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# Optimization of Injection Molding Process Parameters to Reduce Defects in Chlorinated Polyvinyl Chloride Pipe

Dr. D.B. Sadaphale, D.C. Talele

Assistant Professor, Department of Mechanical Engineering, S.S.B.T.'s, C.O.E.T., Bambhori, Jalgaon, Maharashtra, India

Assistant Professor, Department of Mechanical Engineering, S.S.B.T.'s, C.O.E.T., Bambhori, Jalgaon, Maharashtra, India

**ABSTRACT:** Injection molding is widely useful processes in the plastic fabrication industry. Because of production rate is very high and cost is also lower. This report gives out optimal injection molding process parameters for reduce short shot and minimize defects. In this study, DOE procedure of Taguchi method and the Analysis of Variance Method (ANOVA) is use to find out optimal injection molding process conditions for reduced defects and minimize short shot. For this study CPVC plastic specimen was tested. Taguchi method is use to determine optimum injection molding process parameters. By using Signal to noise ratios execute characteristics of injection molding parameter.

**KEYWORDS:** Injection moulding, Fabrication, defects, ANOVA.

## I. INTRODUCTION

### 1.1 Introduction

The injection molding has seen steady growth since its beginnings in the late 1800's. The technique has evolved from the production of the simple things like combs and buttons to major consumer, industrial, medical, and aerospace products.

The invention of an injection molding machine was achieved by John Wesley who injected hot celluloid into a mold which resulted in billiard balls which were used as a replacement for ivory which was based on the pressure die casting technique for metals. [1] The industry progressed slowly over the years, producing products such as collar stays, buttons, and hair combs. The industry expanded rapidly in the 1940s because World War II created a huge demand for inexpensive, mass-produced products. In 1946, American inventor James Watson Hendry built the first screw injection molding machine, which allowed much more precise control over the speed of injection and the quality of articles produced. This machine also allowed material to be mixed before injection, so that colored or recycled plastic could be added to virgin material and mixed thoroughly before being injected. [2]

The main concept of plastic molding is placing a polymer in a molten state into the mold cavity So that the polymer can take the required shape with the help of varying temperature and pressure. There are different ways of molding a plastic some of them are blow molding, Injection molding, rotational molding and compression molding. Each technique has their own advantages in the manufacturing of specific item. [3]

Plastic is known to be a very versatile as well as economical material and is used in many applications. Plastic injection molding is the primary process for producing plastic parts. Although the tooling is expensive, the cost per part is very low. This technology has met the current needs of industry owing to its shorter design cycles and improved design quality. Its area of application is wide which includes manufacturing, military, automobile, aerospace and other industries.

Plastic injection molding uses plastic in the form of pellets or granules as a raw material. It is then heated until a melt is obtained. Then the melt is injected into a mold where it is allowed to solidify to obtain the desired shape. The mold is then opened and the part is ejected. The process parameters such as cycle time, fill time, cooling time, injection time, injection speed, injection pressure, holding pressure, melting temperature, mold temperature and so on need to be optimized in order to produce finished plastic parts with good quality. Various studies have been conducted to improve and optimize the process, so as to obtain high quality parts produced on a wide range of commercial plastic injection molding machines. [4]

The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization. It has been widely used for product design and process optimization worldwide [5]. This is due to the advantages of the design of experiment using Taguchi’s technique, which includes simplification of experimental plan and feasibility of study of interaction between different parameters. Lesser number of experiments is required in this method. As a consequence, time as well as cost is reduced considerably. Taguchi proposes experimental plan in terms of orthogonal array that gives different combinations of parameters and their levels for each experiment. According to this technique, the entire parameter space is studied with minimal number of necessary experiments only [6, 7]. Based on the average output value of the quality characteristic at each parameter level, main effect analysis is performed. Analysis of variance (ANOVA) is then used to determine which process parameter is statistically significant and the contribution of each process parameter towards the output characteristic. With the main effect and ANOVA analyses, possible combination of optimum parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the process parameter design.

### 1.2 The Injection Molding

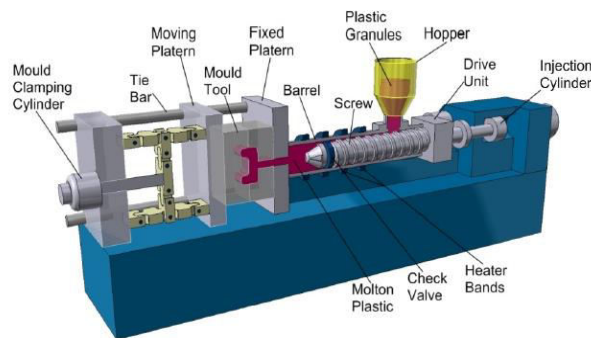


Figure 1.1 Injection Molding Machine

Injection molding is a method of forming a plastic product from powdered thermoplastics by feeding the material through the machine component called the hopper to a heated chamber in order to make it soft and force the material into the mold by the use of the screw. In this whole process pressure should be constant till the material is hardened and is ready to be removed from the mold. This is the most common and preferable way of producing a plastic product with any complexity and size. Injection molding permits mass production net shape manufacturing of high precision, three dimensional of plastic parts. [3]

### 1.3 The injection molding process

The injection molding process stages starts with the feeding of a polymer through hopper to barrel which is then heated with the sufficient temperature to make it flow , then the molten plastic which was melted will be injected under high pressure into the mold the process is commonly known as Injection, After injection pressure will be 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 which is known as mold opening and finally the molded product is ejected or removed from the mold. And the process will repeat itself.

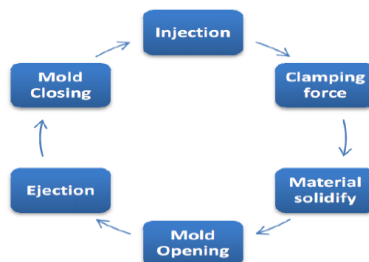


Figure 1.2 Injection molding cycle



## II. LITERATURE REVIEW

Mr. A.J. Yadav, Mrs. S.V. Dravid, Mr. V.D. Rajput, 2012, “ Taguchi Technique In Optimization Of Injection Molding Process Parameters For Manufacturing Plastic Parts”, [4] This paper deals with optimal injection molding process parameters for minimum shrinkage. In this study, optimal injection molding conditions for minimum shrinkage were determined by the DOE technique of Taguchi and the analysis of variance (ANOVA) methods. Injection molding represents one of the most important processes in the mass production of manufactured plastic parts with complex geometries. The quality of the injection moldings depends on the material characteristics, the mold design and the process conditions. Defects in the dimensional stability of the parts result in shrinkage. In order to minimize such defects in plastic injection molding, design of experiment, the Taguchi method is applied. In experimental design, there are many variable factors that affect the functional characteristics of the product. Design parameter values that minimize the effect of noise factors on the product’s quality are determined. In order to find optimum levels, fractional factorial designs using orthogonal arrays are used. In this way, an optimal set of process conditions can be obtained from very few experiments.

Shaik Mohamed Mohamed Yusoff, Jafri Mohd. Rohani, Wan Harun Wan Hamid & Edly Ramly, 2007, “ A Plastic Injection Molding Process Characterisation Using Experimental Design Technique”, [5] This paper illustrates an application of design of experimental (DOE) approach in an industrial setting for identifying the critical factors affecting a plastic injection molding process of a certain component for aircond assembly. A critical to quality (CTQ) of interest is reducing process defects, namely short-shot. A full factorial design was employed to study simultaneously the effect of five injection molding process parameters. The five process parameters are backpressure, screw rotation speed, spear temperature, manifold temperature, and holding pressure transfer. Finally, the significant process parameters influencing the short-shot defect have been found. Empirical relationship between CTQ and the significant process parameters were formulated using regression analysis.

There are mainly three principals of Design of Experiments (DOE) methods in practice today. They are the Classical or Traditional methods, Taguchi methods, and Shainin methods. Sir Ronald Fisher, who applied DOE to agricultural problem in 1930, applied the traditional method to his work. Dr Taguchi of Japan refined the technique with the aim of achieving robust product design against sources of variation. The Shainin method was designed and developed by consultants. Dorian Shainin used a variety of techniques with major emphasis on problem solving for characterising product development. Experimental design techniques are a powerful approach in product and process development, and they have an extensive application in the engineering areas. Potential applications include product design optimisation, process design development, process optimisation, material selection, and many others. There are many benefits gained by many researchers and experimenters, from the application of experimental techniques. The objective of this paper is to obtain the optimal setting of machine process parameters that will influence Critical to Quality (CTQ) and subsequently, reduce the process defects.

M. Stanek, D. Manas, M. Manas and O. Suba, 2011, “Optimization of Injection Molding Process”, [6]. The paper is dealing with description of Moldflow Plastics Xpert (MPX) system and its usage in optimization of injection molding process on real part during its production. Injection molding represents the most important process for manufacturing plastic parts. It is suitable for mass producing articles, since raw material can be converted into a molding by a single procedure. In most cases finishing operations are not necessary. An important advantage of injection molding is that with it we can make complex geometries in one production step in an automated process. The injection molding technique has to meet the ever-increasing demand for a high quality product (in terms of both consumption properties and geometry) that is still economically priced.

This is feasible only if the molder can adequately control the molding process, if the configuration of the part is adapted to the characteristics of the molding material and the respective conversion technique, and a mold is available which satisfies the requirements for reproducible dimensional accuracy and surface quality. Typical injection moldings can be found everywhere in daily life; examples include toys, automotive parts, household articles and consumer electronics goods.

Yu-Hsin Lin, Wei-Jaw Deng, Cheng-Hung Huang, Yung-Kuang Yang, 2009, “Optimization of Injection Molding Process for Tensile and Wear Properties of Polypropylene Components via Taguchi and Design of Experiments Method”, [7] This study analyses the wear and the tensile properties of polypropylene (PP) components, which are applied to the interior coffer of automobiles. The specimens are prepared under different injection molding conditions by changing the melting temperature, the injection speed, and the injection pressure

via three computer-controlled progressive strokes. The wear and tensile properties are adopted as the quality targets. Experiments of sixteen experimental runs are based on an orthogonal array table, and apply the Taguchi method and the design of experiments (DOE) approach to determine an optimal parameter setting. In addition, a side-by-side comparison of two different approaches is provided. In this study, regression models that link the controlled parameters and the targeted outputs are developed, and the identified models can be utilized to predict the tensile and wear properties at various injection molding conditions.

Alireza Akbarzadeh and Mohammad Sadeghi, 2011, “Parameter Study in Plastic Injection Molding Process using Statistical Methods and IWO Algorithm”, [8]. Dimensional changes because of shrinkage are one of the most important problems in production of plastic parts using injection molding. In this study, effect of injection molding parameters on the shrinkage in polypropylene (PP) and polystyrene (PS) is investigated. The relationship between input and output of the process is studied using regression method and Analysis of Variance (ANOVA) technique. To do this, existing data is used. The selected input parameters are melting temperature, injection pressure, packing pressure and packing time. Effect of these parameters on the shrinkage of above-mentioned materials is studied using mathematical modelling. For modelling the process, different types of regression equations including linear polynomial, Quadratic polynomial and logarithmic function, are used to interpolate experiment data. Next, using step backward elimination and 95% confidence level (CL), insignificant parameters are eliminated from model. To check validity of the PP model, correlation coefficient of each model is calculated and the best model is selected. The same procedure is repeated for the PS model. Finally, optimum levels of the input parameters that minimize shrinkage, for both materials are determined. Invasive Weed Optimization (IWO) algorithm is applied on the developed mathematical models. The optimization results show that the proposed models and algorithm are effective in solving the mentioned problems.

### III. EXPERIMENTATION

Experimental Setup: -



Figure 3.1 Photographic view of Milacron 110 Injection Molding Machine

Table 3.1 Specifications of Milacron 110 Injection Molding Machine

POWER PACK		
Injection Capacity Max. (Gpps)	Gm	272
Theoretical Displacement	Cc	286
Injection Pressure	Bar	1502
Injection Rate	cc/sec	172
Injection Screw Stroke	Mm	180
Screw Diameter	Mm	45
Screw L/D Ratio	----	20
Screw Speed	Rpm	251
Screw Torque @ 172 Bar	Nm	876



Plasticizing Rate (Gpps)	gm/sec	22
Plasticizing Rate (Barrier Screw)	gm/sec	27
No. Of Pyrometer (Barrel+Nozzle)		3+1
Total Heat Capacity	kW	13.2
<b>CLAMP UNIT</b>		
Clamp Force	Ton	100
Clamp Stroke	Mm	560
Maximum Daylight	Mm	760
Minimum Mould Height	Mm	200
Platen Size (H X V)	Mm	610 X 610
Distance Between Tie Rod	Mm	410x410
Tie Rod Diameter	Mm	70
Ejector Stroke	Mm	125
Ejector Force	Ton	4.5
<b>GENERAL</b>		
Electric Motor	kW (HP)	18.5 (25)
Oil Tank Capacity	Ltr	315
Water Requirement (Inlet Temp. 29°C)	Lpm	80
Connected Load	kW	25.8
Machine Dimension (L X W X H)	M	4.82 x 1.36 x 2.04
Machine Weight	Kg	4350

**IV. RESULTS & DISCUSSION**

**4.1 Confirmation Experiment**

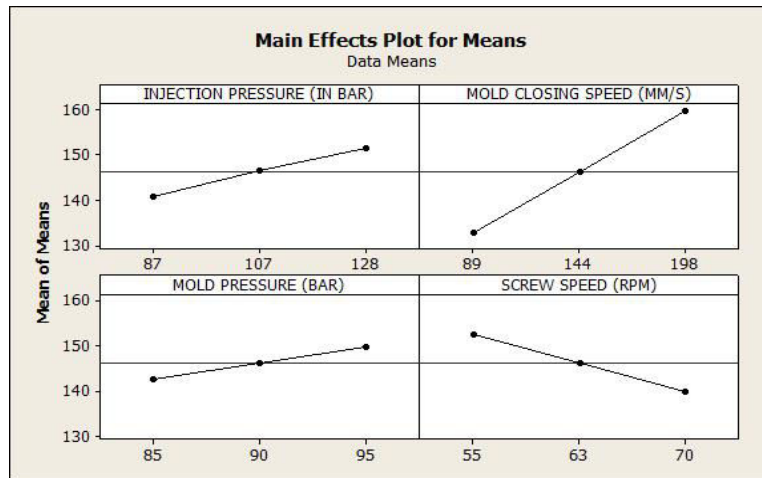
A. In Order to test the predicted result, confirmation experiment has been conducted by running another three trials at the optimal settings of the process parameters determined from the Analysis i.e. A, B, C, D.

Table 4.1 Results

Observation	Trial 1	Trial 2	Trial 3	Average	S/N Ratio
1	175.5	175	176	175.5	44.96

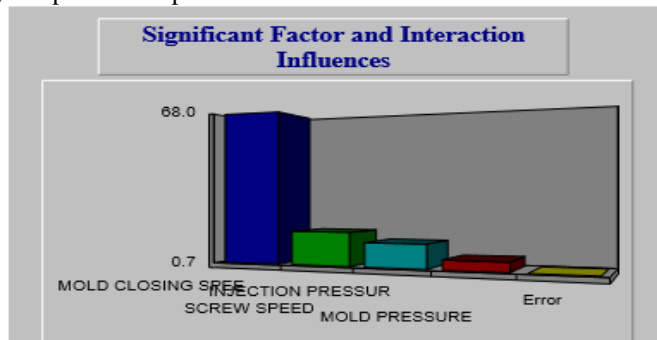
The results are shown in above table and it is observed that the average weight i.e. 217gm and average S/N Ratio 44.96 which falls within predicted 80% Confidence Interval.

After the completion of the experiments and the theoretical investigation for the optimization of injection molding machine parameters we reach to following result:

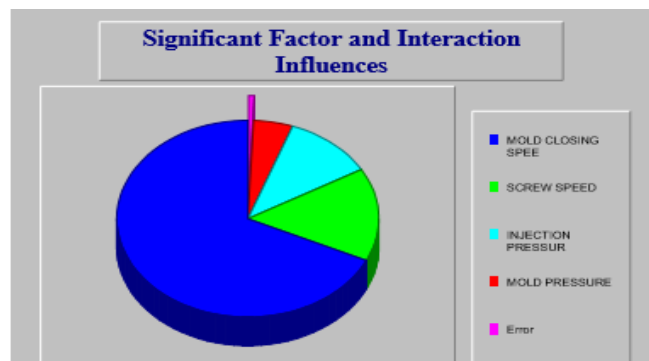


Graph 4.1 Effect of Injection Molding Process Parameters on Average Response (Weight)

The effect of injection molding process parameters on the Average response (Weight) value was shown in Graph 4.1 in this the injection molding machine parameters varying linearly. The weight of component is increases with increase in injection pressure, mold closing speed, mold pressure and decrease in screw speed. The optimal condition of the injection molding machine process parameters are 128 bar injection pressure, 198 mm/s mold closing speed, 95 bar mold pressure, 55 rpm screw speed.

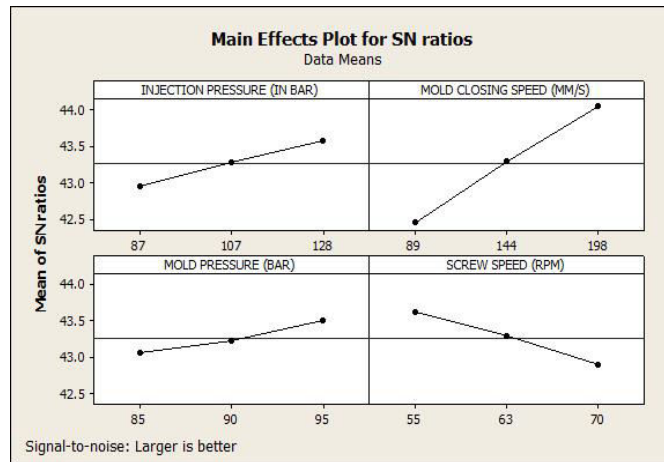


Graph 4.2 Relative Significance of Factors (Bar Chart) for Average Effect



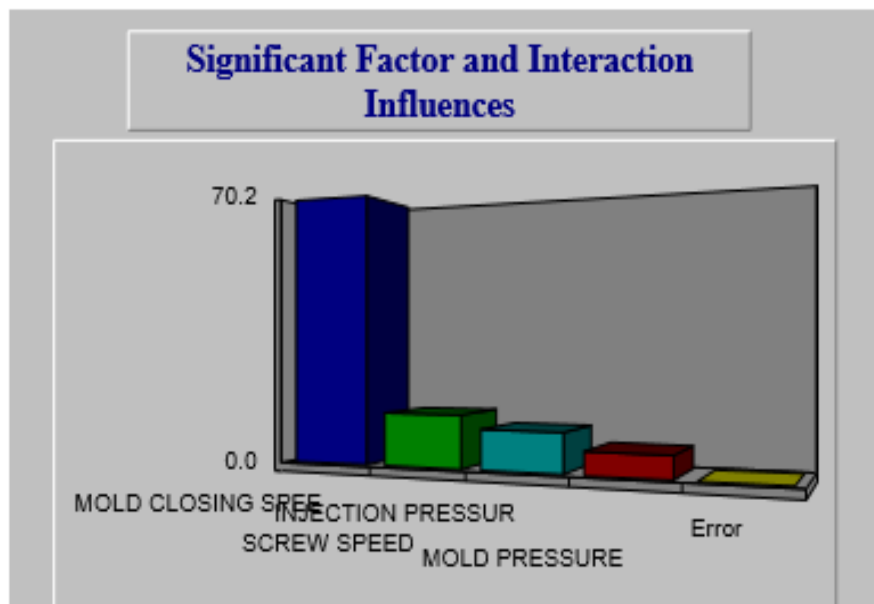
Graph 4.3 Relative Significance of Factors (Pie Chart) for Average Effect

Graph 4.2 and Graph 4.3 is show that relative significance of factor and Interaction influences for Average Effect in form Bar chat and Pie chart respectively in these both graph mold closing speed is highly significant factor. Contributions of factors are 11.130% of Injection Pressure, 67.996% of Mold Closing Speed, 4.857% of Mold Pressure, 15.314% of Screw Pressure and remaining 0.703% of Error.



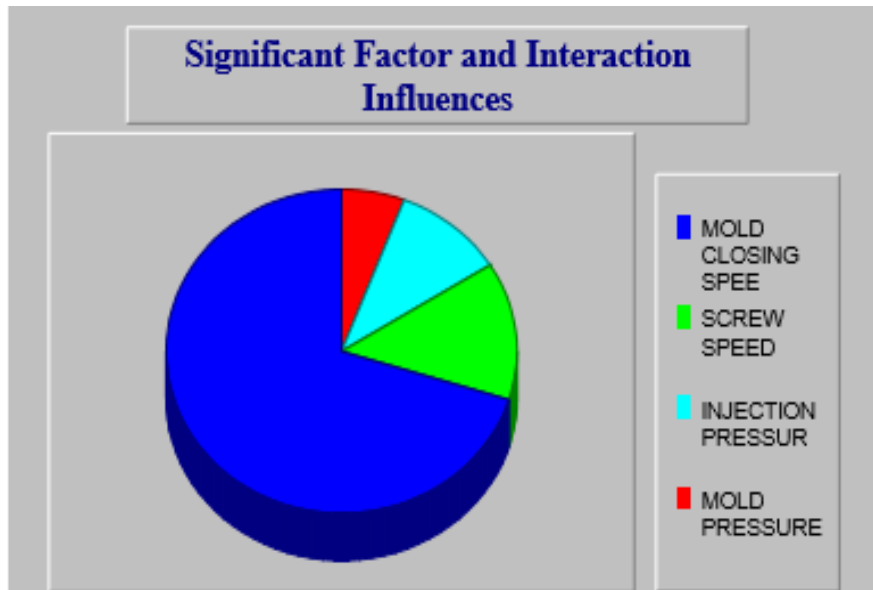
Graph 4.4 Effects of Injection Molding Factors on Average S/N Ratio

The main effect plot for S/N ratio of mean of S/N ratio versus Injection pressure, Mold closing speed, Mold pressure and Screw speed. This is generated from the value of S/N ratio of Average Response (weight). Optimum value for S/N ratio occurred for Injection pressure in 3<sup>rd</sup> level, for Mold closing speed in 3<sup>rd</sup> level, for Mold closing speed in 3<sup>rd</sup> level and Screw speed in 1<sup>st</sup> level. The highest S/N ratio for each factor gave the optimal process condition, which corresponds to an Injection pressure of 128 bar, a Mold closing speed 198 mm/s, a Mold pressure 95 bar and Screw speed 55rpm.



Graph 4.5 Relative Significance Of Factors (Bar Chart) for S/N ratio

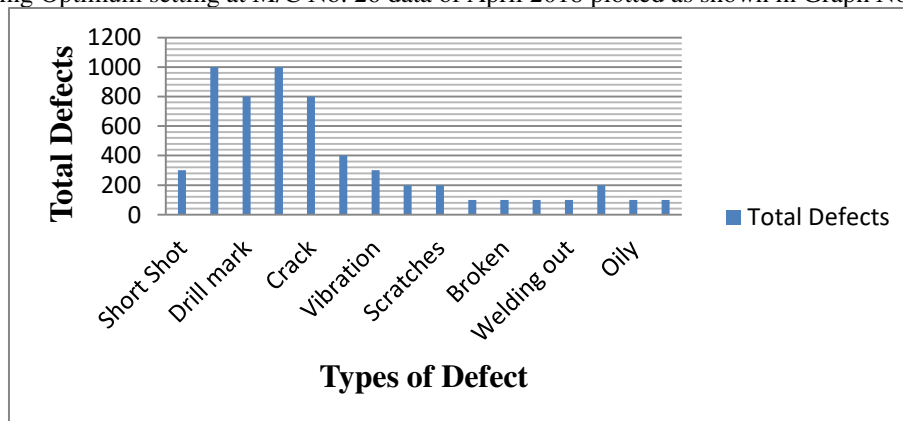




Graph 4.6 Showing Relative Significance of Factors (Pie Chart) for S/N ratio

Graph 4.5 and Graph 4.6 is show that relative significance of factors and Interaction influence for S/N Ratio in form Bar chart and Pie chart respectively.in these mold closing speed is most significant factor. Contribution of factors are 10.252% of Injection Pressure, 70.189% of Mold Closing Speed, 5.822% of Mold Pressure and 13.733% of Screw Speed.

After implementing Optimum setting at M/C No. 26 data of April 2018 plotted as shown in Graph No. 4.7



Graph 4.7 Total defects in Line 26 for the month of April 2018

From Graph 4.7 it is clear that due to maximization of weight from 202gm to 217gm reduces occurrence of short shot from 4500 to 300.

### V. CONCLUSION

The Taguchi method was applied to find an optimal setting of the injection molding process. The result from the Taguchi method chooses an optimal solution from combinations of factors if it gives maximized normalized combined S/N ratio of targeted outputs. The L-9 OA was used to accommodate Four control factors and each with 3 levels for experimental plan selected process parameters are Injection Pressure (87, 107, 128 bar), Mold Closing Speed (89, 144, 198 mm/s), Mold Pressure (85, 90, 95 bar), Screw Speed (55, 63, 70 rpm). The results are summarized as follows:

- i. Among the Four process parameters Mold Closing Speed and Screw Speed is having more significant effect on Quality Characteristic.
- ii. Maximization of Mold Closing Speed and Screw Speed gives maximum weight of component. To maximize the weight of component Mold pressure must minimum.
- iii. The Optimal level of process parameter were found to be Injection Pressure (A) = **128 bar**, Mold Closing Speed (B) = **198 mm/s**, Mold Pressure (C) = **95 bar**, Screw Speed (D) = **55 rpm**
- iv. The prediction made by Taguchi parameter design technique is in good agreement with confirmation results.
- v. The result of present investigation are valid within specified range of process parameters
- vi. Also the prediction made by Regression Analysis is in good agreement with confirmation results.
- vii. From Graph 4.7 it is confirm that maximization of component weight reduces occurrence of short shot.

The Optimal level process parameter are found to be A, B, C, D corresponding to Injection Pressure of 128 bar, Mold Closing Speed of 198 mm/s, Mold Pressure of 95 bar, Screw Speed of 55 rpm, and also the process parameters which affecting weight variations are focused and controlled.

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