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# Prediction of Weld Strength of Resistance Spot Welding Using Artificial Neural Network

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***Abstract***
Resistance Spot Welding is one of the oldest electric welding processes in use by industry today. As the name implies, it is the resistance of the material to be welded to current flow that causes a localized heating in the part. This paper focused on the development and evaluation of neural network-based systems for trial resistance spot welding process control and weld quality assessment. Parametric study shows the effect of different parameters i.e., weld current, cycle time, and thickness on the weld strength. The relations between parameters are plotted on the graphs.
***Index Terms*—** Process Parameters, Artificial neural network,

**ANOVA**

**Nomenclature**:-

C.F. = Correction factor
n = Number of trials
r = Number of repetition
e = Error
P = Percent contribution
F = Variance ratio
T = Total of results
S = Sum of squares
fe = Degree of freedom of error
S' = Pure sum of squares
fT = Total degree of freedom
V = Mean squares (variance)

## I. INTRODUCTION

Resistance welding is a group of welding processes in which coalescence is produced by the heat obtained from resistance of the work piece to electric current in a circuit of which the work piece is a part and by the application of pressure. The weld is made by conducting a strong current through the metal combination to heat up and finally melt the metals at localized point(s) predetermined by the design of the electrodes and/or the work pieces to be welded. The developed systems utilize recurrent neural networks for process control and backpropogation neural networks for weld strength prediction. Numbers of researchers have discussed mostly two sections; the first section describes a system capable of both welding process control and real-time weld quality assessment. The second describes the development and evaluation of a static neural network-based weld quality assessment system that relied on experimental design to limit the influence of environmental variability. Here three spot are made and weld strength is measured on tensile testing machine for different spot welding parameters. In this work, there are three different input parameters are utilized to check the weld strength of the resistance spot welding. Parametric analysis is carried out for the quality of the resistance spot welding, i.e. weld strength. This parametric analysis (ANOVA) shows the percentage contribution of parameters individually, i.e. welding current is 49.81 %, thickness of 37.94 % and cycle time of 2.61 % and the error is of 9.62 %. Existing literature tells about artificial neural network analysis for resistance spot welding done by various researchers. The literature also includes the effect of various process parameter of resistance spot welding on weld strength, heat affected zone, and various mechanical properties for different materials. Ugur Esme in 2009 had described an investigation of the effect and optimization of welding parameters on the tensile shear strength of spot welded SAE 1010 steel sheets in the resistance spot welding (RSW) process [4]. G. Mukhopadhyay S. Bhattacharya, & K.K. Ray in 2009 had described the effect of pre-strain of base metals on the strength of spot welds[5]. Ranfeng Qiu, Shinobu Satonaka & Chihiro Iwamoto in 2009 joined aluminium alloy A5052 to cold-rolled steel SPCC and austenitic stainless steel SUS 304 using resistance spot welding[6]. Oscar Martín & Pilar De Tiedr in 2009 had developed a tool capable of reliably predicting the TSLBC (tensile shear load bearing capacity) and consequently the quality level of RSW joints from three welding parameters:(1) Welding time (WT) (2) Welding current (WC) (3) Electrode force (EF)[7]. HongGang Yang, YanSong Zhang, XinMin Lai, Guanlong Chen in 2008 described different weld length of the elliptical nugget for DP600 resistance spot welding was realized through modified electrode tips[8]. Hongyan Zhang & S. Jack Hu in 2008 investigated expulsion involves loss of metal from the liquid nugget, which often results in the reduction of weld strength[9]. A Aravinthan, K Sivayoganathan, D Al-Dabass, V Balendran in 2007 had shown a neural network system for spot weld strength prediction. Paper described N.N spot weld strength monitoring system based on current and voltage waveform.[10]. P Jung Me Park & Hong Tae Kang in 2007 had described the developed back-propagation N.N to predict the fatigue life of spot welds subjected to various geometric factors & loading conditions [11].

## II. EXPERIMENTAL PROCEDURE

Here three spot are made and weld strength is measured on tensile testing machine for different spot welding parameters. In this study, there are three different input parameters are utilized to check the weld strength of the resistance spot welding. Parametric study shows the effect of different parameters i.e., weld current, cycle time, and thickness on the weld strength. The relations between parameters are plotted on the graphs. It may be helpful to select the proper weld current, cycle time, and thickness for required weld strength. Parametric analysis is carried out for the quality of the resistance spot welding, i.e. weld strength.

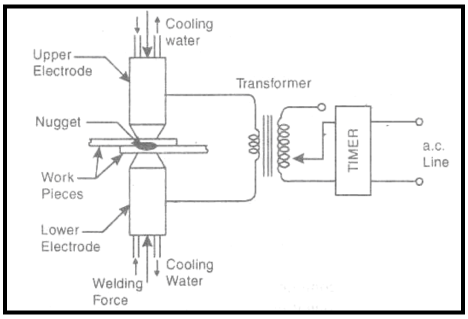


Fig.1 Principle of operation of spot welding

Fig. 2 Sample for testing (a) 1.5 mm thickness (b) 2 mm thickness (c) 2.5 mm thickness

## III. PARAMETRIC ANALYSIS

### A. *The analysis of variance (ANOVA)*

The Analysis of variance is the statistical treatment most commonly applied to the results of the experiment to determine the percent contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not. Once the optimum condition is determined, it is usually good practice to run a confirmation experiment. In case of fractional factorial only some of the tests of full factorial are conducted. The analysis of the partial experiment must include an analysis of confidence that can be placed in the results. So analysis of variance is used to provide a measure of confidence. The technique does not directly analyze the data, but rather determines the variability (variance) of the data. Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted.

### B. *Result Table*

Table:1 Data obtained from experimental work for weld strength of RSW

| Sr. No. | Welding Current (KAmp) | Cycle time (Sec) | Thickness (mm) | Weld Strength ($N/mm^2$) |
|---|---|---|---|---|
| 1 | 3 | 3 | 1.5 | 241 |
| 2 | 3 | 4 | 1.5 | 288 |
| 3 | 3 | 5 | 1.5 | 290 |
| 4 | 3 | 6 | 1.5 | 299 |
| 5 | 4 | 3 | 1.5 | 275 |
| 6 | 4 | 4 | 1.5 | 298 |
| 7 | 4 | 5 | 1.5 | 312 |
| 8 | 4 | 6 | 1.5 | 324 |
| 9 | 5 | 3 | 1.5 | 301 |
| 10 | 5 | 4 | 1.5 | 308 |
| 11 | 5 | 5 | 1.5 | 329 |
| 12 | 5 | 6 | 1.5 | 340 |
| 13 | 6 | 3 | 1.5 | 488 |
| 14 | 6 | 4 | 1.5 | 470 |
| 15 | 6 | 5 | 1.5 | 465 |
| 16 | 6 | 6 | 1.5 | 450 |
| 17 | 3 | 3 | 2 | 155 |
| 18 | 3 | 4 | 2 | 162 |

| | | | | |
|---|---|---|---|---|
| 19 | 3 | 5 | 2 | 173 |
| 20 | 3 | 6 | 2 | 186 |
| 21 | 4 | 3 | 2 | 234 |
| 22 | 4 | 4 | 2 | 264 |
| 23 | 4 | 5 | 2 | 278 |
| 24 | 4 | 6 | 2 | 328 |
| 25 | 5 | 3 | 2 | 304 |
| 26 | 5 | 4 | 2 | 325 |
| 27 | 5 | 5 | 2 | 369 |
| 28 | 5 | 6 | 2 | 430 |
| 29 | 6 | 3 | 2 | 416 |
| 30 | 6 | 4 | 2 | 422 |
| 31 | 6 | 5 | 2 | 430 |
| 32 | 6 | 6 | 2 | 471 |
| 33 | 3 | 3 | 2.5 | 132 |
| 34 | 3 | 4 | 2.5 | 143 |
| 35 | 3 | 5 | 2.5 | 133 |
| 36 | 3 | 6 | 2.5 | 122 |
| 37 | 4 | 3 | 2.5 | 155 |
| 38 | 4 | 4 | 2.5 | 186 |
| 39 | 4 | 5 | 2.5 | 194 |
| 40 | 4 | 6 | 2.5 | 205 |
| 41 | 5 | 3 | 2.5 | 210 |
| 42 | 5 | 4 | 2.5 | 214 |
| 43 | 5 | 5 | 2.5 | 220 |
| 44 | 5 | 6 | 2.5 | 229 |
| 45 | 6 | 3 | 2.5 | 233 |
| 46 | 6 | 4 | 2.5 | 241 |
| 47 | 6 | 5 | 2.5 | 249 |
| 48 | 6 | 6 | 2.5 | 296 |

### *C. Analysis of variance (ANOVA) for weld strength*

Total number of runs, n = 48
Total degree of freedom fT = n-1 = 47

**1) Three factors and their levels**

Welding Current, A – A1, A2, A3, A4
Cycle time, B – B1, B2, B3, B4
Thickness, C – C1, C2, C3

**2) Degree of freedom**

Factor A – Number of level of factors, fA = A-1 = 3
Factor B – Number of level of factors, fB = B-1 = 3
Factor C – Number of level of factors, fC = C-1 = 2
For error, Fe = fT – fA – fB – fC
= 47 – 3 – 3 – 2
= 39
T = Totals of all results = 13587[]
Correction factor C.F. = $\frac{T^2}{n} = \frac{(13587)^2}{48} = 3845970.188$

**3) Total sum of squares**

$S_T = \sum_{i=1}^{n} y_i^2$ - C.F. = 4330899 –3845970.188 = 484928.812

**4) The total contribution of each factor level**

A1= 241+288+290+299+155+162+173+186+132+143+133+122
= 2324
A2= 275+298+312+312+234+264+278+328+155+186+194+205
= 3053
A3= 301+308+329+340+304+325+369+430+210+214+220+229
= 3579
A4= 488+470+465+450+416+422+430+471+233+241+249+296
= 4631
B1= 241+275+301+488+155+234+304+416+132+155+210+233
= 3144
B2= 288+298+308+470+162+264+325+143+186+214+241
= 3321
B3 = 290+312+329+465+173+278+369+430+133+194+220+249
= 3442
B4 = 299+324+340+450+186+328+430+471+122+205+229+296
= 3680
C1= 241+288+290+299+275+298+312+324+301+308+329+340+488+470+465+450
= 5478
C2= 155+162+173+186+234+264+278+328+304+325+369+430+416+422+430+471
= 4943
C3 =132+143+133+122+155+186+194+205+210+214+220+229+233+241+249+296
= 3262

**5) Factor sum of squares**

$$SA = \left(\frac{A_1^2}{N_{A1}} + \frac{A_2^2}{N_{A2}} + \frac{A_3^2}{N_{A3}} + \frac{A_4^2}{NA4}\right) - C.F.$$

$$= \left(\frac{(2324)^2}{12} + \frac{(3053)^2}{12} + \frac{(3579)^2}{12} + \frac{(4631)^2}{12}\right) - 3845970.188$$

$= 4087550.247 - 3845970.188$

= 241580.0586

$$SB = \left(\frac{B_1^2}{N_{A1}} + \frac{B_2^2}{N_{A2}} + \frac{B_3^2}{N_{A3}} + \frac{B_4^2}{NA4}\right) - C.F.$$

$$= \left(\frac{(3144)^2}{12} + \frac{(3321)^2}{12} + \frac{(3442)^2}{12} + \frac{(3680)^2}{12}\right) - 3845970.188$$

= 12658.22

$$SC = \left(\frac{C_1^2}{N_{C1}} + \frac{C_2^2}{N_{C2}} + \frac{C_3^2}{N_{C3}}\right) - C.F.$$

$$= \left(\frac{(5478)^2}{16} + \frac{(4947)^2}{16} + \frac{(3162)^2}{16}\right) - 3845970.188$$

= 184000.872

$$S_e = S_T - (S_A + S_B + S_C)$$

$$S_e = 484928.812 - (241580.0586 + 12658.22 + 184000.872)$$

= 46689.6614

**6) Mean square (Variance)**

$$V_A = \frac{S_A}{f_A} = \frac{241580.0586}{3} = 80526.6862$$

$$V_B = \frac{S_B}{f_B} = \frac{12658.22}{3} = 4219.406667$$

$$V_C = \frac{S_C}{f_C} = \frac{184000.872}{2} = 92000.436$$

$$V_e = \frac{S_e}{f_e} = \frac{46689.66}{39} = 1197.17$$

**7) Variance ratio F**

$$F_A = \frac{V_A}{Ve} = \frac{80526.6862}{1197.17} = 67.26$$

$$F_B = \frac{V_B}{Ve} = \frac{4219.4066}{1197.17} = 3.52$$

$$F_C = \frac{V_C}{Ve} = \frac{92000.436}{1197.17} = 76.84$$

$$F_e = \frac{V_e}{Ve} = \frac{1197.17}{1197.17} = 1$$

Here computed F value for all the factors is higher than the value determined from the standard F tables at the selected level of significance, so the factors contribute to the sum of squares within the confidence level and cannot be pooled.

**8)** Percentage contribution

$$P_A = \frac{S_A}{S_T} = \frac{241580.0586}{484928.812} = 0.4981 = 49.81\,\%$$

$$P_B = \frac{S_B}{S_T} = \frac{12658.22}{484928.812} = 0.0261 = 2.61\,\%$$

$$P_C = \frac{S_C}{S_T} = \frac{184000.872}{484928.812} = 0.3794 = 37.94\,\%$$

$$P_e = \frac{S_e}{S_T} = \frac{46689.661}{484928.812} = 0.0962 = 9.62\,\%$$

Above analysis shows the percentage contribution of individual parameters on weld strength. The percentage contribution of welding current is 49.81 %, thickness of 37.94 % and cycle time of 2.61 % and the error is of 9.62 %.

## IV. RESULTS & DISCUSSION

Welded specimens were tested on standard tensile testing machine. The resulting data and the predicted data are listed in table 2.

**Table 2. Training data for neural network.**

| Sr. No | current | cycle | thickness | Weld strength | Predicted strength | % Change Error |
|---|---|---|---|---|---|---|
| 1 | 3 | 3 | 1.5 | 241 | 249 | 3.21 |
| 2 | 3 | 4 | 1.5 | 288 | 304 | 5.26 |
| 3 | 3 | 5 | 1.5 | 290 | 238 | 17.93 |
| 4 | 3 | 6 | 1.5 | 299 | 274 | 8.36 |
| 5 | 4 | 3 | 1.5 | 275 | 273 | 0.727 |
| 6 | 4 | 4 | 1.5 | 298 | 268 | 10.06 |
| 7 | 4 | 5 | 1.5 | 312 | 311 | 0.32 |
| 8 | 4 | 6 | 1.5 | 324 | 338 | 4.14 |
| 9 | 5 | 3 | 1.5 | 301 | 346 | 13.00 |
| 10 | 5 | 4 | 1.5 | 308 | 353 | 12.74 |
| 11 | 5 | 5 | 1.5 | 329 | 382 | 13.87 |
| 12 | 5 | 6 | 1.5 | 340 | 397 | 12.59 |
| 13 | 6 | 3 | 1.5 | 488 | 417 | 14.54 |
| 14 | 6 | 4 | 1.5 | 470 | 440 | 6.38 |
| 15 | 6 | 5 | 1.5 | 465 | 448 | 3.65 |
| 16 | 6 | 6 | 1.5 | 450 | 452 | 0.44 |
| 17 | 3 | 3 | 2 | 155 | 159 | 2.51 |
| 18 | 3 | 4 | 2 | 162 | 168 | 3.57 |
| 19 | 3 | 5 | 2 | 173 | 185 | 6.48 |
| 20 | 3 | 6 | 2 | 186 | 215 | 13.48 |
| 21 | 4 | 3 | 2 | 234 | 233 | 0.42 |
| 22 | 4 | 4 | 2 | 264 | 258 | 2.27 |
| 23 | 4 | 5 | 2 | 278 | 276 | 0.71 |
| 24 | 4 | 6 | 2 | 328 | 306 | 6.70 |
| 25 | 5 | 3 | 2 | 304 | 324 | 6.17 |
| 26 | 5 | 4 | 2 | 325 | 341 | 4.69 |
| 27 | 5 | 5 | 2 | 369 | 367 | 0.54 |
| 28 | 5 | 6 | 2 | 430 | 391 | 9.06 |
| 29 | 6 | 3 | 2 | 416 | 402 | 3.36 |
| 30 | 6 | 4 | 2 | 422 | 423 | 0.23 |
| 31 | 6 | 5 | 2 | 430 | 448 | 4.01 |
| 32 | 6 | 6 | 2 | 471 | 463 | 1.69 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 33 | 3 | 3 | 2.5 | 132 | 140 | [illegible] |
| 34 | 3 | 4 | 2.5 | 143 | 148 | [illegible] |
| 35 | 3 | 5 | 2.5 | 133 | 164 | [illegible] |
| 36 | 3 | 6 | 2.5 | 122 | 188 | [illegible] |
| 37 | 4 | 3 | 2.5 | 155 | 203 | [illegible] |
| 38 | 4 | 4 | 2.5 | 186 | 210 | [illegible] |
| 39 | 4 | 5 | 2.5 | 194 | 249 | [illegible] |
| 40 | 4 | 6 | 2.5 | 205 | 263 | [illegible] |
| 41 | 5 | 3 | 2.5 | 210 | 271 | [illegible] |
| 42 | 5 | 4 | 2.5 | 214 | 253 | [illegible] |
| 43 | 5 | 5 | 2.5 | 220 | 261 | 15.76 |
| 44 | 5 | 6 | 2.5 | 229 | 234 | 2.13 |
| 45 | 6 | 3 | 2.5 | 233 | 220 | 5.57 |
| 46 | 6 | 4 | 2.5 | 241 | 226 | 6.22 |
| 47 | 6 | 5 | 2.5 | 249 | 231 | 7.22 |
| 48 | 6 | 6 | 2.5 | 296 | 232 | 21.62 |

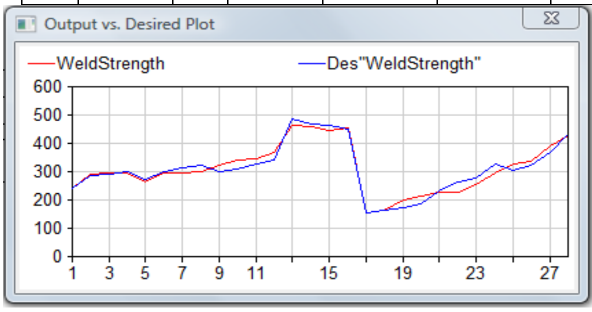


Fig.3. Experimental results Vs ANN results

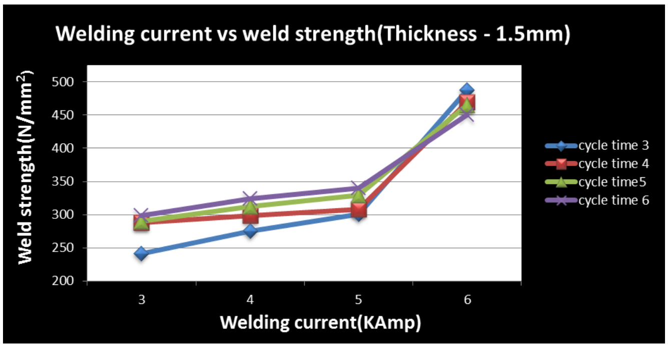


Fig. 4 Welding current Vs weld strength at different cycle time for 1.5 mm thickness for experimental results

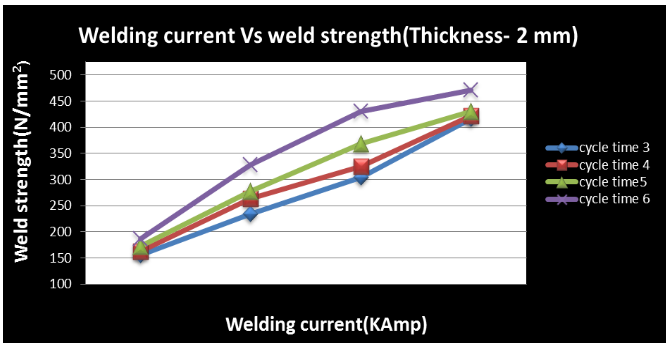


Fig. 5 Welding current Vs weld strength at different cycle time for 2 mm thickness for experimental results

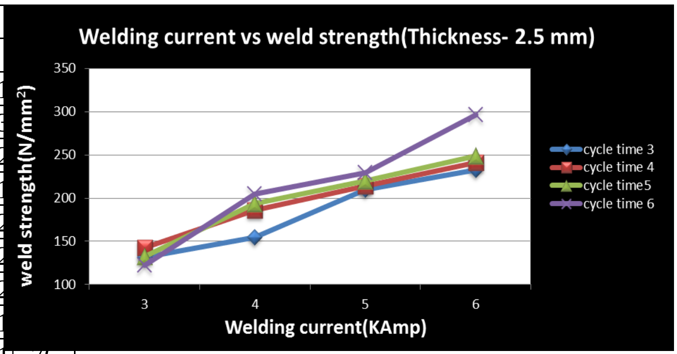


Fig.6 Welding current Vs weld strength at different cycle time for 2.5 mm thickness for experimental results

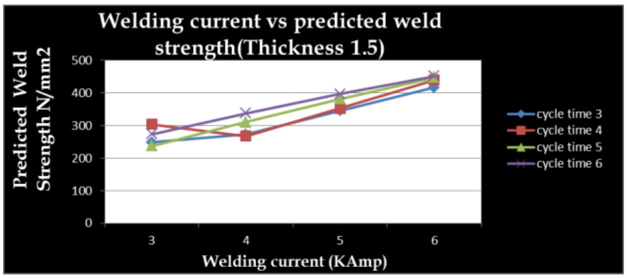


Fig. 7 Welding current Vs weld strength at different cycle time for 1.5 mm thickness for predicted results

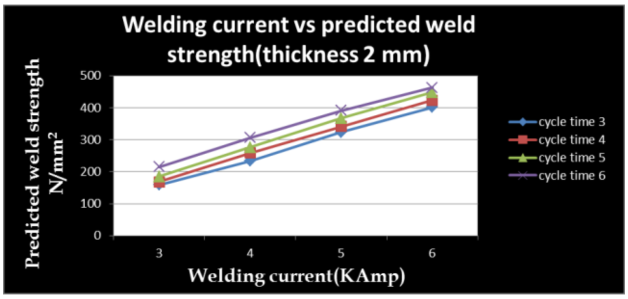


Fig. 8 Welding current Vs weld strength at different cycle time for 2 mm thickness for predicted results

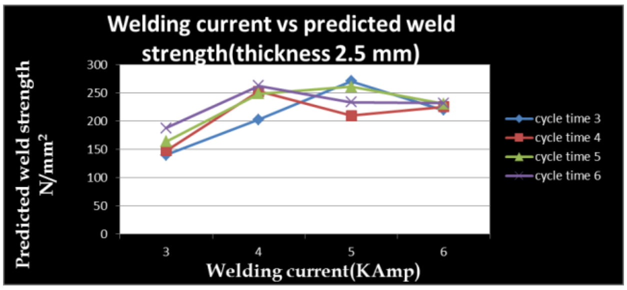


Fig.9 Welding current Vs weld strength at different cycle time for 2.5 mm thickness for predicted results

## V. CONCLUSION

In this study, it was shown that a neural network is a versatile tool for weld strength prediction of resistance spot welding. Facts that derived are

**1)** Prediction of experimental work using Neuro solutions 6.0 the results obtained is within tolerance limits except few reading as manual as well as machine error involved.

**2)** Weld strength will be increase as welding current increases.

**3**) In addition to cycle time and thickness of the material has a significant impact on the observed weld strength. Weld strength will be decrease as thickness of the material increase.

**4)** Based on ANOVA analysis highly effective parameters on weld strength were found as welding current and thickness of the material, whereas cycle time were less effective factors.

**5)** The percentage contribution of welding current is 49.81 %, thickness of 37.94 % and cycle time of 2.61 % and the error is of 9.62 %.

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