

Table 2—Chemical Composition^(a) of Welds Made with Experimental Wires Containing Balanced Additions of Silicon and Manganese

Weld No.	C	O	Si	Mn	S	P	Al	Ti	Cr	Ni	Mo	Cu	V	N
1	0.10	0.081 ± 0.002	1.03	0.33	0.017	0.014	0.015	0.007	0.038	0.026	0.007	0.053	0.011	0.006
2	0.10	0.076 ± 0.002	0.90	0.61	0.018	0.015	0.014	0.006	0.042	0.029	0.007	0.053	0.012	0.008
3	0.10	0.076 ± 0.002	0.80	1.12	0.017	0.018	0.012	0.006	0.044	0.030	0.006	0.056	0.012	0.006
4	0.10	0.075 ± 0.004	0.66	1.61	0.018	0.019	0.013	0.006	0.050	0.033	0.006	0.056	0.012	0.009
5	0.10	0.067 ± 0.003	0.60	2.17	0.018	0.022	0.012	0.005	0.054	0.035	0.006	0.050	0.012	0.005
6	0.11	0.066 ± 0.004	0.50	2.72	0.016	0.021	0.010	0.004	0.065	0.048	0.007	0.061	0.012	0.006
7	0.11	0.068 ± 0.006	0.46	3.35	0.016	0.022	0.012	0.004	0.070	0.054	0.007	0.060	0.012	0.007
8	0.11	0.063 ± 0.006	0.94	2.95	0.017	0.022	0.020	0.005	0.066	0.051	0.006	0.063	0.010	0.007
Base plate	0.18	0.012 ± 0.002	0.23	0.90	0.040	0.028	0.013	0.002	0.130	0.098	0.016	0.24	0.004	0.011

^(a)Composition: weight percent. Niobium content: Less than 0.003 wt-% in all cases.

eter between 1.9 and 2.0 μm. The majority of the particles examined were spherical in shape, a characteristic feature of manganese silicate inclusions. To obtain representative numbers for the true inclusion size distribution, at least 500 particles were counted in each case. A simple computer program was then employed to evaluate the data recorded, using the equations and guidelines of Ashby and Ebeling (Ref. 12). Calculated values for the Mn/Si ratio, inclusion volume fraction, number density, and average spacing are given in Table 3.

Mechanical Testing

The weld metal toughness was assessed by the Charpy V-notch (CVN) test (Ref. 13). Full-size CVN specimens, 10 × 10 × 55 mm (0.4 × 0.4 × 2.2 in.), were oriented transverse to the welding direction, with their upper surface approximately 1 mm below the base plate surface. All specimens were notched from the bottom side on the weld centerline, as shown schematically in Fig. 3. Sufficient tests were carried out to establish the full transition curve for welds 1 and 6. Selected broken CVN specimens were subsequently examined with a scanning electron microscope (SEM) to reveal the fracture mode. The weld metal hardness was measured along the plate centerline on a transverse metallographic section of each weldment.

A limited number of CVN specimens were also subjected to a reheating thermal cycle by means of a thermal cycle simulator, as shown in Fig. 4. Five different cooling programs were used, corresponding to Δt_{B/S} (the cooling time from

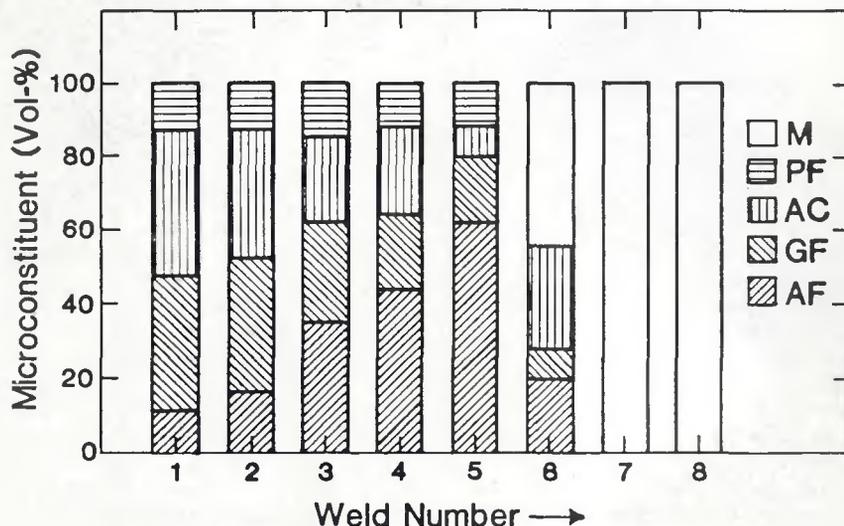


Fig. 2—Measured volume fractions of microconstituents along the weld centerline

800° to 500°C/1472° to 932°F) equal to 5, 10, 15, 20 and 40 s, respectively. For one of the cooling rates (Δt_{B/S} = 20 s), the transformation start and end temperatures were determined by dilatometric measurements. The thermally cycled CVN specimens were subsequently notched from the bottom side on the weld centerline—Fig. 3. The weld metal toughness was assessed at -40°C (-40°F).

Results

Concentration and Size Distribution of Oxide Inclusions

The combined effects of silicon and manganese on the resulting weld metal

oxygen content have been discussed in a separate paper (Ref. 14). In that study, a theoretical analysis of the deoxidation process showed that the oxygen concentrations of C-Mn steel weldments are directly related to the parameter ([% Si] · [% Mn])^{-0.25}. As indicated in Fig. 5, the results of the current investigation agree reasonably with the previous theoretical analysis, although the scatter in the data is greater compared with that observed for basic covered electrodes (Ref. 14). It is interesting to note that the oxygen content (varying in the range from 0.06 to 0.08 wt-%) is only slightly affected by a change in the weld metal manganese or silicon concentrations, implying that control of the oxygen level through additions of deoxidants is limited.

Table 3—Calculated Values for the Mn/Si Ratio, Inclusion Volume Fraction, Number Density, and Average Spacing for Welds 1, 4 and 6

Weld No.	Mn/Si Ratio	Inclusion Volume Fraction (%)	No. of Inclusions per mm ³	Average Volume Inclusion Spacing (μm)
1	0.32	0.81	2.8 × 10 ⁸	0.85
4	2.44	0.93	2.0 × 10 ⁸	0.95
6	5.44	0.78	6.8 × 10 ⁸	0.63

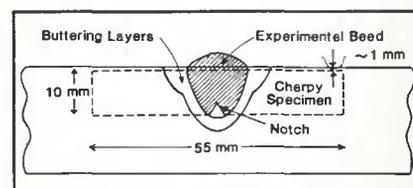


Fig. 3—Schematic diagram showing the dimensions, orientation, and notch location of the Charpy V-notch specimens

