Effect of microfissures on mechanical properties of 308L austenitic stainless steel weld metals

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It is generally recognized that fully austenitic stainless welds are susceptible to weld deposit microfissuring (hot cracking) upon weld solidification. Hot cracking in austenitic stainless steel welds has been extensively discussed in the literature [1–7], and a universal agreement, on a liquidation mechanism, has been reached among the investigators. C. D. Lundin summarized the characteristics of microfissures in his series of articles discussing microfissure investigations. Microfissures occur primarily in ferrite-free areas along grain boundaries in the weld HAZ of a previous weld pass and the occurrence is enhanced by multiple thermal cycling of the HAZ [6]. In addition, a low ductility region exists in the weld metal of previously deposited weld pass from multipass deposits or from repair welding. This region is usually the initial location for microfissuring occurrence when a weld exhibits a low ferrite number (FN), while under a high imposed strain that exceeds the strain tolerance of the microstructure [7]. Furthermore, delta ferrite of a certain level has a beneficial effect in reducing or preventing microfissuring in austenitic stainless steel weldments [8]. This level of ferrite was firmly established by Lundin, DeLong, and Spond in an article documenting the ferrite-fissuring tendency of austenitic stainless steel weld metals [9]. In this letter, we describe the effect of microfissures on mechanical properties of 308L austenitic stainless steel weld metals.

A commercial (FN = 5.7) and a modified E308L (FN = 0) weld deposits were employed. The modified electrodes used in the experiments with a 0 FN level in the weld metal were manufactured especially by adjusting the ratio of the Chromium-equivalent and Nickel-equivalent in order to obtain a ferrite-free microstructure and enhance the production of microfissures for this project. The compositions of all of the weld deposits meet the AWS A5.4 specification, as shown in Table I. The base metal used in the tests is 304 stainless steel. Before welding coupons for tensile sample extraction, 304L base plates were clamped on each side to a heavy welding fixture to prevent distortion. Shielded metal arc welding was used to produce the weld pads with the welding parameters shown in Table II. All-weld-metal specimens with a gage section diameter of 6.35 mm and a gage length 25.4 mm for pre-strain tensile test were extracted, as shown in Fig. 1, along the longitudinal direction of the fusion zone. Fig. 2 shows the microfissure morphologies on a transverse section of a E308L weld coupon. It is obvious that microfissures are clearly distributed along the grain boundaries for modified E308L deposits.

TABLE I Chemical composition of E308L weld deposits

Element	C	Mn	P	S	Si	Cr	Ni	Mo	N	Cu
C308L	0.030	0.61	0.025	0.019	0.30	18.86	10.09	0.05	0.11	0.04
M308L	0.020	0.63	0.032	0.021	0.33	18.19	10.78	0.07	0.10	0.12

TABLE II Welding parameters

Current (A)	Voltage (V)	Travel speed (mm/min)	Number of layers	Interpass temp. (°C)	Heat input (kJ/mm)
95	23	203	3	94	0.7

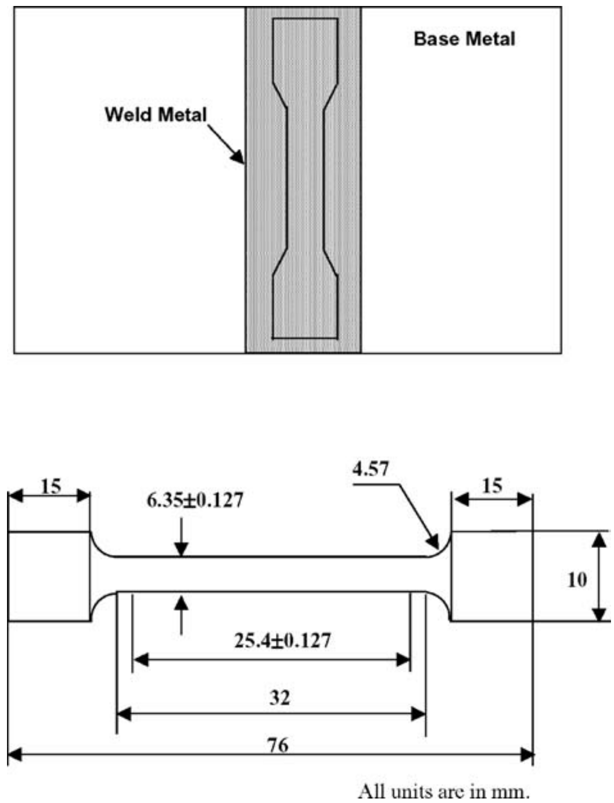

Figure 1 Schematic drawing of grove weld test pad for tension test specimen.

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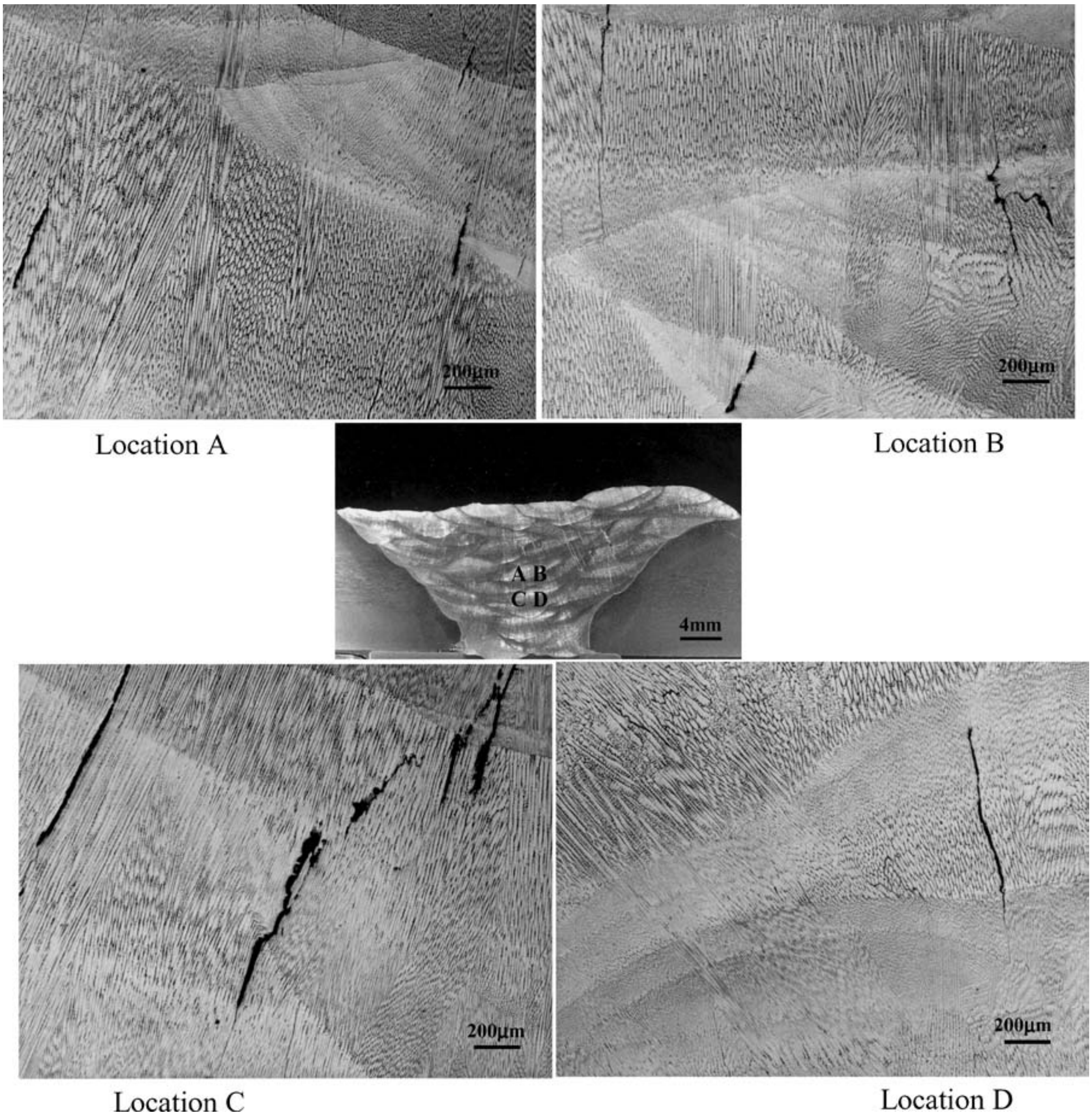

Figure 2 Microfissure morphologies on the transverse section of E308L coupon.

Some microfissures cross the interpass boundary, while others terminate near the interpass boundary. No microfissures were observed on the transverse section of commercial E308L weld coupons.

Pre-strain tension tests of the weld metals with and without microfissures were performed at room temperature. Before tensile testing, the samples were ground and polished to 0.05 μm surface finish and lightly electrolytically etched with 10% oxalic acid to reveal the microstructures and microfissures, as shown in Fig. 3. The numbers of the microfissures on the modified and commercial polished and etched surfaces were 10 and 0, respectively. Pre-strain testing was applied to each sample at 180 MPa (approximate 50% of yield strength) to open the microfissures and enable comparison with fissures observed under the optical microscope before full tension testing. The pre-strain rate was 5×10^{-5}/s. During the pre-strain process, the samples were still in the elastic region. After releasing the pre-strain load, the samples were observed under the optical microscope to count the microfissures. The fissure counts were similar in comparison of those before and after

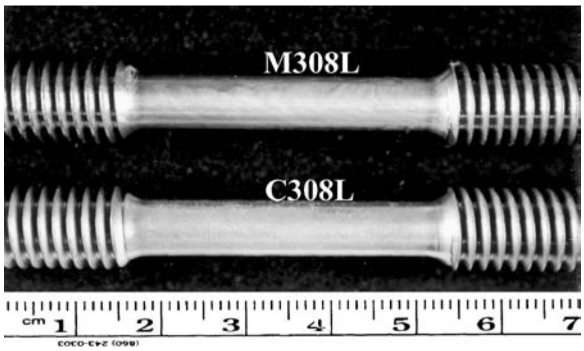

Figure 3 Modified and commercial 308L samples polished and etched with 10% oxalic acid before pre-strain tensile testing.

pre-strain testing. The samples were then tested until fracture occurred. Properties determined from the tests included the 0.2% offset yield strength, tensile strength, percent elongation, and percent reduction in area. It is apparent from the test results shown in Fig. 4 that the yield strength of modified 308L is similar to that of commercial 308L with only 60 MPa difference in

TABLE III Pre-strain tensile test results

Specimen ID	0.2% Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation in 4d (%)	Reduction in area (%)
C308L	388	567	56	62.3
M308L	365	501	25	30.3

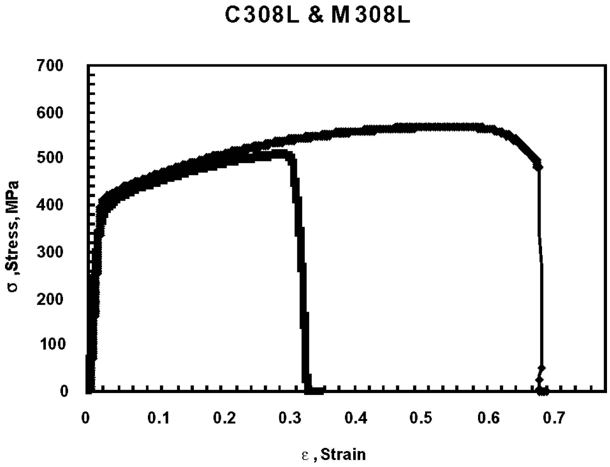

Figure 4 Stress–strain curves for modified and commercial E308L weld deposits.

ultimate strength, but the ductility is lower than for commercial 308L, as summarized in Table III. The results from the 308L weld deposits indicate that the presence of weld metal microfissures has a deleterious effect on the ductility for 308L, but virtually little effect on yield and ultimate tensile strength. These can be attributed to the basic mechanical properties of stainless steel, high ultimate strength and relative low yield strength. Since the high strength and excellent ductility of stainless steels, microfissures did not show much of an effect on ultimate strength in the tensile testing. When the load exceeds a value corresponding to the yield strength, the sample undergoes plastic deformation. With increase of the deformation, the sample begins to neck locally. Because of the fissures in the fissure-containing samples decrease the cross section of the sample to withstand the load subjected to the sample. The sample fractured in the plastic deformation region of the tensile test and shows reduced ductility compared to the commercial fissure-free samples.

In summary, tensile testing of E308L weld deposits with and without microfissures show that microfissures can negatively affect the ductility of 308L, where there is no effect on yield strength and a small effect on tensile strength.

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