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Spot Welding Parameters Effect on Surface Corrosion Behavior of Carbon Steel Sheet

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Abstract

The current article discusses the corrosion behavior of carbon steel SAE1006 with a thickness of 1 mm that was welded by resistance spot welding under various welding conditions. Welding current and time have been adjusted, whereas other welding characteristics have remained constant. The welding process was carried out with a welding current of 7, 7.5, and 8.2 kA and a welding time of 15, 25, and 35 cycles. Following the welding step, every joint was tested for corrosion in a 1 M H_2SO_4 solution using three-electrode polarization resistance methods. The outcome reveals that as the welding current and welding time raised, the corrosion resistance reduced because the welding heat input to the weld nugget zone decreased. As the microstructure of the weld nugget zone altered, the welding heat input was proven to have a more significant influence on the corrosion rate.

"Keywords: Carbon steel; spot welding parameters; corrosion behavior; polarization curves."

1. Introduction

Carbon steels are the most commonly utilized materials used in the infrastructure and manufacturing industries due to their reasonable strength, good weldability and formability, that allow them to be employed in a wide range of engineering implementations [1]. Welding is among the most common joining methods used in manufacturing and fixing machinery. These are prone to corrosion in service because they are subjected to various environmental conditions[2, 3].

Resistance spot welding is a crucial industrial procedure. The overlapping work is situated between the water-cooled electrodes in electric resistance point welding, and heat is acquired by carrying a large electrical current for a narrow time [4]. Because of its benefits in welding efficiency and automation, resistance spot welding is common for making sheet metal pieces like automobiles, truck cabins, rail vehicles, and home projects.[5].

Resistance spot welding (RSW) is a common way to join sheets of metal together for things like car structures because it could be done quickly and consistently[5]. Because of the alignment of sheets and electrodes, and the surface situation, every spot welding is not accomplished on the identical condition. As a result, a spot welding process requires optimal operating conditions that allow for parametric quantity allowance for excellent welding quality. The ideal condition must take into account the quantity and duration of electric current, the form and material qualities of the electrode, the surface situation, and sheet orientation. As a result, the resistance spot welding process's performance is critical to the overall welding structure's quality[4].

Past research has looked at the impact of spot welding criteria on metal corrosion resistance. The influence of welding current on the resistance spot weld efficiency of atmospheric corrosion resistance steels was explored by Akkas et al.[6]. They discovered that small weld nugget widths had been acquired at low welding current owing to reduced heat application to the welding region. The cross-section area decreases at high welding current. Banerjee et al. [5] utilized potensiostatic and galvanostatic polarization to investigate the impact of resistance spot welding criteria on the corrosion rate. They also studied the stability of intermetallic phases at the heat influenced zone of galvannealed "HIF340" steel weldment. They discovered that as weld heat input raised, so did the corrosion rate of heat affected zone. Jannifar et al. [7] investigated whether the welding current variable would influence changes in the rate of corrosion of the base metal st37. The current welding procedure has had a substantial impact on the corrosion rate.

The primary goal of this research was to investigate the effect of welding parameters ("spot welding

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current and time”) on the corrosion performance of spot-welded carbon steel sheets. The corrosion effectiveness of the spot-welded joints of the carbon steel sheet was evaluated using potensiodynamic polarization. The microstructural analysis was evaluated to analyze the importance of spot welding criteria on the microstructure of welded carbon steel and decide how these adjustments could hinder the corrosion rate. After corrosion, the “scanning electron microscope (SEM)” was utilized for this investigation.

2. Experimental

2.1. Material

The base metal employed in this study for all testing was a single sheet of carbon steel (SAE1006) with a nominal thickness (1 mm). Table 1 demonstrates the chemical constituents of the carbon steel sheet. The carbon steel sheet was cut into small samples with specific dimensions. The schematic diagram of the joint is shown in Figure 1. The specimens were 100 mm long × 25 mm width, with overlap equivalent to the width. Both samples were taken in a cold rolled state. The suggested configuration and dimensions of the samples are based on the American Welding Society (AWS) [8]. No surfaces coating were applied for the samples.

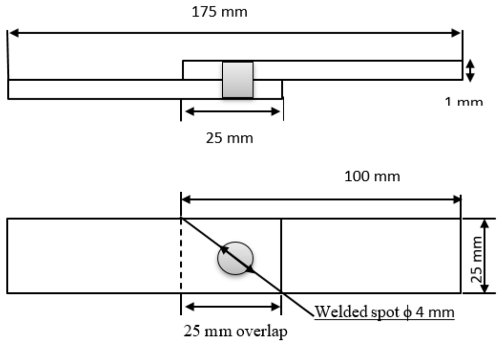

Figure 1. Dimensions of RSW specimen.

Table 1.
Chemical compositions of the test sheet.

Elements	Composition (weight %)
Carbon (C)	0.056
Chromium (Cr)	0.016
Nickel (Ni)	0.024
Manganese (Mn)	0.213
Sulfur (S)	0.003
Molybdenum (Mo)	0.002
Silicon (Si)	0.036
Phosphorus (P)	0.004
Iron (Fe)	Base

2.2. Spot welding Process

A resistance spot welding device with a timer and current control was employed. The ZP18 welding device has a maximum power capacity of 15 kVA and a primary voltage frequency of 50-60 Hz. A 4 mm diameter pure water-cooled copper electrode was chosen for welding. Figure 2 demonstrates how the specimens were layered and welded with a 25 mm interval. Other welding variables like electrode force and welding environment were held constant, whereas two factors, welding current and electrode welding duration, were chosen as governing variables. Welding currents of 7, 7.5, and 8.2 kA were adopted, with 15, 25, and 35 cycles of welding times.

Figure 2. Appearance for resistance spot welding joint.

2.3. Sample preparation

The welded samples were cut into the square section after the spot welding was done in order to perform the electrochemical experiment and investigate their microstructure. As indicated in Figure 3, the spot-welded samples were immersed in epoxy resin, exposing just the spot welding cross-sectional area to the solution with 0.1256 cm2. Detailed mounting information can be obtained from Ghalib et al.[9].

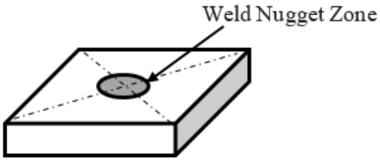

Figure 3. A Schematic diagram of the cross-section of spot welding joint indicating the locations examined for corrosion test.

The test specimens were gradually ground with silicon carbide (SiC) grits ranging from 500 to 4000 grit before being washed with distilled water. A 3electrode electrochemical cell was implemented to analyze the electrochemical behavior of individual specimens. The working electrode’s potential was evaluated against a saturated calomel electrode (“SCE”) standard electrode. A platinum (Pt) wire served as the auxiliary electrode. At a concentration of 1M, Sulfuric acid was utilized as the electrolyte in this experiment. At temperatures of 25°C, the corrosion behavior of the specimens was investigated. A GAMRY potentiostat model was used to acquire individual polarization scans for all spot-welded specimens at a rate of “1 mV/s”. The sample was allowed to equilibrate in the test solution for a minimum of 1000 seconds before every polarization to achieve a stable open cell potential (OCP). It was necessary to evaluate the materials' overall electrochemical behavior using Tafel extrapolation to calculate their "corrosion potential (Ecorr)" and "corrosion current density (icorr)". Scanning electron microscopy (SEM) was utilized after corrosion to evaluate the materials in order to determine any microstructural differences caused by spot welding parameters in spot-welded carbon steel.

3. Result and Discussion

3.1. Effect of spot-welding current

The potentidynamic polarization approach was used to study the impact of welding current on the corrosion characteristics of a nugget surface for carbon steel joint. Tafel extrapolation was employed to determine the "corrosion current and potential related with various welding currents based on the electrochemical properties of the nugget surface region. For every welding current, corrosion rate observations were taken on various specimens. Figure 4 displays the polarization curves for the nugget surface region, which found similar tendencies. According to the observations of polarization curves, increased welding current resulted in a higher corrosion rate. Large welding currents alter the heat intake value throughout the welding technique, causing this behavior.

The quantity of heat generated determines the welding current. The heat input energy is raised as the welding current is raised. As a result, the amount of molten metal produced grows. On the other hand, excess welding current causes nugget overgrowth, resulting in nugget expulsion. As previously reported [10], this could induce weld flaws into the weldment, like excessive and voids electrode indentation, lowering the nugget weld's corrosion resistance.

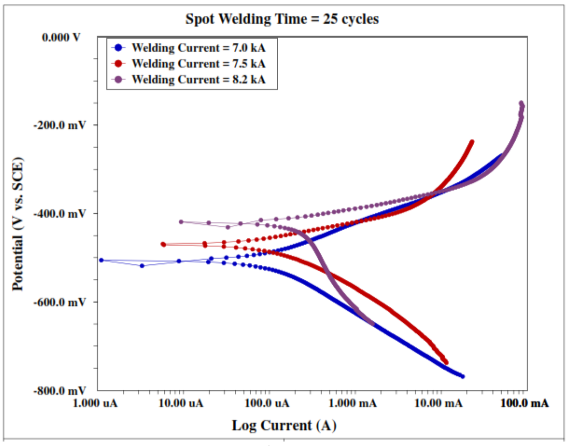

Figure 4. Polarization curves of samples in 1 M H_2SO_4 at various welding currents

Table 2 demonstrates that spot-welded carbon steel has a higher Icorr (corrosion current density) and a higher Ecorr (corrosion potential). This rise in corrosion proved the impact of welding current on corrosion behavior.

The rate of corrosion has gradually grown as the welding current has raised. For welding specimens with a 7 kA current, the mean corrosion rate was 59.76 mpy. The mean corrosion rate estimate for welding specimens with 7.5 kA was 317.2 mpy, representing a 257.44 mpy improvement over 7 kA current. The average corrosion rate for welding specimens with a current of 8.2 kA was 485.9 mpy, indicating a 168.7 mpy improvement from welding specimens with a current of 7.5 kA and a 426.14 mpy increase from welding specimens with a current of 7 kA

Table 2.
The results of different welding parameters' potentiodynamic polarization tests.

Spot welding parameters		Potentodynamic polarization test				
Current (kA)	Time (cycles)	βc (V/dec.)	βa (V/dec.)	Ecorr. (mVSCE)	Icorr. (μA/cm^2)	Corrosion rate (mpy)
7	25	8.18E-02	5.43E-02	-508	17.6	59.76
7.5	25	9.67E-02	5.13E-02	-470	93.5	317.20
8.2	25	2.26E-02	3.71E-02	-420	143	485.9

3.2. Effect of spot welding Time

Figure 5 displays the potentiodynamic polarization curves of nugget surface welds generated at various welding times. Table 3 also includes Ecorr (corrosion potential), Icorr (corrosion current density), βc (cathodic branch slope), and βa (anodic branch slope) calculated using potentiodynamic polarization curves.

According to the polarization curves, raising welding duration causes a higher heat input to the weld area and a longer weld nugget, which increases the corrosion rate of joints, as illustrated in Figure 5. Because the higher the heat intake value generates a phase balance disturbance in the weld metal section, the corrosion rate at welding time 15 cycles is less than the corrosion rate at welding time 35 cycles. On the other hand, a minimal heat input value might not accomplish the required weld penetration[11]. Heat input that isn't too high will push the polarization curve to the positive side, improving corrosion resistance [12]. The molten metal expands and fused metal spurts when held for a long time. Peaks and valleys develop on the surfaces of metal components on a micro level, and the crystalline arrangement of the material changes.

Table 3 shows that raising the welding time from 15 to 25 cycles shifts the corrosion potential toward more negative values at constant welding. By increasing the welding period from 25 to 35 cycles, the potential corrosion is shifted approach smaller negative values and the corrosion current density is increased. As a result, corrosion resistance is reduced. The primary reason for this issue could be the high heat input from the welding current (7.5 kA) combined with increased welding time, reducing the weld zone cooling rate. As a consequence, extending the welding time reduces corrosion resistance.

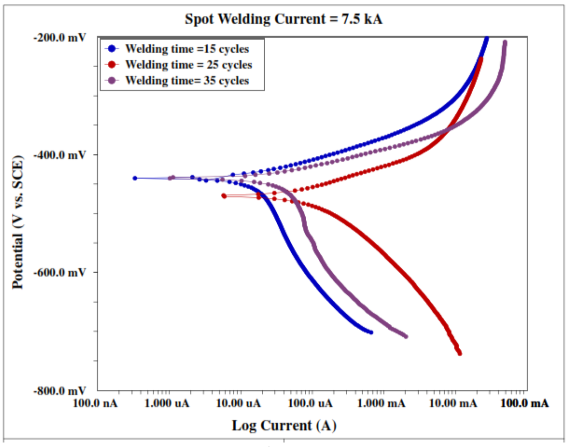

Figure 5. Polarization curves of samples at various welding time in 1 M H_2SO_4 solution

Table 3.
Resistance spot-welded carbon steel potentiodynamic polarization experiments in 1 M H_2SO_4 solution at various spot-welding time

Spot welding parameters		Potentodynamic polarization test				
Current (kA)	Time (cycles)	β_c (V/dec.)	β_a (V/dec.)	$E_{corr.}$ (mV_{SCE})	$I_{corr.}$ ($\mu A/cm^2$)	Corrosion Rate (mpy)
7.5	15	2.36E-01	3.93E-02	-440	16.4	55.56
7.5	25	9.67E-02	5.13E-02	-470	93.5	317.20
7.5	35	1.67E-01	1.38E-01	-440	112	379.30

The nugget welds built at varied welding time and currents display active behavior in “1 M H_2SO_4 solution”, as shown in Figures 4 and 5. On their surfaces, no passive film formed. Earlier studies conducted in “0.1 M H_2SO_4 solutions” [13] revealed the active characteristics. Moreover, with increasing welding time, the samples’ corrosion potentials and current densities are more significant than those with the increasing welding current. Figures 4 and 5 show that uniform corrosion is the major corrosion mechanism for the welded specimen in 1 M H_2SO_4 solution.

3.3. Microstructure analysis

The weld nugget zone is a critical zone of resistance spot welded joints, and its microstructure properties directly impact welded joint corrosion behavior. Under varied welding conditions, heat generation and heat transport in the nugget zone were distinctive, resulting in a highly diverse microstructure. Figures 6 and 7 depicted the impact of welding time and current on the microstructure of the weld nugget zone after corrosion, respectively.

Figure 6a shows that the welding current was low (7 kA), the welding heat input was minimum, and the weld nugget was primarily uniform structure. Simultaneously time, the weld nugget zone’s plastic deformation was significant, and there was no welding defect in the weld nugget zone. The welding heat increased as the welding current was raised to 7.5 kA, and the microstructure got coarser. The weld nugget’s microstructure was relatively homogeneous, and there were no evident welding defects. When the welding current was raised to 8.2 kA, a large number of spatters resulted in heat loss and a quick cooling rate, causing the grains in the weld nugget core to grow and coarsen dramatically, as indicated in Figure 6b. In summary, as the welding current increased from 7 kA to 8.2 kA, the weld nugget columnar structure became coarser, owing to the increased heat input and slower cooling rate.

Following the electrochemical experiment, Figure 7 depicts the surface shape of the weld nugget zone after corrosion as welding time is increased. The weld nugget zone coarsened as welding time increased from 15 cycles (Figure 7a) to 35 cycles (Figure 7b). Furthermore, a cavity grew larger as welding time rose, and corrosion resistance decreased after 35 cycles.

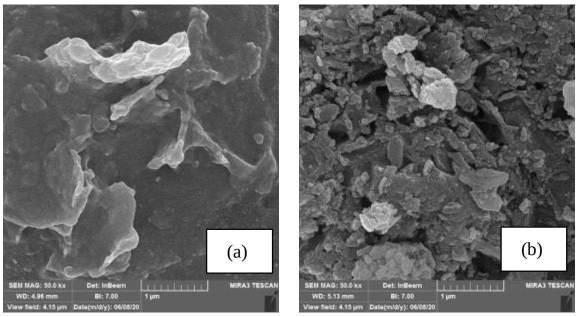

Figure 6. Impact of the spot welding current on the microstructure of the weld nugget zone for 25 cycles after corrosion at a) 7 kA and b) 8.2 kA

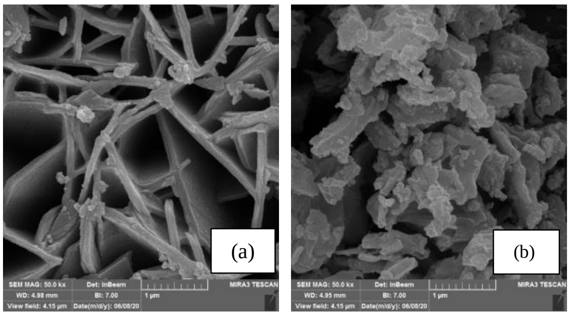

Figure 7. Impact of the spot welding time on the microstructure of the weld nugget zone for 7.5 kA after corrosion at a) 15 cycles and b) 35 cycles

4. Conclusion

The corrosion intolerance of spot-welded joints made under various welding parameters for carbon steel sheets was investigated in this work. It’s worth noting that as the welding parameters varied, the corrosion behavior of the weld nugget area altered as well. As a result, it’s possible to deduce that welding parameters influenced the corrosion attitude of spot welds formed in carbon steel sheets. Variations in welding time and current led the welding operation to vary in electrochemical characteristics and affected the corrosion behavior of the weld nugget zone, as demonstrated by the corrosion potentials and current density of the weld nugget zone. The corrosion resistance of spot welding joints was altered due to microstructural variation on the scale generated by welding parameters. The corrosion attitude of welded carbon steel sheet samples in 1 M H_2SO_4 solution was active, and these samples corroded uniformly, according to the outcomes of potensiodynamic polarization tests.

5. Acknowledgment

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