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# Optimization and Predication of Spot TIG Welding Parameters of Stainless Steel Sheets (AISI 304L)

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**ABSTRACT**: This research aims to investigate the effect of TIG spot welding parameters such as welding current , welding time and sheet thickness on the maximum shear force and spot diameter of austenitic stainless steel AISI 304L with thickness of 0.6 mm, 0.8 mm & 1.0 mm .Taguchi method with using L27 orthogonal array was applied to select the optimum welding parameters. Results show that the maximum shear force of spot weld would increase with increasing welding current and welding time to a specific amount, afterwards it would drop at higher current and longer times. MATLAB software had been used to make 27 samples, spot TIG welding parameters were (3) therefore minimum of number for experiments should be not less than 27. The random samples 21 were taken for training the network and 6 random samples for test the network. The relationship between the 21values of spot diameter and max shear force was determined from experiments and those of predicted the ANN (Artificial Neural Network) model was drawn in figures. It was shown from these figures that a good concurrence is observed between the measured and the predicted of spot diameter and max shear force values.

KEYWORDS: spot TIG welding, optimization, stainless steel, mechanical properties.

### I. INTRODUCTION

Welding is the process of joining two pieces of metal by creating a strong metallurgical bond between them by heating or pressure or both. A welded joint is obtained when two clean surfaces are brought into contact with each other and either pressure or heat, or both are applied to obtain a bond [1].

The necessary heat for Gas Tungsten Arc Welding (TIG) or (GTAW) is generated by an electric arc maintained between a non consumable tungsten electrode and the work piece to be welded. The heat affected zone, the molten metal, and the tungsten electrode are all shielded from the atmosphere by a blanket of inert gas fed through the TIG torch. The shielding gas, such as argon and helium do not chemically react with other gases and serves to blanket the weld and exclude the active properties in the surrounding air [2]. The greatest advantages of GTAW welding are concentrated arc, no slag, no spatter and spark, little smoke or fumes, good for welding thin material and it will join more kinds of metals and metal alloys than any other arc welding process. GTAW can be used to weld similar, most steels including stainless steel, nickel alloys, titanium, aluminum, magnesium, copper, brass, bronze and even gold. GTAW can also weld dissimilar metals to one another such as copper to brass and mild steel to stainless steel [3].

The improvement of high efficiency resistance spot welding process systems seems now largely to have phased out the TIG spot welding process although it is still to be found, often using the same hard –wearing original equipment which was sold up to the mid 1960 s [4].

Some researchers investigated the effect of resistance spot welding variables, such as welding current, welding time, electrode pressure and surface conditions of parts to be welded on the shear strength of spot welds of different materials such as wrought aluminum alloys and austenitic stainless steels as follows;



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Rafat Abdul Rahman 2001[5] investigated the influence of TIG spot variables on the mechanical and metallurgical characteristics of dissimilar plates from stainless steel AISI 304L with carbon steel ASME (A516) in different thicknesses. Results show that maximum shear force for the spot weld would increase with increasing the welding current and time to a specific amount, afterwards the shear force would drop at larger currents and longer times. Also it has been noticed that the value of delta- ferrite phase for spot weld would increase with increasing of the thickness of the weld.

Thakur et al. 2010[6] presented an experimental study on optimization of tensile shear force or strength of resistance spot welding(RSW) for galvanized steel by using "Taguchi method" with orthogonal array of L27 in order to determine signal to ratio(S/N) and analysis of variance (ANOVA). The experimental studies were carried out under varying welding current, welding time, electrode force and electrode diameter. The results show that it is possible to increase the tensile shear strength (13.43%) by using the statistical technique and enhance the RSW performance and optimizing the RSW parameters.

Ahmed N.Al-Khazraji et al. 2014[7] studied residual stresses induced from spot welding of stainless steel AISI 316 sheet with 1.5 mm thickness using shot preening process. XRD diffraction method was used to measure the residual stresses created in spot weld and numerical analyses obtained by finite element method (FEM) using ANAYS software version 11 to stimulate the nonlinear transient thermal analysis and residual stresses analysis for spot welds. They showed a good agreement between the experimental and the numerical results due to creating the compressive residual stresses.

Shaymaa A.K. 2015 [8] studied optimization of resistance spot welding (RSW) parameters of stainless steel (AISI 304L) sheets with 0.8 mm thickness which were welded under various welding parameters such as welding current ,welding time and electrode force and their effect on the mechanical properties and failure modes. These parameters were optimized using Taguchi L9 orthogonal array design of experiment (DOE). They showed that the increase in the welding current and welding time causes rapid increase in the shear force of joint up to the expulsion point.

In this research using "Taguchi's method " of design of experiments a mathematical model was developed using spot TIG parameters such as, welding current, welding time and sheet thickness of stainless steel AISI 304L. After experimental data were collected, signal-to-noise ratios (S/N) were calculated and used in order to obtain the optimum levels for every input parameter.

#### II. EXPERIMENTAL WORK

#### A. THE MATERIALS USED:

In this study stainless steel (AISI 304L) sheets in different thickness (0.6, 0.8 and 1.0 mm) were used for their wide industrial applications such as the process of lining the storage tanks and the pressure vessels and others. The chemical compositions of these sheets were analyzed by using ARL spectrometer as indicated in Table (1). Tensile test was performed to find the mechanical properties of stainless steel sheets according to "ASTM standard E8M -09 "for sub size specimen as shown in Table (2).

#### **B.** SAMPLES PREPARATION:

For spot TIG welding, stainless steel AISI 304L sheets were cut into strips of dimensions of 175 mm x 25 mm. Figure (1) shows the design and dimensions of overlap work pieces to be spot welded according to standard specification of the IIW[ 9]as follows:

L= 175 mm, W= 25 mm, t= various (0.6, 0.8, 1.0 mm)

#### C. TIG SPOT WELDING PROCESS:

The basic equipment for TIG welding comprises a power source, a welding torch, a supply of an inert shield gas, a supply of filler wire and perhaps a water cooling system. For welding most materials the TIG process conventionally uses direct current with the electrode connected to the negative pole of the power source, DCEN (direct current electrode negative) (straight polarity) [2].



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In this study, TIG spot welding was carried out using welding machine type (Messer Griesheim Multiwig G350-1) and without filler rod. A single spot for each specimen was performed with using DCEN under constant conditions as follows: arc length was 1.6 mm, argon flow rate was 6L/min, and tungsten electrode diameter was 3.25 mm of type EWth2 according to AWS.

A set of welding specimens was made by variation of welding parameters as follows: welding current, welding time, sheet thickness to obtain different weld joint properties. Twenty seven sets of specimens were made in order to optimize the spot welding parameters ,each set consists three specimens for each current, time, and thickness therefore average of three specimens are taken.

#### D. TENSILE SHEAR TEST:

Tensile shear test was carried out on a TIG spot welded specimen with 175 mm length, 25mm width and 25mm overlap distance to find the tensile shear force or strength. Overlap welded specimens were tested on an Instron machine ,TGM –France machine Model (03M3818.1) at a constant crosshead speed of 5 mm/min with maximum load 100 KN. Stainless steel sheets were gripped with using shims of thickness equal to that of the specimens . The maximum shear force is recorded at fracture point during the test for each TIG spot welded specimen.

### III. RESULTS AND DISCUSSION

#### A. ARTIFICIAL NEURAL NETWORK MODELING:-

In maximizing spot diameter & MAX shear force, a mathematical model that expresses spot diameter & MAX shear force in terms of parameters is needed. The mathematical model in this study was established utilizing ANN. ANN is a multilayered architecture made up of one or more hidden layers placed between the input and output layers. Layers include several processing units known as neurons. They are connected with variable weights to be determined. In the network, each neuron receives total input from all of the neuron in the previous layer as [10]:

$$net_j = \sum_{j=0}^{N} w_{ij} x_i \qquad \dots \dots \dots (1)$$

Where  $net_j$  is the total or net input and N is the number of inputs to the jth neuron in the hidden layer.  $w_{ij}$  is the weight of the connection from the ith neuron in the forward layer to the jth neuron in the hidden layer and  $x_i$  is the input from the ith neuron in the preceding layer. A neuron in the network produces its output (out<sub>j</sub>) by processing the net input through an activation (transfer) function f, such as tangent hyperbolic function chosen in this study as below [11]:

$$out_j = f(net_j) = \frac{1 - e^{-net_j}}{1 + e^{-net_j}}$$
 ......(2)

In this study, the Bayesian regularization back-propagation based on Levenberg –Marquardt algorithm was selected for training of the NN. It minimizes a combination of squared errors and then determines the correct combination to produce a well-generalized network. Optimal neural network architecture was designed by MATLAB Neural Network Toolbox. One hidden layer with three inputs and one output were used to model the process, as shown in Figure (2). The three most important input parameters are thickness, time, current and the output parameter is average spot diameter & MAX shear force. The distribution of experimental data consists of 27 groups was done so that the training subset includes 21groups or 75% of the data and the testing subset includes 6 groups or 25% of the data. The sequential mode of training was used for the training of the network. In order to find the suitable architecture of the network, different architectures have been studied. The model with 3-5-1 architecture was found to be the most suitable for the task.

In order to measure the accuracy of the prediction model, percentage error  $\phi_i$  and average percentage error  $\overline{\phi}$  were used and defined as [12]:



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 $\phi_i = \frac{|R_{aie} - R_{aip}|}{R_{aie}} \times 100\% \qquad \dots \dots (3)$ 

Where

$$\overline{\phi} = \frac{\sum_{i=1}^{m} \phi_i}{m} \qquad \dots \dots (4)$$

Where  $\overline{\phi}$  = average percentage error. m = number of experiments.

#### B. COMPARISON OF THE RESULTS:

A measured and predicted result is compared in order to validate the ANN model.

Figures (3 to 6) show the variation of 27 values of spot diameter & MAX shear force with the number of experiments. The 21 values of spot diameter & MAX shear force were utilized to train the ANN model, while the remaining data (six spot diameter & MAX shear force values) were employed to test the trained ANN in 'MATLAB' Toolbox. The relationship between the 21 values of spot diameter & MAX shear force measured from experiments and those of predicted the ANN model is plotted in Figures (3 and 5) for spot diameter & MAX shear force respectively. It is seen from these figures that the measured spot diameter & MAX shear force values match very close to the predicted spot diameter & MAX shear force values.

The relationship between the 6 values of spot diameter & MAX shear force from experiments and those of predicted the ANN model is plotted in Figures (4 and 6) for spot diameter & MAX shear force respectively. It was seen from these figures that a good agreement is observed between the measured and the predicted of spot diameter & MAX shear force values.

Tables (3 and 4) indicate the results obtained from the testing of the trained ANN model compared with experimental measurements results. The data set consisting of six spot diameter & MAX shear force values which were randomly selected from 27 experiments, and they were not used for training of ANN. it is seen from these tables that ANN prediction presents a good agreement with the experimental measurements.

Tables (5 and 6) presents the test data for spot diameter & MAX shear force. It can be observed from this table that the average prediction error for data set is found to be 1.44%, i.e., the accuracy is 98.56% and the MSE is 0.001746415 consecutively.

#### C. REGRESSION GRAPHS FOR ANN MODEL:

Regression graph shows the relationship between the targets and the outputs of the network. Figures (7 and 8) show the regression graphs of validation data, learning data, test data and all data. In these graphs the dotted line shows Y (output) = T (target) like the optimal condition. While the dots show the actual output for particular sample and the solid line represents the best fit linear regression line between outputs and targets .This solid line should be as close as the dotted line.

Figures (7 and 8) represent Regression coefficients model based on the data which is (1) for training set, (0.997) for validation set, (1) for test set and (0.99958) for all data sets which show that the learning of the network is proper and this application can be used to predict the spot diameter & MAX shear force.

This figure show that the Regression coefficient for training set is to be 1; this indicates that there is an exact linear relationship between targets and outputs.

#### D. ANALYSIS OF VARIANCE:

The experimental results are analyzed by using analysis of variance (ANOVA) to determine the effect of parameters on the spot diameter & MAX shear force, spot diameter & MAX shear force as the dependent variable and thickness,



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time and current as independent variables. The results of the ANOVA with spot diameter & MAX shear force are shown in Tables (3 and 5). This analysis was carried out for significance level of  $\alpha = 0.05$ , i.e. for a confidence level of 95%.

The *F* ratio value of 175 & 30 for the thickness of process is greater among the parameters (see Tables (7 and 8).Therefore, the most influential parameter is the thickness (38% & 46%) is almost larger of the time and current for spot diameter & MAX shear force respectively.

#### E. OPTIMAL DESIGN CONDITIONS:

The main effects plots are used to determine the optimal design conditions to obtain the optimum spot diameter & MAX shear force and hence selecting the better region by using SPSS program.

Figures (9 and 10) show the main effect plot for spot diameter & MAX shear force. These plots show the variation of individual response with three parameters, like thickness, time and current separately.

The results show the optimal conditions for spot diameter & MAX shear force are: thickness (1mm) time at level-3(6 sec) and current at level-3(175 Amp). The percentage distributions calculated are given in Figures (11 and 12). The most influential effects within the range of specified cutting conditions are thickness for spot diameter & MAX shear force

#### F. EFFECT OF TIME AND CURRENT ON THE SPOT DIAMETER:

Figures (13 to 15) show the change of spot diameter for different welding conditions (thickness, time and current) and the effect of process on it. Increasing the current increases the spot diameter. From these figures the experimental result shows that the change of welding current at different times gives the same relationship.

The first case, when the thickness = 0.6 (mm), the results give the best spot diameter near the current = 175 (Amp) for the three times .Then decreasing the welding current leads to deteriorate the spot diameter.

In the second case, when the thickness = 0.8 (mm) (large than the first case), the results show that when the current increases to 175 (Amp) the spot diameter increases, increasing the time to 6 (sec) and more gives better spot diameter for three time. In the third case, when the thickness = 1 (mm), the results give the large spot diameter for the three time. Increasing current leads to better spot diameter while decreasing thickness deteriorates the spot diameter.

### G. EFFECT OF TIME AND CURRENT ON THE MAX SHEAR FORCE:

Figures (16 to 18) show the change of Max shear force for different cutting conditions (thickness, time and current) and the effect of process on it. Increasing the current improves the Max shear force. From these figures the experimental result shows that the change of current at different time gives the same relationship.

The first case, when the thickness = 0.6 (mm), the results give the best Max shear force near the current =175 (Amp) for the three time .Then decreasing the current leads to deteriorate the Max shear force.

In the second case, when the thickness = 0.8 (mm) (large than the first case), the results show that when the current increases to 175 (Amp) the Max shear force increases, increasing the time to 6 (sec) and more gives better Max shear force for three time.

In the third case, when the thickness = 1 (mm), the results give the large Max shear force for the three time. Increasing current leads to better Max shear force while decreasing thickness deteriorates the Max shear force.

#### IV. CONCLUSION

1-TIG spot welding was carried out successfully to join stainless steel sheets of different thicknesses and gave good spot joints

2-The optimum welding conditions for spot diameter & MAX shear force are: thickness (1mm) time at (6 sec) and current at (175 Amp).

3-Increasing welding current and time lead to increase in tensile shear force until expulsion of metal limit

4- Weld or nugget diameter increases with increasing in the welding current, time and thickness.

5- The effect of sheet thickness parameter has the major effect on maximum shear force of TIG spot weld.

6-The ANNs models of structure 3-5-1 were found to be the best neural networks that can predict the MAX shear force and spot diameter with 99.8% and 99.77% accuracy respectively.



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7- From ANOVA results it was shown the sheet thickness was the most important parameter in TIG spot welding affecting on the MAX shear force and spot diameter by 46.18% and 38.71% respectively.

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Material type	Element wt%									
	С	Mn	Si	Р	S	Cr	Ni	Mo	Cu	Al
1 mm Stainless steel	0.03	1.48	0.58	0.025	0.01	18.33	8.33	0.2	0.19	0.01
0.8 mm Stainless steel	0.028	1.77	0.52	0.016	0.01	18.0	8.65	0.11	0.13	0.0
0.6 mm Stainless steel	0.03	1.17	0.68	0.017	0.016	18.45	8.77	0.12	0.12	0.0

Table (1): Chemical composition of stainless steel AISI 304L sheets

Mechanical Properties	Material type							
	1 mm Stainless steel	0.8 mm Stainless steel	0.6 mm Stainless					
Tensile strength (N/mm <sup>2</sup> )	558.9	550.6	563.2					
Yield strength (N/mm <sup>2</sup> )	269.1	255.4	267.6					
Elongation % (50.8)	55	52	49					

85

Table (2): The mechanical properties of stainless steel sheets

### Table (3): Tensile shear force values and spot diameter for all welded specimens

No.	Thickness	Time	Current	Measured		
	( <b>mm</b> )	(sec)	(Amp)	Spot diameter, mm	MAX shear force,N	
1	0.6	2	125	5.2	4700	
2	0.6	2	150	6.1	5200	
3	0.6	2	175	7.1	5900	
4	0.6	4	125	6.1	5200	
5	0.6	4	150	7	5800	
6	0.6	4	175	8.2	6300	
7	0.6	6	125	7.1	5600	
8	0.6	6	150	8	6000	

Hardness (HRB)

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steel

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9	0.6	6	175	9.1	7000
10	0.8	2	125	6.2	4500
11	0.8	2	150	7	6600
12	0.8	2	175	8.8	8800
13	0.8	4	125	7.4	6600
14	0.8	4	150	8.4	8700
15	0.8	4	175	10.4	9300
16	0.8	6	125	8.9	7200
17	0.8	6	150	9.2	9100
18	0.8	6	175	11.4	10400
19	1.00	2	125	7.2	3400
20	1.00	2	150	8	8000
21	1.00	2	175	10	10500
22	1.00	4	125	9	9800
23	1.00	4	150	9.4	11500
24	1.00	4	175	11.6	13200
25	1.00	6	125	10.4	10400
26	1.00	6	150	11.2	12200
27	1.00	6	175	12.8	14000

Table (4): Measured and predicated values of spot diameter and MAX shear force

No.	Thickness	Time	Current	Spot dian	neter,mm	MAX sh	ear force,N
	( <b>mm</b> )	(sec)	(Amp)	Measured	Predicted	Measured	Predicted
1	0.6	2	125	5.2	5.20	4700	4713.431
3	0.6	2	175	7.1	7.10	5900	5979.916
4	0.6	4	125	6.1	6.07	5200	5428.584
6	0.6	4	175	8.2	8.19	6300	6348.801
7	0.6	6	125	7.1	7.14	5600	5303.699
8	0.6	6	150	8	7.99	6000	5999.172
9	0.6	6	175	9.1	9.13	7000	6627.103
10	0.8	2	125	6.2	6.20	4500	3789.116
12	0.8	2	175	8.8	8.79	8800	8787.068
14	0.8	4	150	8.4	8.40	8700	8697.819
15	0.8	4	175	10.4	10.39	9300	9365.795
16	0.8	6	125	8.9	8.89	7200	7194.026
17	0.8	6	150	9.2	9.19	9100	8570.863
18	0.8	6	175	11.4	11.39	10400	10486.81
19	1.00	2	125	7.2	7.44	3400	3649.766
20	1.00	2	150	8	7.79	8000	7931.174
21	1.00	2	175	10	9.99	10500	10515.98
23	1.00	4	150	9.4	9.47	11500	11487.2
25	1.00	6	125	10.4	10.21	10400	10388.23
26	1.00	6	150	11.2	11.19	12200	12168.51
27	1.00	6	175	12.8	12.79	14000	13891.16



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Table (5): Comparison of neural network predictions with experimental measurement for test set (spot diameter).

No	Thick	Time	Current	Spot diame	eter, mm	Eman	ANN result		
INO	(mm)	(sec)	(Amp)	Measured	predicted	Error	$\overline{\phi}$	MSE	accuracy
1	0.6	2	150	6.1	6.10	0		0.23	00.77%
2	0.6	4	150	7	6.97	0.428571			
3	0.8	2	150	7	6.98	0.285714	0.0068		
4	0.8	4	125	7.4	7.5	-1.35135			99.77%
5	1.00	4	125	9	8.97	0.333333			
6	1.00	4	175	11.6	11.56	0.344828			

Table (6): Comparison of neural network predictions with experimental measurement for test set (MAX shear force)

No	Thick	Time	Current	MAX shear	force ,N	Ennon	ANN result		
INO	(mm) (sec) (Amp)		Measured	predicted	EIIOI	$\overline{\phi}$	MSE	accuracy	
1	0.6	2	150	5200	5200	6.45231E-07		0.001518 183	99.8
2	0.6	4	150	5800	5744.666	0.954034409			
3	0.8	2	150	6600	6600	-2.6107E-07	0.1545		
4	0.8	4	125	6600	6601.781	-0.02698926	00723		
5	1.00	4	125	9800	9800.001	-5.1316E-06			
6	1.00	4	175	13200	13200	-5.8965E-08			

### Table (7): ANOVA for present work (spot diameter)

Source of variance	Degree	Sum of squares	Variance	F ratio	P(%)
Thickness (mm)	2	36.761	18.38	175	38.71%
Time(sec)	2	28.156	14.07	134	29.65%
Current (Amp)	2	27.921	13.96	132	29.4%
Error ,e	20	2.105	0.105		2.21%
Total	26	94.943			100

### Table(8): ANOVA for present work (MAX shear force)

Source of variance	Degree	Sum of squares	Variance	F ratio	P (%)
Thickness (mm)	2	94858518	47429259	30.39	46.18%
Time(sec)	2	36080740	18040370	11.75	17.56%
Current (Amp)	2	43769629	21884814	132	21.3%
Error ,e	20	30700742	1535037	14.25	14.9%
Total	26	205409629			100





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Figure (1): Design and dimensions of overlap work pieces to be spot welded



Figure (2): Neural network architecture designed.



Figure (3): The comparison between the measured with the predicted values of spot diameter for training set



Figure (4): The comparison between the measured and the predicted values of spot diameter for testing set



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Figure (5): The comparison between the measured with the predicted values of MAX shear force for training set



Figure (6): The comparison between the measured and the predicted values of MAX shear force for testing set.



- (a) Regression coefficient of learning data.
- (b) Regression coefficient of validation data.
- (c) Regression coefficient of test data.
- (d) Regression coefficient of all data.

Figure (7): Regression graphs for model (spot diameter)



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(a)Regression coefficient of learning data.

(b) Regression coefficient of validation data.

(c)Regression coefficient of test data.

(d) Regression coefficient of all data.

Figure (8): Regression graphs for model (MAX shear force)



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Figure (9): Main Effect Plots for spot diameter



Figure (10): Main Effect Plots for MAX shear force.



Figure (11): Influential effects based on percentage of distributions.



Figure (12): Influential effects based on percentage of distributions.



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Figure (13): Effect of welding time and current on the experimental spot diameter at constant thickness of 0.6 mm



Figure (14): Effect of welding time and current on the experimental spot diameter at constant thickness of 0.8 mm



Figure (15): Effect of welding time and current on the experimental spot diameter at constant thickness of 1 mm



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Figure (16): Effect of Time and current on the experimental MAX shear force at constant thickness of 0.6 mm



Figure (17): Effect of Time and current on the experimental MAX shear force at constant thickness of 0.8 mm



Figure (18): Effect of Time and current on the experimental MAX shear force at constant thickness of 1 mm