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Characterization of galvanized steel-low alloy steel arc stud welded joint

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ABSTRACT

Purpose: This paper investigates the possibility of successfully welding a Low Alloy Steel (LAS) stud to Galvanized Steel (GS) plate.

Design/methodology/approach: Arc Stud Welding (ASW) was performed on joining LAS studs to GS plates. Welding parameters were selected based on weld trails. The first tests of the welded joints were based on visual inspection for welding defects such as lack of fusion and undercut welding defects. The good quality should be free of these defects and have full weld reinforcement. Other weld qualifications included torque strength test, microhardness test, and microstructure examination.

Findings: The LAS studs have been successfully welded to a galvanized steel plate using the arc stud welding process. Higher welding current with adjusted welding time (800 A, 0.3 s) gave full weld reinforcement, the best joint appearance, and strength. Martensite phase was detected in the weld area and heat affected zone (HAZ), affecting the joint mechanical properties. Hardness property varied across the welded joint, and maximum hardness was recorded at the HAZ at the stud side. Hardness increased with the increasing welding current. At 800 A, welding current hardness was 10% higher than at 400 and 600 A. Torque strength was affected by weld reinforcement, and 800 A gave the best weld reinforcement that produced the highest torque strength.

Research limitations/implications: The main research limitation is the difficulty of welding LAS studs and GS plates. In conventional welding methods, such as gas metal arc welding, it is hard to get full weld penetration due to the geometry restrictions of the joint, which results in partial weld penetration between the studs and the plates. Furthermore, the issue of zinc evaporation during welding can be reduced by the advantage of the very high welding speed (in milliseconds) of ASW that overcomes the problem of continuous welding that usually results in the formation of harmful porosities and poor weldability.

Originality/value: In this research, galvanized steel plates were successfully welded to LAS studs using the ASW process. The welding parameters for this dissimilar welding joint were carefully selected. Microstructure changing due to the welding process was investigated. The joint mechanical properties were evaluated.

Keywords: Arc stud welding, Dissimilar welding, Low alloy steel, Galvanized steel, Martensite, HAZ

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MANUFACTURING AND PROCESSING

1. Introduction

Galvanized steel is a popular material for constructing lattice towers and other power transmission and distribution facilities employed in the electric power industry [1]. The utilization of galvanized steel in this field is attributed to its good performance in most environments and atmospheres. The galvanizing of zinc protects the carbon steel substrate by serving as a corrosive barrier layer and acting as a sacrificial anode [2]. Most structures of transmission towers usually get connected with bolts [3]. Welding can be done by joining bolts and studs to the galvanized steel body of a lattice power structure [4]. However, many difficulties arise when welding galvanized steel, and precautions must be taken during welding. One of the main problems is the zinc coating which must be removed prior to welding to ensure a sound weld [5]. Zinc is likely to evaporate during welding due to its lower boiling temperature than carbon steel substrate, which causes the ejection of the weld metal from the joint [6].

On the other hand, the low alloy steel studs are a good candidate to connect lattice power structures. However, welding of low alloy steel must be monitored precisely due to the effect of alloying elements on weldability, especially with a high carbon percentage. Increased levels of alloying elements and carbon result in increased hardenability and, as a result, decreased weldability. Since the presence of martensite is more likely to exist and causes brittleness in the heat-affected zone (HAZ) [7,8]. According to the fact that the base materials determine the final attributes of dissimilar junctions, microstructural changes in the fusion zone, and the welding process used. The arc stud welding (ASW) process strongly presents itself for joining galvanized steel body of a lattice power structure with studs.

On the one hand, the ASW process specializes in welding bolts, pins, and studs to plates [9]. On the other hand, the procedure of ASW uses an electric arc's heat to melt a relatively small region and then applies pressure to form the junction in fractions of a second [10]. This would be an advantage for joining dissimilar metals since the localized and short-time weld provides overcomes most galvanized and alloy steel welding issues [11]. Therefore, this research focused on welding low alloy steel studs to galvanized steel plates using the arc stud welding process. The welding parameters for this dissimilar welding joint were carefully selected. Microstructure changing due to the welding process was investigated. The joint mechanical properties were evaluated.

2. Experimental work

Galvanized steel plates with dimensions of 12×12×5 mm and low alloy steel partially threaded studs with dimensions of M10 mm×70 mm were used in this research. The production conditions of the studs and the plates were as quenched and annealed conditions, respectively. The chemical compositions of the utilized materials are presented in Table 1. ASW machine type DABOTEK DT (1000) was used to perform the weld. The welding operation involved utilising different welding currents and times listed in Table 2 to investigate their impact on welding properties. The welding gun was positioned in the centre of the plate to avoid arc blow occurrence. To secure the plate, an appropriate fixture was created. To improve electrical conductivity, two earth poles were placed horizontally in opposing directions. A copper foil was also put between the workpiece and the fixture. The microstructure evolution in the welding zone and HAZ was investigated using an optical microscope.

The samples of microstructure examination were extracted from the welding joints at the weld cross-section, as shown in Figure 1. Standard grinding and polishing techniques were used to prepare the samples for the microstructure examination, followed by etching with Nital solution (98% water + 2% HNO_3) to reveal the micro-structural features. Microhardness and torque strength tests were used to examine the mechanical properties of the weldments. The Vickers microhardness test was carried out in accordance with the ASTM 384 standard, employing the LARYEE microhardness testing instrument. The measurements were taken along the BM, HAZ, and FZ, with a 500 g load and a 15-second dwell duration. The torque test was carried out using a German-origin MANESSMAN torque wrench device. The torque test was performed in accordance with BS EN ISO 14555:2014, as presented in Figure 2.

Table 1.
Chemical composition of the base metals

	Alloying elements, wt.%									
	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Fe
LAS	0.360	0.218	1.480	0.0069	0.0073	0.0194	0.0165	0.0077	0.0042	Bal.
GS	0.056	0.010	0.407	0.017	0.016	0.017	0.031	0.004	-	Bal.

Table 2.
Arc stud welding parameters utilized in this work

Welding current, A	Welding time, s
400	0.3, 0.4, 0.5
600	0.3, 0.4, 0.5
800	0.3, 0.4, 0.5

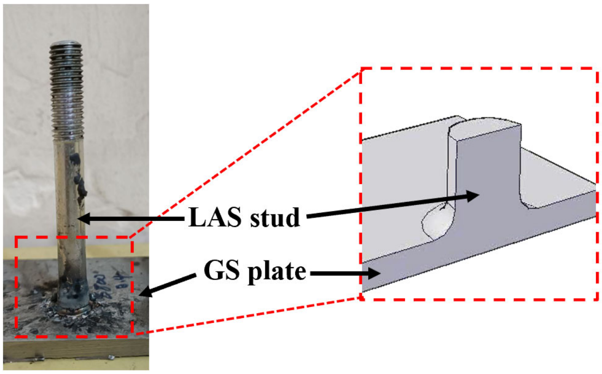

Fig. 1. Schematic plot of the samples extracted from arc stud welded joint

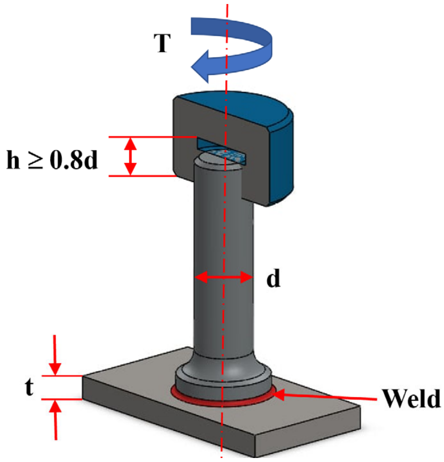

Fig. 2. A schematic of the torque test assembly according to the BS EN ISO 14555:2014, *T*: torque, *d*: stud diameter, *h*: length of threaded part of the nut, *t*: BM plate thickness

3. Results and discussion

Weld quality was first evaluated by visual inspection. One of the important indications for better welding is the presence of complete weld reinforcement around the base of the stud shank. It was found that using the combination of 800 A welding current with 0.3 s welding time gave the best weld reinforcement. Figure 3 shows three stud-welded joints welded with three welding currents (400 A, 600 A, and 800 A) at 0.3 s welding time. The higher welding current provided enough heat input to melt the stud and the plate at the joint area and create a good weld reinforcement around the stud shank. The short welding time produces partial welding reinforcement; the other hand, extra high welding time causes excessive melting metal and defective weld reinforcement [12].

Metallographic examination for the joint welded with 800 A current and 0.3 s time, which showed the best weld reinforcement, showed the microstructure heterogeneity at the joint area, as seen in Figure 4. The base metal (BM) region at the stud side was martensite with some primary ferrite (Fig. 5a). While the BM at the galvanized steel side is characterized by ferrite-pearlite microstructure (Fig. 6a). Generally, the microstructure of the BMs was affected by chemical composition (Tab. 1), and the production conditions of the stud and plate where the stud was in as-quenched condition while the plate was in the annealed condition. Near the weld zone, the heat-affected zone (HAZ) experienced transformation into martensite microstructure on both stud and plate (Fig. 5b, Fig. 6b,c). However, the martensite was coarser than the original martensite at stud (plate-like martensite vs needle like). At the plate side, the transformation into martensite was due to the effect of high-speed cooling of the welding process based on continuous transformation theory [13].

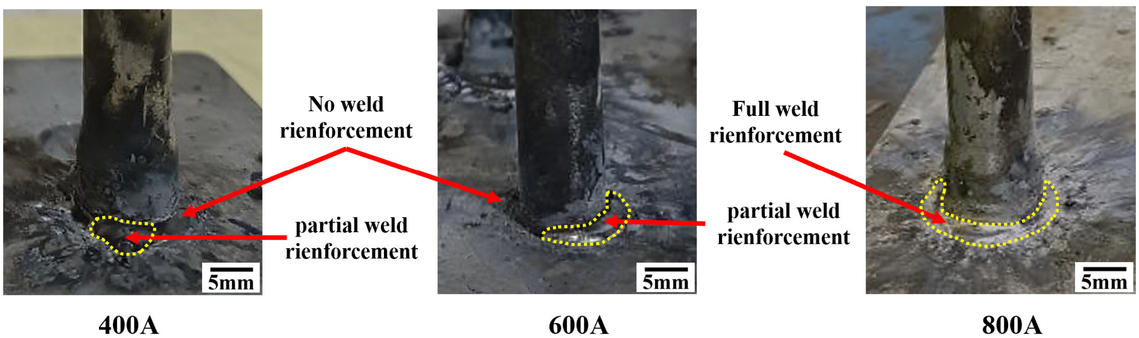

Fig. 3. Weld reinforcement development with welding current on arc stud welded joints at 0.3 s welding time

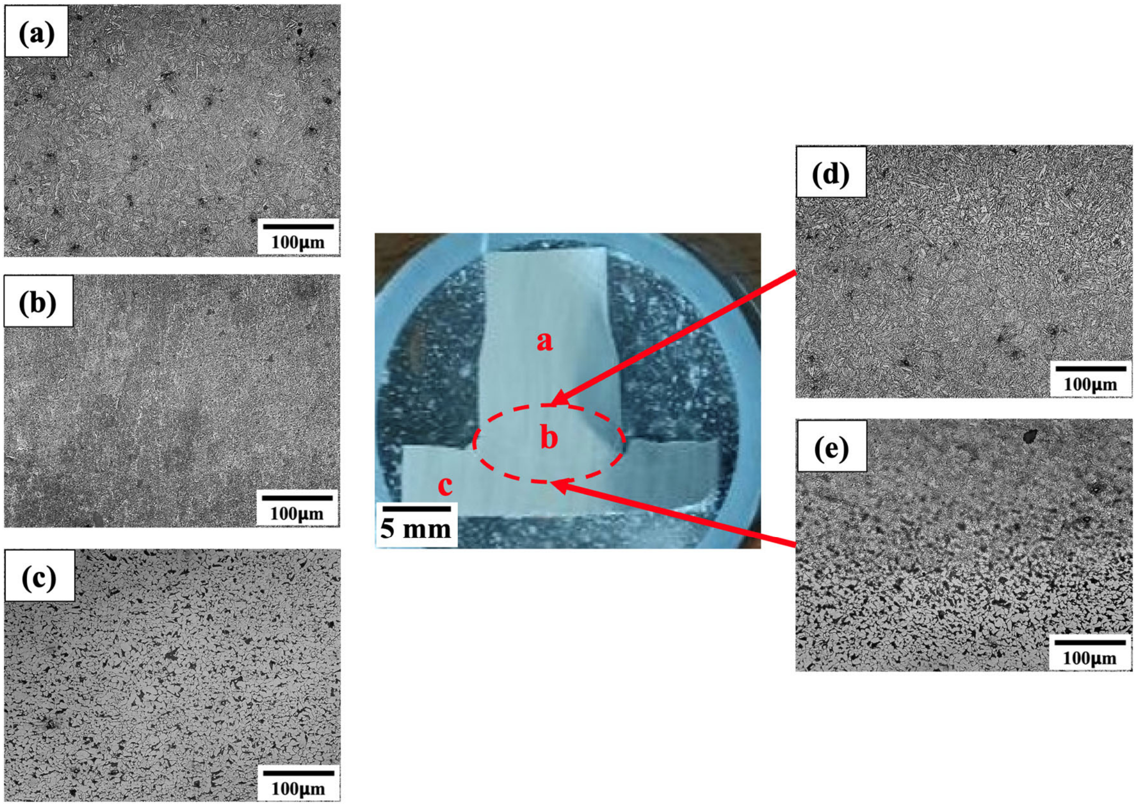

Fig. 4. Microstructures at different regions of arc stud welded joint at 800 A welding current and 0.3 s welding time. (a) Stud-BM, (b) Weld Zone, (c) Plate-BM, (d) Stud-Weld boundary, and (e) Plate-Weld boundary

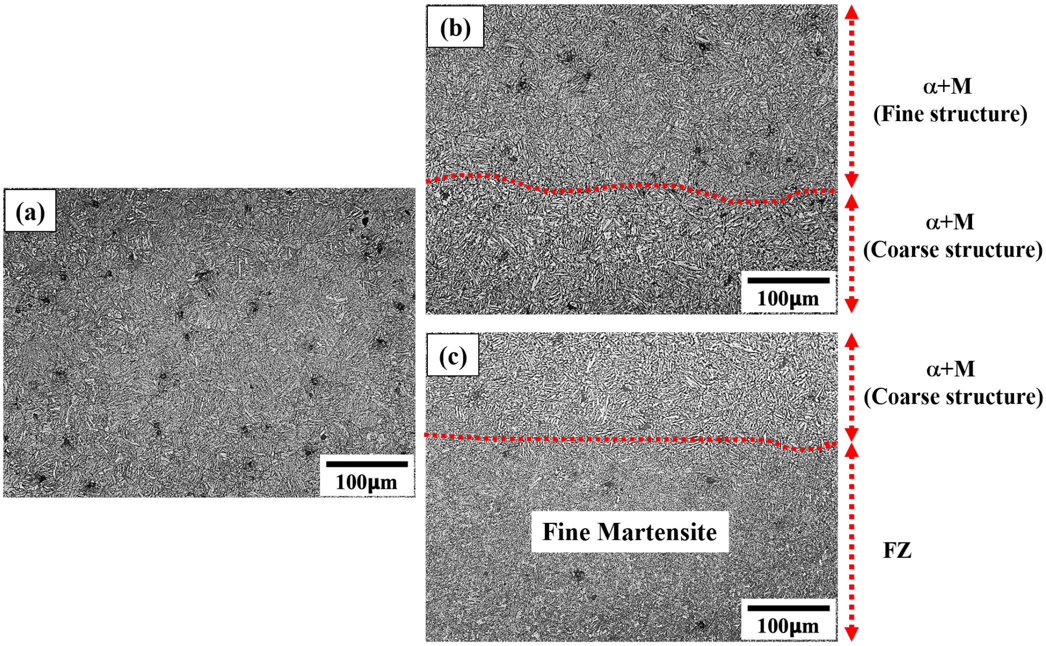

Fig. 5. Microstructure at different regions of arc stud joint at LAS stud welded with 800 A welding current and 0.3 s welding time (a) BM (b) HAZ (c) Fusion boundary zone

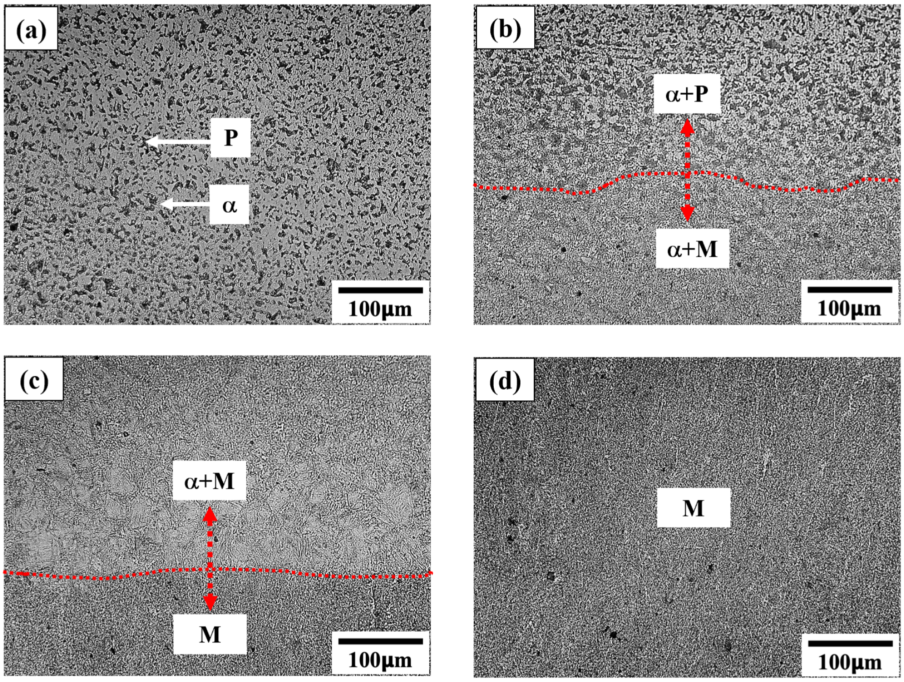

Fig. 6. Microstructure at different regions of arc stud joint at GS plate welded with 800 A welding current and 0.3 s welding time (a) BM (b) HAZ (c) Fusion boundary zone (d) Weld zone

The welding parameters and microstructure govern the mechanical properties of the welded joint. This can be noticed in the microhardness test results (Fig. 7). Generally, the hardness distribution showed an increment in the martensite regions at the BM, HAZ, and fusion zone (FZ). At 800 A and 0.3 s welding parameters, starting from the stud side, the hardness recorded an average of 367 HV at the BM and 478 HV at the HAZ. While at the plate side, the hardness increased from 157 HV at the BM to 279 HV at the HAZ. At the FZ, the hardness was recorded 357 HV. The slight decrease in hardness at the FZ compared to the stud is due to the dilution effect of the galvanized steel, which reduces the alloying elements and carbon content existing in the stud. At 400 A and 600 A welding currents at 0.3 s welding time, the hardness showed the same behaviour and slightly lower hardness compared to 800 A due to the relatively lower heat input, which means a lower carbon diffusion and consequently lower martensite formation. Since the high welding current generates high heat input that encourages more carbon and alloying element to migrate toward the HAZ and FZ, which increase the probability of martensite formation and hardness increment in these zones.

The torque test results are shown in Figure 8. At 400 and 600 A, the torque strength increases with increasing welding time. The torque strength data for welding samples of 400 A is between 18, 22, and 31 N.m for welding time 0.3, 0.4, and

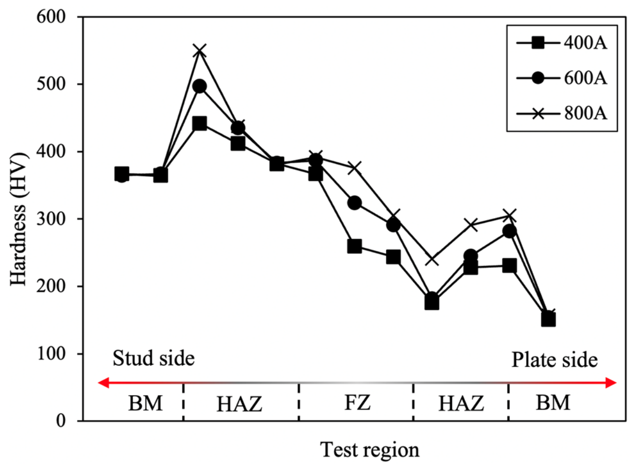

Fig. 7. Microhardness test data across arc stud welded joints at 0.3 s welding time

0.5 s respectively. Increasing the welding current to 600 A contributed toward increasing torque strength and reached 48 N.m at 0.5 s welding time. The increment in weld torque strength at 400 and 600 A with increasing welding time was achieved due to increased weld reinforcement around the stud by increasing heat input, which raises the resistance to torque failure. At 800 A, the torque strength increased significantly and reached its maximum (68 N.m) at 0.3 s welding time.

However, with a further increase in welding time, the torque strength decreased to 32 N.m at 0.4 s and instantly failed at 0.5 s. This might be contributed to higher welding power that causes excessive melting and produces a welded reinforcement with an undercut defect as shown in Figure 9. Furthermore, the long time and excessive heat input gave enough time for carbon to diffuse inside the weld region, which causes brittleness in the joint. According to ISO 3506-1, 2009, 65 N.m is the minimum torsional stress. Therefore, the only passed welding joint was at 800 A and 0.3 s parameters. Welding galvanized steel to low alloy steel is too critical. Thus, the successful parameters were limited. It can be concluded that with 400 A and 600 A, the weld reinforcement was partial that causing failure of the weld at low torque strength. Increasing welding current and time increases torque strength due to the production of sufficient weld reinforcement at higher parameters, especially at 800 A and 0.3 s.

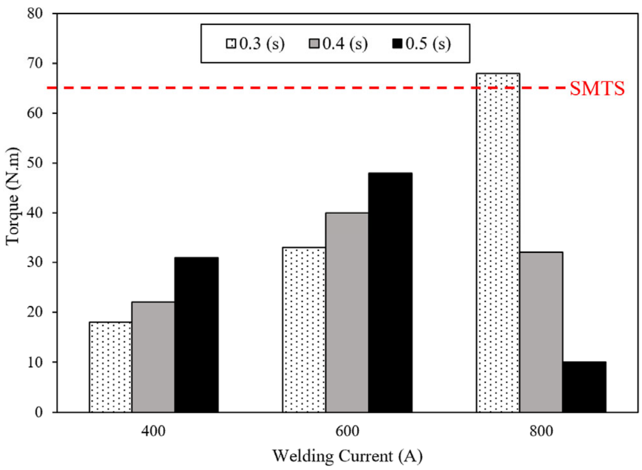

Fig. 8. Torque strength test results for three welding currents and three welding times. SMTS: Standard Minimum Torque Strength

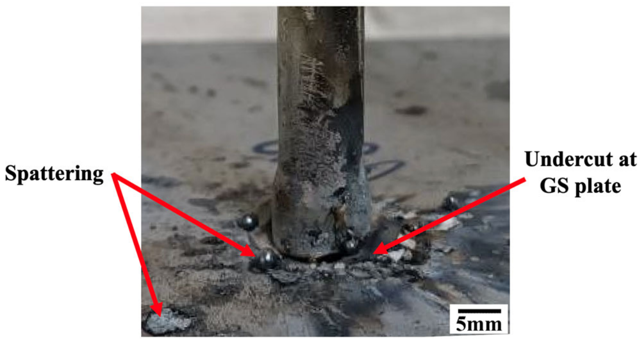

Fig. 9. Undercut and spattering in the arc stud welded joint at 800 A and 0.5 s

4. Conclusions

The following points can be concluded from this research:

1. The arc stud welding process has successfully welded low alloy steel studs to agalvanized steel plate.
2. Higher welding current with adjusted welding time (800 A, 0.3 s) gave good weld reinforcement.
3. Martensite phase was detected in the weld area and HAZ.
4. Hardness property varied across the welded joint. Maximum hardness was recorded at the HAZ at the stud side.
5. Hardness increased with the increasing welding current. At 800 A, welding current hardness was 10% higher than at 400 and 600 A.
6. At 400 and 600 A, the torque strength increased with increasing welding time. While at 800 A, deceased with increasing welding time.
7. Torque strength was affected by weld reinforcement. 800 A and 0.3 s gave the best weld reinforcement and recorded the highest torque strength.
8. High welding power produces a welded reinforcement with an undercut defect and increases the carbon opportunity to diffuse inside the weld region, which causes brittleness in the joint.

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