TAGUCHI EXPERIMENTAL DESIGN AND ARTIFICIAL NEURAL NETWORK SOLUTION OF STUD ARC WELDING PROCESS

Prof.Dr. Nabeel K. Abid Al-sahib	M.s.C Riyadh M.A Hamza	Ass.prof.Dr. Ismail I.Al-kazaz
Baghdad University	Baghdad university	Baghdad university
Alkhwarzmi college of engineering	College of engineering	College of Engineering
Mechatronic Eng. Dept	Mechanical Eng. Dept	Mechanical Eng. Dept

ABSTRACT

Stud arc welding has become one of the most important unit operations in the mechanical industries. The need to reduce the time from product discovery to market introduction is inevitable. Reducing of standard deviation of tensile strength with desirable tensile strength joint as a performance character was use to illustrate the design procedure. The effects of (welding time, welding current, stud material, stud design, sheet material, sheet thickness, sheet cleaning and preheating) were studied. Design of Experiment (DOE) is a structured and organized method to determine relationships between factors affecting a process and output of the process itself. In order to design the best formulation it is of course possible to use a trial and error approach but this is not an effective way. Systematic optimization techniques are always preferable. Tensile strength quality is one of the key factors in achieving good stud welding process performance. 225 samples of stud welding was tested. Computer aided design of experiment for the stud welding process based on the neural network artificial intelligence by Matlab V6.5 software was also explain. The ANN was designed to create precise relation between process parameters and response. The proposed ANN was a supervised multi-layer feed forward one hidden layer with 8 input (control process parameters), 16 hidden and 2 output (response variables) neurons. The learning rule was based on the Levenberg-Marquardt learning algorithm.

The work of stud welding was performed at the engineering college laboratory, Baghdad University by using the DABOTEKSTUD welding machine, for 6 mm diameter stud. The sheet materials are (K14358 and K52355) according to (USN standards, and stud materials are (54NiCrMoS6 and 4OCrMnMoS8-6) according to (DIN standards).

The eight control parameters (welding time, sheet thickness, sheet coating, welding current, stud design, stud material, preheat sheet and surface condition) were studied in the mixed L16 experiments Taguchi experimental orthogonal array, to determine the optimum solution conditions.

The optimum condition was reached for the stud welding process tensile strength, where the researcher develops a special fixture for this purpose. The analysis of results contains testing sample under optimum condition, chemical composition of usage materials and micro structure of optimal condition sample.

According to that:

- Practicality: the influence parameters that affect the stud welding process are welding time, which have a major effect on stud welding process, followed by sheet material and stud material.

- The reduction in standard deviation was approximately (30.06 per cent) and for the range was as approximately (29.39per cent). In the other side the increase in the tensile strength mean was as approximately (30.84 per cent). The influence parameters that affect the tensile strength stud welding process are: the factor welding time has a major effect on stud welding process, followed by factor C (sheet coating) and factor F (stud material).

الخلاصة

تصميم التجارب هو طريقة هيكلية وتنظيم لحساب العلاقات بين عوامل تؤثر في إجراء معين ومخرجات هذا الأجراء، لإجراء تصميم معين بأفضل صياغة من الممكن استخدام طريقة التجربة والخطأ ولكنه ليست بالطريقة الفعالة. طرق الأفضلية المنظمة هي أمثل دائماً، وقد تم اختيار 225 نموذج من هذا اللحام فيها.

مع التصميم بمعاونة الحاسوب للجانب العملي لتجارب أجراء لحام البرغي اعتماداً على الشبكات العقدية للذكاء الصناعي باستعمال البرنامج الجاهز (Matlab V6.5)، صممت الشبكات العقدية لخلق دقة أكثر بين العوامل ومخرجات الإجراء لتصميم تجارب تاكوجي. الشبكات العقدية المقترحة هي متعددة الطبقات أمامية موجهة وظفت في ثماني عقد مدخلات (عوامل السيطرة للإجراء)، 16 عقدة مخيفة وعقدتين خارجيتين (متغيرات الاستجابة). قاعدة التعليم أعتماد على آلية (Levenberg – Marquardt) للتعلم.

باستعمال ماكنة لحام البراغي (DABOTEK) في هذه الدراسة للحام القوس البرغي قياس قطر 6 ملم. معادن الصفيحة K14358 وK52355 نسبة إلى (USN) ومعادن البرغي هي 4OCrMnMoS8-6 54NiCrMoS6 نسبة إلى (DIN). عوامل سيطرة ثمانية هي (زمن اللحام، سمك الصفيحة، طلاء الصفيحة، تيار اللحام، تصميم البرغي، معدن البرغي، التسخين المسبق وحالة السطح) درست في مصفوفة تصميم تجارب تاكوجي L16 المختلطة عوملت لحساب حالة الحل الأفضل، خطوات التطوير لتحسين طريقة تاكوجي هي خطوة تحليل بيانات التجربة. كان الانخفاض في الأنحراف المعياري (30.06%) تقريباً وكان الأنخفاض في المدى كان (29.39%) تقريباً. من ناحية أخرى كانت الزيادة في متوسط مقاومة الشد (30.84%) تقريباً. العوامل الأكثر تأثيراً على لاإجراء هي زمن اللحام ويليه نوعية معدن الصفيحة ثم نوعية معدن البرغي.

KEY WORDS: Taguchi experimental Design, Stud Welding Optimization, Artificial Neural Network, Stud Welding.

INTRODUCTION

Stud arc welding is a widely used operation in mechanical structure, where high tensile strength with minimum variation required. The variation of tensile strength affects the cost of stud welding unit operations such as rework and time consume. These are often limiting steps in mechanical manufacturing processes; therefore, significant cost reduction can be realized by producing the stud welding joint having reliable tensile strength.(Jibson J 1979).

Usually, to find the influence of controlling parameter on welding process a large number of experiments are needed. In order to avoid this, two statistical methods can be used to design the optimum number of experiments. Classical design of experiments (DOE) emphasizes prediction of future behavior of experiments from empirical model while running a fraction of full factorial design .However; the classical DOE suffers the following limitations: two designs for the same experiment may yield different results and the designs normally do not permit determination of the contribution of each parameter. Taguchi DOE method, based on the classical one, is standardized design methodology that can easily be applied by investigators. Furthermore, designs for the same experiment by two different investigators will yield similar data and lead to similar conclusions. (Montgomery D.C 1985)

Allen T.T. and et at 2002, present optimizing process settings method which was developed and demonstrated for the application in robotic GMAW of sheet metal. The study it include an objective formulation that addressed variation of noise factors. The method and the formulation allow direct maximization of the travel speed of the welding robot. As the formulation was implemented with standard spreadsheet software packages since it was based on ordinary least-square regression so the method required no special software and minimal training. Kackar R.N. 1985, introduces the concepts of off-line quality control and parameter design and discusses the Tguchi method for conducting parameter design experiments. At the product design stage, the objective of parameter design is to identify settings of product characteristics, which make the product's performance less sensitive to the effects of environmental variables, deterioration, and manufacturing variations. Because parameter design reduces performance variation by reducing the influence of the sources of variation rather than by controlling them, off-line quality control reduces cost-effective for impro ing product quality. Ottoy K. N. and Antonsson E. K. 1991, Taguchi's method was extended to involve a more design variables together with more ranges for these variables. The method is also extended to solve design problems with constraints, invoking the methods of constrained optimization. Finally, the Taguchi method uses a factorial method to search the design space, with a confined definition of an optimal solution. The method is compared with others for finding optimal solution. Accordingly, Taguchi method can be used instead of other different searching techniques. Galdmez E.V.C. and Carpinetti L.C.R. 2004, describe the application of the experimental of designs and analysis of variance in the process of manufacture of products for plastic injection modeling. The led experiments brought significant results, the adjustment considered, only two factors, injection pressure and temperature of the machine, the researchers presented a significant effect on the quality characteristic considered. Coit D. W. Jackson B. T. and Smith A. E. 1998, consider practical aspects of building and validating neural network models of manufacturing processes, and illustrate the recommended approaches with two diverse case studies. When using a neural network to control and optimize a manufacturing process, the integrity and balance of the training and validation data sets dictate the quality of the resultant model. The experimental data was combined with the production data. and neural networks were trained and validated on the combined data set. Su c. and Miao C. 1998, apply neural networks to analyze an experiment with singly censored data (incomplete data). Iwo procedures are developed; the first procedure is quite straightforward and can be easily used to rapidly determine the optimal condition. Hsu C.M.2001 ,proposes a four-phased procedure based on neural networks and principal component analysis to resolve the parameter design problems with multiple responses. The quality characteristics of a product are first evaluated through Taguchis quality loss function a neural model is then trained to map out the functional relationship between control factors and responses' quality loss. The functional relationship is then fed into the principal component analysis procedure to transfer a set of responses into a set of uncorrelated principal components. A feasible combination of control factors can be obtained through the recalling function of a neural model.

Once the variation of tensile strength was chosen as the main performance characteristic (the measure of quality) then the design factors, which will have an influence on it, have to he selected. Since most welding experiments usually involve a significant number of factors, according to the Taguchi method, the number of experiments can be reduced. Using a special orthogonal array only a small set from all the possible ones is selected. The sense of the orthogonal arrays method lies in choosing the level combinations of the design factors for each experiment. A practical definition of experimental design that can be applied to stud of 6 mm diameter arc welding process is presented in this study.

The survey shows this method has some weakness in the required number of experiments where it equals the number of inner array multiplied by the number of outer array that may cause higher number of experiments than that which is needed, The survey also shows that it can make a good relationship between the input parameters and the output with minimum error by using neural network.

Taguchi Approach to Parameter Design

Taguchi method provides a systematic and efficient approach for conducting experimentation to determine near optimum settings of design parameters for performance and cost. The method pushes quality back to the design stage, seeking to design a product/process. which is insensitive to quality problems. The Taguchi method utilizes orthogonal arrays to study a large number of variables with a small number of experiments. It can reduce research and development cost by simultaneously studying a large number of parameters. Using orthogonal arrays the method can significantly reduce the number of experimental configurations. In order to analyze the results. the Taguchi method uses a statistical measure of performance called 'signal-to-noise' ratio, (S/N) After performing the statistical analysis of S/N ratio, an analysis of variance (ANOVA) needs to be employed for estimating error variance and determining the relative importance of various factors. From their relative importance and from the S/N ratio, the optimum condition of factors is chosen. The result at this point is estimated using equation:

$$R=T+\Sigma(A_i-T)$$

Where:

R= predicate mean response at the optimal condition

T= overall mean of all observation in the data

Ai= average value of significant factors at level i

Cause and Effect Diagram

The total variation in the stud arc process may be due to any or a combination of the six sources (machine, measurement, method, material, manpower and environment). For this study of stud arc welding the effect of manpower on variation is limited because the machine is operating in a semiautomatic process, also the experiments have been executed in the laboratory environment. so it includes consider the first four ,the other are ignored. Problem identification is very important for any industrial experiment. One of the most used methods for identifying the problem is brainstorming. Brainstorming is an activity that promotes team participation, encourages creative thinking and generates many ideas in a short period of time. For an investigation into the possible causes of the undesirable variability in stud welding process, a cause-and-effect diagram that lists several suspected causes of this variability, is shown in figure (1). Brainstorming in conjunction with cause and effect analysis (CEA) is used to identify the control factors which are to be considered for the experiment.

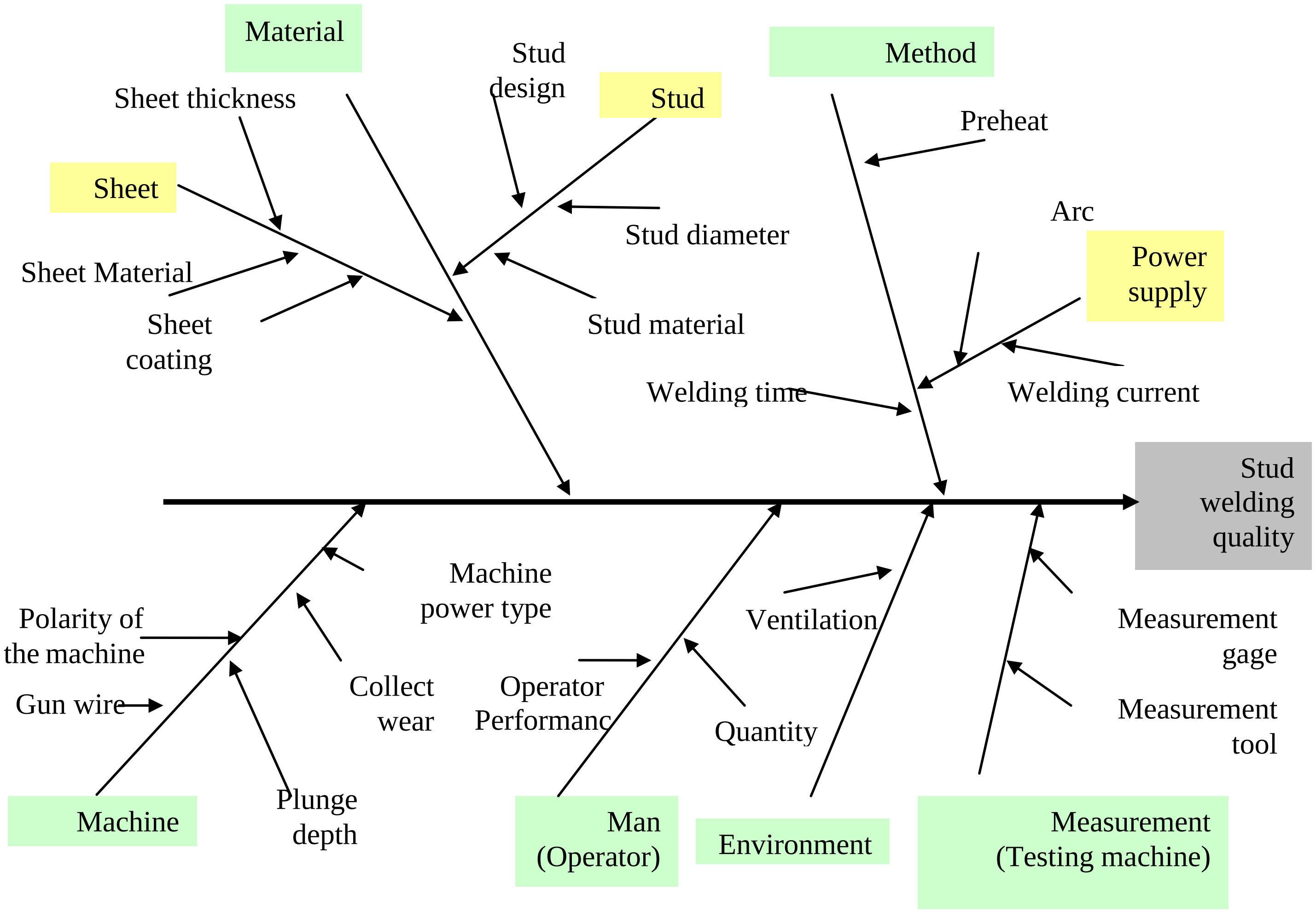

Figure (1) the suggested stud welding cause-and-effect diagram

MATERIALS

The diameter of stud to be studied was (6 mm) that is widely used in the mechanical structure and also require low energy for welding from other stud diameter. For sheet, the first was galvanized (K52355 steel) and the second was non- galvanized (Kl4358steel), with two dimensions thickness gage 16 (1.6002 mm) and gage 12 (3.175 mm). For stud, the first was (54N1CrMoS6 steel) and the second was (4OCrMnMoS8-6 steel).

Method (Identification of Process Parameters)

There are (20) factors identified in this study. Eight independent control factors are considered to improve the stud welding process. These factors are (welding time, sheet thickness, sheet material. welding current, stud design, stud material, preheat sheet and surface cleaning). There other factors were classified as noise factors.

Selection of Factor Levels and Range of Factor Setting

Once independent factors are decided, then the number level for each factor is selected. Selection of levels depends on how the outcome (tensile strength) is affected by different level settings.

Determining the number levels of selected factors from brainstorming is another major concern to many researchers in industries. Brainstorming session it was suggested that suitable to use eight factors on of them in multi-level. Seven of the eight control factors have two levels, and one has eight levels that is welding time.

After determining the number of levels required for each factor, it is needed to specify the range of operation for each control factor. It is usually best to experiment with the largest range feasible, so that the variation inherent in the process does not mask the factor effects on the response. The levels for welding time is shown in table (1), and the list of seven control factors and their level are shown in table (2).

Table (1) Levels of Welding Time Control Factor and for the Experiments

Factor	Factor label	Unit	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Welding time (second)	A	second	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5

Table (2) Control Factors and Levels for the Experiments

Factors	Factor labels	Unit	Level1	Level 2
Sheet thickness	B	mm	1.6	3.175
Sheet material	C	None	K52355	K14358
Welding current	D	Ampere	350	540
Stud design	E	None	Small stud	Flange stud
Stud material	F	None	54NiCrMoS6	40CrMnMoS8-6
Preheating	G	None	Preheating	No preheating
Surface cleaning	H	None	Oil sheet	Clean sheet

Measurement (Tensile Testing Technique)

The response measurement should be well defined. This includes choosing the measurement and processing equipment to be used, how to measure, where to measure and where to document the data. The stud welding specimen is not the standard specimen tensile test dimension because one side is screw and the other is sheet, so the tensile testing was made by developing a special fixture for testing operation, special fixture is shown in figure (2):

Figure (2) the special fixture for the stud welding

Design of Experiments

Normally, in the case of eight factors one of them in eight levels and other in two levels are 8 = 125 experiments should be conducted. In accordance with the Taguchi's method the standard orthogonal array L16, with only 16 experiments (Table 3) could be used.

Table (3) code design matrix orthogonal array $L_{16}\, 2^7 8^1$.

run	welding time	sheet thickness	sheet material	welding current	stud design	stud material	preheat	surface cleaning
1	1	1	1	1	1	1	1	1
2	1	2	2	2	2	2	2	2
3	2	1	1	1	1	2	2	2
4	2	2	2	2	2	1	1	1
5	3	1	1	2	2	1	1	2
6	3	2	2	1	1	2	2	1
7	4	1	1	2	2	2	2	1
8	4	2	2	1	1	1	1	2
9	5	1	2	1	2	1	2	1
10	5	2	1	2	1	2	1	2
11	6	1	2	1	2	2	1	2
12	6	2	1	2	1	1	2	1
13	7	1	2	2	1	1	2	2
14	7	2	1	1	2	2	1	1
15	8	1	2	2	1	2	1	1
16	8	2	1	1	2	1	2	2

Experimental Preparation and Process Run

The experimental preparation involves those activates that occur prior to actual running of the experiment. Poor preparation is the most frequent cause of inconclusive results. Errors in the experimental procedure this step can affect the experimental validity. The experiment of the study was conducted in a laboratory at which air conditioning is similar to outdoor environment. Also all the important material, machine was prepared in similar of an experimental area. In this step. the main task was to construct the uncoded design matrix for the experiment. The uncoded design matrix is shown table (4).

Table (4) uncoded design matrix array $L_{16}2^7 8^1$

Run	welding time (second)	sheet thickness (mm)	sheet material	welding current (Ampere)	stud design	stud material	preheat	surface cleaning
1	0.15	1.6	K14358	350	Small	54NiCrMoS6	Preheat	Clean sheet
2	0.15	3.175	K52355	540	Large	40CrMnMoS8-6	No preh.	Oil sheet
3	0.2	1.6	K14358	350	Small	40CrMnMoS8-6	No preh.	Oil sheet
4	0.2	3.175	K52355	540	Large	54NiCrMoS6	Preheat	Clean sheet
5	0.25	1.6	K14358	540	Large	54NiCrMoS6	Preheat	Oil sheet
6	0.25	3.175	K52355	350	Small	40CrMnMoS8-6	No preh.	Clean sheet
7	0.3	1.6	K14358	540	Large	40CrMnMoS8-6	No preh.	Clean sheet
8	0.3	3.175	K52355	350	Small	54NiCrMoS6	Preheat	Oil sheet
9	0.35	1.6	K52355	350	Large	54NiCrMoS6	No preh.	Clean sheet
10	0.35	3.175	K14358	540	Small	40CrMnMoS8-6	Preheat	Oil sheet
11	0.4	1.6	K52355	350	Large	40CrMnMoS8-6	Preheat	Oil sheet
12	0.4	3.175	K14358	540	Small	54NiCrMoS6	No preh.	Clean sheet
13	0.45	1.6	K52355	540	Small	54NiCrMoS6	No preh.	Oil sheet
14	0.45	3.175	K14358	350	Large	40CrMnMoS8-6	Preheat	Clean sheet
15	0.5	1.6	K52355	540	Small	40CrMnMoS8-6	Preheat	Clean sheet
16	0.5	3.175	K14358	350	Large	54NiCrMoS6	No preh.	Oil sheet

The outer array of (12) noise factors with three combinations will be L16, so the total number of runs to be conducted in this case would be l6 × 12 × 2 = 384 experiments as minimum. Performing of many unimportant experiments is costly and time consuming; the operating characteristic (OC) curve was used to develop the sample size. The experiment tensile outputs are shown in table (5)

Table (5) tensile strength runs

Run	actual run order	Tensile strength (N/mm²)						Mean N/mm²	Standard deviation N/mm²
1	5	175.73	213.23	143.66	195.09	210.50	155.60	182.302	28.860
2	9	288.70	251.20	330.40	284.99	225.90	300.70	280.315	36.946
3	13	284.39	198.56	225.89	245.87	276.24	263.54	249.082	32.539
4	3	359.99	420.50	428.42	300.03	387.38	367.54	377.310	46.790
5	12	190.70	245.87	235.90	298.46	164.33	289.46	237.453	52.977
6	11	370.45	392.68	191.74	360.38	288.70	383.26	331.202	77.637
7	8	321.60	139.00	349.05	310.00	362.93	457.50	323.375	104.318
8	1	331.96	326.32	331.15	401.60	387.26	314.78	348.828	36.095
9	4	388.10	233.60	372.20	287.95	225.43	278.00	297.547	68.611
10	2	530.00	460.72	549.85	375.12	410.53	375.89	450.352	76.343
11	15	305.40	383.20	456.00	378.00	478.00	375.00	395.933	62.388
12	7	152.09	160.74	170.76	166.80	250.88	132.45	172.287	40.835
13	16	219.19	152.97	250.85	257.16	266.78	198.75	224.283	43.258
14	10	155.65	180.45	289.40	220.68	225.35	248.78	220.052	47.705
15	14	289.36	215.62	318.43	256.84	288.23	145.63	252.352	62.900
16	6	185.32	178.45	223.21	155.82	298.33	188.43	204.927	50.651

Analysis of variance

Equations for conducting the variance are presented in this section. Sum of squares (Si) of factor i at level k was calculated according to the equation:

$$S_i = \sum_{K}^{L} \frac{\left(\sum_{J}^{N} Y_j\right)^2}{N_K} - \frac{\left(\sum_{J}^{N} Y_J\right)^2}{N}$$

Where, N is the total number of experiments. N_k the number experiments of each level and Y_j the mean response.

The total sum of squares (S_T) was calculated using equation:

$$S_T = \sum_{J}^{N} Y_J^2 - \frac{\left(\sum_{J}^{N} Y_J\right)^2}{N}$$

Experimental error (Se) was calculated:

$$S_e = S_T - \sum S_i$$

Mean square of factor i (Vi) vas computed using the following equation:

$$V_i = S_i / f_i$$

Where, f i is degree of freedom, which is one less than the number of levels. The total degree of freedom of the result (fT) is one less than the total number of experiments. The degree of freedom for error variance (fe) is the total degree of freedom minus sum of degree of freedom of factors. The next step was the calculation of the variance ratio (Fi), which is the quotient of mean square of factor and error. The fraction of importance of each factor (in percents) was calculated according to the equation:

$$F_a = v_a / v_e$$

The variance ratio, commonly called F statistic (named after Sir Ronal A. Fisher). is the ratio of variance due to the effect of a factor and variance due to the error term. This ratio is used to measure the significance of the factors included in the error term. The F value obtained in the analysis of variance is compared with a value from standard F tables for a given statistical level of significance. Confidence interval, C.I., of the factor effect and estimated value of the result at the optimum condition was computed using the following equation:

$$\text{C.I. of } m = \hat{m} \pm \sqrt{\frac{F(\alpha, 1, f_2) \times v_e}{N_e}}$$

F (α, 1, f_2) = table value of F, α significant level with 1 degree of freedom for the numerator and f_2 degrees of freedom for the error term.

v_e = error variance = MSE , N_e = is effective number of replications ,Where each factor can be calculate from:

$$a = \left(\frac{s_a}{s_t}\right) \times 100 \text{ , } e = \left(\frac{s_e}{s_t}\right) \times 100$$

Results and Discussion

After creating a Taguchi orthogonal array, the selected experiments were performed. A statistic analysis summary of the tensile strength, called S/N ratio, is employed to find the optimum level of the selected factors. The average s/n ratio of each run is shown in (Table 6).

$$S/N_{LTB} = -10 \log \left(\frac{\sum \frac{1}{y_i^2}}{n} \right)$$

Table (6) The SNR values for experimental trials

Trial no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S/N (dB)	44.9	48.7	47.7	51.3	46.9	49.4	48.1	50.7	48.9	52.7	51.6	44.2	46.5	46.3	47.0	45.7

After obtaining the SNR values, the next step was to obtain the average response values of SNR at low and high levels of each factor and hence the effect of each factor on the SNR. The results are shown in table (7) and table (8).

Table (7) Average SNR Table for factor A

Factor A	Average SNR at level 1	Average SNR at level 2	Average SNR at level 3	Average SNR at level 4	Average SNR at level 5	Average SNR at level 6	Average SNR at level 7	Average SNR at level 8	Effect of the factor	rank
Factor Effect dB	46.83	49.53	48.19	49.43	50.84	47.96	46.41	46.38	4.52	1

Table (8) Average SNR Table for other factor

Factors	**Average SNR at level 1** dB	**Average SNR at level 2** dB	**Effect of the factor** dB	**rank**
B	47.73	48.69	0.96	6
C	47.10	49.31	2.21	2
D	48.18	48.23	0.05	8
E	48.23	48.46	0.23	7
F	47.41	49.00	1.69	3
G	48.98	47.43	-1.65	4
H	47.55	48.86	1.31	5

Tables (7) and (8) show that factors A and C have a dominant effect on the SNR, followed by factors F, G, H, B, F, and D. The main effects plot for the SNR is shown in figure (3).

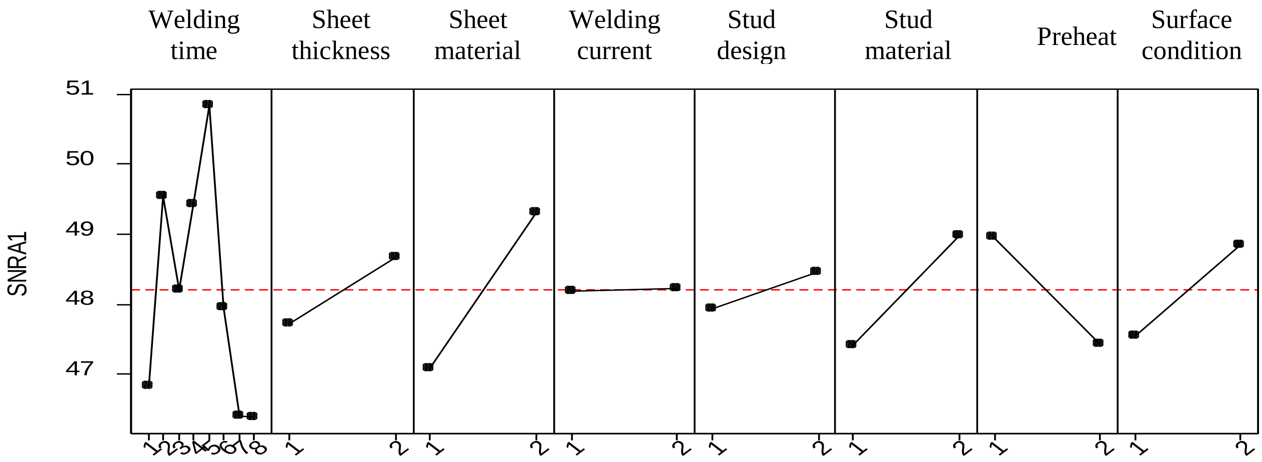

Figure (3) the main effects plot for S/N ratio

The relative magnitude of the effect of different factors can be obtained by decomposition of variance, called ANOVA (Table 9). The Sum of Squares column in Table (9) was calculated using equations (2), (3) and (4), the Mean Square column with equation (5) and the F-ratio column as calculated with equation (6). The ANOVA table has shown that the most dominant factor effects arc D (welding current), E (stud design) and A (welding time). The optimal conditions setting of factors. which will maximize the SNR is (i.e. the best control factor settings) depend on the SNR arc AS, 132. C2, D2, E2, F2, G1 and H2.The calculations of Analysis of Variance for the factors by using Matlab software are:

Table (9) ANOVA for the SNR

Source of variation	Sum of Squares	df	Mean Square	F-ratio
A	37.384	7	5.341	0.88
B	3.529	1	3.529	0.58
C	19.769	1	19.769	3.26
D	0.004	1	0.004	0.00
E	1.129	1	1.129	0.19
F	9.899	1	9.899	1.63
G	9.402	1	9.402	1.55
H	6.679	1	6.679	1.10
error	6.070	1	6.070	1
Total	93.865	15	6.257	

Stage (2): Performing the SNR analysis and (*S.D.*) analysis, then the next step was to identify the factor effects that have significant impact on the mean response. The average response values at each level of the factor A and the effects are present in table (10), and the average response values at low and high level for the other factors and their effects are present in table (11).

Table (10) the average response of welding time control factor

Factor A	Average mean at level 1	Average mean at level 2	Average mean at level 3	Average mean at level 4	Average mean at level 5	Average mean at level 6	Average mean at level 7	Average mean at level 8	Effect of the factor	rank
Factor Effect N/mm^2	231.3	313.1	284.3	336.1	382.3	284.1	222.1	228.6	160.6	1

Table (11) the average response values at each level of the factors and their effects

Factors	**Mean response at level 1** N/mm^2	**Mean response at level 2** N/mm^2	**Effect** N/mm^2	**rank**
B	270.29	298.16	29.96	6
C	257.07	313.47	56.4	3
D	278.73	291.81	13.08	8
E	278.43	292.11	13.68	7
F	255.61	314.93	59.32	2
G	310.17	260.37	-49.8	4
H	269.55	300.99	31.44	5

The main effects plot factor effects are illustrate in Figure (4).

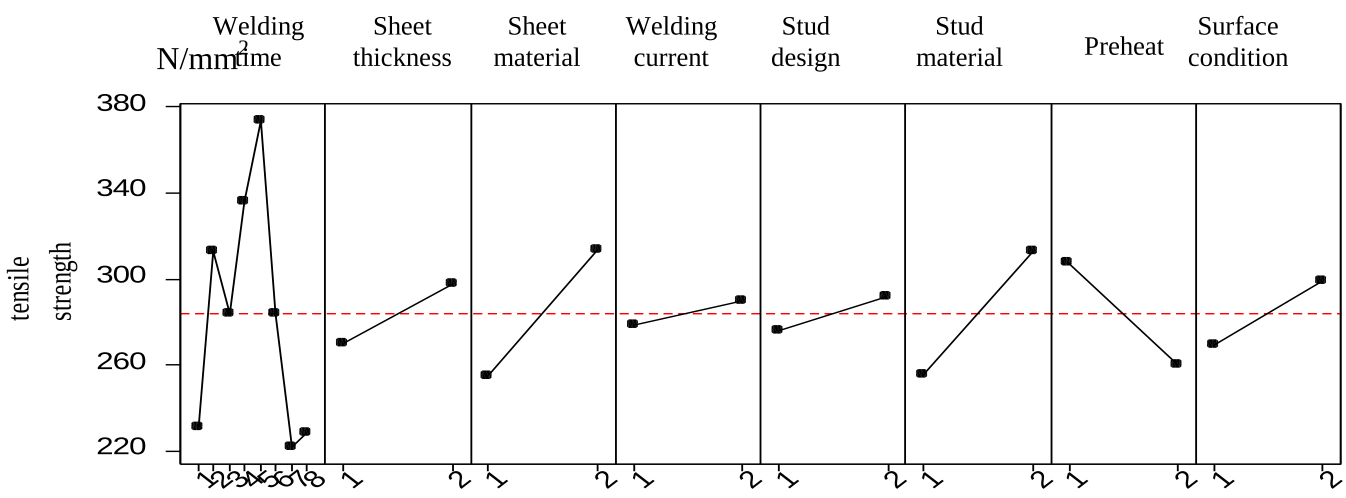

Figure (4) main effects plot for the mean response

Figure (4) shows factors A, C, E and F have a significant impact on the mean response (i.e. mean tensile strength). This will be followed by factors B, H, D and E.

The variance ratio (F-value statistic) represents the ratio of variance due to the effect of a factor and variance due to the error term. This ratio is used to measure the significance of factors included in the error term [17, 18]. The F value obtained in the analysis of variance is compared with a value from standard F tables, to decide significance of statistical level. It can be seen from table (12) that factor A (welding time) has a large affect on the mean of stud welding tensile strength (43.37° of fraction of importance). Value of factor C (sheet material) and F (stud material) are (13.84%). (13.53%) respectively.

Table (12) ANOVA for the response

Source of variation	Sum of Squares	df	Mean Square	F-ratio	Percent contribution (ρ)
A	42304.33	7	6043.48	42.35	43.37
B	3089.23	1	3089.23	21.6	3.17
C	13493.92	1	13493.92	95.14	13.84
D	519.19	1	519.19	3.35	0.53
E	1005.63	1	1005.63	63.25	1.04
F	13203.33	1	13203.33	91.04	13.53
G	8817.68	1	8817.68	63.25	9.05
H	3271.65	1	3271.65	23.94	3.35
error	11829.65	81	143.84	1	12.12
total	97534.58	95	1119.02	-	100

Added the factors B,D,E,G and H can be pooled. A new table without the above factors was constructed (table13)

Table (13) the pooled ANOVA for response

Source of variation	Sum of Squares	df	Mean Square	Variance ratio (F-ratio)	Percent contribution (ρ)
A	42644	7	6092	14.2	40.36
C	13686	1	13686	31.91	13.5
F	13095	1	13095	30.53	12.89
error	28779	86	428.86	1	33.25
total	98204	95	1033.72		100

The sum of squares of pooled factors was added to the error term, and then new mean square of the error term was calculated using equation:

$$V_e = \frac{\sum_i s_i^p + s_e}{\sum_i f_i^p + f_e} ,$$ Where superscript *p* indicates the pooled factors.

Since the degree of freedom of the factor A is 7 and for error term is 86, so, F7 = 2.11 at level of significance (950 o confidence), see (F-table)(Fisher -table).

As the computed value of variance ratio (14.2), (table 13), is bigger than the value from (F table), so there is in 95% of confidence this factor A (welding time) has an effect on stud welding process. For (C and F) factors, the degree of freedom is 1 so the F1, 3.97, since computed F-ratio are 31.91 and 30.53 respectively for each (table 13) which is higher than from F-table, then the above two factors also have an effect in the stud welding process, as well as for A.

After identifying the significant factor effects, the next step was to determine the optimal setting for these factors which will bring the mean response as close as possible to the target. He optimum condition (i.e. the best control factor settings) based on the mean response figure (4) was:

A_5, B_2, C_2, D_2, E_2, F_2, G_1 and H_2.

Here the factors B, C, F and H are the same with the last setting (see stage one). While for factor A this is difference, when we choose A5 or A6, if choose A5 (the welding time is0.35 second), then the tensile strength and standard division will be (382.341N/mm2 and 72.47 N/mm2) respectively, while when choose A6 (the welding time is 0.4 second), the tensile strength and standard division will he (284.110 N/mm2 and 51.61N/mm2). So, in this study an estimated of factor A (A6=0.38 second) is considered. For factor D, the mean and standard deviation of this factor, in level D1, is (278.73 N/mm2, 50.56 N/mm2) respectively, while them, in level D2, are (292.11 N/mm2, 58.04 N/mm2) respectively, so D1 would be considered. The same thing for factor E1. For factor G, the mean and standard division of this factor, in level G . are (310.17 N/ni2, 51.75 N/mm2) respectively, while them, in level C , are (260.37 N/mm2, 56.84 N/mm2) respectively, so C I would be considered. The factors levels are:

$\mathring{A}_6$, B_2, C_2, D_1, E_1, F_2, G_1 and H_2.

In order to reach the optimal factor settings, the factor setting that yields minimum quality loss can he study. The quality loss function for larger the better is:

$$L(y) = A_o \Delta_o^2 \frac{1}{y^2}$$

The summarized calculation is shown in table (14).

Table (14) loss function calculation

Run	(yˆ)²	L(y)/*K* (money unit/piece)
1	**299094.4**	**3.3×10^{-6}**
2	202216.8	4.9×10^{-6}
3	230924.9	4.33×10^{-6}
4	125509.6	7.97×10^{-6}
5	243914.1	4.1×10^{-6}
6	163858.9	6.1×10^{-6}
7	174992.3	5.71×10^{-6}
8	145438.5	6.89×10^{-6}
9	190410.7	5.25×10^{-6}
10	83183.4	1.2×10^{-5}
11	160655.2	6.22×10^{-6}
12	290938.1	3.43×10^{-6}
13	256371.3	3.9×10^{-6}
14	260776.3	3.83×10^{-6}
15	230653.3	4.33×10^{-6}
16	276680.6	3.61×10^{-6}

From table (14), run (1) which represented in bold yield the rnininmm loss. Settings based on the loss-function analysis was therefore obtained as:

A_1, F_1, C_1, G_1 and H_1

For factor A, level 1 will yield a veiy low tensile strength (182.302N/mm2), so this level is not taken. ibr the three factors F, C and G the level is the same, for factor H in level 1 the tensile strength is (269.55N/rnrn2), while in level 2 it is (300.99N/mm2) the reduction is also high, so the final optimum stetting is:

$\mathring{A}_6$, B_2, C_2, D_1, E_1, F_2, G_1 and H_2.

Predicted Mean Response at the Optimal Condition

The predicted mean response at the optimal condition is estimated only from the significant main effects. The main factor effects, which has a significant impact on the mean response were A. F. C, C and H. The predicted mean response based on the optimal factor levels of A, F, C, C and II is given by:

R= T+ (Å 6-T) + (C2-T) + (F2-T) + (G1-T) + (H1-T)

Where

R= predicted mean response at the optimal condition

T = overall mean of all observation in the data

R=284.225+(310.5-284.225)+(313.47-284.225)+(314.93-284.225) +(310.17-284.225)+(300.99-284.225)

R=413.185 N/mm^2

Interpretation, Experimental Conclusions and Confidence Interval for the Predicted Mean Response

After interpreted the results of the analysis, it is advisable to ensure that the experimental conclusions are supported by the data. The confidence interval is the variation of the estimated result at the optimum condition.

MSE = error variance =143.84 N/mm^2

$F_{1, 96}$ = 3.96

$$N_e = \frac{96}{7+1+1+1+1+1} = 8$$

Therefore, the 99 per cent confidence interval for the mean tensile strength is given by:

$$99\,percentCI = 413.185 \pm \sqrt{\frac{3.96\times143.84}{8}}$$

=413.185 ±8.43 N/mm^2

The result at the optimal condition is 413.185±8.43 N/mm2 at the 99 percent confidence level. After determination the confidence level for the predicate mean response, makes a confirmation experiment or run. The confirmation experiment/run is used to verify whether the predicated mean response based on the optimal combination of factor levels give process response within the confidence limits or not. If conclusive results are obtained from the confirmation run, a specific action on the process may be taken for improvement.

Confirmation Run

A confirmatory run/experiment (or follow-up experiment) is necessary in order to verify the results from the statistical analysis. This is to demonstrate that the factors and levels chosen for the influential factors do provide the desired results. The insignificant factors should be set at their economic level during the confirmation run/experiment. If conclusive results have been obtained, improvement action on the product or process under investigation is recommended. On the other hand, if the result does not turn out as expected, further investigation may be required.

In industrial experiments, once the solution has been implemented, it is recommended to monitor the process by constructing control charts on the experiment's response variable (s) and critical factors that influence the response. Control charting will ensure that the problem does not reoccur [133]. For the study, the sample taken contains ten pieces were produced under the optimal condition that is in table (15):

Table (15): the optimum stud welding condition based on Taguchi methodology optimization

factor	level
$\hat{A}_6$: welding time	0.38 second
B_2 :sheet thickness	3.175 mm
C_2 :sheet material	non- galvanized (K14358steel)
D_1: welding current	350 Ampere
E_1: stud design	Small stud
F_2: stud material	40CrMnMoS8-6 steel
G_1	Preheating
H_2: Surface cleaning	Clean sheet

The results are shown in table (16):

Table (16) the sample tensile strength based on Taguchi methodology optimization

Sample	Tensile strength N/mm^2
1	443.52
2	421.32
3	410.63
4	390.48
5	472.40
6	422.67
7	398.93
8	431.88
9	408.33
10	524.55

The mean tensile strength from the confirmation run was 432.47 N/mm2 the standard division is 39.950 N/mm2 and the range is 134.07 N/mm2.

The effect of every factor of the study can be summarized as:

Welding Time

This factor strongly effects on tensile strength measure. the mean value of tensile strength in levels (0.15 ,0.2 ,0.25 ,0.3 ,0.35 ,0.4 ,0.45 ,0.5) second is (231.3 ,313.196 ,284.32 ,336.l ,373.95, 284.11 , 222.16 . 228.64) N/mm2 respectively. The effect of factor on the mean is (42.3 9perccnt) which shows 110W much the variation of stud welding tensile strength from one level of welding time to another, The welding time has a relationship with the input energy rate; there is when the welding time increases the average input energy increases that lead to increase in tensile strength until value it decrease due to over energy.

Sheet Material

Macrograph pictures show that the sheet material had two effects. First, galvanizing appeared to result in greater porosity in the joints. The mean of tensile strength in level l(K52355) is 157.07 Nmm2 and in level 2 (K14358) is 313.47 N/mm2. Also, there appeared to be considerably less heat and retained liquid metal in the joints on coated sheet. Second, the non-galvanized sheet (K14358stec1) indicates higher tensile strength, this may be due to the percentage of carbon contain (O.l44°o) is higher than for galvanized (K52355) sheet (0.0689%). The effect of factor on the mean tensile strength is (13.78percent).

Stud Material

This factor also effects in the stud welding process, the different value of tensile strength call he shown from one level to another. The mean tensile strength in level 1(54NiCrMoS6) is 255.61 N/mm2 and in level 2 (4OCrMnMoS8-6) is 314.93 N/mm2.The effect of factor on the mean is (l3.l8percent). The higher value of strength for (4OCrMnM0S8-6) from the strength for (54NiCrM0S6) may be due to the containing of carbon where for the first (0.229%) while for the second (0.139%) , as described previously for sheet material, and also due to other alloy elements for example tile percentage of Mg is (1.07°) ill 4OCrMnMoS8-6 and (0.405%) in 54NiCrMoS6.

Preheating

This factor gives a positive effect on both the increase of the tensile strength and a decrease in the variation of process. The mean tensile strength in level l(preheating) is 310.17 N/mm2 and in level 2 (no- preheating) is 260.37 N/mm2 .The factor effect on the mean is (9.1 percent).

The base metal must he preheated to prevent the formation of cracks. This is similar to the effect on arc welding process for reducing heat effect (heat tear) that reducing the cooling rate for tile welding area and HAL which reducing the hardness of these areas especially when the carbon percentage more than 0,25 that yield hardness phases (without preheating). All oxyfuel gas heating torch is used for heating because only a localized preheated zone is needed; the preheating temperature is between (31 5-3 70) °C.

Stud Design

The design of tile stud influenced the working area of the stud surface. This factor was found to completely dominate the tensile results. Despite of the fact that flange studs are going to have a greater area for welding and subsequently greater strengths, flange stud joints susceptible to porosity compared to smaller studs as micrographic pictures show, this appears to be due to a geometry effect. Tile mean of tensile strength in level l(small stud) is 278.43 N/mm2 and in level 2 (flange stud) is 292.1 IN/mm2 Flange stud actually appeared to increase tensile strength performance and this is showing in many specimens but the variety is more may be due to preparing of flange stud is not at accuracy enough that causes porosity. The effect of this factor on the mean is (9.11 percent).

Surface Cleaning

This factor has little effect on the measured tensile strength compared with tile previous factors; the effect of this factor on the mean is (3.36 percent). The mean of tensile strength in level 1(oil sheet) is 269.55 N/mm2 and in level 2 (clean sheet) is 300.99 N/mm2 .The clean sheet already shows the greatest tensile strength and this is logic, but limited and which may be due to the wielding area is small that lead to little effect.

Sheet Thickness

Increasing sheet thickness has two effects; the first; a thicker sheet is stiffer during mechanical testing and this minimizes the peel characteristic of the tests and increases strength. The second thicker sheet present increase in the area of heat diffusion that lead to high cooling rate which creating inherently stronger welds. The mean of tensile strength in level 1(1.6 mm) is 270.29 N/mitt and in level 2(3.175 mm) is 298.16 N/mm2 The effect of this factor on the mean is (3.0 percent).

Welding Current

This factor has the smallest effect factor where the effect is (0.34percent). The mean of tensile strength in level 1(350 ampere) is 278.73 N/mm2 and in level 2 (540 ampere) is 291.81 N/mm2. I his result is far from the expected result where the welding current play important role in arc welding process. But this happen here may be due to the two levels of welding current that choosing represent the boundaries of welding current, and there no intermediate grade between this two levels in the welding current selector of stud arc machine.

CONCLUSIONS

The study has showed a significant improvement (approximately 30.84 percent) increase in stud joint tensile strength and (approximately 30.06 percent) decrease in stud joint tensile strength variation.

Measures of weld quality in this study included tensile strength testing and some macrograph photos. Statistical techniques used to produce a series of main effect plots for factors and results are analyzed. These robustness plots allowed direct observation of how weld quality measure was affected by each factor of interest. Specific conclusions from this study are as follows:

- Dominant factors in the Performance of Stud Welds - the dominated effective factors of stud welds performance are (welding time), (plate material) and (stud material) study.
- Effect of preheating plate - preheating has positive effects on the increasing of the tensile strength with reducing variability.
- Effect of Stud design - increasing stud area appeared to decrease of measures of tensile strength. This was true where the levels of internal porosity also increased with the larger studs.
- Effect of Plate Thickness - increasing thickness led to increases in mechanical measure (tensile strength) of weld quality. The benefits appeared to come from increased stiffness of the joint as well as increased peel strengths associated with the thicker material.
- Effect of Plate Material - Welding onto galvanized plates appears substantial porosity in the joint, so the non-galvanized plates obtain better tensile strength.
- Effect of Other Factors - weld quality measurements (tensile strength) as well as macrograph sections show the other factors in the study, welding current and the presence of surface cleaning, all had little effect.

REFERENCES

- Jibson J.”Advance Welding”, John Wiley & Sons, 1997.

- Montgomery D.C” Design and Analysis of Experiments” Second Edition John Wiley &Sons, Inc., 2001.

- Montgomery D.C. "The Use of Statistical Process Control and Design of Experiments in Product and Process Improvement" JIB Transactions, Vol.24 No. 5. PP. 4-17, 1992.

- Montgomery D.C “Introduction to Statistical Quality Control” John Wiley & Sons, Inc.1985.

- Allen IT. and et al” Statistical Process Design for Robotic GMA We dipg of Sheet Metal” Welding Journal, PP.69-s_77-s, May 2002.

- Kackar R.N.” Qft4Jng Quality Control, Parameter Decigppnd the Tagnehi ‘VIe/hod”. .1. Qual. Techn. , Vol. 17, No. 4, PP 176-188, 1985.

- Ottoy K. N. and Antonsson E. K.” Extensions to the Taguchi Method of Product ASME Journal of Mechanical Design. January 6, 1991.

- Galdmez E.V.C. and Carpinetti L.C.R. “Application as Design oLpgrimentu7 the Process of Manufhcturing of Plastic Products”, ASME Journal of Manufacturing Science and Engineering, Vol. 122, PP. 360-369, 2004.
- Coit D. W. Jackson B. T. and Smith A. E.” Static Neural IVetwork Process Models: Considerations and Case Studies”. mt j. Prod. Res., Vol. 36. No. 11, 2953- 2967, 1998.

- Su C. and Miao C. “Neural Network_Procedures fbr ExperpgjtilAigil.sisJ/h Censored Data”, International Journal of Quality Science, Vol.3, No.3, PP.239-253. 1998.

- Hsu C.M.” Solving Multi-Response Problems through Neural Networks aJgLj’iI7cipp7 J22gnepd’ApglJis”. Journal of the Chinese Institute of Industrial Engineers, Vol. 18. No. 5, pp. 47-54, 2001.

- Roy R., "Design of Experimental Using the Tagpchi Approach’ Wiley, New York, 2001.

- Montgomery D. C. “Design andAnalsis QjExperiments”. New York. Wiley. 1991.
- Buyske S. and Trout R.” Robust Design and Taguchi Methods” .Journal of Quality Technology, vol. 22, No. 1, PP. 15 22, Jan. 2003.

- Steiner 5.1-1. and MacKay R. J.” Statistical Engineering: an Algorithm far Reducing Variation in Majfpcturing Processes” American Society for Quality ASQ, 2005.

- Taguchi G. and Yokoyama Y.” Taguchi Method’s: Design of Experiments “Quad ity Engineering, Vol.4, Dearbon, MI, 1993.

- Mukhopadhyay S. K. and Chakraborty D. “Optimal Process Variance under Tqggjj Loss” International Journal of Quality & Reliability Management. Vol. 12 No. 9, PP. 14-29, 1995.

- Antony J. and et al “Process Optimization using Taguchi Me1fpfExperimeJ7/ul çin” Work Study, Volume 50, Number 2, PP. 51-57, 2001.

- Lofthouse T. “The Taguchi Loss Function” Work Study, Volume 48, Number 6. PP. 218-222, 1999.