Taguchi Robust Design as a Way to Determine Optimal Parameters in Rubber Glove Production

Zaharah Wahid
Department of science in engineering
International Islamic University of Malaysia
Selangor, Malaysia
zaharahwahid @iium.edu.myemail

Ming T. Tham
Deparment of chemical and process engineering
University of newcastle upon tyne
Newcaste, United Kingdom
ming.tham@newcastle.a.c.uk

Najiah Nadir
Department of science in engineering
International Islamic University of Malaysia
Selangor, Malaysia
najiahnadir@gmail.coml

Abstract—In this paper, Taguchi concept of robust process design and classical statistical experimental design methodology are integrated as a way of improving both product quality and efficiency. Hence, yield more consistent and better quality gloves. 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 was considered in this study was the tensile strength. Taguchi L16 orthogonal array is employed to run the experiments. ANOVA has been performed and compared with Taguchi signal to noise ratio (SNR). mean tensile strength. The BG interaction plays an important role in the mean response. However, factor B is not affected by factor G when it is at high but enhances the strength when both are 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. The preferred optimal setting are: $A_2B_1C_1D_1F_2H_1G_1$.

Keywords—robust design, design of experiment, noise, signal to noise, anova

I. 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 process 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. According to [1] "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. [2][3] stated that Taguchi's approach to experimental design is similar to the classical statistical approach. [4] also added that Taguchi's work is widely acknowledged. Before Taguchi's concept became known, [5] 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 [6][7] Taguchi's Signal to Noise (S/N) ratios are sometimes misleading and can lead to wrong decisions [8]. Information on dispersion and location effects are confounded with each other and all of the information in the data is not used. S/N ratios are ineffective in identifying dispersion effects [9], although they serve to identify location effects [10]. [11] highlighted that data

transformation to improve its statistical properties, explanation and prediction were not well addressed in Taguchi's approach. [12] suggested a better alternative to S/N ratios was to use the log transformation to decouple the dispersion and location effects and so simplify finding those conditions that simultaneously locate the process on target and reduce dispersion about the target

.There has been considerable research aimed at integrating robust design principles with sound statistical techniques [22][18][15][17] [19]. [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.

II. Methodology

A. *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. The controllable factors are factors that can be controlled, in this study they were curing temperature profile, temperature of latex in dip tank, oven temperature before coagulant dip (former's temperature), percent calcium nitrate, percent calcium carbonate, oven temperature before latex dip and pH of latex compound. These factors and 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 asses "robustness" and proper selection of the controllable factor levels that are used to reduce the variability in the response as shown in Fig. 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

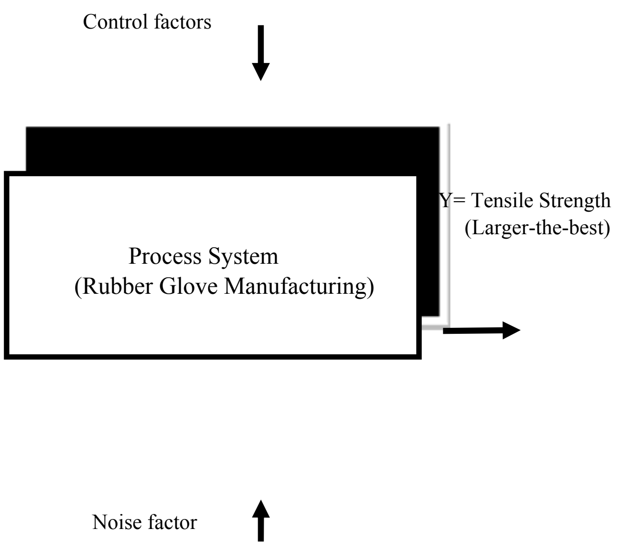

Fig.1. Parameter diagram of product/process

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.

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.

TABLE 1. EXPERIMENTAL FACTORS AND LEVELS

Factor levels		
Factors	Low (1)	High (2)
A	80, 100, 115, 115, 120,130	95, 110, 125, 130, 150
B	25-26 ° C	29-30 ° C
C	75 -80 ° C	90-95 ° C
D	7.0 -8.0 %	11.0-12.0 %
D	Low humidity	High humidity

B. 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 [21]. 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.

TABLE 2. DESIGN OF L_{16} ORTHOGONAL ARRAY

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

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 analyzed for both mean responses and standard deviations by the analysis of variance and signal to noise ratio.

C. *Concept of Signal to Noise*

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. In this study tensile strength is chosen as the response, therefore, the larger the better characteristic of S/N ration is deployed and it is calculated as depicted in the following formula:

$$S/N = 10\log \beta^2/\sigma^2 \quad (1)$$

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.

III. Results and discussion

A. *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

TABLE 3. Analysis of Variance for means

Source	DOF	AdjSS	AdjMS	F-value	P-value
Model	6	37.9353	6.3225	9.86	0.000
Linear	4	27.6873	6.9218	10.79	0.000
A	1	7.5063	7.5063	11.70	0.002
B	1	0.0425	0.0425	0.07	0.799
D	1	0.4510	0.4510	0.70	0.410
G	1	19.6875	19.6875	30.69	0.000
2-Way interactions	2	10.2480	5.1240	7.99	0.002
BG	1	10.2005	10.2005	15.90	0.001
DG	1	0.0475	0.0475	0.07	0.788
Error	25	16.0381	0.6415		
Lack of Fit	9	7.7260	0.8584	1.65	0.182
Pure error	16	8.3121	0.5195		
Total	31	53.9733			

Freedom", 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 below would be used.

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

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 ($p \leq 0.05$) = 4.24. 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 so should be rejected and accept H_1: factor means are different and conclude that factor A (curing temperature) does affect the mean response.

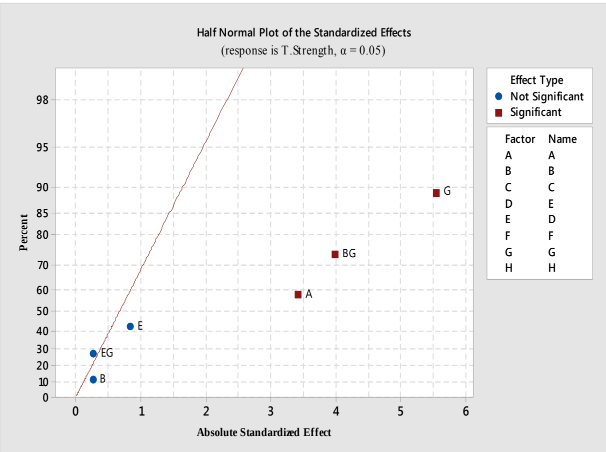

Fig.2. Half-Normal plot of mean tensile strength

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 influence on the mean response. Nevertheless, factor B is insignificant at ($p \leq 0.779$) and has an F-value of 0.07.

An alternative approach to determine which should be treated as real and which should be treated as arising from random variation a half-Normal probability is used. This plot is also used to determine whether any outliers are affecting the results. [12][13] suggested that outliers are present when points falling near zero appear to follow two different parallel lines rather than one, with negative values on one line and positive values on the other line. [14] also suggested that outliers are detected using half-Normal plots when the intercept of the plot is not zero. The half-Normal probability plot of the 15 contrasts is shown in fig. 2. The absolute contrast values of the mean tensile strength are plotted against the half Normal scores. It indicates that four points are separated from the other. It is noted that factors G, A and BG, interactions stood away from the rest of the points. The overall near linear appearance of the plot suggest that the remainder of the factors appear to be insignificant.

A follow-up analysis of Table 3 was performed. Factors having strong effects on mean tensile strength are shown in fig 3. 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 of BG.

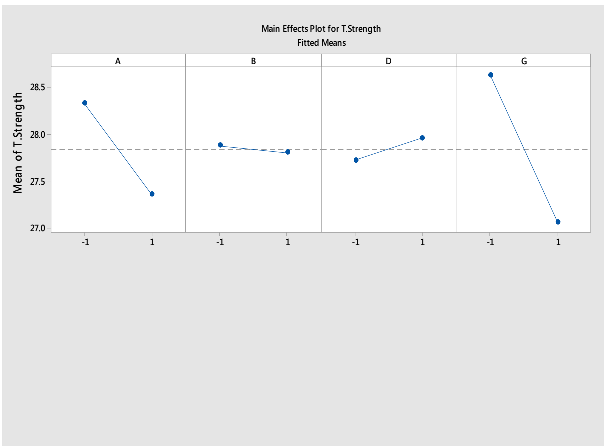

Fig.3. Main effects for mean tensile strength

A graphical representation of the estimated effects of interaction is shown in fig 4. 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.

fig. 4, interaction between factor B and G averages are plotted, and lack of parallelism indicates the presence of interaction effects. Examination of fig 4 indicates that setting factors G and B at low is the optimal choice in order to maximize the mean strength. 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.

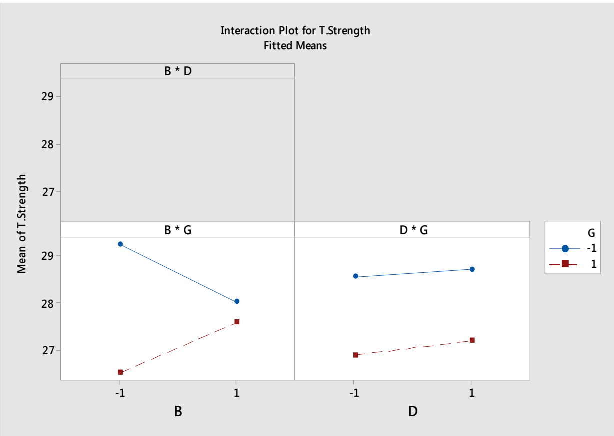

Fig.4. Interaction effect for tensile strength

B. Analysis of Variance for Standard Deviation

TABLE 4. Analysis of Variance for ln standard deviation

Source	DOF	AdjSS	AdjMS	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	1.5310	1.5310	3.85	0.061
E	1	2.2620	2.2620	5.69	0.025
D	1	0.5048	0.5048	1.27	0.271
F	1	2.6217	2.6217	6.60	0.017
2-Way interactions	2	3.6000	1.8000	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	0.5330		
Total	31	22.2648			

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 5. 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. Fig. 4 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.

Fig.5. Main effect for ln standard deviation

That is the standard deviation response will increase if factor A is high. On the other hand, moving E and F from low to high minimize the process variability.

Consequently factors A, E and F are dispersion effect. It is also observed that factor A influences both the mean and process variability. Therefore factor A cannot be used as adjustment factor. Controllable factors B,C, D and H do not apparently affect either the mean or standard deviation of the tensile strength. This means that they can be adjusted to any desired level without affecting the process average or process variability. Hence, they should be set at economical operating level. The best optimal settings for tensile strength of the gloves are $A_2B_1C_1D_1F_2H_1G_1$

C. Larger the Best

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 factor. Since the delta value for factor G 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 SN 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.

TABLE 5. TAGUCHI ANALYSIS OF SIGNAL TO NOISE

Response Table for tensile strength larger- the -better noise ratios (S/N)				
Level	A	E	F	A
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

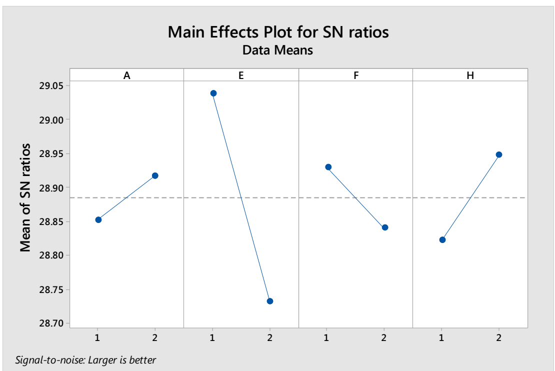

Fig.6. Main effect for signal to noise

The main effect plot shows the effect of factors on the response. Main effect plot represents the variation in the response variable with the variation in control factors. It is deployed to examine differences between level means for factors as in fig.6.

IV. 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 closely match with ANOVA. The conclusion of this work found that factors G, A and BG interaction strongly influence the mean tensile strength. The BG interaction plays an important role in the mean response. However, factor B is not affected by factor G when it is at high but enhances the strength when both are 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. The preferred optimal settings are:$A_2B_1C_1D_1F_2H_1G_1$.

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