IDENTIFYING ACTIVE FACTORS TO ADDRESS THE EXCESS FLASH PROBLEM IN PLASTIC INJECTION MOLDING PROCESS

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Abstract

A pivotal paradigm in injection molding is to produce the molded parts in good quality. Attributes like mechanical characteristics, dimensional conformity, and appearance defines the quality of molded parts. The quality is affected by many factors, the most important of which is determination of process parameters for injection molding. A most typical situation may involve one dozen of process parameters in context of injection molding. All of them are potent enough to affect the quality of molded parts. The primary objective of this paper is to implement Design of Experiment (DoE) in order to envisage causes of defects associated with injection molding processes during early phases of designing. Common quality problems that come from an injection molding process include but are not limited to void, surface blemish, excessive flash, short shot, sink mark, spruce sticking, bubbles and flow marks. Multiple sources, including preprocessing treatment of injection molding process, the selection of injection molding machine, experience of machine operator and setting of the injection molding process parameters are usually responsible for focusing quality problem. In this study, DoE was used to determine an optimal setting of machine process parameters, in a real life situation, to reduce the variation consequently resulting in a quality product. Taguchi orthogonal array was used and optimal combination was determined.

Key Words: Factorial Experiments, Fractional Factorials, Taguchi Arrays, Orthogonal Arrays, Molded Parts, Plastic Injection.
JEL Classification: C61; C91; C93; L21; Q55

1. Introduction

Design of experiment (DoE) is a well established statistical field with solid theoretical backup and multiple practical applications. Literature is full of DoE applications in versatile fields (see Box, et. al. 1979, Montgomery, 2007, for example). Molded parts are a common commodity with very sophisticated and complicated structures and recently researchers have discussed problems faced by manufacturers of molding parts. Statistical tools especially DoE has received much attention to address such problems. In this article we discuss a similar problem where extra flash in a molded part was identified as a major problem and we used a L16 orthogonal array to determine the optimum factor level combination. Factors responsible for extra flash were identified after extensive brainstorming sessions. A properly planned experiment was used and the amount of extra flash at each factor-level combination was measured in extra flash was observed with optimal factor-level combination. In the next sections we will discuss some past studies that have addressed similar problems, details of the experimental run, analysis and results are reported at the end.

2. Molding Part Problems

In this competitive environment companies strive hard to improve continuously their performances with an ultimate goal of a satisfied customer. Proper use of Deming's Plan-Do-Check-Act, PDCA cycle (see for historical background, Moen and Norman, 2010) can help companies to achieve targeted performances on a regular basis. DoE is an established branch of statistics that can be used effectively to apply PDCA cycle. Lin and Chananda (2003) used a designed experiment to identify factors creating excessive flash on an injection molding product. They used a 2^4 factorial experiment and identified three main factors and two 2-factor interactions significantly responsible for the excessive flash on their college mascot. Various authors have used DoE in different situations and came with fruitful results. Alagomurthi, Palaniradja and Soundrarajan (2006) used a Taguchi

L4 array and traditional 2^3 designed experiment (12 runs in all) and studied the effect of surface roughness in a grinding process. Gijo and Ravindran (2008) used DoE to identify optimum combination of water and plasticizer to develop cement with better workability and strength. Since Gijo and Ravindran (2008) were measuring optimum combination to maximize workability and strength in addition to ANOVA they used goal programming technique.

A local company manufacturing parts of motorcycles contacted the authors showing concern on multiple problems they were facing with the finished product- the headlight of CD 70 motorcycle of a specific brand. Prior to the formal study we surveyed different molding manufacturers at two major industrial sites of Karachi namely, SITE (Sindh Industrial Trading Estate) and KATI (Korangi Association of Trade and Industry). This survey revealed that an abundance of the managers rely on experience of engineers and machine operators while many of them apply trial and error procedures to find optimum setting of parameters. Setting these parameters is a highly skilled job and is based on the skilled operator's knowledge and intuitive sense acquired through long term experience rather than through a theoretical and analytical approach. Our study also emphasizes on the importance of scientific approaches.

3. Purpose of the Study

Huge research work is available in literature in the domain of parameter setting for injection molding. The major objective of this research in injection molding is to produce the molded parts carrying good quality. Quality performances are affected by multiple factors and determination of process parameters for injection molding is one of the foremost objectives of our study. For instance, increasing both the holding time and holding pressure may reduce the sink marks, while decreasing the injection speed may eliminate the flow marks for the case of plastic polymer.

Commonly process parameters of injection molding are determined by experienced molding personnel. Setting these parameters is a highly skilled job and is based on the operator's knowledge and experience rather than the theoretical approach. The corresponding tested molding parameters with intuitive adjustments and modifications are used at the start for a new molding application. Unfortunately, the growing demand in industry for expert molding personnel is increasing and molding personnel need many years to become experts. In a competitive environment the trial and error approach is very expensive and time taking and can't be recommended.

Traditional one-factor-at-a-time (OFAT) technique is used where one process parameter is varied at a time until the quality of the molded part is found satisfactory. This method ignores the effect of injections among the combinations of parameters. In fact, in injection molding process parameters are interacting with each other. Factorial experiments play a vital role to obtain the 'best' combination (interaction) of parameters in injection molding process.

Thus the Design of Experiment approach requires expert knowledge of both Statistics and Process Engineering while planning, executing or analyzing experiments.

4. Headlight Lens Problem

To discuss the problem in detail, the authors met a team comprising of floor shop workers and engineers of the company multiple times. It was told that excessive flash among void surface blemish, short shot, sink mark, bubbles and flow marks for this particular product (highlight lens of CD70 motorcycle) was the most acute and frequent problem. Figure 1 shows the product that we considered for this study. Excessive flash was causing wastages of material, time, delayed supplies, and loss of goodwill and trust. Brainstorming sessions were conducted and it was agreed that four factors namely, injection pressure, injection speed, melting temperature and back pressure were probably the main causes of excessive flash. Table 1 displays factors and levels selected for this study after detailed discussions with the team members.

Table 1 Process Parameters (Factors) and their settings (Levels)

Process Parameters	Low Level (-)	High Level (+)
Injection Pressure	$90 kg / cm^2$	$140 kg / cm^2$
Injection Speed	$50 kg / cm^2$	$60 kg / cm^2$
Barrel temperature	$190\,^0C$	$220\,^0C$
Back Pressure	$20 kg / cm^2$	$50 kg / cm^2$

Some of the selected parts with excessive flash are shown in Figure 2 for illustration. Removal of flash is a tedious job and results in wastages of resources, time, material and human efforts. Figure 3 is an illustration of how traditionally excessive flash is removed from the plastic molded part.

Figure 1 Reflector CD 70 Headlight Lens**-** Our selected Product

Figure 2 Selected Parts with excessive flash

Figure 3 Removal of Excessive Flash

Figure 4 Screw Type Injection Molding Machine JetMaster

5. Experimental Protocol And Data Collection

To accommodate the above mentioned factors (Table 1) complete experiment was planned with three replicates. Orthogonal array, as shown in Table 2, of 16-run was used to conduct the proposed experiment. Experiments were run in a random order to minimize bias. Each experimental run was replicated three times. Vernier caliper and centimeter scale were used to measure excessive flash (in millimeters) around each headlight lamp. Molding Machine Jet Master (see Figure 4) was used to perform experiments as described in Table 2. At the end of each experimental run excessive flash attached with each molded part, so produced, was measured and is reported in Table 2. To maintain discipline and to minimize bias proper times were allowed between each run for the machine to settle down. MINITAB®, a powerful statistical software was used for analyzing the collected data.

Table 2 L16 Orthogonal Array used for experimentation and recorded observations

Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run

Table 3 Average excessive flash as observed under each experimental run

Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order
Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order
Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order
Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order
Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order
Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order
Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order
Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order
Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order	Run order

6. Analysis

Analysis of Variance (ANOVA) is an established technique to answer two major questions in a study, How much variation is caused and what are the causes (and respective contribution) of variation? This finding (similar to the Pareto 80/20 principle) states that there are a vital few sources and trivial many and our goal is to identify 'vital few' causing major problems and to remove those to reduce variation significantly.

The fitted model with interactions, given in Table 4, clearly indicates that main effects Injection Speed and Back Pressure are highly significant (P value < 0.005) while Barrel Temperature is moderately significant (P value < 0.10) whereas interaction Injection Speed *Barrel Temperature is significant (P value < 0.05). It has been observed that if barrel temperature is reduced to 190^0C from 220^0C then process may face a flow mark problem. Normal probability plot as shown in Figure 5 supports this conclusion and we observe a significant deviation from linear trend of the above mentioned two main effects and one two-factor interaction. Residuals behave very well and support the selection of model. We conclude, using the outcome of Figure 6, that residuals are not deviating from the assumption of normality (residuals fall on the linear line of normal probability plot), distributed independently (there is no specific pattern observed in Figure 6) and do not face the heteroscedasticity problem. The model is, therefore, satisfying basic assumptions and may be recommended for use.

The main effect plot (Figure 7) shows the insignificant effect on excess flash by changing the levels of Injection Pressure. Other three main effects Injection Speed, Back Pressure and Barrel Temperature indicate a higher excessive flash on plastic molded parts when these factors are assigned higher settings (levels). Since our goal is to develop plastic molded parts with minimum flash the recommended settings for the four factors are given in Table 5. These recommendations were communicated to the manufacturing company with a request to produce the next few lots with these settings. The company informed us about the positive results they observed. A plastic molded part produced under the recommended factor level combinations is shown in Figure 8 for illustration.

Table 4 Fitted Model including main effects and 2-Facor interactions

Estimated Effects and Coefficients for Flash (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		1.55625	0.08062	19.30	0.000
Injection Pressure	0.13750	0.06875	0.08062	0.85	0.399
Injection Speed	0.72083	0.36042	0.08062	4.47	0.000
Barrel temp	0.28750	0.14375	0.08062	1.78	0.083
Back Pressure	0.63750	0.31875	0.08062	3.95	0.000
Injection Pressure*Injection Speed	0.12917	0.06458	0.08062	0.80	0.428
Injection Pressure*Barrel temp	0.19583	0.09792	0.08062	1.21	0.232
Injection Pressure*Back Pressure	0.11250	0.05625	0.08062	0.70	0.490
Injection Speed*Barrel temp	0.37917	0.18958	0.08062	2.35	0.024
Injection Speed*Back Pressure	0.12917	0.06458	0.08062	0.80	0.428
Barrel temp*Back Pressure	0.26250	0.13125	0.08062	1.63	0.112

Figure 5 Normal Probability Plot of Effects of Model fitted in Table 4

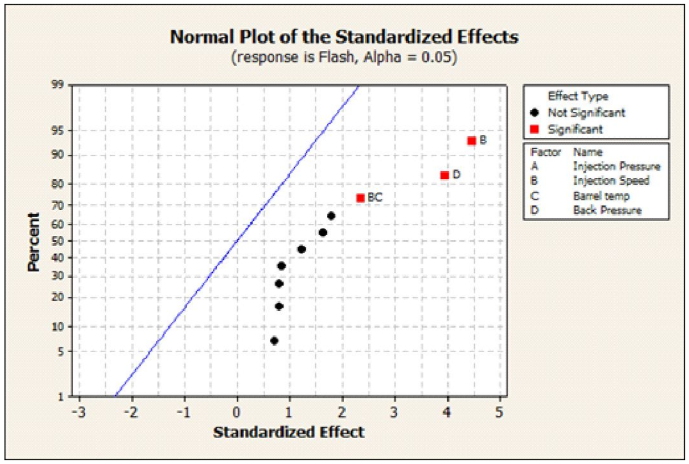


Figure 6 Residual Plots

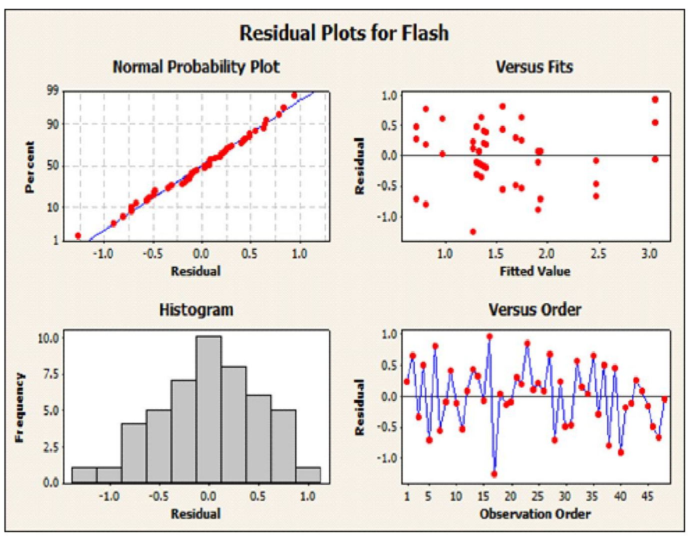


Figure 7 Main Effect Plot Identifying Optimal Factor Settings

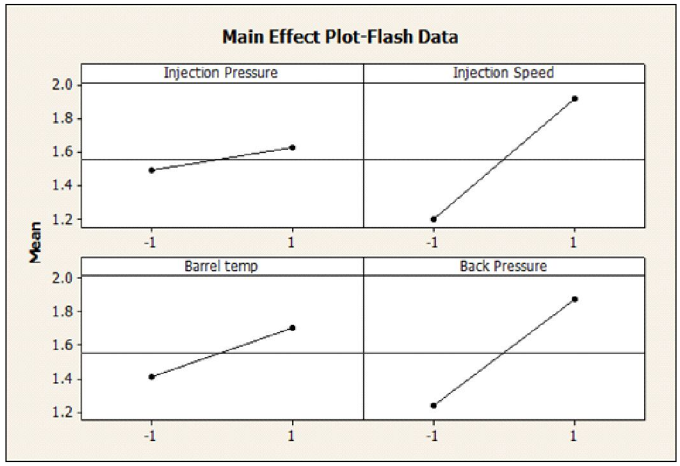
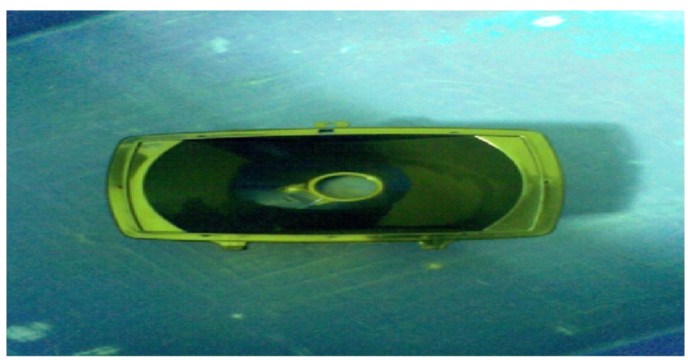


Table 5 Recommended Factor leve combination and average ecess flash noted

Setting	Injection Pressure	Injection speed	Barrel Temperature	Back pressure	Flash around molded part
1.	90kg/cm^2	50 kg/cm^2	220 C	20 kg/cm^2	0.05cm^2

Figure 8 Molded part produced under suggested combinations- showing no extra flash



9. Conclusion

Plastic molded parts are quite common and are extensively in use. They are used in various situations such as , household, laboratories, automobiles, for example. In this article we discussed a very acute problem called the 'excessive flash problem'. When melted plastic is placed in a predefined structure extreme care is required. Our main focus was to study factors most responsible for generating excessive flash on the head light of a specific brand of motorcycle. L16 orthogonal array was applied and four factors were selected after extensive brainstorming sessions with technical people. Our analysis identified a vital few factors and determined optimal factor level combination. The optimal factor-level combination was conveyed to the manufacturer who has communicated a significant reduction in molded parts with excessive flash.

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References

Alagumurthi, N., Palaniradja, K . and Soundararajan, V. Optimization of Grinding Process through design of Experiment (DOE) – A comparative study. Materials and Manufacturing Process, 2006, 19-21.

Azeredo, M.B., Da Silva, S. and Rekab, K. Improve Molded Part Quality. Quality Progress, July 2003, 72-76.

Banda, H. Optimization an injection Molding Process. Quality Progress, ASQ. August, 2007, 30-37.

Ben Cheikh, A. R., Campos A. R. and Cunha, A. M. Injection Molded Composites of Short Alpha Fibers and Biodegradable Blend. Polymer Composites, 2006, 341-348.

John T., Grinde H., and Rostad, H. The use of a 12-run Plackett-Burman Design in the Injection Molding of a Technical Plastic Component. Quality and Reliability Engineering International, 2006, Vol: 22, 651-657.

Lin, T. and Chananda, B. Quality Improvement of an Injection-Molded Product Using Design of Experiment, A case study. Quality Engineering. 2003-04. Vol, 16, No1, 99-104.

Cha. D.H., Kim, H.J., Lee, J. K., Kim. H. U., Kim, S. S. , and Kim, J. H. A Study Of Mold Grinding and Pressing Condition in the Molding of Aspheric Glass Lenses for Camera Phone Module. Materials and Manufacturing Processes. August, 2008, 23:(7),683-689.

Gijo, E.V., Ravindran, G. Quality in the Construction Industry: An application of DOE with Goal Programming. Total Quality Management and Business Excellence. May 2009, 37-41.

Monk, S.L., Kwong C.K. and Lau, W. S., Review of Research in the Determination of Process Parameters for Plastic Injection molding. Advances in Polymer Technology.1999. Vol. 18 (3), 225-236.

Yang, Y.K., Optimization of Injection-Molding Process of Short Glass Fiber and Polytetrafluoroethylene Reinforced Polycarbonate Composites via Design of Experiments Methods: A case study. Materials and manufacturing processes. October 2009.Vol:21, 915-921.

Yusoff, S. M., Rohani , J.M., Hamid, W.H. and Ramly, E. Y. A Plastic Injection Molding Process Characterization using Experimental Design Technique, A Case Study. Journal Technology, December, 2004 Vol:41(A):1-16.