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Mechanical Properties of Resistance Spot Welded Components of High Strength Austenitic Stainless Steel

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Resistance multi-spot welding (MSW) in column, triangle and tetragonal symmetry arrangements was prepared using cold-rolled 301L high-strength sheets, and their static and fatigue properties were investigated. The effects of spot welds on the fracture strengths and fatigue limits were discussed. The results show that the static strengths can be estimated using an inherent linear relationship formula of the load versus the welding area. It was based on the 28%–33% volume fraction of α′ martensite induced at the interfacial spot weld fracture because of the failure deformation. The fatigue limits of the MSW nonlinearly increase with the number of spot welds. The arrangement of spot welds in the MSW significantly affects the average fatigue limit of each spot weld; its 26% maximum reduction occurred in the triangle, and the interaction stress between spot welds led to its 18% reduction in the tetragonal symmetry. The calculated fatigue stress of all MSW loadings with their mean fatigue limits was 230–270 MPa.

1. Introduction

Railroad passenger cars made of austenitic stainless steel have been widely used in subways and intercity express trains because of the advantages of low energy consumption, high safety, recyclable material composition and low operating costs. Cold-rolled 301L high-strength sheets with good plasticity, corrosion resistance and excellent low-temperature performance are used to manufacture the main load-bearing skeletons of the side-walls, bearer-beams and columns of the base-chassis in railroad car bodyworks, where overlap resistance spot welding is used as the primary joining method[1–4]. The yield strengths of the experimental 301L sheets are notably high because much of the strain induced α′ martensite transforms during cold rolling[5–9]. The welding process makes the work-hardening microstructure disappear, and the hardness in the spot weld and heat-affected zone (HAZ), which is much lower than that in the base metal, makes the weldment different from most alloys with harder welds[10–15]. This hardness profile makes their welding joint failure behaviour unconventional[16–19].

Welding strength is the fundamental reference to vehicle design and manufacture; in particular, the fatigue strength and failure behaviour have been an interdisciplinary research focus[20–25]. There are more than 10^4 resistance spot welds in a passenger railroad car, and various types of multi-spot welding (MSW) were designed for the structure strength and stiffness requirements of the vehicle bodywork. Because of the structural stress distribution and stress interaction among the spot welds, the number and arrangement of those spot welds severely affect the strength[26–29]. Available studies on MSW cold-rolled 301L high-strength sheets were hardly found. The objective of this work is to investigate and estimate the static and fatigue strengths of MSW high-strength 301L structures.

2. Experimental

The MSW specimens were prepared using 2, 3 and 4 mm sheets of the hardest-grade cold-rolled 301L-HT steel. The chemical compositions and mechanical properties of the sheets are provided in Table 1. There are numerous deformation shear-bands and a 9%–13% volume fraction of deformation-induced α′ martensite in the cold-rolled 301L-HT sheets, which gives the sheets notably high strength. There is also notably a small amount of δ ferrites in the cold-rolled austenitic sheets[30]; these δ ferrites were too small to count in the magnetic measurements. The MSW specimens with one to four spot welds were arranged, as shown in Fig. 1, in column, triangular and tetragonal symmetries. The space among the spot

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Table 1
Chemical compositions and mechanical properties of spot welded 301L sheets

Plate (mm)	Chemical compositions (wt%)						Mechanical properties		
	C	Si	Mn	Ni	Cr	N	$R_{0.2}$ (MPa)	R_m (MPa)	δ (%)
2.0	0.022	0.37	1.00	7.10	17.10	0.09	660	850	26
3.0	0.022	0.42	1.23	7.11	17.17	0.09	660	850	28
4.0	0.020	0.46	1.00	7.10	17.31	0.10	650	860	29

welds is 60 mm for all specimens. The spot-welding parameters and fusion zone diameter are provided in Table 2.

Tensile shear experiments were conducted for each spot-welded specimen. Fatigue tests under a frequency of 90 Hz were performed using sinusoidal-pulse loads with constant amplitudes and a load ratio of $R = 0.1$. The microstructures of the spot-welded specimen were examined by scanning electron microscopy (SEM). The volume fraction of α′ martensite and bcc δ-ferrite in the fusion zone was measured using a Fischer FERITSCOPE FMP30 device with magnetic permeability.

3. Results and Discussion

3.1. Microstructures of the welding fusion zone

The microstructures of the spot-welding cold-rolled 301L sheets are shown in Fig. 2(a). The fusion zone is a dual-phase metal of δ-ferrite dendrites and austenite matrix, and it is annealed austenite in the HAZ. The average volume fraction of δ-ferrite in the fusion zone was 7%–9%. The amount of δ ferrite dendrites are mainly determined based on the chemical compositions in the plate, particularly the contents of carbon, nitrogen, nickel and chromium. The chemical compositions of the original 301L sheet were reassigned in the austenite matrix and δ ferrite dendrites during fusion zone solidification. More carbon, nitrogen and nickel were concentrated in the austenite matrix, and more chromium was concentrated in the δ ferrite dendrites.

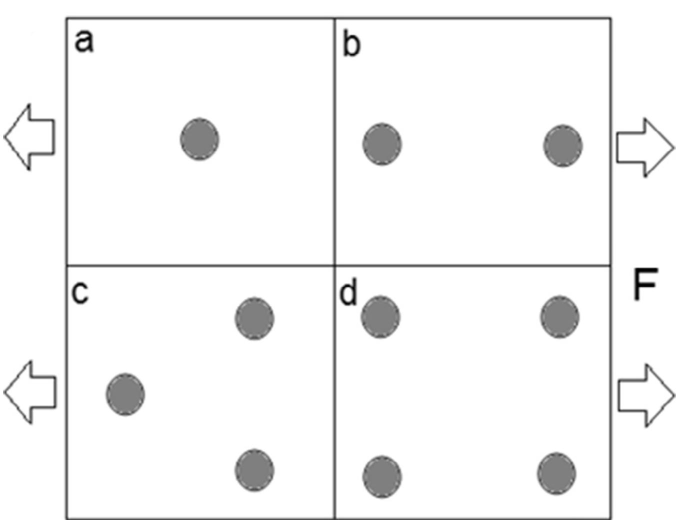

Fig. 1. Spot welds in 60 mm space and 30 mm to edges for all MSW specimens.

Table 2
Spot welding parameters and mean fusion zone diameters

Specimen	*I* (kA)	*T* (ms)	*P* (kN)	*d* (mm)
2 + 2	9.5	250	9	7.2
3 + 3	10	350	11	9.7
4 + 4	10.5	450	13	11.2

Fig. 2(b) shows the microstructure of an interfacial failure spot-welding fusion zone. Because of the metastable austenite substrate in the fusion zone, the tensile shear deformation induced a 28%–33% volume fraction of an α′ martensite transformation on the interfacial welding fractures, which were the magnetic measurement values on the fractures in Fig. 2(b) immediately below minus the volume fractions of its δ-ferrite in Fig. 2(a). The microstructure in Fig. 2(b) was the polished flat under the fracture surface, where the embossed

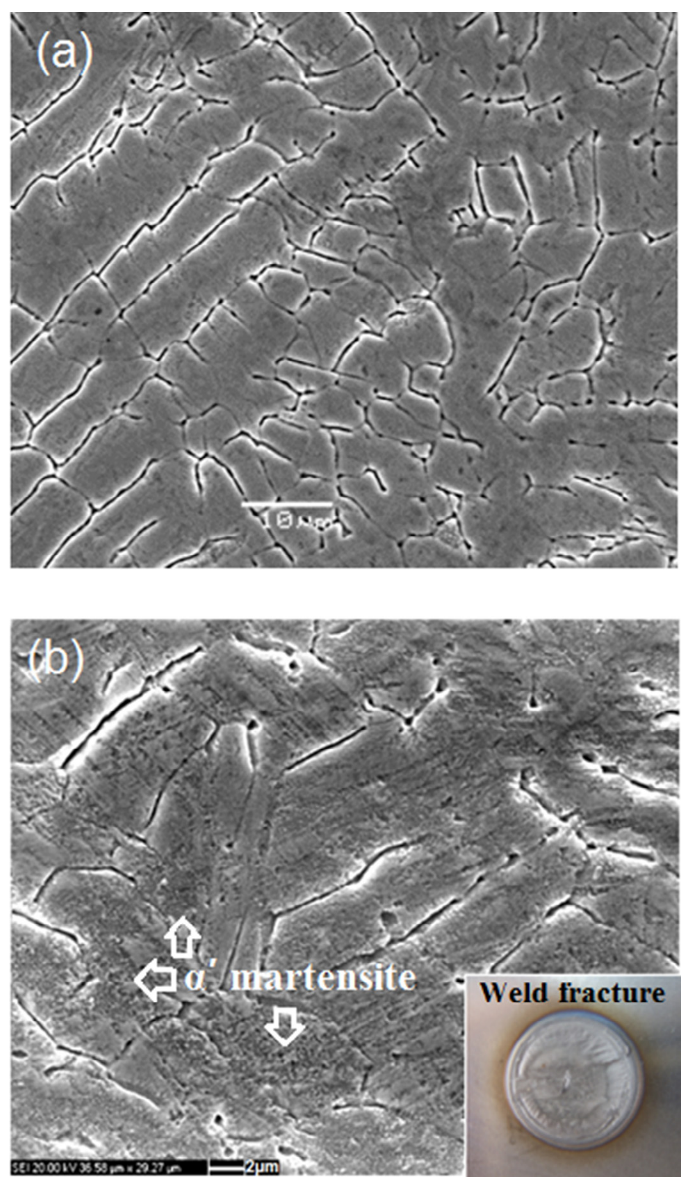

Fig. 2. (a) Microstructure of a spot-weld and (b) an interfacial failure spot-weld.