Use of Taguchi Robust Design to Optimize Rubber Glove Process

Z Wahid[1], T T Ming[2] and K Ahmad[1]

[1] Department of Science in Engineering, Faculty of Engineering, International Islamic University Malaysia, P. O. Box 10, 50728 Kuala Lumpur, Malaysia
[2] Department of Chemical and Process Engineering, University of Newcastle Upon Tyne Newcastle, United Kingdom

E-mail: [1]zaharahwahid@iium.edu.my

Abstract. In this paper, Taguchi concept of robust process design and the classical statistical experimental design methodology are integrated for improving both the product quality and efficiency. It is a systematic method of optimizing a production process, and is concerned with productivity enhancement and cost effectiveness. . The aim of this study is to investigate the effect of the inputs on the outputs in the presence of a noise factor and also to choose the best level settings of the control factors that will maximize the mean and minimize the variation in the glove's quality characteristics at minimal cost. The quality characteristic of the rubber glove that is considered in this study was the tensile strength. Taguchi L16, the orthogonal array is employed to run the experiments. The analysis of variance (ANOVA) and the signal-to-noise (S/N) ratio were performed. The BG interaction was identified as the important mean effect. However, factor (B), the latex temperature was not affected by factor (G), oven temperature after coagulation dip when it was at high but enhanced the strength when both were set at low. Factor (A), curing temperature profile affected both the mean and the process variability. The effect of humidity (H) appeared insignificant using ANOVA, but was significant in S/N ratio for the mean tensile strength. The preferred optimal setting were: $A_2B_1C_1D_1F_2H_1G_1$.

Keywords
 Robust design; design of experiments; ANOVA; signal to noise; noise; interaction; larger the best

1. Introduction

The concept of robust design was first introduced by Taguchi in the United States in the 1980's. In Taguchi's view, robustness means the ability of the design to express its intended performance during use with minimal variation. Taguchi robust design for off-line quality control has received much attention in the literature. The parameter design provides a systematic approach for optimization of various parameters in context of performance, quality and cost. This criterion requires the design to be

stable and consistent with the least sensitivity to all types of noise effects. . Noise may include the effects of environment, degradation over time/aging and manufacturing variations. "Robust design is an engineering methodology for improving productivity during research and development so that high-quality products can be produced quickly and at low cost," [1]. [4] reported that Taguchi's work is widely acknowledged. Before Taguchi's concept became known, [1, 4, 17] the statistical design of experiments was seldom used by engineers, but after he had demonstrated their practical power, engineers started to use them more widely. Although Taguchi's concepts provide a powerful tool for improving product and process design, the efficiency of his statistical techniques has been challenged [4]. A robust design focuses on reducing quality variation and bringing the mean closer to the desired target. Taguchi robust design embraces many concepts from statistical experiments for optimizing the design of processes or products [1, 2, 3, 17]. It can be used to derive optimal processes and products, as well as to identify the control factors that significantly influence a particular quality characteristic [31]. The Taguchi method involves two major tools. First one is the orthogonal array (OA) and second one S/N ratio [1, 2, 3, 6, 7, 15, 16].

The OA is a fractional factorial matrix that balances a factor and interactions among the factors, and it acts as the basis of experimental design. In production sectors, many parameters need to be considered To solve this problem, the Taguchi method employs the OA to study the entire design parameter by using only a few experimental samples. The S/N ratio is used as a quality characteristic that can be analysed using analysis of variance (ANOVA) to ascertain both the effects of the design parameters and the contribution percentage of each design parameter or variable. In addition, on the basis of S/N ratios, a response table and a response graph can be derived and, then, the optimal design can be determined.

There has been considerable research aimed at integrating robust design principles with sound statistical techniques [8, 9, 10, 11, 12, 13, 14, 15, 17]. [16] conducted a comprehensive case study on an industrial thermostat using Taguchi's method. And concluded that the new robust process attains through this investigation allow the company to penetrate new markets due to their ability to function in a severe environment. It is obvious that to benefit from Taguchi's idea of robustness and classical statistical methods, we should integrate the merits of both. This study will adopt this approach in order to seek continuous quality improvement in the rubber glove industry.

2. Methodology
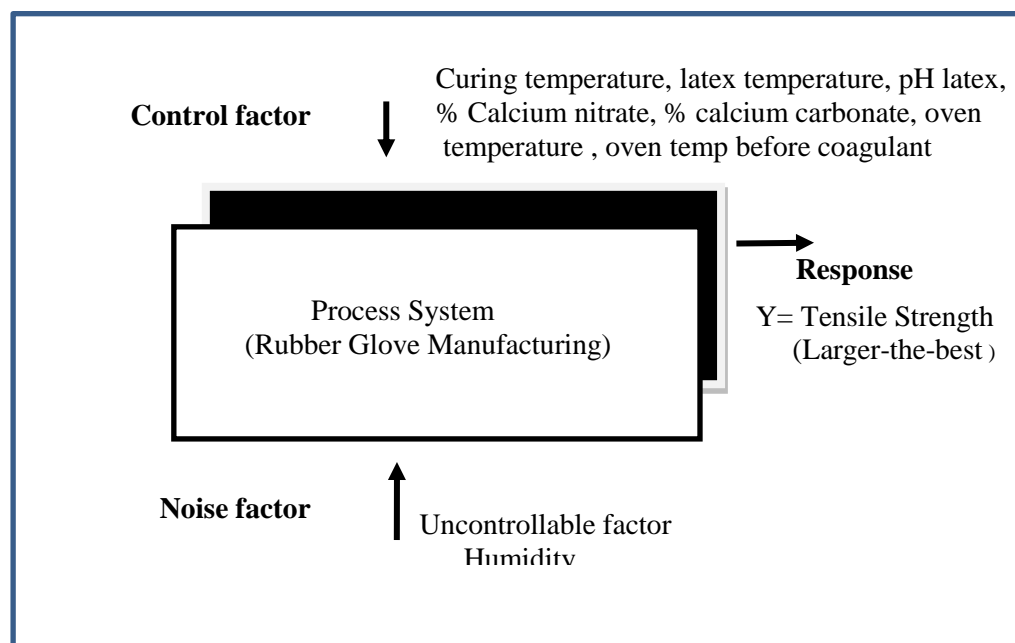### 2.1. Planning and selection of parameters
Planning of an experiment is crucial to the success of a project. The concept of PDSA (Plan Do Study Act) was adopted in solving the problem. During the planning stage a brainstorming session was conducted to identify factors affecting process outcome. Seven controllable factors and one noise factor (uncontrollable) were selected for the robust process design their levels are listed in Table 1.
The response variables of interest (quality characteristics) identified is tensile strength and relative humidity is identified as a noise factor that is impossible or expensive to control in actual operation. The noise factor was intentionally included in the experiment in order to assess the "robustness" and proper selection of the controllable factor levels that are used to reduce the variability in the response as shown in Figure 1 below. The parameters that influence the quality characteristics are also known as factors. The diagram helps researcher to view the product as a system and to distinguish the different factors influencing it. It is essential to identify control factor setting that make the product insensitive to the various type of noise factors.

TABLE 1. Experimental Factors and levels.

	Factor levels	
Factors	Low level (1)	High level (2)
A = curing temp profile	80, 100, 115, 115, 120,130	95, 110, 125, 130, 150
B = latex temperature in dip tank	25-26 °C	29-30 °C
C = oven temp before coagulation	75 -80 °C	90-95 °C
D = calcium nitrate	7.0 -8.0 %	11.0-12.0 %
E = humidity (noise)	Low humidity	High humidity
F = calcium carbonate	2.5-23.5 %	4.5 -5.5 %
G = oven temperature before latex dip	170-180 °C	190-200 °C
H = pH of latex compound	10.0 -10.4	10.5-10.7 pH

Two levels fractional factorial or L16 orthogonal array were employed in this experiment and the use of this L16 reduces the number of runs required. The experiments were replicated twice under the same conditions. The standard deviation of the response at each experimental point was calculated and the standard deviation between these replicates was estimated for the variability. Ten samples were taken after each trial run. Each sample was subjected to tensile test. Calculations were performed using the statistical package MINITAB software.

Figure 1. Parameter diagram of product/process.

2.2. Construction of design layout

Orthogonal arrays are special matrices that allow the manufacturer to choose the parameter values with minimum number of experiments. They provide a powerful method for experimentation and table 2 illustrates the standard L16 orthogonal array. L16 has eight columns and sixteen rows. The eight vertical columns contain the control factors and the noise factor. They are fixed and set at two different levels. Both control factors and noise are combined in a single set-up, also called a combined array [2]. The sixteen rows composed of codes (1) low level and (2) high level designate the levels of factors used to run the experiment. The factor is designated by capital letters such as A, B, C and till H. The factors are varied simultaneously, to study not only the effect of each factor, but also how the effect of one factor changes as the levels of other factor change.

The latter is generally referred to as an interaction effect among factors. The randomization procedure dictates the running order of the experiments. At total of thirty trial runs were conducted in the industrial environment. The experimental data were analysed for both mean responses and standard deviations by the analysis of variance and signal to noise ratio.

TABLE 2. Orthogonal Array (OA) L16.

Experiment No.	Column Numbers and Factor Assignments							
	1	2	3	4	5	6	7	8
	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	2	1	1	2	2	2	2	1
3	1	2	1	2	2	2	1	2
4	2	2	1	1	1	1	2	2
5	1	1	2	2	2	1	2	2
6	2	1	2	1	1	2	1	2
7	1	2	2	1	1	2	2	1
8	2	2	2	2	2	1	1	1
9	1	1	1	1	1	2	2	2
10	2	1	1	2	2	1	1	2
11	1	2	1	2	2	1	2	1
12	2	2	1	1	1	2	1	1
13	1	1	2	2	2	2	1	1
14	2	1	2	1	1	1	2	1
15	1	2	2	1	1	1	1	2
16	2	2	2	2	2	2	2	2

2.3. Concept of signal to noise ratio

One of the important features of Taguchi method is the signal to-noise (S/N) ratio employed as a measure of the impact of noise factors on performance. There are three types of (S/N) ratios used in Taguchi method. These are nominal is-best, small and larger- is –better. In this study tensile strength is chosen as the response, therefore, the larger the better characteristic of S/N ratio is deployed as in equation (1) and it is calculated as depicted in the following formula:

$$S/_N \ the \ larger \ the \ better = 10 \log \frac{\beta^2}{\sigma^2} \qquad (1)$$

Where: β = Slope of the best fit line

σ^2= Mean square around the best fit line(Average of the square of distance from individual point to the best fit line).

The unit of S/N ratio is decibel (dB). In addition, Taguchi method implies that if the variation of the process from the mean is reduced, quality loss reduces. This reduction in variation is brought about by adjusting the mean near to the target with help of a scaling factor. The response table and the response graph can be deployed to derive the optimal design.

3. Results and Discussion

3.1 Analysis of variance for Mean tensile Strength

The results from the analysis of variance (ANOVA) for tensile strength are displayed in table 3. The analysis of these data revealed that two of the controllable factors, A (curing temperature), G (oven temperature after coagulation dip) and interaction effect BG were found to be statistically significant at $(p \leq 0.001)$ for the response of tensile strength. This means that there is some evidence that these factors and interactions have significant influence on the tensile strength. In the table, DOF is the abbreviation for "degree of freedom".

TABLE 3. Analysis of variance for means.

Source	DOF	Adj SS	Adj MS	F-value	P-value
Model	6	37.9353	6.3225	9.86	0
Linear	4	27.6873	6.9218	10.79	0
A	1	7.5063	7.5063	11.7	0.002
B	1	0.0425	0.0425	0.07	0.799
D	1	0.451	0.451	0.7	0.41
G	1	19.6875	19.6875	30.69	0
2-Way interactions	2	10.248	5.124	7.99	0.002
BG	1	10.2005	10.2005	15.9	0.001
DG	1	0.0475	0.0475	0.07	0.788
Error	25	16.0381	0.6415		
Lack of Fit	9	7.726	0.8584	1.65	0.182
Pure error	16	8.3121	0.5195		
Total	31	53.9733			

for Adj SS is the abbreviation for"Adjusted sum of squares", Adj MS is the abbreviation for "adjusted mean square", F is the F-statistic (Adj MS factor/Adj MS error) and p-value is the level of significance. The term 'adjusted' indicates that MINITAB has taken into account additional factors in the model. Although a trial run of 32 experiments were performed for tensile strength, there were eight factors, so Adj SS factor as and Adj SS error have seven and one degrees of freedom, respectively. The error or deviation sum of squares is the sum of squares minus the sum of squares for factors. The sum of squares for error has twenty five degrees of freedom. Each sum of squares divided by its

degrees of freedom is an adjusted mean square. Therefore to test the equality of factor means, the test statistic (F) below would be used.

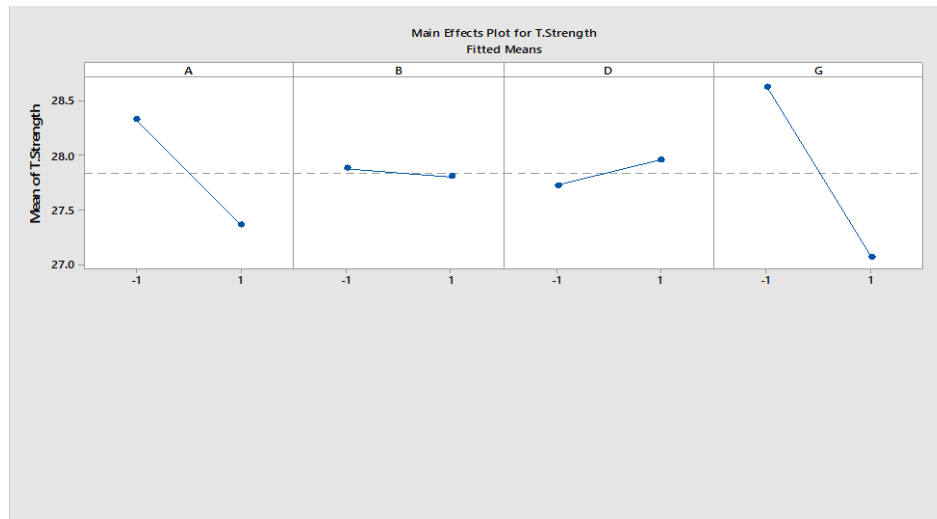$$F = \frac{MS_{treatments}}{MS_{error}} = \frac{Adj_{factor}}{Adj_{error}}$$

Figure 2. Main effects for tensile strength.

The tested probability level is 95% ($\alpha = 0.05$). It revealed that factors A (temperature of latex), and G (oven temperature after coagulant dip) are the most important main controllable factors. The critical F-value is 4.24 at ($p \leq 0.05$) . Since factor A has an F-value of 11.70 and exceeds the critical value 4.24, the null hypothesis H_0: factor means are the same should be rejected and accept H_1: factor means are different, and conclude that factor A (curing temperature) does affect the mean response

Similarly, factor G, has an F-value of 30.69, which exceeds 4.24. Hence factors B and G have large positive effects on the tensile strength of the gloves($p \leq 0.05$). That is, changing the controllable factors from high to low or vice versa changes the average of the response variables. Examination of the ANOVA Table 3 it is also noted that factor G has the largest effect followed by factor A. The interaction BG has an F-value of 15.90, and it is statistically significant at ($p \leq 0.002$) . There is a good reason to suppose that BG has an effect on the mean response. Nevertheless, factor B is insignificant at ($p \leq 0.779$) and has an F-value of 0.07.

A follow-up analysis of table 3 was performed. Factors having strong effects on mean tensile strength are shown in figure 2. We are tempted to interpret the main effects for G separately which in this case could be quite misleading. This is because of the presence of interaction effect between factor B and G.

A graphical representation of the estimated effects of   interaction is shown in figure 2. It revealed that when oven temperature after coagulant dip (G) and curing temperature profile (A) are set at their low levels, the highest average tensile strength was achieved. However, a significant interaction was found between the main controllable factors, latex temperature (B) and oven temperature after coagulant dip (G). This interaction is important. Although factor B is not significant by itself, its interaction with factor G which is highly significant requires B to be considered. Factors B, C, D, E, F

and H have very small F-values and appear to be insignificant at $(p \leq 0.05)$. They should be set at their most economical levels which are at their low levels since these are the least expensive levels. The goal here is to maximize the tensile strength and minimize variability at low cost.
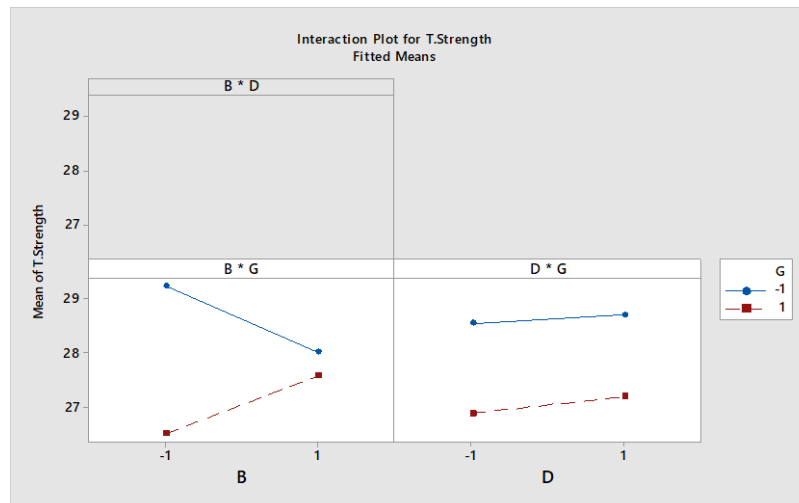

Figure 3. Interaction effect for tensile strength.

Figure 3, interaction effects between factor B and G averages are plotted, and lack of parallelism indicates the presence of interaction effects. Examination of figure 3 indicates that setting factors G and B at low is the optimal choice in order to maximize the mean strength of the glove. The rest of the factors B, C, D, E, F and H have very small F-values and appear to be insignificant at $(p \leq 0.05)$. They should be set at their most economical levels which are at their low levels since these are the least expensive levels. The goal here is to maximize the tensile strength and minimize variability.

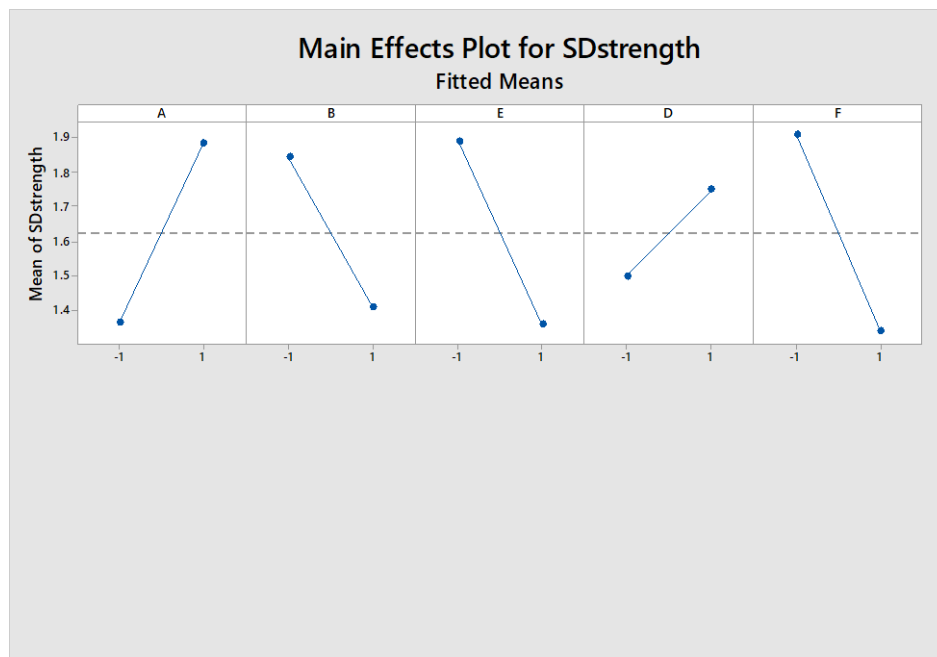### 3.2 Analysis of Variance for Standard Deviation

Noise factors which are considered critical are treated just like control factors. Variability due to noise factors which are not being controlled are evaluated by replicating the experiment and calculating sample standard deviations at each trial run. To study the dispersion effects the standard deviation was deployed as the response variable.

The standard deviations were transformed by taking the natural log so that they will be much closer to being normally distributed.

The results from the ANOVA computations for the ln(standard deviation) of tensile strength are given in table 4. The F-tests showed that factor A, E, F are statistically significant at $(p \leq 0.05)$ with F-values of 5.55, 5.69, 6.60 respectively as shown in table 4. The only interaction term that is statistically significant is AB with F-value of 5.39. It appears that factor F has the highest coefficient, followed by factor A and E. Thus, the analysis suggests that these factors affect process variability. Figure 5 was constructed at each factor level for the main effect. Examination of this plot reveals that when factor A, moves from low to high the variability in the process increases.

Table 4. Analysis of variance for ln standard deviation.

Source	DOF	Adj SS	Adj MS	F-value	P-value
Model	7	12.7244	1.8178	4.57	0.002
Linear	5	9.1244	1.8249	4.59	0.004
A	1	2.2048	2.2048	5.55	0.027
B	1	1.531	1.531	3.85	0.061
E	1	2.262	2.262	5.69	0.025
D	1	0.5048	0.5048	1.27	0.271
F	1	2.6217	2.6217	6.6	0.017
2-Way interactions	2	3.6	1.8	4.53	0.021
A*B	1	2.1438	2.1438	5.39	0.029
A*D	1	1.4562	1.4562	3.66	0.068
Error	24	9.5404	0.3975		
Lack of Fit	8	1.0123	0.1265	0.24	0.97
Pure error	16	8.5282	0.533		
Total	31	22.2648			

Figure 4. Main effect for signal to noise.

3.3 Signal-to-noise (S/N) ratio analysis (Larger the better)
The S/N ratio is the ratio of signal factor to the noise factor in the experiment. In this study larger the best is chosen to maximize the tensile strength of the glove and minimize the effect of noise factor on

the response. Table 5 shows the response table for S/N ratio. The ranks are given according to delta values. Delta values represent overall change in the value of control factors. Since the delta value for factor G was the largest in case of S/N and standard deviation it can be said that, it has the highest impact on the process. Table 5 shows that the S/N ratio is maximum at low level of factor G and A, whereas almost constant for factor B and F. This discovery is similar with ANOVA in table 3.

Figure 5 shows the effect of factors A, E, F and G on the S/N ratio. The S/N ratio at high level is minimized the humidity (E) and maximize A, F, G, at high level. These control factors are deployed to optimize the process and at the same time the noise factor (humidity) is minimized, thus making the process robust.

Table 5. Analysis of Variance for ln standard deviation.

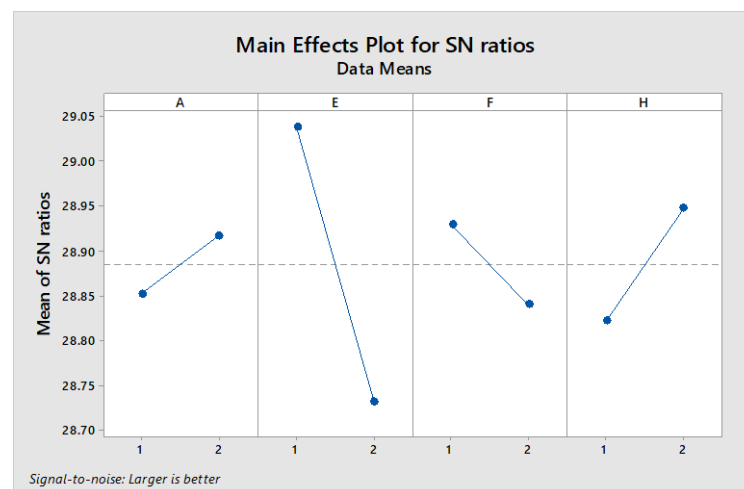| Level	A	E	F	G
1	28.85	29.04	28.93	28.82
2	28.92	28.73	28.84	28.95
Delta	0.07	0.31	0.09	0.13
Rank	4	1	3	2

Figure 5. Main effect for signal to noise.

4. Conclusion

Integration of the Taguchi method and sound classical statistics has been applied for optimizing tensile strength of rubber glove. Result obtained from Taguchi Method S/N ratio closely matches with ANOVA. The conclusion of this work found that factors G (oven temperature before latex dip), A (curing temperature profile) and BG interaction strongly influence the mean tensile strength of the glove. The BG interaction plays an important role in the mean response. However, factor B was not affected by factor G when it was at high but enhances the strength when both were set at low. Factor A affected both the mean and process variability. The effect of humidity appears insignificant using ANOVA, but is significant in S/N ratio for the mean tensile strength. This study suggests that Taguchi

method was found to be promising technique to achieve the optimum conditions. Consequently, the preferred optimal settings are:$A_2 B_1 C_1 D_1 F_2 H_1 G_1$.

Acknowledgement

References

[1]   Phadke M S 1989 *Quality Engineering Robust Design*. (Prentice Hall, New Jersy) 45-59

[2]   Taguchi G, Chowdhury S and Wu Y 2005 *Taguchi's Quality Engineering. Handbook,* (John Wiley & Sons, Inc. Hoboken, NJ, USA) 223-311

[3]   Montogomery D C 2019 *Design and Analysis of Experiments*.(John Willey & Sons,INC.) 464-477

[4]   Wu C F J 1992 Discussion Taguchi's parameter design: a panel discussion. Ed. N.V. Nair,*Technometrics,* **34** 127-159

[5]   Farbodi M 2017 Application of Taguchi method for optimizing of mechanical   properties of polystyrene-carbon nanotube nanocomposite. *Polymers & Polymer Composites,* **25** 177-183

[6]   Alexander B, Coser E, Aguzzolo C, Pedott A, Khan S and Malfatti, C D F 2018 Application of Taguchi method to study morphological evolution of TiO_2 nanotubes obtained via anodization process. *Mat. Res.*, **21** 1-11

[7]   Kulkarni S, Duttagupta S and Phatak G 2015 Taguchi design of experiments for optimization of ionic conductivity in nanocrystalline Gadolinium doped Ceria. *Ceramic international,***41** 8973-78

[8]   Yousefieh M, Tamizifar M. Boutorabi S M A and Borhani E.2016. Taguchi Optimization on the Initial Thickness and Pre-aging of Nano-/Ultrafine-Grained Al-0.2 wt.%Sc Alloy Produced by ARB. *J. of material Eng Performance*, **25** 4239-44

[9]   Padmaja and Haritha D 2018 Optimization of process parameters using Grey-Taguchi method for software   effort   estimation   of   software   project. *Int. J. of Image, Graphics   and   Signal Processing* (IJIGSP), **10** 10-16

[10]   Amir A D, Abdul Rahman B S and Anuradha N 2018 An application of Taguchi L9 Method in Black Scholes Model for European Call Option.*Int. J. Entrepreneurship.* **22** 1939-4675-3117

[11]   Hafee Hafeez K, Rowlands H, Kanji G and Igbal S 2010 Design optimization using ANOVA. *J. Applied Statistics.* **29** 895-906

[12]   Mitra A C, Jawarkar M., Soni T and Kiranchand G R 2016 Implementation of Taguchi method for robust suspension design. *Procedia Engineering,* **144** 77-84

[13]   Ekawati Y and Hapsari A A 2018 Taguchi experimental design to determine the taste quality characteristic of candied carrot, IOP conference series*, Mat. Sci. Eng*.**319** 012050

[14]   Xiao S, Sun W J, Du, and Guoliang L 2014 Application of CFD, Taguchi Method, and ANOVA Technique to optimize combustion and emission in a light duty diesel engine, *Hindawi* **2014** 1-9

[15]   Kumar D K, Parashar V, Jasveersingh M K Gour 2014 Taguchi method and ANOVA: An Approach for selection of process parameters of EDM of EN-353 steel, *Int. J. of Emerging Tech and Advced Eng,* **4** 313-321

[16]   Rahul D and Pretesh J 2018 *StatisticalApproaches With Emphsise on Design of Experiment Applied to Chemical Processes*. Edited Valter S. (Open access book)

[17]   Sharon S B, Deepak R, Suresh A and Vishwanathamoorty 2016 Optimization of process parameters of stir casting technique using orthogonal *arrays Int.J.of Res in Eng & Tech* **5** 623-28