Optimizing resistance welding parameters on adhesion strength of C45 steel shaft by using Taguchi method

Minh Tan Nguyen¹, Van Nhat Nguyen¹,², Van Chau Hoang³ and Shyh-Chour Huang²,⁴

¹Faculty of Mechanical Engineering, Hung Yen University of Technology and Education (UTEHY), Khoai Chau 39000, Hung Yen, Vietnam
²Department of Mechanical Engineering, National Kaohsiung University of Science and Technology, 415, Chien-Kung Road, Sanmin District, Kaohsiung 80778, Taiwan, ROC
³Viet Nam Welding Society, No 4, Pham Van Dong Road, Cau Giay District, Hanoi City, Vietnam
⁴E-mail: shuang@nkust.edu.tw

Abstract. Adherence strength of metal coating plays an important role in workability of recovery shaft. This paper presents a Taguchi method combined Analysis of Variance (ANOVA) to optimize technological parameters for the adherence strength when restoring C45 steel shaft with a diameter of 100 mm by resistance welding using AISI 1070 filler wire. A set of welding parameters such as welding current (Iₜ₉), force (F), welding speed (Vₜ₉), is established to obtain the highest adherence strength. The optimal results have shown that the adherence strength reaches the maximum value when the welding current, force, and welding speed are Iₜ₉² = 7.5 (kA), F₁ = 1.7 (kN), and Vₜ₉₁ = 1.5 (cm / s), respectively. This value is about 90% of parent metal strength; while the metal coating is still maintains hardness as its C45 steel with hardening (50-55HRC).

1. Introduction
Welding resistance of wire is a most effective welding method in the process of welding to repair worn shaft [1, 2]. This method creates on the surface of the shaft a metal layer with a high hardness and thick enough to be able to proceed to the next machining steps. The advantage of this method is to produce a small heat-affected zone and not create a hazardous environment affecting workers’ health. Welding seam is created in solid state and does not produce melting at the contact surface. The quality of the welding joint is mainly influenced by the input welding parameters. Although, to choose a mode of welding parameters optimized using experimental welding process is very costly and inaccurate. Because empirical models need to describe the welding process close to reality and need to take into account the effect of welding parameters on the quality of welding join. For this reason, it is difficult to choose the optimal welding parameters through the experimental welding process and the results are inexact. To solve this problem satisfactorily, a Japanese engineer invented the method and later it was named after him as Taguchi method. This method is used to design parameters based on the analysis and evaluation of the influence of the input factors to the output parameters, and identify the optimal welding parameters. This method utilizes an orthogonal array to design the experiment. The purpose of this method is to determine the parameters to achieve the
highest efficiency by detecting and eliminating the effects of noise. The Signal to Noise ratio analysis is also done to select the parameters. Because of its high efficiency, the Taguchi method has been used extensively in optimizing welding parameters [3, 4].

The purpose of this study is to use a combination of Taguchi method with variance analysis to determine the optimal welding parameters for adhesion strength of the coating layer during the welding recovery process of C45 shaft by a resistance welding method. The influence of each parameter on the adhesion strength of the coating layer was also shown.

2. Experimental procedures
In this study, the steel shaft C45 with a length of 200 mm, a diameter of 100 mm was chosen to make base metal. The filler rod utilized is AISI 1070 welding wire, with a diameter of 1.8 mm. The chemical composition of base metal and filler wire were show in Table 1 and Table 2, respectively. The oxide layer on the surface of the shaft has been removed before welding. The welding process is carried out by a resistance welding machine AR072500 (Figure 1) with a set of welding parameters and their levels have been selected through the preliminary experimental results and shown as in Table 3.

![Figure 1. Resistance welding process.](image)

| Material | C  | Si  | Mn  | Mo  | S   | P   |
|----------|----|-----|-----|-----|-----|-----|
| C45      | 0.40 | 0.25 | 0.76 | 0.003 | 0.03 | 0.03 |

| Material | C  | Mn  | Si  | P   | S   | Cr  | Ni  | Mo  | Cu  | Al  |
|----------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| AISI 1070 | 0.71 | 0.86 | 0.19 | 0.026 | 0.019 | 0.06 | 0.05 | 0.02 | 0.09 | 0.0005 |
Table 3. Welding parameters and their levels.

| Parameters      | Unit | Symbol | Level 1 | Level 2 | Level 3 |
|-----------------|------|--------|---------|---------|---------|
| Welding Current | kA   | I₀     | 6,5     | 7,5     | 8,5     |
| Force           | kN   | F      | 1,7     | 2,0     | 2,3     |
| Welding Speed   | cm/s | V₀     | 1,5     | 1,75    | 2,0     |

According to Taguchi method, the total number of degrees of freedom of orthogonal array must be greater than or equal to the total number of degrees of freedom required for the experiment. So in this paper, an orthogonal array L9 has been selected for experiments by Minitab 18 and exhibited in Table 4. During the welding process, the temperature has been generated because the high-frequency current runs through the contact position between the solder surface and the compensated metal. This temperature caused the metal in the contact position to reach the plastic flow state, under the pressure of the welding electrode, causing the metal at that position to diffuse into each other and form a weld. After welding, a process of adhesion strength testing has been carried out by pulling the pins that have been placed inside of the welding specimens. The pins are made of materials with the same chemical composition and mechanical properties as the base metal, its shape and dimensions are demonstrated in Figure 2.

Table 4. L9 Orthogonal array.

| Experimental run | Control factors |
|------------------|-----------------|
|                  | I₀(kA) | F(kN) | V₀(cm/s) |
| 1                | 1      | 1     | 1        |
| 2                | 1      | 2     | 2        |
| 3                | 1      | 3     | 3        |
| 4                | 2      | 1     | 2        |
| 5                | 2      | 2     | 3        |
| 6                | 2      | 3     | 1        |
| 7                | 3      | 1     | 3        |
| 8                | 3      | 2     | 1        |
| 9                | 3      | 3     | 2        |

Figure 2. The shape and dimension of the pin for adherence strength testing (Unit: mm).

3. Results and discussion.

3.1. Analysis of S/N ratios
In this study, adhesion strength is the property considered to describe for the quality of coatings made by resistance welding wire method. Signal to Noise ratio and Means of each factor has been calculated.
to investigate their influence on the response. S/N ratio must be chosen according to criterion Larger is Better [7].

\[
SN_L = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i} \right)
\]

Where: \( y \) is the adhesion strength in a survey, \( u, n \) are the number of repetitions in one experiment.

Analysis of S/N ratio and Mean for each experiment to show the optimal level of welding parameters for higher adhesion strength of coating. The results of the analysis were shown in Table 5. Table 6 shows the value of the S/N and Mean ratios when they change from low to high level. The results show that the adhesion strength is highest at level 2 of the welding current \( I_h = 7.5 \text{kA} \), level 1 of the Force \( F = 1.7 \text{kN} \), and level 1 of the welding speed \( V_h = 1.5 \text{cm/s} \).

### Table 5. Summary of experimental results for adherence strength.

| Experimental run | Welding parameters | Adherence strength | S/N Ratios | Mean values |
|------------------|-------------------|--------------------|------------|-------------|
|                  | \( I_h (\text{kA}) \) | \( F (\text{kN}) \) | \( V_h (\text{cm/s}) \) |               |              |
| 1                | 6.5               | 1.7                | 1.5        | 440         | 52.8691      | 440 |
| 2                | 6.5               | 2.0                | 1.75       | 424         | 52.5473      | 424 |
| 3                | 6.5               | 2.3                | 2          | 393         | 51.8879      | 393 |
| 4                | 7.5               | 1.7                | 1.75       | 467         | 53.3863      | 467 |
| 5                | 7.5               | 2.0                | 2          | 446         | 52.9867      | 446 |
| 6                | 7.5               | 2.3                | 1.5        | 443         | 52.9281      | 443 |
| 7                | 8.5               | 1.7                | 2          | 438         | 52.8295      | 438 |
| 8                | 8.5               | 2.0                | 1.5        | 451         | 53.0835      | 451 |
| 9                | 8.5               | 2.3                | 1.75       | 430         | 52.6694      | 430 |

### Table 6. Response table for S/N ratios and means.

| Level | S/N ration | Mean |
|-------|------------|------|
|       | \( I_h (\text{kA}) \) | \( F (\text{kN}) \) | \( V_h (\text{cm/s}) \) | \( I_h (\text{kA}) \) | \( F (\text{kN}) \) | \( V_h (\text{cm/s}) \) |
| 1     | 52.43      | 53.03 | 52.96 | 419 | 448.3 | 444.7 |
| 2     | 53.10      | 52.87 | 52.87 | 452 | 440.3 | 440.3 |
| 3     | 52.86      | 52.50 | 52.57 | 439.7 | 422 | 425.7 |
| Delta | 0.67       | 0.53  | 0.39  | 33  | 26.3  | 19   |
| Rank  | 1          | 2     | 3     | 1   | 2     | 3     |

3.2. Analysis of variance and effect of input factors on adhesion strength

The importance of the influence of welding parameters on coating quality has been indicated by the ANOVA analysis results in Table 7. From the analysis results show that the F value is very important to evaluate the meaning of the input parameters. When the value of F is large, the change of the input factors was created a big change in the rank. Whereas the P value should be less than 0.05 to demonstrate the influence of welding parameters on the quality of the coating.

Figure 3 shows main effects plot for S/N ratio and Means. In this study, the larger signal/noise ratio is considered better, so the value of the plot in the top locations illustrates better results. Based on the diagram of dependence of adhesion strength on welding parameters in Figure 4. The adhesion strength increases when the welding current increases and the welding speed decreases (Figure 4a). Figure 4 b shows that the welding current at the optimal level \( I_h = 7.5 \text{kA} \), the adhesion strength of the coating will increase when reducing the welding speed and reducing the electrode force. The welding rate at the optimum level \( V_h = 1.5 \text{cm/s} \), the adhesion strength of the welding layer will increase if the welding current is increased and the force from the electrode roller is reduced (Figure 4.c).
Table 7. Analysis of Variance.

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|--------|----|--------|--------------|--------|--------|---------|---------|
| A      | 2  | 1668.22| 49.40%       | 1668.22| 834.11 | 82.49   | 0.012   |
| B      | 2  | 1093.56| 32.38%       | 1093.56| 546.78 | 54.08   | 0.018   |
| C      | 2  | 594.89 | 17.62%       | 594.89 | 297.44 | 29.42   | 0.033   |
| Error  | 2  | 20.22  | 0.60%        | 20.22  | 10.11  |         |         |
| Total  | 8  | 3376.89| 100.00%      |        |        |         |         |

Figure 3. Influences of welding parameters on adherence strength; (a) Main effects plot for SN ratios; (b) Main effects plot for Means.
Figure 4. (a) Surface plot of adherence strength vs $I_h$, $V_h$; (b) Surface plot of adherence strength vs $F$, $V_h$; (c) Surface plot of adherence strength vs $F$, $I_h$. 
3.3. Percent contribution of factors

The percentage contribution of parameters indicates the relationship of each factor to performance of the process. The higher the contribution percentage, the greater the influence of the factor on output quality and vice versa [8]. Table 7 and Figure 5 show the percentage contribution of welding parameters to adhesion strength. The results indicated that the welding current is the most influential parameter, followed by Force, and finally the welding speed. The percentage contribution of welding current, Force, welding speed were 49.4%, 32.38%, and 17.62%, respectively. While only 0.06% is an error that was generated during the welding process, which demonstrates that the welding process design is very successful.

![Figure 5. Percent contribution of welding parameters.](image)

4. Conclusions

The welding metal adhesion strength is high at about 81 - 96% compared to the tensile strength of the base metal, while the hardness of the welded surface layer still ensures the working conditions of the shaft. Optimal welding parameters to achieve maximum tensile strength include $I_2 = 7.5$ (kA), $F_1 = 1.7$ (kN), and $V_1 = 1.5$ (cm / s). The influence of parameters to the adhesion strength is different. In which, the biggest effect is the welding current of 49.4%, followed by the force of 32.38%, the lowest is the welding speed of 17.62%. When the welding current and force increase, the welding speed decreases, resulting in spattering and metal spill will be reduced adhesion strength. The success of this study can be applied to recover parts such as grinding rollers, shaft neck of sugarcane press, xupap of the hydraulic machine, tumbling-shaft, and steel rolling shaft.

References

[1] M Nafikov 2016 Welding International vol. 30 pp. 236-243
[2] M Nafikov 2006 Uprochnayushchie Tekhnol Pokr vol. 9 pp. 24-29
[3] U Eşme 2009 Arabian Journal for Science & Engineering (Springer Science & Business Media BV) vol. 34
[4] Y Hsiao, Y Tarng and W Huang 2007 Materials and Manufacturing Processes 23 51-58.
[5] E Kaluc and E Taban 2008 Fabrication and Economy of Welded Structures ed: Elsevier pp. 469-475
[6] M Ortiz and J Ovejero-Garcia 1992 Journal of materials science 27 6777-6781
[7] R K Roy 2010 Society of Manufacturing Engineers
[8] A Thakur, T Rao, M Mukhedkar and V Nandedkar 2010 ARPN Journal of engineering and Applied Sciences 5 22-26