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Dissimilar Arc Stud Welding AISI 304/ AISI 1008: Mechanical Properties

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Abstract. Dissimilar arc stud welding is one of the most important tasks in manufacturing processes used to join the various metals with different dimensions. In the present work, AISI 304 austenitic stainless steel studs were joined to AISI 1008 low carbon steel base plate using an arc stud welding technique. The quality performance of the weld joint was analyzed employing the bending and torque test. A range of welding current and welding time were used to elucidate the effect of welding parameters on weld quality corresponding to bending and torque strength. The statistical method based on the Taguchi technique was applied for determining the optimum parameters. The results revealed that welding time play important role in arc stud welding followed by welding current. The actual torque of 90 N.m can be obtained according to the optimum condition for the stud welding by using (DOE) at 600 AMP and 0.3 second.

Keywords: Arc stud welding; Dissimilar welding; Mechanical properties; Welding parameters; Design of experimental

1. Introduction
In manufacturing operations, the term ASW refers to the arc stud welding that is widely utilized to weld for metals with various dimensions such as sheets and plates. The heat source supplied by an electric arc is the major factor that is used to melt the metal employing the pressure on the joint area for a short time.[1]. The stud welding process is applied to increase the quality of the welding joint for the parts. The arc stud welding process is well-known and widely applied in various industries and production areas such as steam boiler production, bridge, automotive construction, electric, and electronic industries. The main reason for the multiplicity of these applications is the short time of the welding cycle, the production of strong welding joint and its adaptability to automation [2]. The manufacturers can address many of the cost reduction targets using drawn arc stud welding, but the quality and reproducitively of such stud welds have been a concern. The improvement of product quality can be obtained using the appropriate selection of digital equipment and controlling the process parameters automatically [3]. It is a well-known fact that the optimal selection of welding parameters plays an important role in the quality of arc stud welding processes. These parameters include the current of welding, time of welding, length of the stud (plunge), and space between the stud tip and the plate (lift). The quality of the weld can be determined based on both the current welding and the time of welding that directly affect the size of penetration for the weld and effective heat zone [1-4]. Dissimilar welding has a strong effect on the industry since it gives more efficient and cost-effective combined alloys. The welding of dissimilar materials such as copper plates and other different can be
applied with various process parameters [5]. In dissimilar welding, the selection of the right materials leads to active meet for the materials during the process, thus reducing corrosion causes [6-7]. Designers applied new technique to join austenitic stainless steel with high corrosion resistance to low carbon steel with high strength. Carbon steel is considered to be a low cost in many applications such as pipes, vessels, evaporators, heat exchangers, and petrochemical industries [8]. Heat input is the most important factor that affects the cooling rate which has an impact effect in defining the final metallurgical structure of the weld and heat affected zone [9]. However, the failure behavior of dissimilar ASW can be problematic due to the difference in the properties of the materials (strength, ductility, and work hardening) of the stud and the base. On the other hand, the microstructural gradient across the weld is more complicated.

As mention above, the joining of dissimilar metals is more complex compared to the joining of similar metals because of the differences in physical metallurgical and mechanical properties [7,10,11]. In most weldments, there are metallurgical problems by means of the degradation of mechanical properties because of the brittleness part weldments. Generally, the reduction in mechanical properties and corrosion resistance is due to the welding between austenitic stainless steel and low alloy steel because of the segregation of the alloying element at the grain boundaries [12]. Therefore, the selection of appropriate parameters utilizing a high speed for stainless steel welding and low alloy steel must be taken into consideration [8].

Based on previous articles, many works of ASW have been achieved on the welding of the parts of the same metal. While the arc stud welding by different materials is extensively performed to design the joint parts according to the required mechanical properties. Samardzic et al. [1] used the application of an on-line monitoring system to record welding current and voltage. Recorded values were analyzed off-line for the weld with both the stable arcs and processes of intentionally induced instabilities. Ramasamy et al. [3] focused on the effect of variation in the welding process and manufacturing factors on the quality of short duration drawn arc stud welding. Stefaniﬂa et al. [13] presented an investigation on the influence of the welding parameters during the drawn stud welding process with a ceramic ferrule on the depth of penetration of the weld. Lee et al. [14] explained the importance of the stud welding process in the shipbuilding industry by emphasizing the importance of the welding parameters on the weld joint performance. Necip et al. [4] studied arc stud welding of AISI 304 stainless steel which was welded on the same type of base plate. They observed that welding current, welding time, plunge, and lift are prominent stud welding parameters welding current and welding time must be selected properly to obtain a high quality performance joint. Ehab et al. [15] made research on the microstructure and mechanical properties of parts produced by various factors of the arc stud welding process. Sobhani and Pouranvari [16] showed metallurgical and mechanical properties of dissimilar spot welds. They used both stainless steel by means of the 2304 duplex and high strength steel based on MS 1200 martensitic. Khdir et al. [17] applied austenitic AISI 304 and low CS AISI 1018 with different heat parameters to obtain the mechanical properties and microstructure for the dissimilar welds. They concluded that there is a possibility to join low CS AISI 1018 with austenitic AISI 304 as well as they revealed that the tensile strength of joint raises. Silva and Brito [18] conducted the dissimilar welds through stainless steel and low carbon steel according to the spot welding. They showed a positive relation below the max. current 13.8 kA based on max. load obtained by tensile-shears test.

According to the previous reports that introduced above, the arc stud welding process using the dissimilar type needs in-depth study to show the effect of parameters on welding operation as well as the behavior of weld material can change according to the heat factors that depend on welding current and time as well as heat transfer between the material and environment temperature. On the other hand, the complexity of the dissimilar welds due to the coupled thermo-mechanical case requires continuous investigation to control the welding process to obtain the products with high quality. In this work, arc stud welding of AISI 304 austenitic stainless steel studs to AISI 1008 low carbon steel plates according to the different welding current and welding time is developed. The aim of the study is to correlate arc stud welding parameters with mechanical properties of the weldments by means of the bending and torque test.
2. Materials properties of AISI 304 and AISI 1008

In this paper, AISI 304 and AISI 1008 were selected as materials of partially threaded studs with a diameter of 10 mm and plate thickness 6 mm respectively. The chemical composition and mechanical properties of the materials are put in Tables 1 and 2 in order.

Table 1. Chemical composition of AISI 304 and AISI 1008 [19]

| Element | C | Si | Mn | P  | S  | Cr  | Ni  |
|---------|---|----|----|----|----|-----|-----|
| AISI 304 | 0.08 | 1  | 2  | 0.045 | 0.03 | 18-20 | 8-11 |
| AISI 1008 | 0.1 | ---- | 0.3-0.5 | 0.04 | 0.05 | ---- | ---- |

Table 2. Mechanical properties of AISI 304 and AISI 1008 [19]

| Material type | Tensile strength | Yield strength | Percent elongation |
|---------------|------------------|----------------|-------------------|
| AISI 304      | 515 MPa          | 205 MPa        | 30%               |
| AISI 1008     | 305 MPa          | 170 MPa        | 30%               |

3. Experimental procedure

For obtaining a high quality for the weld joint, careful attention is important to select the process parameters and their levels. In this study, two parameters with four different levels were considered. Arc stud welding machine Dabotek type DT 1000 was used to join the studs to plates as shown in Figure 1. The welding operation sequence for arc stud welding with ceramic ferrule is shown in Figure 2. Stud metals have a length of 57 mm with a diameter of 10 mm and the base metal plate has a length of 100 mm, width 100 mm, and thickness of 6 mm are welded to produce the sample.

Figure 1. (DABOTEK) Arc stud welding DT (1000).

Figure 2. Steps sequence for stud welding with ceramic ferrule [20]
To analyze S/N ratio, all data were obtained and fed as input into the design expert. Then, the value of S/N ratio was used to estimate which any parameter was more statistically significant. Also, the level of the parameter was identified to show better data quality that represents optimum parameter values. The calculations of the S/N ratio can be identified by three main categories. First is larger-the-better, second is nominal-the-better, and finally, smaller-the-better. In this study, the raw data of responses are (current, time, and torque) and all these smaller-the-better were utilized [21-22].

\[ SN_s = -10 \log \left( \frac{\sum_{u=1}^{N_i} y^2u}{N_i} \right) \]  

(1)

Where \( SN_s \) represents signal to noise ratio of experiment number \( i \), \( N \) is the number of measurements, \( y \) known measure value, \( i \) is experiment number, and \( u \) trial number.

Table 3 depicts the value of welding parameters and corresponding levels. The array is with type of \((4^2)\) and the magnitudes design experiment according to Taguchi approach is shown in Table 4 while, Table 5 is shown variable of stud welding which were used in experiment.

### Table 3. Stud welding parameters and corresponding levels.

| level  | 1       | 2       | 3       | 4       |
|--------|---------|---------|---------|---------|
| Current AMP | 200     | 200     | 200     | 400     |
| Time Second | 0.2     | 0.25    | 0.35    | 0.2     |

Table 4. L16\((4^2)\) orthogonal array for the stud welding parameters.

| No. | 1       | 2       | 3       | 4       | 5       | 6       | 7       | 8       | 9       | 10      | 11      | 12      | 13      | 14      | 15      | 16      |
|-----|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Time Second | 1       | 1       | 1       | 1       | 2       | 2       | 2       | 2       | 3       | 3       | 3       | 3       | 3       | 4       | 4       | 4       |
| Current AMP | 1       | 2       | 3       | 4       | 1       | 2       | 3       | 4       | 1       | 2       | 3       | 4       | 1       | 2       | 3       | 4       |

Table 5. Variables of stud welding experiments.

| No. | 1       | 2       | 3       | 4       | 5       | 6       | 7       | 8       | 9       | 10      | 11      | 12      | 13      | 14      | 15      | 16      |
|-----|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Time Second | 0.2     | 0.2     | 0.2     | 0.25    | 0.25    | 0.25    | 0.25    | 0.3     | 0.3     | 0.3     | 0.3     | 0.3     | 0.35    | 0.35    | 0.35    | 0.35    |
| Current AMP | 200     | 400     | 600     | 800     | 200     | 400     | 600     | 800     | 200     | 400     | 600     | 800     | 200     | 400     | 600     | 800     |

In order to perform the bending and the torque test, sixteen different experiments were carried out according to the design of the experiment layout. Welding parameters that are employed for welding are 200, 400, 600, and 800 AMP while welding time represents 0.2, 0.25, 0.3, and 0.35 second. Bending was conducted according to the ISO 14555 standard. The bending test was conducted by the torque wrench to test the samples until the stud bend 30° away from its axis while the welding is subjected to the bending in an undefined manner. This test serves as a simple bench test for approximate checking of the chosen welding data as illustrated in Figs. 3A, 3B, and 3C. On the other hand, Figure 3D presents the photo from the microscope for fractured specimen by bending test.
Figure 3. Bending test (A) passed sample (B) failed sample (C) bend test and (D) fracture of specimen based on the bending test

In the torque test, the stud should be torqued till a pre-specified load is attained or until the stud fails, and failure occurs in the stud material itself on the thin plate, then the plug of base metal should be torn out. The tensile load was applied on an arc welded stud and adopts on both the stud design and a special tool that uses to grip the stud properly without damage. Figure 4A presents the torque test with a simple tensile load to straight-threaded studs. In this test, a hardened sleeve, washer, and nut of the appropriate size were provided. The nut is tightened with a torque wrench against a washer bearing on the sleeve by applying the tensile load with some shear effect on the stud. Figure 4B indicates the photo from the microscope for the fractured specimen by torque test.

Figure 4. (A) Torque test and (B) fracture of specimen based on the torque test
4. Results and Discussion

4.1. Bending test results

According to the bending test, the results were shown that some samples passed the test while the others did not, due to the improper welding parameters selection. High or low welding heat energy affects the weld quality in bending due to the formation of non-uniform weld fillet, incomplete fusion, or excessive fusion. Bending test results are presented in Table 6 that indicates the samples have welding time at 0.3 second recorded 400 AMP and 600 AMP while the time 0.25 second gave 800 AMP. It can be said that the optimum welding time parameter equals 0.3 second.

| ` ` | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Current AMP | 200 | 200 | 200 | 200 | 400 | 400 | 400 | 400 | 600 | 600 | 600 | 600 | 800 | 800 | 800 |
| Time Second | 0.2 | 0.25 | 0.3 | 0.35 | 0.2 | 0.25 | 0.3 | 0.35 | 0.2 | 0.35 | 0.2 | 0.25 | 0.3 | 0.35 | 0.35 |
| Fracture location. | Failure Weld | Weld zone | No fract. | Weld zone | No fract. | Weld zone | No fract. | Weld zone | No fract. | Weld zone | No fract. | Weld zone | No fract. | Weld zone | No fract. |
| Assessment | ------- | Failed | Pass | Failed | Pass | Failed | Pass | Failed | Pass | ------- |

4.2. Torque test results

The variation in torque values observed in different welding currents as illustrated in Figure 5. For the AISI 304, the minimum torsional stress of 32 N.m was determined at weldments according to the ISO 3506-1,2009 standard while torsion stress for all tests was recorded larger than the standard value and failure occur for samples. At the current of 400 AMP, the torque value begins from 35.5 N.m at the time of 0.2 second and raises with increasing the time of welding until reaches to 75 N.m at 0.3 second. The welding current raises to 600 AMP while the torque reached to 50 N.m at 0.2 second and increased to the peak value of at 0.3 second with 90 N.m. This represents enough time for the welding that gives good penetration and sufficient fillet around the stud [15]. In welding current 800 AMP, torque was determined 39 N.m at 0.2 second. Finally, It can be said that the optimum welding condition can be obtained at 600 AMP and 0.3 second.

![Figure 5. Torque strength and welding current.](image-url)
4.3 Design of experimental (DOE) Taguchi method

In Table 7, the lowest value of SN ratio gives better data quality as compared with other levels. It can be observed that sample 11 gave the lower value of SN ratio therefore they have the highest value of the torque equals 90 N.m. After the preparation for stud welding, the statistical approach of Taguchi was utilized to choose the optimum condition for stud welding of dissimilar material. The highest values of torque equal to 90 N.m at 600 AMP and 0.3 Second were chosen from SN ratio at the best one as illustrated in Table 7 and Figure 6.

Table 7. Signal to noise ratio and mean for torque

| Time(second) | Current (AMP) | Torque | SN ratio | Mean     |
|--------------|---------------|--------|----------|----------|
| 0.20         | 200           | 0.000  | *        | 0.000    |
| 0.20         | 400           | 35.450 | -30.9923 | 35.450   |
| 0.20         | 600           | 50.240 | -34.0210 | 50.240   |
| 0.20         | 800           | 33.880 | -30.5989 | 33.880   |
| 0.25         | 200           | 0.000  | *        | 0.000    |
| 0.25         | 400           | 55.650 | -34.9093 | 55.650   |
| 0.25         | 600           | 43.550 | -32.7798 | 43.550   |
| 0.25         | 800           | 39.826 | -32.0033 | 39.826   |
| 0.30         | 200           | 0.000  | *        | 0.000    |
| 0.30         | 400           | 74.803 | -37.4784 | 74.803   |
| 0.30         | 600           | 90.380 | -39.1214 | 90.380   |
| 0.30         | 800           | 0.000  | *        | 0.000    |
| 0.35         | 200           | 0.000  | *        | 0.000    |
| 0.35         | 400           | 47.140 | -33.4678 | 47.140   |
| 0.35         | 600           | 48.330 | -33.6843 | 48.330   |
| 0.35         | 800           | 0.000  | *        | 0.000    |

Figure 6. SN ratio and mean torque.

5. Conclusions

The experiments of arc stud welding based on dissimilar metals were successfully performed to obtain a good weld joint by AISI 304 austenitic stainless steel and AISI 1008 low carbon steel. The welding current and welding time were deeply studied, and they should be selected properly. The main conclusions are drawn as follow:

- Welding time is the most important parameter in arc stud welding followed by welding current, proper welding time produces a good weld penetration.
• Low welding current and welding time cause uncompleted fusion weld while using a high level of welding current and welding time causes burned weld. It is revealed that over fusion energy (uncompleted fusion) in the first case and high fusion energy (excessive fusion) in the second case.
• To get good weld quality both the current and time for the welding must be chosen properly according to each other.
• The highest value of torque strength was evaluated at 600 AMP and 0.3 second that reduce with high welding parameters.
• All the fractures in bending tests were noticed in weld zone.
• The optimum condition recorded that the high value of torque can be determined with current welding 600 AMP and time welding 0.3 second.

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