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Minimization of Defects Percentage in Injection Molding Process using Design of Experiment and Taguchi Approach

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Abstract

Injection molding is one of the most important forming processes for thermoplastic polymers. Setting the injection molding parameter such as injection pressure, injection speed, cooling time and packing pressure plays a very important role in controlling the quality of the products forming by injection molding process. Taguchi approach is a widely used technique for optimizing the molding process parameters. This paper presents a simple and efficient way to study the influence of injection molding parameters on defects percentage. Using Design of experiments and Taguchi approach, the significant parameters are optimized to minimize the defects percentage of the most common defects (inverted label and incomplete plastic filling) that appeared in thin walled containers for food packaging. The results of the experimental study indicate that Injection speed and Injection pressure are the dominant factors determining the quality. The injection speed of 300 CCm/Sec give lower inverted label defect and the injection pressure of 2000 bar give lower incomplete filling defect.

Keywords: Plastic injection molding; Taguchi optimization; Process optimization; ANOVA; Inverted label defect; Incomplete plastic filling

Introduction

Injection molding is ideally suited for manufacturing large quantities of mass produced plastic parts of complex shapes and sizes, Over 30% of all the plastic parts are manufactured by the injection molding process [1]. It 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.

The injection molding process starts with the feeding of a polymer through hopper to barrel which is then heated with the sufficient temperature to make it flow, The molten plastic which was melted is then injected under high pressure into the mold, As shown in Figure 1 injection pressure is applied to both platens of the injection molding machine (moving and fixed platens) in order to hold the mold tool together. Afterwards the product is set to cool which helps it in the solidification process. After the product gets its shape the two platens will move away from each other in order to separate the mold tool known as mold opening. Finally the molded product is ejected or removed from the mold [2].

Adjusting the molding process parameters play an important role in the plastic injection molding. The quality of the molded part including strength, warpage, and residual stress is greatly influenced by the conditions under which it is processed. It also affects the productivity, cycle time, and energy consumption of the molding process. Molding conditions have a close relationship with other factors such as materials, part design, and tooling, which determine the quality of the plastic products [3]. Kurt et al. investigated the plastic injection molding process experimentally by considering the influence of process parameters on the quality of the final parts. The results of this experimental study indicated that cavity pressure and mold temperature are the dominant factors determining the quality of the final product in plastic injection molding [4].

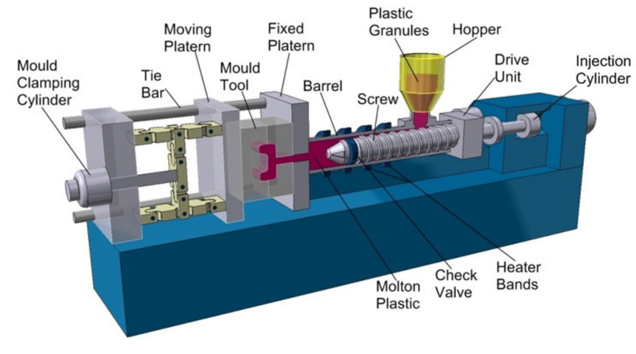

Figure 1: The injection molding process.

Numerous researches are carried out to understand, identify critical factors and possibly to optimize the molding process. Akbarzadeh et al. [5] used Analysis of Variance (ANOVA) and regression method technique to study the effect of melting temperature, injection pressure, packing pressure and packing time on the shrinkage in polypropylene (PP) and polystyrene (PS) and the optimum levels of these parameters that minimize shrinkage, for both materials. Xie et al. [6] combined ANOVA with Taguchi method to control the process parameters, the most significant factors are first determined then the parameters are optimized to get the good performance.

Park et al. [7] used Response surface methodology and non-dominated sorting genetic algorithm in order to resolve multi-object optimization problems. Sahoo et al. [8] also Mixed Response surface methodology with Six sigma to optimize radial Forging process

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focusing in minimize the residual stress developed in components manufactured by the radial forging. In the same context Kumaravadivel et al. [9] worked on minimizing the defects in flywheel casting process using DMAIC methodology and response surface methodology.

Meiabadi et al. [10] used Artificial Neural Network (ANN) and Process conditions Genetic Algorithm (GA) for modeling the process to find the optimized conditions.

Dang discussed the characteristics, advantages, disadvantages, and scope of application of all of the common optimization approaches such as response surface model, Kriging model, artificial neural network, genetic algorithms, and hybrid approaches [11].

Taguchi approach is widely used in DOE process optimization, Pareek and Bhamniya described the effect of temperature, pressure and cooling time on the Tensile strength using Taguchi method, by using Taguchi and ANOVA an optimum value or the best value of melting temperature, injection pressure and cooling time is obtained [12]. Wang et al. also determined the optimal process parameters with the application of computer aided engineering integrating with the Taguchi method to improve the compressive property of a brake booster valve body [13]. Kavade and Kadam corrected the optimal parameters for acceptable performance of injection molding process using Taguchi approach carried out using polypropylene (PP) as the molding material [14].

Taguchi views design of any system as a three phase program: 1. System design, 2. Parameter design and 3. Tolerance design. Genesis of new idea, concepts, processes etc., due to technological advancements, comes under system design. Technological advantage gained by a new system design can be lost quickly when competitors produce the same idea in a more uniform manner. Hence, as a holistic approach, one needs to incorporate parameter design as well as tolerance design. Parameter design improves product/process uniformity and can be used to cost savings at no cost. This means that certain parameters are set to make the performance less sensitive to causes of variations. Tolerance design phase improves quality at a minimal cost [15].

In this research parameter design is utilized to arrive at the optimum levels of process parameters for minimization of injection defects during manufacturing.

In this paper, Design of Experiment (DOE) used to improve the quality level of the injection molding process. The choice of a DOE strategy (Taguchi or classical DOE) depends a great deal on the degree of optimization required, resolution required, and time and cost constraints, nature of the problem. Analysis of variance (ANOVA) determined the significant parameters then they had been optimized to minimize the defects percentage of the most common defects (inverted label and incomplete plastic filling) that appeared in product. Different steps involved in the construction of this research as follows:

1. Screening the Current situation and collecting data

2. Design the experiments Selection of processing Parameters and their levels

3. Initial screening Taguchi's experiments, data collection and analysis

4. Arriving at critical variables based on initial screening

5. Additional expanded Taguchi's experiments for minimization of defects percentage.

Problem Definition

This study was conducted in Plastics Injection Plant called International Engineering Union Company in the Six of October City, Giza, Egypt. The company is one of the huge plastic plants in Egypt. The Company produce thin –walled containers for food packaging. The variation in plastic injection production line creates several types of defects during the injection process that lead to increasing the wasted material that reached to 26.8 ton in the last six month in 2014. The available data measured and analysed in the Pareto diagram as given in Figure 2 to find the most significant defects in a thin - walled containers for food packaging shown in Figure 3. As shown in Figure 2, the major defect is inverted label defect and the second defect is incomplete filling defect. The study focused on these two major defects to solve about 60% of company problem.

From the previous pareto it is obvious that the major defect is inverted label defect and the second defect is incomplete filling defect and this study concentrate on this two major defect appeared in the most important product in the company

The Molding machine

Arburg injection molding machine with 2000 KN clamping force were selected for the study.

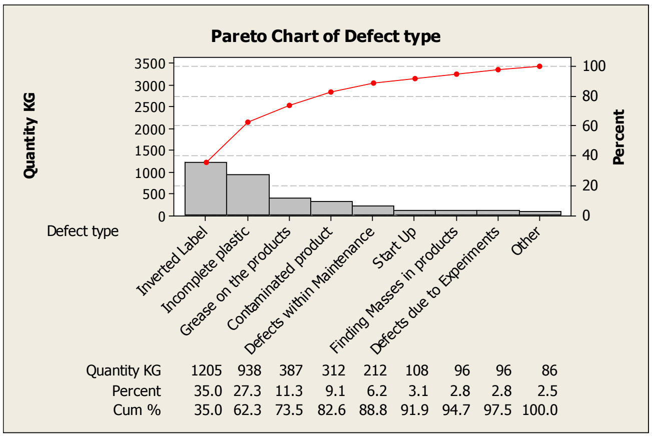

Figure 2: Pareto Diagram of defects type in container.

Figure 3: A thin –walled containers for food packaging.

The Molding material

Moplen poly propylene is extensively used in housewares and in thin-walled containers for food packaging

Commercially available, Moplen poly propylene EP548U Copolymer with antistatic additivations, suitable for injection moulding applications and it is the material used in experiments

Properties of the Moplen EP548U resin are given in Table 1.

Experimental Work

The design of experiment by means of Taguchi approach is selected to find the optimum parameters among the effective factors by running a number of experiments.

The process of performing a Taguchi experiment could be summarized in distinct steps:

Step1: formulation of the problem – the success of any experiment is dependent on a full understanding of the nature of the problem.

Step 2: identification of the output performance characteristics most relevant to the problem.

Step 3: identification of control factors.

Step 4: selection of factor levels.

Step 5: design of an appropriate orthogonal array (OA).

Step 6: preparation of the experiment.

Step 7: running of the experiment with appropriate data collection.

Step 8: statistical analysis and interpretation of experimental results.

Step 9: undertaking a confirmatory run of the experiment

Selection of processing Parameter and their levels

Molding conditions comprise the following important parameters

Mold temperature: Generally, cooling time is the rate-determining factor for overall cycle time. To obtain the best part properties and consistent dimensional tolerances, uniform heat removal is critical. Using a mold temperature controller will minimize temperature variations.

Cooling lines should be properly placed and spaced around the part for effective heat removal. The cooling lines should be adequately sized, without restrictions in the connectors or associated piping. The flow rate of the cooling medium should be sufficient to provide for turbulent flow through the cooling lines. Cleanliness of the cooling medium should also be maintained to prevent blockage of the cooling lines.

Resin type	Polypropylene, impact Copolymer
Density	0.9 g/cm^3
Melt flow rate (MFR)	70 g/10 min (230°C/2.16 kg)
Tensile Moddulus	1550 MPa
Heat deflection temperature B(0.45 MPa) Unannealed	95°C
Ductile Brittel transition temperature	-53°C
Ball independent hardness	68 MPa (H 358/30)
Charpy notched impact strength	5.0 KJ/m^2 (23°C)

Table 1: Moplen EP548U resin technical data sheet.

No	Parameter coded	Parameter coded	Levels	
			Low	High
1	A	Injection pressure(bar)	1800	2000
2	B	Injection Speed (CCm/Sec)	300	350
3	C	Cavity Temperature (°C)	200	250
4	D	Packing Pressure (bar)	30	40

Table 2: Initial screening parameters and their levels.

Hydraulic pressure: The injection molding process is generally divided into two stages. The first is injection (or fill), and the second is packing (or hold). During the first – or filling – stage, it is suggested that you set your machine pressure near its maximum setting and control the speed of the ram with velocity controls. The machine will only use whatever pressure is necessary to move the ram at the set speed. This technique will help produce consistent parts because the cavity is filled at a uniform rate, despite differences in viscosity due to temperature fluctuations and other factors.

Injection speed: Injection speed depends on the particular part and machine. Since erratic injection speed can cause a variety of part defects, a uniform injection speed is best High injection speeds will create high shear as the melt passes through the runners, gates, and along the cavity surface.

Selection of orthogonal array and factors levels

In an L16 (2^4) orthogonal array two levels of four factor are conducted where the selection of the array is because of its suitability for four factors with two Levels.

The Four factors and their level shown in Table 2.

The factor levels controlled by the nature or the range of the Arburg injection molding machine and the capability of controlling the process and the historical data of adjusting values to overcome problems.

Running the Injection molding experiments

Taguchi array screening experiments were conducted to identify the "most significant" input variables by ranking with respect to their relative impact on the sink mark.

Taguchi uses the S/N ratio to measure quality characteristic deviating from the desired value. The S/N ratio characteristics can be divided into three categories: the-nominal-the-best, the smaller-the-better, and the-larger-the-better when the quality characteristic is continuous [15].

Since the objective of this study was to minimize inverted label and incomplete plastic defects, smaller-the-better quality characteristic was employed.

The S/N ratio η is given by:

$$\eta = -10\log(\mathrm{MSD}) \tag{1}$$

Where MSD is the mean-square deviation for the output characteristic. MSD for the smaller-the-better quality characteristic is calculated by the following equation,

$$\mathrm{MSD}\frac{1}{n}\sum_{i=1}^{n}\mathbf{Y}_i^2 \tag{2}$$

MSD = Mean Square Deviation

Y_i = Observations

n= No. of tests in a trial.

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Experimental Results

Experimental result of the first response (Inverted label defect)

S/N Ratio results: Defects weight obtained is used to calculate the signal-to-noise (S/N) ratio to obtain the best setting of the parameters arrangement. Signal to noise (S/N) ratio is calculated as shown in Table 3.

The prime objective of this study was to find optimum level for each of the variables and to arrive at a combination of these factors that could result in minimum inverted label. From Figure 4, it can be observed that A1-B1-C2-D1- is the optimum combination for inverted label.

The results produce that the lower injection speed 1800 gives a better quality in the container and the higher injection speed give more defects.

ANOVA results: ANOVA results DF = degree of freedom, SS = Sum of squares, MS = Main square, F= F- Ratio summarized in Table 4.

Test for significance: This test is performed as an ANOVA procedure by calculating the *F*-ratio, which is the ratio between the factor mean square and the mean square error. The *F*-ratio, also called the variance ratio, is the ratio of variance due to the effect of a factor and variance due to the error term. This ratio is used to measure the significance of the factors under investigation with respect to the variance of all the terms included in the error term at the desired significance level, α.

From Significance Test it is observed that:

- FA = 0.18 lower than F tabulated at α = 0.25 (F0.25 value is 1.47) and this results shows that the Injection pressure not significant on affecting the special type of defect (inverted label defect)
- FB = 9.19 higher than F tabulated at α = 0.25 (F0.25 value is 1.47) and this results shows that the Injection speed is the most significant factor affecting on the special type of defect (inverted label defect) and finding the optimum value of injection speed lead to minimizing this defect
- FC = 0.13 lower than F tabulated at α = 0.25 (F0.25 value is 1.47) and this results shows that the Cavity temperature not significant on affecting the special type of defect (inverted label defect)
- FD = 0.65 lower than F tabulated at α = 0.25 (F0.25 value is 1.47) and this results shows that the Packing pressure not significant on affecting the special type of defect (inverted label defect)

Experiment No	Factors				Response 1 Defect (Kg)	S/N ratio
	A	B	C	D		
1	1	1	1	1	0.0	-
2	1	1	1	2	700.0	-56.9020
3	1	1	2	1	2100.0	-66.4444
4	1	1	2	2	150.2	-43.5334
5	1	2	1	1	1260.0	-62.0074
6	1	2	1	2	0.0	-
7	1	2	2	1	0.0	-
8	1	2	2	2	720.0	-57.1466
9	2	1	1	1	235.0	-47.4214
10	2	1	1	2	700.0	-56.9020
11	2	1	2	1	1980.0	-65.9333
12	2	1	2	2	2100.0	-66.4444
13	2	2	1	1	1320.0	-62.4115
14	2	2	1	2	0.0	-
15	2	2	2	1	700.0	-56.9020
16	2	2	2	2	2100.0	-66.4444

Table 3: Summary of results of tests and S/N values.

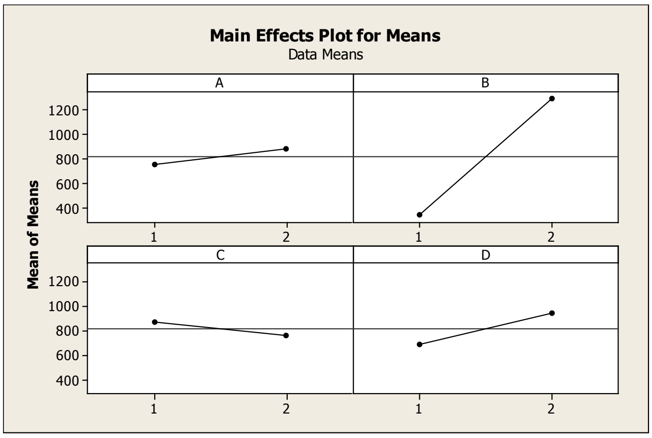

Figure 4: Main effects plot on the first response (inverted label defect).

A	DF	SS	MS	F	P	F test at
B	1	68382	68382	0.18	0.683	Not Significant
C	1	3568699	3568699	9.19	0.011	Significant
D	1	48841	48841	0.13	0.73	Not Significant
Error	1	253512	253512	0.65	0.43	Not Significant
Total	11	4270534	388230			
	15	8209968				

Table 4: ANOVA.

Experiment No	Factors				Response 2 Defect (Kg)	S/N ratio
	A	B	C	D		
1	1	1	1	1	0	-
2	1	1	1k	2	600	-55.5630
3	1	1	2	1	326	-50.2644
4	1	1	2	2	1580	-63.9731
5	1	2	1	1	650	-56.2583
6	1	2	1	2	2760	-68.8182
7	1	2	2	1	0	-
8	1	2	2	2	420	-52.4650
9	2	1	1	1	500	-53.9794
10	2	1	1	2	0	-
11	2	1	2	1	0	-
12	2	1	2	2	460	-53.2552
13	2	2	1	1	650	-56.2583
14	2	2	1	2	100	-40.0000
15	2	2	2	1	0	-
16	2	2	2	2	0	-

Table 5: Summary of results of tests and S/N values.

Experimental result of the second defect (incomplete filling)

S/N Ratio results: Defects weight obtained is used to calculate the signal-to-noise (S/N) ratio to obtain the best setting of the parameters arrangement. Signal to noise (S/N) ratio is calculated as shown in Table 5.

Table 5 summary of results of tests and S/N values

The combination of these factors that could result in minimum inverted label shown in Figure 5,

From S N results in Table 4 and Figure 5 it can be observed that A2-B1-C2-D1- is the optimum combination for incomplete filling defect

ANOVA results: Analysis of Variance for response 2 (incomplete filling) summarized in Table 6

Test for significance: The F ratio also calculated for the second response (incomplete filling defect) to measure the significance of the factors under investigation with respect to the variance of all the terms included in the error term at the desired significance level, α.

From Significance Test it is observed that:

- FA = 2.67 higher than F tabulated at α = 0.25 (F0.25 value in I is 1.47) and this results shows that the Injection pressure is the most significant factor affecting on incomplete filling defect and finding the optimum value of injection pressure lead to minimizing this defect
- FB = 0.16 lower than F tabulated at α = 0.25 (F0.25 value is 1.47) and this results shows that the Injection Speed not significant on affecting the on incomplete filling defect
- FC = 0.79 lower than F tabulated at α = 0.25 (F0.25 value in 1.47) and this results shows that the Cavity temperature not significant on affecting the incomplete filling defect
- FD = 1.86 higher than F tabulated at α = 0.25 (F0.25 value in 1.47) and this results shows that the Packing pressure significant on affecting the incomplete filling defect

Results and Discussion

The main goal of this study is to optimize (minimize) the two major defects that had been analyzed (inverted label defect and incomplete filling defect), these two defects appeared in the most important product called container 2,25 liter (a thin walled containers for food packaging). Achieving this goal come from optimizing the most important parameter affecting the injection molding process.

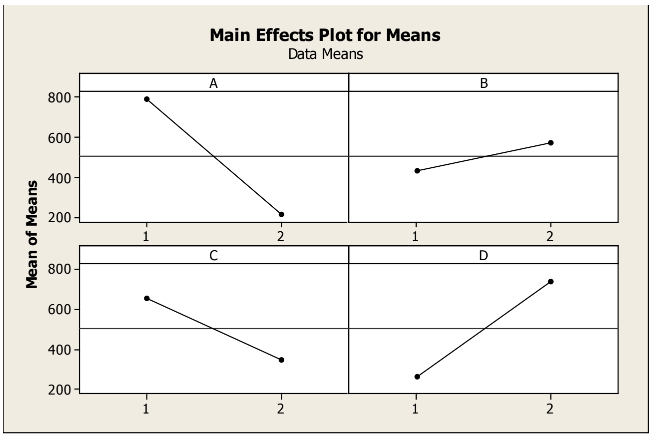

Figure 5: Main effects plot on the first response (Incomplete filling defect).

A	DF	SS	MS	F	P	F test at
B	1	1337492	1337492	2.67	0.125	Significant
C	1	77562	77562	0.16	0.697	Not Significant
D	1	382542	382542	0.79	0.393	Not Significant
Error	1	899652	899652	1.86	0.20	Significant
Total	11	5329895	484536			
	16	8027144				

Table 6: ANOVA.

It is it is observed that, Injection Speed is the significant factor affecting on the inverted label defect and finding the optimum value of Injection Speed will minimize this defect as proved in S/N ratio in Table 3, ANOVA Table 4 and Figure 4. This factor needs to be considered while designing the injection process when producing products with label at the same time using a robot supporting the injection machine with label. The S/ N ratio for the first response (inverted label defect) in Table 3 and Figure 2 prove that the injection speed at level one at Injection Speed = 300 CCm/Sec give lower inverted label defect than the injection speed at level two at Injection Speed =350 CCm/Sec.

The SN ration in Table 5, ANOVA Table 6 and Figure 5 prove that Injection pressure and packing pressure are the significant factors affecting on the incomplete filling defect and injection pressure is the most significant. And the optimal combination between injection pressure and backing pressure that give lower incomplete filling defect are the injection pressure at level two (injection pressure equal 2000 bar) with backing pressure at level one (packing pressure equal 30 bar). These factors and values needs to be considered while designing the injection process for minimizing the incomplete filling defect

This results is the output of a case study in atypical plastic injection plant and the result Reflect the actual parameter affecting the quality of products produced by mold injection products.

The inverted label defect is a special defect but it can be considered as a special Warpage defect. The result that higher injection speed or velocity affecting on warpage defect agreed with Chih Nian et al. [16], they estimate that the warping of thin walled parts like container 2.25 ltr container because of high injection velocity using a simulation program. They also concluded that high injection pressure also affecting on the warbage defect but in our case study the injection pressure not significant on affecting the inverted label defect.

The incomplete filling plastic defect is a common defect appears in products produced by plastic injection molding process and all machine parameters and material characteristics may effect on it. In this study the injection pressure and packing pressure affecting on the quality of product because they are affecting on the incomplete filling defect. This study agree with the Shin and Park [17], they concluded that the injection and packing pressure affecting on the incomplete filling defects but they take the characteristics of plastic material in the experiments and studying the effect of this characteristics on the quality of products.

Conclusion

This paper studies the influence of injection molding variables such as injection pressure, packing pressure, injection speed and cavity temperature on Inverted label and incomplete plastic filling defects using design of experiment approach. Then the Taguchi method was applied to find the optimal values for parameter settings. It was concluded from this study that injection speed affect the most the inverted label defect. The lower the injection speed the better the results are obtained regarding the inverted label. It was also found that the injection pressure and Baking pressure have significant effect on the incomplete filling defect. The injection speed of 300 CCm/Sec and the injection pressure of 2000 bar, these results would enhance the quality level for the company which in turn increases customer satisfaction. Moreover, material utilization and energy consumption are improved, which in turn reduce the production cost for the company and increase profit.

This study focused on the inverted label and incomplete plastic filling Because Pareto chart proved to be the most important two major defects. It can be extended to other defects and also for improving overall quality. In future work optimum parameters for characteristics like hardness, tensile strength and good surface finish of different materials may also obtain the methodology adopted in this research is limited in term of finding the relationship between multiple quality characteristics and process parameters. This is due to the limited capability of Taguchi method. Grey relational analysis might be a good candidate to obtain the optimum processing parameters combination for multiple quality characteristics simultaneously. The adopted methodology can also be used in the part design process in order to minimize variation in output.

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