, everyone has a warehouse to keep their product safely until the delivery time or to keep stock. Warehousing is an important part of any manufacturing industry as it is a link between producers and consumers. Plastic pallets are actually used in the warehouse to keep any manufacturing product either in stacking mode or to keep on the floor. The structural design of the plastic pallets are the keys to determine the maintenance of the quality of any product that kept on the pallets. Many alternative materials that have been used in plastics manufacturing like Polypropylene (PP) and High Dense Polythene (HDPE) and so on to get the highest quality output. In the disposable of the warehouse, the use of plastic pallets material has grown rapidly for several years due to its performance, durability, and quality compared to wooden pallets. The difficulty in adjusting the complex injection parameter is to balance the influence factors involved correctly to provide the performed product part [9]. In this study, a plastic pallet was molded using several sets of process parameters. The performance of a plastic pallet is evaluated in term of compressive strength which is reflected by the compressive deflection when subjected to a constant load. The most influential process parameter is identified after the Taguchi optimization. Finally, a prediction model for product quality is also determined using Linear regression method.

THEORETICAL BACKGROUND

i) Optimization Technique

Taguchi's concept is based on the effective application of engineering approach rather than advanced statistical analysis. It focused on both upstream and shopfloor quality engineering concept. Upstream methods effectively reduce the cost and variability by use of small-scale experiments and used robust designs for large-scale production and market aspect. Shop-floor techniques facilitate economical, real-time methods for monitoring and maintaining quality aspects in production. The farther upstream a quality method is applied, the greater the leverages it produces on the improvement, and the more it reduces the cost and time. The cost of quality should be measured as a function of deviation from the standard and the losses should be measured systemwide. Taguchi proposes an off-line strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. Taguchi observes that poor quality cannot be improved by the process of inspection, screening, and salvaging. No amount of inspection can put quality back into the product. Taguchi recommends a three-stage process: system design, parameter design, and tolerance design.

His approach gives a new experimental strategy in which a newly developed form of design of experiment is used. In other words, the Taguchi approach is a form of DOE with some new and special application approach. This technique is helpful to study the effect of various process parameters (variables) on the desired quality and productivity in a most economical manner. By analyzing the effect of various process parameters on the results, the best factor combination has taken [10]. Taguchi designs of experiments using specially designed tables known as "orthogonal array". With the help of these experiments table, the design of experiments very easy and consistent [11] and it requires only a few numbers of experimental trials to study the entire system. In this manner, the whole experimental work can be made economical. The experimental outcomes are then transformed into a S/N ratio. Taguchi suggests the use of the S/N ratio to investigate the quality characteristics deviating from the standard values. Usually, there are three types of classification of the quality characteristic in the study of the S/N ratio, i.e. the-lower-the better, the-higher-the-better, and the nominal-the-better. The S/N ratio for each category of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimum level of the process parameters is the level with the greatest S/N ratio, so in this manner, the optimal combination of the process parameters can be predicted.

ii) Process Parameter

There are a number of machine settings that allows the control of all steps of slurry or melt preparation, injection into a mold cavity and subsequent solidification. Some important parameters of them are like Injection pressure, Injection speed, mold temperature, Processing Temperature; hold pressure, Back pressure, Hydraulic oil temperature, Cooling time, Suck back pressure etc. The concept of product quality is ambiguous and there are several product quality definitions that can be classified into the following three categories: (a) dimensional properties (for e.g., weight, length, and thickness), (b) surface properties represented by the appearance of surface defects (for e.g., sink marks and jetting), and (c) mechanical or optical properties (for e.g., tensile and impact strength). Yang and Gao [12] claimed that the performance of a manufacturing process and its quality control are monitored through product weight because the quality is inversely proportional to variability and this is reflected in the product weight variation while product weight is closely related to other quality properties. closed mold cavity and is subsequently held to compensate for polymer shrinkage. This is followed by cooling it down to obtain the desired product. The volume of the mold cavity is constant, and thus the product weight changes with variations in melt specific volume. The causes of the variation in melt specific volume can be classified into the following three categories: (a) Initial melt pressure that is potentially influenced by inconsistent material supply such as incomplete drying or material from different production batches. (b) Initial melt temperature that is potentially influenced by barrel heating and shear heat due to screw rotation. (c) Flow resistance that is potentially influenced by the mold temperature due to inconsistent cycle time and causes different melt compression while filling the cavity. So, the control variable that will affect all these categories is mold temperature, holding pressure and charging speed [13]. These three parameters are studied in this research in parameter optimization for better compressive strength

METHODOLOGY

i) Flow Chart

Figure 3.1 below shows the proposed framework for process parameter optimization. This research consists of three main stages of process parameter optimization. The stages are Phase 1, Phase 2, and Phase 3. Before optimizing the process parameter, the variables that need to be considered must be known in order to have a successful parameter. The first phase is about determining all the component values required in design regarding the first objectives. The 2nd phase is to optimize the identified parameters and the 3rd is to analyze the optimized parameters.

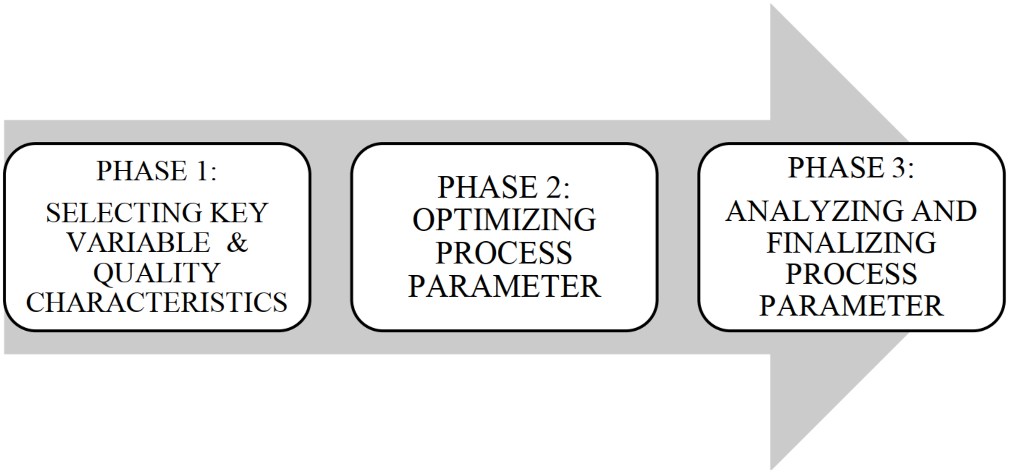


Figure 3.1 The Flow Chart of Process Optimization

ii) Phase 1: Selecting Key Variable & Quality Response

The first phase is to select a suitable parameter which is directly influenced the selected products quality. So, the first step in phase 1 is to select the quality of the product which we want to study and optimized, there are so many quality problems in plastics injections moldings and we tend to choose the compressive strength of the product or well known as the ultimate load the product can withstand. Then we proceed to study on the parameters which can affect this quality. Several previous research works had been gone thru to determine the influential parameters. Once selected, some preliminary test had to be done to identify the maximum, minimum and average value of the parameter to construct the taguchi experiment table. Figure 3.2 below shows the order of all the phase 1 steps.

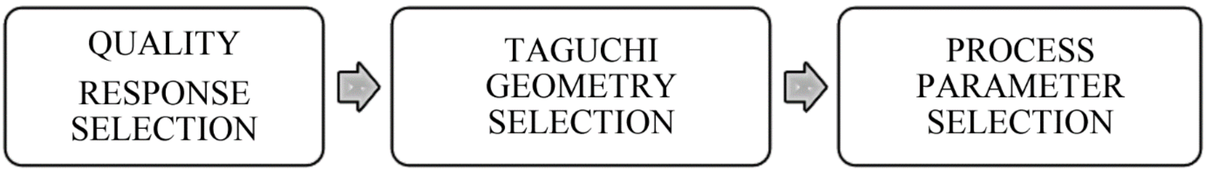


Figure 3.2 Phase 1 Flow chart

iii) Phase 2: Optimizing Process Parameter

The taguchi experimental design is constructed after the orthogonal array is selected. Based on the number of parameters and the number of values L9 orthogonal array is selected. It consists of three factors and 3 levels for each factor. Each experiment is run for an hour before the testing product is selected. 5 specimens are selected for quality testing. Total of 45 Compression testing was done to get the accurate results of quality for each set of parameters. Last but not least, the signal to noise ratio is selected. There are three types of signal to noise ratio which is larger the better, nominal the better and smaller the better. For the compressive test, the larger the compressive strength of the product, the better the quality of the product. So, the larger the better signal-noise ratio is selected. Below shows the formula used to calculate the signal to noise ratio for each set of the experiments.

$$\frac{S}{N} = -10\log_{10}(\frac{1}{n}\sum\frac{1}{{y_i}^2}) \quad (1)$$

where, i=1 to n , n = no. of replications applied to the problems where maximization of quality characteristics of interest is needed.

A) Material

The polymer material used during the experiments was recycled polypropylene. This material is quite popular because its price is relatively low and it is suitable for use in various applications; for instance, in the automotive industry where it is usually used for dashboard components, fans, ductwork and some other under the bonnet components [14]. The properties of this PP material are summarised in Table 1. Drying of this material was unnecessary prior to start the experiments since we had ensured proper storage.

Table 1: The material properties of PP polymer

Material structure	Semi-crystalline
Melt density	1.0639 g/cm3
Solid density	1.259 g/cm3
Moldflow viscosity index	VI(240)0081
Thermal conductivity	0.2274 W/m _C
Specific heat	3002 J/kg _C
Elastic modulus	1788.65 MPa
Shear modulus	648.59 MPa
Poisson ratio	0.3789
MFR	13 g/10 min
Shrinkage	0.9-2.5%, complete after 40 h

B) Mold and Injection Machine

Experiments were carried out on a Haitian (JU24000) injection molding machine, which has a 40 mm diameter screw and maximal clamping force of 2400N. We used a test mold with one cavity insert for the injection molding of Plastic pallets [15] with square dimensions of 1700 mm × 1700 mm (length × width) and thickness of 200 mm. The diameter of the hot runner had a typical value of 7 mm. Fully round sprues and hot runners (modified trapezoidal type) were used, which are recommended for PP materials, and the mold had a film-type gate, which is commonly used for straight edges. The distance of the pressure sensor from the gate was approximately 5 mm. It has to be stated that in order to avoid the sharp corners of the test specimen, we intentionally added a small radius to prevent stress concentration within those areas, which can cause the part to have significant differential shrinkage and warping, and also to fail under heavy load. The other reason for this action was the fact that toolmakers often avoid such problematic corners since they do not have the necessary special machines to create them.

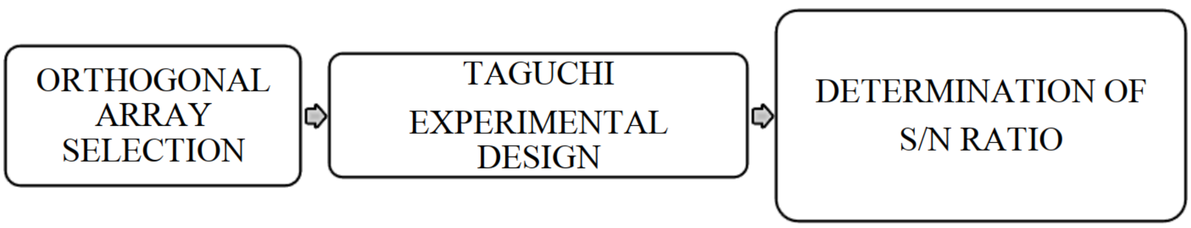


Figure 3.3 Phase 2 Flow chart

iv) Phase 3: Analyzing Process Parameter

In this phase, two analysis had been done, S/N analysis and Regression analysis. From the first analysis, the most influential process parameter is identified and the value of the factors which gives the best compressive strength is also identified. The regression analysis is done and the quantitative relationship between the process and quality is identified. Both of the analysis is done using the help of Minitab 18 software.

RESULTS AND DISCUSSION

i) Selected Process Parameter

There are a number of machine settings that allows the control of all steps of slurry or melt preparation, injection into a mold cavity and subsequent solidification. Proper selections of all the process parameter put direct impact on the quality and productivity of the plastic product so by considering all these factors some important process parameters like mold temperature, holding pressure and charging speed are selected and for conducting the experiments some set of definite values of all the process parameters are taken in Table 2. Three values for each parameter is identified by conducting a preliminary test and the maximum, minimum and average values are listed out. After confirming the significance of all the process parameters the values of the process parameters are listed as a table

Table 2 The selected processs parameter and their values.

Process Parameter	Level 1	Level 2	Level 3
Mold Temperature (°C)	230	220	210
Charging Speed (RPM)	98	93	88
Holding Pressure (MPa)	45	35	25

ii) Taguchi L9 Orthogonal Array Design System

Table 3 Ultimate load results

Test	Mold temperature (°C)	Charging speed (RPM)	Holding pressure (MPa)	Ultimate load test (Kg)
1	230	98	45	5160.2
2	230	93	35	6376.7
3	230	88	25	6091.1
4	220	98	35	4407.8
5	220	93	25	4900.0
6	220	88	45	4454.9
7	210	98	25	5626.7
8	210	93	45	4716.1
9	210	88	35	4810.4

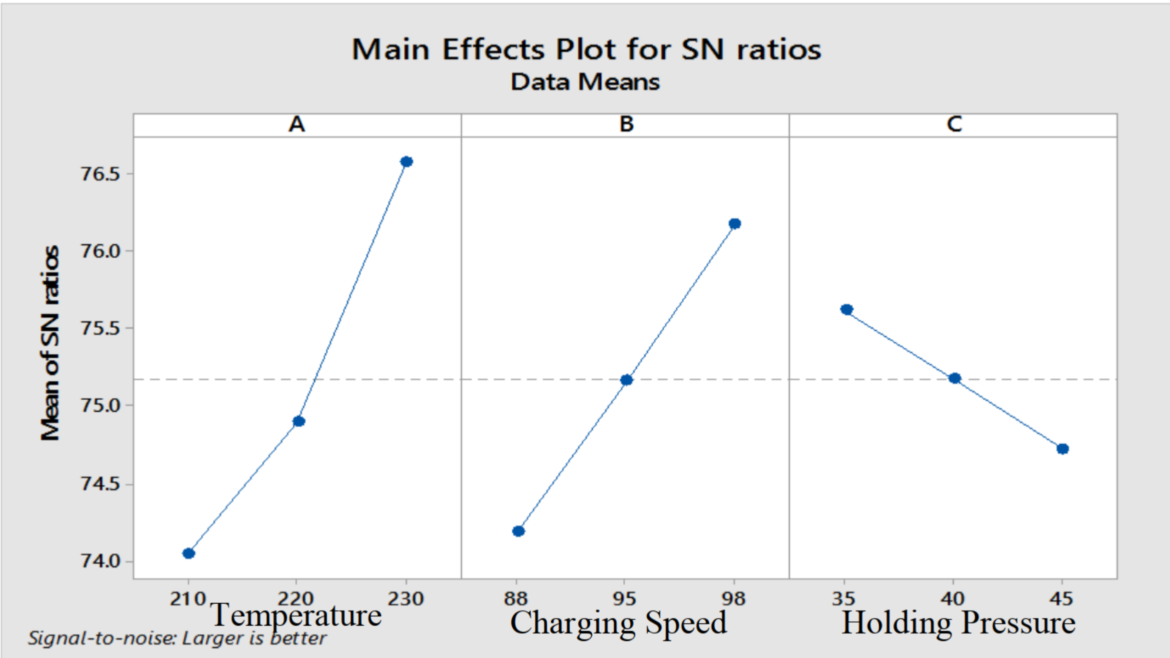
Table 3 above shows the Taguchi table constructed using L9 orthogonal array design system. For each set of parameters, 5 plastic pallets were chosen for the compressive test. The average value of compressive strength for each test is tabulated above.

iii) SN Ratio and Main Plot Effects Result

Results of all 9 experiments are presented in the table below. The advantage of the orthogonal array method is in identifying the effect of each factor at each level [16]. Mean S/N ratio for each experiment are calculated, it gives the S/N ratio for each factor for each level. Graph 1 shows Main effect plots for ultimate strength. Based on the results of S/N ratio analysis, optimal parameters for maximum ultimate load are given in table 4. It is observed from the mean plot, an increase in mold temperature results increase in the signal ratio.

Table 4 Signal to noise ratio

Test	Manifold tempera ture (°C)	Charging speed (RPM)	Holding pres sure (MPa)	Ultimate load test (Kg)	S/N ratio
1	230	98	45	5160.2	77.7169
2	230	93	35	6376.7	76.0919
3	230	88	25	6091.1	75.9343
4	220	98	35	4407.8	75.793
5	220	93	25	4900	75.9176
6	220	88	45	4454.9	72.9768
7	210	98	25	5626.7	75.0051
8	210	93	45	4716.1	73.4728
9	210	88	35	4810.4	73.6438



Graph 1 Main effects plot for SN ratios

iv) Regression analysis

Regression analysis is done on Minitab software to get the regression model and the table below shows the coefficient of each factor.

Table 5 Coefficient of each factors from regression analysis.

Term	Coefficient	SE Coeff.	T Value	P Value	VIF
Constant	-23028	6151	-3.74	0.013	
Mold temperature	86.2	20.7	4.16	0.009	1
Charging Speed	123.6	40.4	3.06	0.028	1
Holding Pressure	-42.6	41.4	-1.03	0.351	1

A regression predictive model is determined, which describe the relationship among process parameter and ultimate load strength. The predictive model is as follow:

Load =-23028 + 86.2(Mold temperature) + 123.6(Charging speed) – 42.6(Holding pressure) (2)

The r-square of the regression model is 84.74%. All the factors of process explain 84% of the difference in the quality responses. Which means the model is the best fit for a prediction.

CONCLUSION

The key process parameter of injection molding which directly influences on mechanical property of product is identified which is Mold temperature, charging speed and holding pressure. Taguchi method was used to determine the optimum combinations of the process conditions for the best quality of PP material. The result showed that the mold temperature of 230C, charging speed of 95rpm and holding pressure of 25MPa gave the best load test results which are the 7000kg load. Mold temperature was found to be the most effective factor followed by charging speed. Since the P-value was less than 0.05, this parameter had a statistically significant effect on the max load capacity at the 95% confidence level. Holding pressure was found to be the least effective factor. The relationship between process parameters and the ensuing product quality is expressed in a mathematical equation using regression equation with an R (square) of 84%. All the factors of process explain 84% of the differences in the quality responses.

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