www.dergipark.gov.tr
ISSN:2148-3736
El-Cezerî Fen ve Mühendislik Dergisi
Cilt: 4, No: 3, 2017 (334-340)

El-Cezerî Journal of Science and Engineering
Vol: 4, No: 3, 2017 (334-340)

ECJSE

Research Paper / Makale

Mathematical Formulation of 304 Stainless Steel Welded Arc Stud Welding Method

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Received/Geliş: 24.10.2016 **Revised/Düzeltme:** - **Accepted/Kabul:** 30.01.2017

Abstract: In this work, effects of arc stud welding parameters on ultimate tensile strength of AISI 304 austenitic stainless steels welded arc stud welding method were investigated using neural network approach. It was observed that optimum model architecture is 5-6-1 ratio for this study. A mathematical formulation was derived to estimate the ultimate tensile strength of these joints and experimental results were compared with test results. Mathematical formula is presented in explicit form. The proposed model shows good agreement with experimental results and can be used to predict the ultimate tensile strength of these joints. R and R^2 values of training and test sets are higher 0.95 and 0.93, and 0.90 and 0.87, respectively. Percentage error value for test set is not exceeded 13%.

Key Words: Arc stud welding, welding, neural network, modelling.

Ark Saplama Kaynağıyla Birleştirilen 304 Paslanmaz Çeliklerin Matematik Olarak Formüle Edilmesi

Özet: Bu çalışmada, ark saplama kaynak yöntemiyle birleştirilen 304 östenitik paslanmaz çeliklerin çekme dayanımına ark saplama kaynak parametrelerinin etkisi yapay sinir ağları modeli kullanılarak araştırılmıştır. Bu çalışma için optimum model yapısının 5-6-1 olduğu gözlenmiştir. Birleştirmelerin çekme dayanımını hesaplamak için bir matematik Formülasyon önerilmiş ve deneysel ve test sonuçları karşılaştırılmıştır. Formülasyon açıkça verilmiş ve önerilen model ile uyum içerisinde olduğu belirlenmiş ayrıca birleştirmelerin çekme dayanımını tahmin etmede kullanılabileceği kanaatine varılmıştır. Eğitim ve test setlerinin R ve R2 değerleri 0,95, 0,93 0,90 ve 0,87 olarak bulunmuştur. Test setinin hata değeri %13'ün altında olduğu görülmüştür.

Anahtar kelimeler: Ark saplama kaynağı, kaynak, yapay sinir ağları, modelleme.

1. Introduction

Arc stud welding method as a fabrication method is widely used in many sectors like automotive, construction, shipbuilding and aviation. In this method, a metal fastener is welded to another metal object or plate and the method is a fast, reliable and accurate method. The high speed of process, adaptability for automation in the production is major advantages. Stud welding, instead of rivets and drilling holes, has advantages such as high efficiency, good welding quality, reliability,

How to cite this article
Oduncuoğlu, M., Yılmaz, N.F., Kurt, H.İ., "*Mathematical Formulation of 304 Stainless Steel Welded Arc Stud Welding Method*" El-Cezerî Journal of Science and Engineering, 2017, 4(3); 334-340.

Bu makaleye atıf yapmak için
Oduncuoğlu, M., Yılmaz, N.F., Kurt, H.İ., *"Ark Saplama Kaynağıyla Birleştirilen 304 Paslanmaz Çeliklerin Matematik Olarak Formüle Edilmesi"* El-Cezerî Fen ve Mühendislik Dergisi 2017, 4(3); 334-340.

repeatability and non-pollution [1, 2]. Drawn arc stud welding with shielding and capacitor discharge stud welding are the most commonly using types of arc stud welding. The most important parameters in this method are stud diameter, welding current, welding time, plunge and lift. In order to get the maximum mechanical properties and high quality joining, these parameters should properly be selected [2-4].

The quality improvement requirement and the optimization of processes parameters are became a vital issue and should be given more consideration and attention. The principle of arc stud welding of austenitic stainless steels, the relationship between the input parameters and output variables of welding parameters for the desired output variables and the mechanical and microstructural properties are studied in this paper. The theoretical optimization process of these parameters is the key step for achieving high quality joints without increasing cost.

2. Material And Method

In this study, AISI 304 stainless steels as stud and plate and Soyer – BMK-16i type arc stud welding machine were used. Welding operation was carried out by using different parameters. These parameters and effects of these parameters on the ultimate tensile strength of the joints were shown in Table 1.

Table 1. The used welding parameters and results of UTS

Stud diameter (mm)	Welding Current (A)	Welding Time (msec)	Plunge (mm)	Lift (mm)	UTS (Mpa)	Partition
6	300	100	1	1,5	648,71	Training
6	300	200	2	2	718,66	Test
6	300	300	3	2,5	798,47	Training
6	300	400	4	3	655,86	Training
6	400	100	2	2,5	812,32	Training
6	400	200	1	3	807,72	Training
6	400	300	4	1,5	672,07	Training
6	400	400	3	2	573,90	Training
6	500	100	3	3	811,90	Training
6	500	200	4	2,5	800,38	Training
6	500	300	1	2	578,47	Training
6	500	400	2	1,5	405,12	Training
6	600	100	4	2	651,39	Training
6	600	200	3	1,5	571,54	Training
6	600	300	2	3	419,82	Test
6	600	400	1	2,5	308,04	Training
8	500	100	1	1,5	828,32	Training
8	500	200	2	2	857,54	Training
8	500	300	3	2,5	829,84	Training
8	500	400	4	3	690,05	Training
8	600	100	2	2,5	757,94	Training
8	600	200	1	3	747,16	Training
8	600	300	4	1,5	742,47	Test
8	600	400	3	2	590,14	Training
8	700	100	3	3	762,87	Training
8	700	200	4	2,5	845,93	Training

8	700	300	1	2	512,84	Training
8	700	400	2	1,5	509,23	Test
8	800	100	4	2	761,60	Training
8	800	200	3	1,5	723,34	Training
8	800	300	2	3	539,63	Test
8	800	400	1	2,5	340,62	Training
10	600	100	1	1,5	689,07	Training
10	600	200	2	2	867,99	Training
10	600	300	3	2,5	838,82	Test
10	600	400	4	3	809,05	Training
10	700	100	2	2,5	702,30	Training
10	700	200	1	3	856,71	Training
10	700	300	4	1,5	804,08	Training
10	700	400	3	2	801,38	Test
10	800	100	3	3	739,76	Test
10	800	200	4	2,5	802,41	Training
10	800	300	1	2	751,49	Test
10	800	400	2	1,5	652,65	Training
10	900	100	4	2	782,21	Test
10	900	200	3	1,5	771,06	Training
10	900	300	2	3	712,66	Training
10	900	400	1	2,5	625,03	Training
12	700	100	1	1,5	562,52	Training
12	700	200	2	2	685,23	Training
12	700	300	3	2,5	814,35	Training
12	700	400	4	3	812,45	Training
12	800	100	2	2,5	675,10	Training
12	800	200	1	3	756,34	Test
12	800	300	4	1,5	845,82	Training
12	800	400	3	2	870,65	Test
12	900	100	3	3	715,56	Training
12	900	200	4	2,5	771,20	Training
12	900	300	1	2	835,12	Training
12	900	400	2	1,5	796,45	Test
12	1000	100	4	2	723,11	Training
12	1000	200	3	1,5	752,34	Training
12	1000	300	2	3	826,81	Training
12	1000	400	1	2,5	795,31	Training

The welded specimens and joint quality of these specimens were tested using universal tensile test machine according to the related international standard [5]. Each variable for neural network is scaled to the range of 0.1 to 0.9 by the following the formula:

$$V_N = 0.8x\frac{V_r - V_{min}}{V_{max} - V_{min}} + 0.1 \quad (1)$$

where V_N is the variables used in the model, V_{max} and V_{min} are the maximum and minimum values of the variables used in the model, respectively.

The data were divided into training and testing groups, and selected in random systematic way where 51 sets of data were the training data and 13 sets of data were the testing data. In order to fix the optimum model architecture, different neuron numbers (4-6) in one hidden layer were used. The correlation coefficient (R) was chosen to estimate the performance of the model and also mean absolute error (MAE), mean absolute percentage error (MAPE) and mean square error (MSE) were utilized as error-evaluation criteria [6-8]. The related equations by R, MSE, MAE and MAPE were given below respectively.

$$R = \frac{cov(y_t, \acute{y}_t)}{\sqrt{var(y_t).var(\acute{y}_t)}} \tag{2}$$

$$MSE = \left(\frac{1}{N}\sum_{i=1}^{N}|ti - \hat{t}i|\right)^2 \tag{3}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|ti - \hat{t}i| \tag{4}$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\frac{|ti - \hat{t}i|}{ti}(100) \tag{5}$$

where N is the total number of the data, t_i and $t\,\hat{}_i$ are the experimental value and predicted output values from the neural network model for a given input, respectively.

3. Results And Discussion

Table 2 shows the influence of neuron numbers on statistical parameters of the model. It is clear that the optimal results were obtained with 6 neurons as shown in Figure 1. R values for the training and testing sets are 0,950248 and 0,936516, which indicates that the performances of the trained and tested models were significantly high and reliable. It was found that the 5-6-1 ratio is the optimal modelling structure for this study.

Table 2. Statistical parameters of the present model

Neuron numbers	Training			Test		
	MSE	R	MAE	MSE	R	MAE
4	0,215672	0,9398	2,572356	0,05598	0,929409	0,634036
5	0,221218	0,944491	2,722639	0,081956	0,91656	0,745016
6	0,169636	0,950248	2,339279	0,051081	0,936516	0,655826

The correlations of experimental and the estimated results for training and testing sets were illustrated in Figures 2 and 3, respectively. R^2 values shown in these figures analogise the trueness of the model. R^2 values for training and test sets are higher than 0.90 and 0.87, respectively. There are a few minor deviations between the experimental and theoretical results in training and test sets of NN. These can be attributed to the variation in experimental conditions. Figure 4 shows the % error values of testing set. It is clear from the figure that the maximum error is not exceeded 13%. MAPE of testing set is 5.29%. It can be concluded that the ultimate tensile strength of these joints can be estimated with 94.71% accuracy.

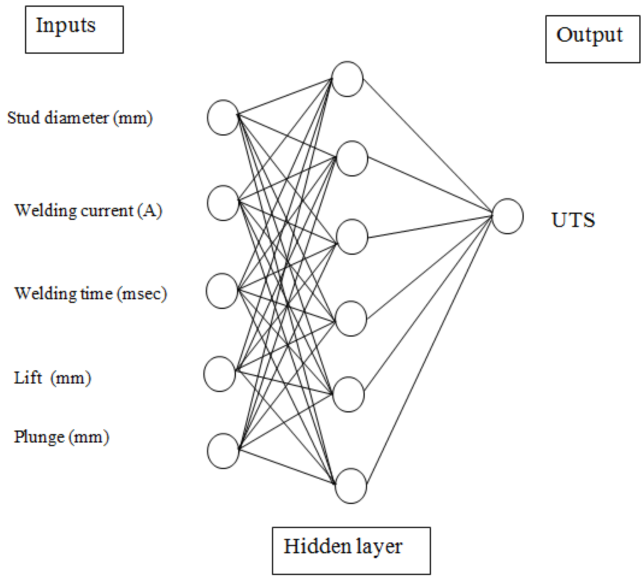

Figure 1: The optimal network architecture

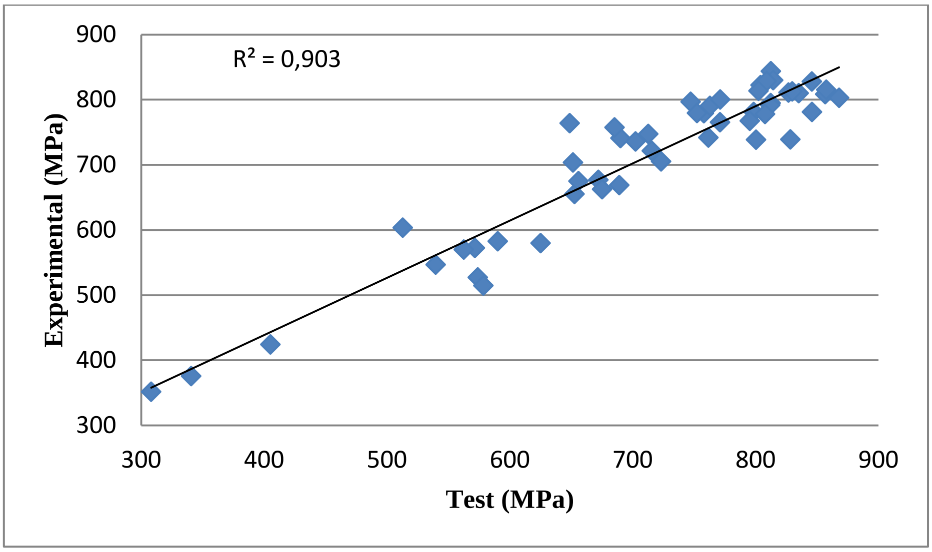

Figure 2: Correlations of estimated and experimental results for training set

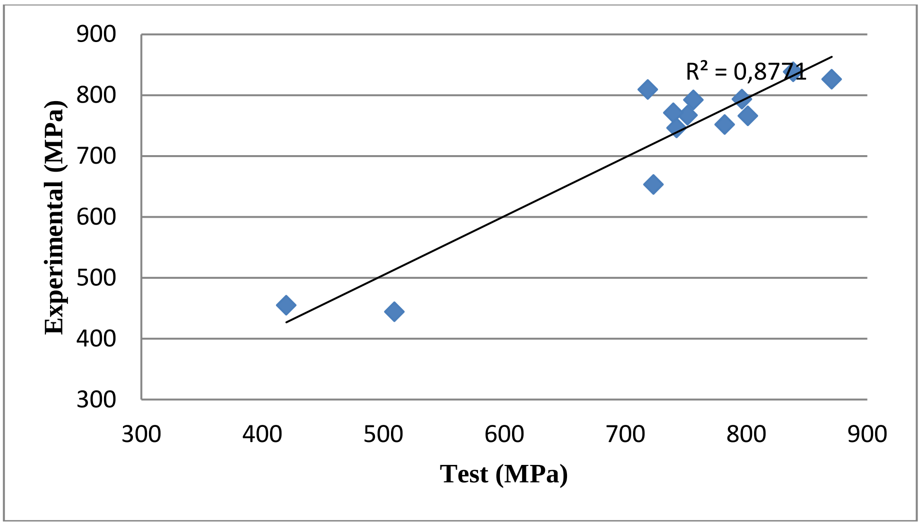

Figure 3: Correlations of estimated and experimental results for test set

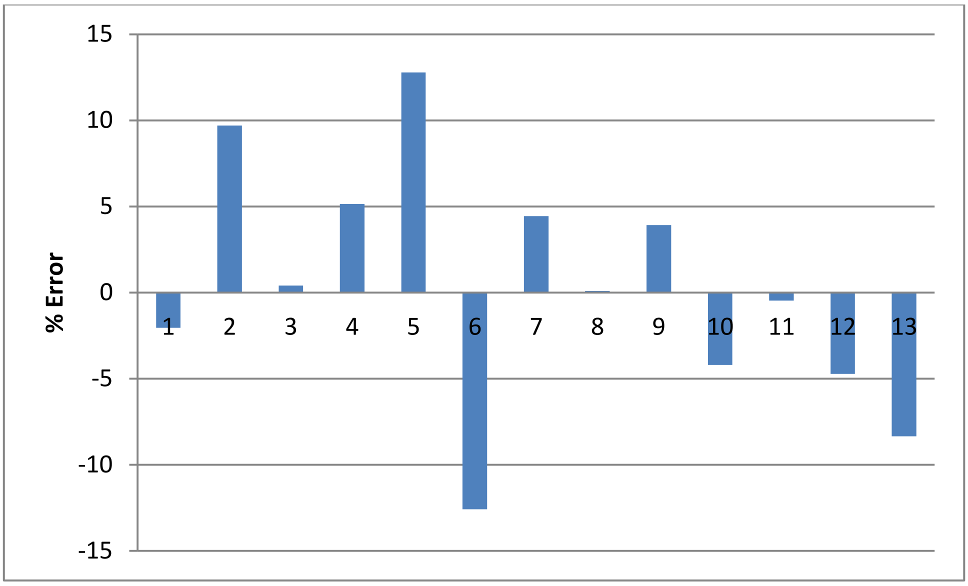

Figure 4: % Error of test set

The aim of the present study was to investigate the influences of welding parameters on the ultimate tensile strength of AISI 304 austenitic stainless steels welded arc stud welding method and to develop a mathematical equation for prediction of the experimental results. The formulation of the proposed model can be expressed as Eq. 6:

$$UTS = \frac{\left(\left(\frac{1}{1+e^{-w}}\right) - (-0.063034)\right)}{1.1303440} \quad (6)$$

Where *w* is

u1+u2+u3+u4+u5+u6+(-3,617970)

and where

u1=(((1/(1+exp(-1*(((A1*(1)+(0,1))*(2,141788))+((B1*(1)+(0,1))*(-2,877371))+((C1*(1)+(0,1))*(-3,763102))+((D1*(1)+(0,1))*(0,419524))+((E1*(1)+(0,1))*(-0,790751))+(1,052962)))))*(-4,312601)))

u2=(((1/(1+exp(-1*(((A1*(1)+(0,1))*(-1,220024))+((B1*(1)+(0,1))*(-2,040380))+((C1*(1)+(0,1))*(-0,517825))+((D1*(1)+(0,1))*(0,718839))+((E1*(1)+(0,1))*(-1,281335))+(1,757470)))))*(1,976651)))

u3=(((1/(1+exp(-1*(((A1*(1)+(0,1))*(6,186032))+((B1*(1)+(0,1))*(-3,554848))+((C1*(1)+(0,1))*(-3,039084))+((D1*(1)+(0,1))*(-0,109193))+((E1*(1)+(0,1))*(0,548697))+(1,633069)))))*(6,381210)))

u4=(((1/(1+exp(-1*(((A1*(1)+(0,1))*(1,033860))+((B1*(1)+(0,1))*(-0,552551))+((C1*(1)+(0,1))*(-2,530517))+((D1*(1)+(0,1))*(-0,380549))+((E1*(1)+(0,1))*(-0,916221))+(-0,309874)))))*(-1,636596))) u5=(((1/(1+exp(-1*(((A1*(1)+(0,1))*(-0,432342))+((B1*(1)+(0,1))*(0,758503))+((C1*(1)+(0,1))*(0,248213))+((D1*(1)+(0,1))*(-0,299538))+((E1*(1)+(0,1))*(0,790223))+(-0,405364)))))*(-0,657497)))

u6=(((1/(1+exp(-1*(((A1*(1)+(0,1))*(-1,702275))+((B1*(1)+(0,1))*(-1,748945))+((C1*(1)+(0,1))*(-0,496193))+((D1*(1)+(0,1))*(0,924614))+((E1*(1)+(0,1))*(-0,088468))+(0,801202)))))*(2,091326)))

It should be noted that the presented explicit formulation is valid for the large ranges. As expressed before, the ultimate tensile strength of these joints can be estimated with 94.71% accuracy by using the proposed formulations.

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