Vol. XIII & Issue No.12 December - 2020
INDUSTRIAL ENGINEERING JOURNAL

# A CASE STUDY- OPTIMIZATION OF PLASTIC ROTOMOLDING PROCESS BY ANOVA AND TAGUCHI METHODS

**Ms. Karishma Raut**
**Mrs. Niyati Raut**

**Abstract**

*In manufacturing world demand of hollow plastic product is increasing which are mainly produced by Plastic Rotomolding Process. To produce better qualitative product, some operating parameters and its composition plays important role. By using ANOVA method, we get the most significant factor. Study describes the factors rotational speed, cooling time and oven temperature as operating parameters that produce better product in terms of tensile strength. Low density polyethylene was considered as polymeric matrix produced by bi-axial turret plastic rotomolding machine with the sets of different rotational speed, cooling time and oven temperature decided by design of experiments according to the L16 orthogonal array of Taguchi approach. Tensile-test of workpieces is done with Tinus-Olsen-H10KTUTM. Water tank gets optimum quality by having compositions of parameters, with the help of ANOVA and Taguchi methods. The result of study suggests for both academia and industrialist to consider the correct factors with their specific limit while manufacturing in plastic rotomolding process for achieving better quality of product.*

***Keywords: ANOVA, Taguchi, LDPE, Rotomolding process.***

## 1. INTRODUCTION

The rotomolding is well-known process for hollow plastic production, without weld line. Among all the cavity plastic products about many made by rotomolding process. The principle of rotational molding process and its basic steps are simple as follows (a) mold loading (b) mold heating (c) mold cooling and (d) part removing [1]; the process consists of introducing a known amount of plastic in powder form into a mold. The mold is rotated as well as rocked about two principal axes at relatively low speeds as it is heated so that the polyethylene enclosed in the mold adheres to and forms a uniform layer against the surface [2]. The mold rotation continues during the cooling time so that the plastic retains its desired shape as it solidifies. After determined time, mold rotation and cooling both are stopped to allow the removal of the plastic product from the mold. The process settings are essential, as the optimal rotational speed is important, as wall thickness of product get influenced by the rotational speed of rotomolding process [3]. Quality of rotomolded product is important for customer satisfaction. This study demonstrates a rotomolding process for finding the optimum parameters for producing products with strength. So using Taguchi method, we get different specimens. Tensile tests were carried out using specimens. By using ANOVA method, we get most significant parameter, which directly contribute to improve tensile strength. And hence quality of rotomolded products is achieved. This will give significance and promotion to enlarge rotomolding industry.

Zhang L, gives techniques to improve our business performance. They describe lean manufacturing. In which customer are at focus and for customer satisfaction we have to increase quality of product [4]. To increasing quality in rotational molded product, we must avoid premature failure. This can be achieved by giving proper importance to material selection while manufacturing [5]. LDVE Leo`n, demonstrated in the literature search conducted on scientific research of rotomolding, 117 articles on rotational molded polymer composites were published and only 22 articles related to polyethylene composites [6]. So we focused our interest in polyethylene-based material. There are many more composites which are polyethylene-based. By Antonio Greco, the main drawback lies in the poor mechanical properties by linear low density polyethylene i.e. LLDPE [7]. So considering all environment conditions of rotomolding process, we gives more refer to low density polyethylene than LLDPE. Chen W., as stated in this paper, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are used to obtain a combination of parameter settings [8]. Also, for Taguchi method we studied Zerti O., the Taguchi method is a powerful problem-solving technique for process performance and improving productivity. It allows finding answers for problems which need to reduce scrap rates and manufacturing costs due to excessive variability in processes. Taguchi supports the use of orthogonal array designs to assign the chosen factors for the experiment. The ability of the Taguchi method is that it integrates statistical methods into the engineering process [9]. For choosing factors, we study some research articles. Ramin Shaker and Denis Rodrigue, in their study they give importance to some main factors as oven temperarture, heating time, rotational speed and particle concentration. They conclude that as increasing rotation speed of LDPE rotomolded product, decreasing number of bubble formation on part surface of product [10]. This gives suggestions to avoid such failure related to quality of product; we concentrated to increase speed of rotation. In our study main part is to selecting proper operating parameters, and rotation speed is taken. For more parameters we studied research article by M. shirinbayan, in which they specified parameters followed by oven temperature, heating time and cooling rate. They mentioned these parameters depended also on some reasons: [11]

- Quantity of material
- Required products thickness
- Surface to volume ratio of mold.

H. Xu, reported that the thermal properties of rotomolded polyethylene are affected by the cooling time, and that unequal cooling results in compromising quality by warping, deformation, and the formation of residual stresses in the final product [12]. From this we got our second parameter as cooling time. Now for the third parameter as mentioned above oven temperature is important, we started study. A. Greco, describes in his paper to increases oven temperature for rotomolding process [13]. All required parameters taking into consideration but for achieving quality we perform tensile tests. As M. Daryadel, concluded that rotational speed and processing temperature are most important parameters while rotational molding process. And they are the most effective parameters on the studied tensile properties. They recommended using low rotational speed and high processing temperature is more helpful [14]. After studying these literatures, our study is novel as we selected untouched and different combination of control factors, material, product, process, etc.

## 2. EXPERIMENTAL PROCEDURE

### 2.1. Material

In this study low density polyethylene material is used. As LDPE is branched version polymer [15]. With its specification semi-rigid polymer, translucent, good processability, high impact strength, good weather ability, excellent electrical insulator, very low water absorption and its density 0.925 g/cm$^3$ [16]. Above mentioned properties of LDPE satisfies the requirement by water tank product. Nowadays rotomolding process turning to eco-friendly, as it is recyclable also reusable, by replacing the low density polyethylene with natural fibers, this gives result by product is comparability tougher and more sustainable [17]. For future of rotomolding process in the India, this study will help. The modern rotational molding process is characterized as being a nearly atmospheric pressure process that begins with fine powder form and produce products. Owing to the absence of pressure, rotational molds usually have relatively thin and uniform walls. Advanced, rotomolding machines allow multiple molds of different size and shape to be run at concurrently. With correct mold design and suitable process control, the wall thickness of rotationally molded parts is quite uniform and also yields complex part as triple layer complexed design product. It is also a vital requirement that the polymer withstands particular temperatures for long periods of time.

### 2.2. Problem definition

We decide to optimise in a company 'PIXEL POLYCAST', Pune for improving quality of product water tank using ANOVA and Taguchi methods. In 'Pixel Polyplast' industry, manufacturing takes place by Bi-axial Turret Rotomolding Machine with an oven and cooling unit. Their engineers use known amount of LDPE (with the different ratios of an outer layer, intermediate layer and inner layer, etc.) for manufacturing a triple layered water tank. In this study we have to work on parameters that are responsible for products quality improvement. Because customers are not satisfied by product 'TL Blue 2000' i.e. triple layered blue colored water tank with capacity 2000 liters. Its processing time varies 50-60 minutes.

### 2.3. Design of experiment

The Taguchi method from Design of Experiment is selected to identify the best set of parameters among the effective factors by studying a number of experiments. The major steps to complete the actual designed experiment are:

A. Selection of proper factors.

B. Selection of orthogonal array (OA) and levels of factors.

C. Conduct tests described by trials in OA.

D. Interpret and analyse results of every experimental trial.

#### 2.3.1. Selection of proper factors

In rotomolding there are a number of possible factors that produce significant effects on tensile strength, which are rotational speed, oven temperature, filling time, mold dimensions, gas pressure, melt temperature and cooling time [18]. But as discussed earlier in literature for experiment, we take the factors into considerations are rotational speed, cooling time and oven temperature.

#### 2.3.2. Selection of orthogonal array (OA) and levels of factors

In an L16 ($4^3$) orthogonal array four levels of each factor are accompanied where the selection of the array is because of its suitability for three factors with four Levels [19]. The trial with L16 ($4^3$) orthogonal array is shown in Table 1.

**Table 1. Trials with L16 ($4^3$) Orthogonal array**

| Trial No. | Column No. | | |
|---|---|---|---|
| | A | B | C |
| 1. | 1 | 1 | 1 |
| 2. | 1 | 2 | 2 |
| 3. | 1 | 3 | 3 |
| 4. | 1 | 4 | 4 |
| 5. | 2 | 1 | 2 |
| 6. | 2 | 2 | 1 |
| 7. | 2 | 3 | 4 |
| 8. | 2 | 4 | 3 |
| 9. | 3 | 1 | 3 |
| 10. | 3 | 2 | 4 |
| 11. | 3 | 3 | 1 |
| 12. | 3 | 4 | 2 |
| 13. | 4 | 1 | 4 |
| 14. | 4 | 2 | 3 |
| 15. | 4 | 3 | 2 |
| 16. | 4 | 4 | 1 |

The four different levels of rotational speed are chosen based on the thermal properties of LDPE, followed for cooling time and oven temperature. The suggested levels and factors are all shown in Table 2

**Table 2. Combination selected factors and Levels.**

| Factors | Levels | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Rotational Speed, A (mm/min) | 10 | 15 | 20 | 30 |
| Cooling Time, B (min) | 08 | 10 | 12 | 14 |
| Oven Temperature, C (˚C) | 260 | 280 | 300 | 320 |

### 2.3.3. Conduct tests described by trials in OA.

The tests are conducted on rotomolding machine according to the sets of control factors (processing parameters) obtained from trials of orthogonal array (OA) [20]. The control factors and levels of control factors according to orthogonal array (OA) are shown in Table 3.

### 2.3.4. Interpret and analyse results of the experimental trials.

By using Tinius Olsen H 10K T universal testing machine, all tensile specimens were designed according to machine standard. In Table 3, the tensile strength of each test specimen produced according to trials of orthogonal array is shown. The tensile strength obtained is used to calculate the signal-to-noise (S/N) ratio to calculate the finest setting of the parameter's arrangement [21]. Calculated signal to noise (S/N) ratio is as also shown in Table 3. The results obtained are analysed by using (ANOVA) analysis of variance. The significance of factors to affect strength is determined by calculating the percentage of contribution from this method.

**Table 3. Summary of result of tensile strength (Mpa) and S/N Ratio**

| Trial No. | Control Factors | | | Tensile strength (Mpa) | S/N Ratio |
|---|---|---|---|---|---|
| | A | B | C | | |
| 1 | 10 | 08 | 260 | 8.00 | 18.06 |
| 2 | 10 | 10 | 280 | 7.81 | 20.86 |
| 3 | 10 | 12 | 300 | 7.66 | 22.45 |
| 4 | 10 | 14 | 320 | 7.50 | 23.52 |
| 5 | 15 | 08 | 280 | 7.20 | 24.13 |
| 6 | 15 | 10 | 260 | 7.18 | 24.90 |
| 7 | 15 | 12 | 320 | 7.28 | 25.69 |
| 8 | 15 | 14 | 300 | 7.30 | 26.29 |
| 9 | 20 | 08 | 300 | 22.43 | 36.55 |
| 10 | 20 | 10 | 320 | 22.6 | 37.08 |
| 11 | 20 | 12 | 260 | 22.15 | 37.32 |
| 12 | 20 | 14 | 280 | 22.51 | 37.83 |
| 13 | 30 | 08 | 320 | 8.40 | 29.62 |
| 14 | 30 | 10 | 300 | 8.32 | 29.86 |
| 15 | 30 | 12 | 280 | 8.18 | 30.01 |
| 16 | 30 | 14 | 260 | 8.23 | 30.34 |

High strength of rotomolded product is needed for a water tank. Therefore, more the strength is better and S/N ratio is calculated for the higher the better. Taguchi has outlined for an equation 'larger the better' this case to calculate S/N ratio. The equation to obtain the values of S/N ratio is shown below [22].

$$S/N = -10 \log_{10}(MSD)$$

For larger is better

$$MSD=\frac{1}{N}\Sigma\frac{1}{y_1^2}$$

MSD= Mean Square Deviation
y= Observations
n= No. of tests in trial
S/N ratio for other trials is obtained and show in Table 3.

## 3. RESULT AND DISCUSSION

As applying above calculations, S/N ratio for each level of each factor is obtained. And the results of average S/N ratio for each level are shown below,

**Table 4. Response tables of S/N ratio for each level of each factor.**

| Level | A | B | C |
|---|---|---|---|
| 1 | 21.22 | 27.09 | 27.65 |
| 2 | 25.25 | 28.17 | 28.08 |
| 3 | 37.195 | 28.86 | 28.78 |
| 4 | 29.95 | 29.49 | 28.97 |
| Max Difference | 15.97 | 2.4 | 1.32 |

From the S/N ratio response is as shown in Table 4, the finest combination of parameters can be identified by selecting the greater difference value from each factor. In this case, the most significant factor that has an effect on strength is Rotational Speed (A) followed by cooling time (B) and Oven temperature (C). Table 5 shows the summary of best combinations of optimum parameters.

**Table 5. Response tables of S/N ratio for each factor of each level.**

| Factor | Values |
|---|---|
| Rotational Speed (A) | 20 mm/min |
| Cooling Time (B) | 14 min |
| Oven Temperature (C) | 320°C |

By using minitab19 software the main effects plot for S/N ratios is obtained and shows in fig 1

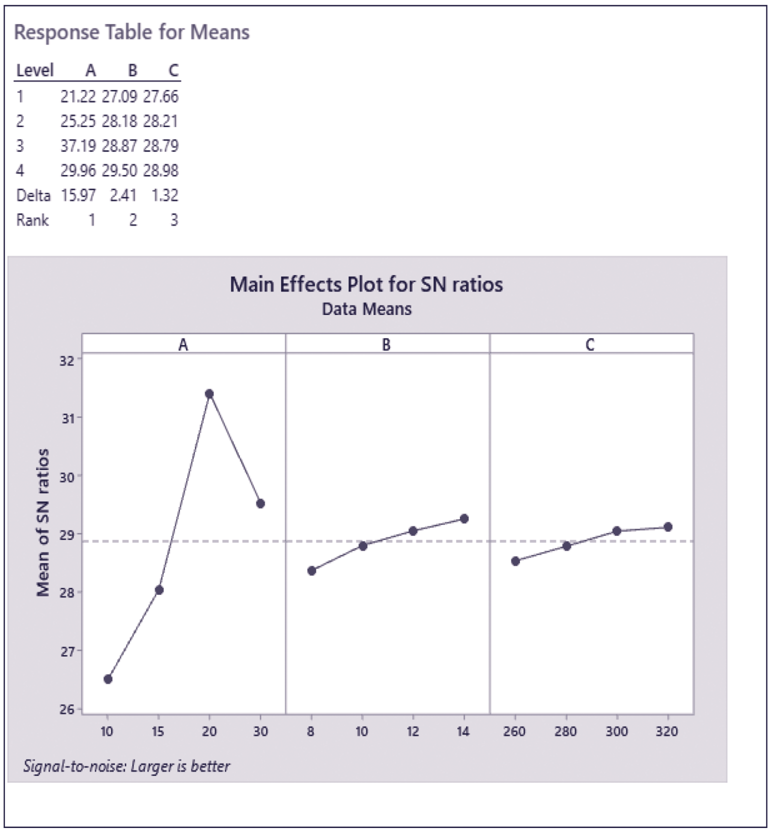


**Figure 1. Main effect plot S/N Ratio.**

### 3.1. Calculation of ANOVA

Analysis of variance method utilised to evaluate percentage of contribution for each factor. The percentage of contributions p (%) for all factors is shown in Table 6.

**Table 6. ANOVA approach for tensile strength**

| Factors | | S | V | F | P(%) |
|---|---|---|---|---|---|
| Rotational Speed | 3 | 647.57 | 215.85 | 6508.22 | 99.95 |
| Cooling Time | 3 | 0.09 | 0.03 | 0.9047 | 0.0138 |
| Oven Temperature | 3 | 0.011 | 0.0037 | 0.11 | 0.00169 |
| Error | 6 | 0.199 | 0.03316 | | 0.0345 |
| Total | 15 | 647.87 | 215.91 | | 100 |

In Table 6, f = Degree of freedom, S= Sum of squares, V = Values of variance, F = F- Ratio, p (%) = Percentage contribution

This result shows that the rotational speed contributes the most by 99.95% and this is followed by cooling time by 0.0138% and oven temperature 0.00169%. This proves that rotational speed is the most significant parameter contributes to improve tensile strength in the process while cooling time and oven temperature only have very small effects less than 1% towards the tensile strength.

## 4. CONCLUSION

By using ANOVA and Taguchi methods, we obtained the result of optimum conditions. The influence of all factors has been identified. For improving quality, as per our study rotational speed is found to be the most significant factor which contributes 99.95% followed by cooling time by 0.0138% and oven temperature 0.00169%. The results show that, for LDPE water tank 'TL Blue 2000' the best combination of processing parameters in terms of tensile strength are 20 mm/min rotational speed, 14 minutes for cooling time and 320˚C oven temperature. Study concludes that these key factors are helping engineers in determining optimum process conditions for producing better quality product in rotomolding process parameters.

**Conflict of Interest:** No conflict of interest.

## REFERENCES


[1] *R. J. Crawford, J. L. Throne, "Rotational molding technology", William Andrew Publishing, New York, 2002.*
*(Book chapter:)*

[2] *K. O. Ogila et. al., "Rotational molding: A review of the models and materials", eXPRESS Polymer Letters, Vol. 11, No. 10, pp.778-798, May 2013.*

[3] *T. Jachowicz, J. Sikora, "Investigation of the influence of mold rotational speed on the cast wall thickness in rotational molding process", Advances in Science and Technology Research Journal, Vol. 7, No.19, pp.79-87, Sep. 2013.*

[4] *L. Zhang, B. E. Narkhede, A. P. Chaple, "Evaluation lean manufacturing barriers: an interpretive process", Journal of Manufacturing Technology Management, Vol. 28, No. 8, pp. 1086-1114, Sep 2017.*

[5] *C. Bhavesh, P. L. Ramkumar, A. Kumar, "Material Selection for Rotational Moulding Process Using Grey Relational Analysis Approach", Materials Today: Proceedings, Vol. 5, No. 9, pp. 19224-19229, Oct 2018.*

[6] *LDVE Leo`n, VA Escocio et al., "Rotomolding and polyethylene composites with rotomolded lignocellulosic materials: A review", Journal of Reinforced Plastics and Composites, Vol. 39, No.11-12, pp. 459-472, June 2020.*

[7] *A. Greco, F. Ferrari et al., "Thermal and Mechanical Analysis of Polyethylene Homo-Composites Processed by Rotational Molding", polymer, Vol. 11, No. 3,528, Mar 2019.*

[8] *W. Chen, M. Nguyen, W. Chiu, T. Chen, P. Tai, "Optimization of the plastic injection molding process using the taguchi method, RSM, and hybrid GA-PSO", Industrial Journal of Advanced Manufacturing Technology, Vol. 83,pp.8-12, Aug 2015.*

[9] *O. Zerti, M. A. Yallese, K. Riad et al., "Design optimization for minimum technological parameters when dry turning of AISI D3 steel using taguchi method", International Journal Advanced Manufacturing Technology, Vol. 89, pp. 1915-1934, Mar 2017.*

[10] *R. Shaker and D. Rodrigue, "Rotomolding of Thermoplastic Elastomers Based on Low-Density Polyethylene and Recycled Natural Rubber", Applied Sciences, Vol. 9, No. 24, 5430, Dec 2019.*

[11] *M. Shirinbayan, A. Montazeri, N. Sedeh et al., "Rotational Molding of Polyamide-12 Nanocomposites: Modeling of the Viscoelastic Behavior", International Journal of Material Forming, https://doi.org/10.1007/s12289-020-01558-9, May 2020*

[12] *H. Xu and CT. Bellehumeur, "Thermal residual stress development for semi-crystalline polymers in rotational molding", Polymer Engineering and Science,Vol.48, No. 2, PP. 283–291, Dec 2007.*

[13] *A. Greco, A. Maffezzoli et al., "Simulation of Heat Transfer During Rotational Molding", Advanced Ploymer Technology, Vol. 22, No.04, pp. 271-279, 2003*

[14] *M. Daryadel, A. Taher, et al., "investigation on tensile properties of polymeric nanocomposite samples in the rotational molding process", Polymer Bulletin, https://doi.org/10.1007/s00289-020-03225-0, May 2020.*

[15] *R. J. Crawford, "Introduction to Rotational Molding", in R.J. Crawford, Ed., Rotational Molding of Plastics, 2nd ed., Research Studies Press, London, pp. 16, 1996.*

[16] *J. A. Nikerson, "Rotational Molding", Modern Plastics Encyclopedia, 44:12.*

[17] *F. Hanana, "Rotational molding of polymer composites reinforced with natural fibers", Journal Plastics Engineering, Vol.71, pp.28-31, July 2015.*

[18] *R. Pareek, J. Bhamniya, "Optimization of Injection Moulding Process using Taguchi and ANOVA", International Journal of Scientific and Engineering Research, Vol.4, No.1, Jan. 2013.*

*[19] P. J. Ross, "Taguchi Techniques for Quality Engineering", Mc. Graw Hill Publication, ISBN 0070539588, 1996. (Book:)*

*[20] D. C. Montgomery, "Design & Analysis of Experiments", 8th Ed., John Wiley &sons Inc., pp.554-570, 2013. (Book:)*

*[21] Dean, D. Voss and D. Draguljic, "Design and Analysis of Experiments", 2nd ed., springer publication, pp.285-301, 2017. (Book:)*

*[22] P. Bharti, M. Khan and H. Singh, "Six Sigma approach for quality management in plastic injection moulding process: a case study", International Journal of Applied Engineering Research, Vol. 6, No. 3, pp.303-314, 2011.*

**AUTHORS**

**Ms. Karishma Raut**, M.E. (Manufacturing System Engineering), VIVA Institute of Technology, Shirgaon, Veer Sawarkar Road, Virar (East), Tal-Vasai, Chandansar, Virar- 401303, Maharashtra
Email: karishmaraut99@gmail.com / 7350034429

**Mrs. Niyati Raut**, M.Tech. (Thermal), HOD, VIVA Institute of Technology. Shirgaon, Veer Sawarkar Road, Virar (East), Tal-Vasai, Chandansar, Virar- 401303, Maharashtra
Email: shubhangi.nr@gmail.com