WELDING RESEARCH

SUPPLEMENT TO THE *WELDING JOURNAL*, FEBRUARY 1996
Sponsored by the American Welding Society and the Welding Research Council

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Dilution Control in Single-Wire Stainless Steel Submerged Arc Cladding

Reduced stepover, high-chromium flux, and DCEN are effective in promoting ferrite in a single-layer cladding

BY DAMIAN J. KOTECKI

ABSTRACT. An experimental study of the effects of bead-to-bead stepover, wire size, wire feed speed, voltage, flux chromium content, and polarity on dilution and ferrite in single-wire submerged arc cladding of ER309L on mild steel plate is described. Low dilution was found to be promoted by reduced stepover, reduced wire feed speed, and DC electrode negative polarity. Use of a high-chromium flux can broaden the tolerance for dilution, providing an austenitic deposit free of martensite, and containing at least 4 FN for assurance of freedom from hot cracking over a broader range of dilutions.

Introduction

Work by Jackson (Ref. 1) and others has shown that dilution of single weld beads can be controlled to a limited extent by choice of welding parameters in single-wire submerged arc cladding of stainless steel on mild steel or low-alloy steel. Campbell and Johnson (Ref. 2) reported that bead overlap could be used to reduce dilution in cladding. But further studies on single-wire submerged arc relating to dilution seem to have been abandoned in view of easily obtained low dilution with strip cladding.

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However, inquiries from fabricators about limiting dilution in single-wire submerged arc cladding continue to be received. Fabricators request help with one or both of two problems, typically using AWS ER309L or similar filler metal for the cladding. The more common problem is that the weld cladding cracks during bend tests for procedure qualification, and the first layer of weld cladding is found to consist largely of martensite. Less common is that the weld cladding exhibits centerline cracks in the as-welded condition, without bending, and the weld cladding is found to be virtually fully austenitic (nearly devoid of ferrite).

Both of these problems relate to excessive dilution of the weld cladding by the substrate. Accordingly, a procedure development program was undertaken to provide technical support to fabricators, in particular to offer welding procedures that will limit dilution and provide austenitic stainless steel cladding, containing a small amount of ferrite for crack resistance, in a single layer over mild steel.

KEY WORDS

Stainless Steel
Cladding
Submerged Arc Welding
Dilution
Austenitic Stainless
Ferrite
Martensite
Neutral Flux
Alloy Flux

It should be recognized that a small amount of ferrite in the weld metal at room temperature is only an indication of the solidification mode, which actually seems to determine whether or not hot cracking is likely. If the weld metal solidifies as primary ferrite, hot cracking resistance is maximized. But if the weld metal solidifies as primary austenite, then the likelihood of hot cracking is rather high unless the weld metal is exceptionally free of impurities. Lefebvre (Ref. 3) describes this situation very well, and proposes that an appropriate specification requirement is 4 FN (Ferrite Number) minimum (determined with a magnetic instrument calibrated according to ISO 8249 or ANSI/AWS A4.2) to guarantee primary ferrite solidification in ordinary austenitic stainless steel welding. Lefebvre further notes that an upper limit on weld FN might be imposed if the weldment is to see extended high-temperature service (8 FN maximum), or if the highest ductility and toughness are demanded in the as-welded condition (12 or 15 FN maximum). However, Lefebvre also notes that stainless steel weld metal with excellent ductility and toughness can have up to 70 FN maximum if used in the as-welded condition. In the present study, the emphasis is on obtaining 4 FN minimum for assurance of

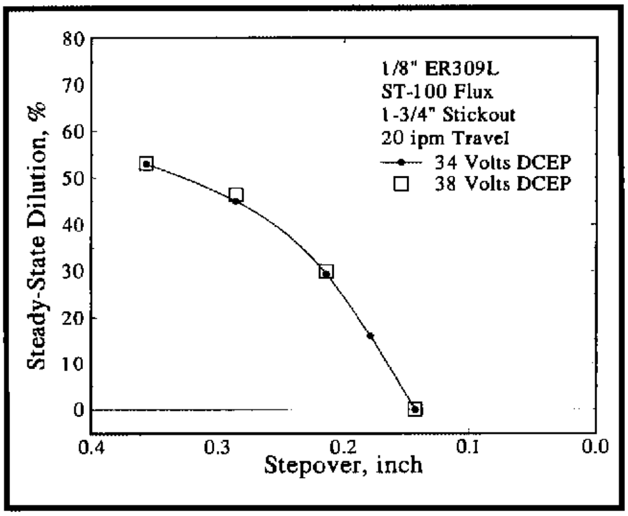

Fig. 1 — Effect of stepover on dilution in single-wire submerged arc cladding.

freedom from hot cracking along with avoiding martensite.

Experimental Procedure

A table was constructed with a lead screw for accurately and reproducibly indexing the stepover from bead to bead. All welding was carried out with a 600-A DC rectifier having constant potential electrical characteristics and feedback control to maintain digitally preset voltage. A side-bead carriage carried the welding head. Wire feed speed was preset using a digital control with feedback to maintain constant wire feed speed. Claddings, at least eight beads wide, were deposited on 1-in. (25-mm) thick A36 mild steel using ER309L wire, in sizes 5/64 in. (2.0 mm), 3/32 in. (2.4 mm), and 1/8 in. (3.2 mm). For a given wire size and set of wire feed speed (A), volts, travel speed, etc., single-layer claddings were made with stepovers from as much as 0.36 in. (9.1 mm) to as little as 0.14 in. (3.6 mm). Chemical composition and Ferrite Number were determined on the later beads of each single-layer cladding, where a steady-state condition was obtained. At 0.14 in. (3.6 mm) stepover, no base metal penetration was often observed, and the composition of this cladding could be taken as undiluted weld metal. Alternately, a very low dilution deposit was prepared, if necessary, under otherwise identical conditions by building a six-layer pyramid of weld metal consisting of six beads in the first layer, five beads in the second layer, and so forth, until the sixth layer contained only a single bead. The chemical composition and Ferrite Number of the sixth layer were then determined for comparison to the results from the single layer. Dilution was then calculated from the cladding chromium and nickel contents compared to those of all-weld metal under the same conditions, using the following formulas:

% Dilution = 100 [1 – (% Cr in one layer)/(% Cr in six layers)] (1)

% Dilution = 100 [1 – (% Ni in one layer)/(% Ni in six layers)] (2)

Average Dilution = [Equation (1) + Equation (2)]/2 (3)

More than 70 different cladding conditions have been examined. Typical conditions provided by fabricators served as starting conditions. These typically involved producing a weld bead approximately 3/4 in. (19 mm) wide, and indexing the base metal relative to the welding wire a distance of approximately one-half bead width for each additional weld bead. This approach was found to often produce over 50% dilution. Then conditions were adjusted to try to obtain lower dilution. In setting welding conditions, wire feed speed was always predetermined. Wire feed speed in turn determines welding current, but this relationship is affected by electrode ex-

Table 1 — Cladding Test Results

Sample Number	Step-over, in.	Angle Towards Previous Bead, Degrees	Arc Volts, DCEP	Composition of Last Beads in First Layer, % C	Mn	P	S	Si	Cr	Ni	Mo	Cu	FN	Comments	Percent Dilution Based on: Cr	Ni	Avg.
Wire Lot 309N	—	—	—	0.022	2.12	0.024	0.011	0.55	23.84	13.43	0.04	0.41	12.7	N = 0.051	—	—	—
309 100 5	0.36	0	34	0.114	1.78	0.017	0.007	0.41	10.38	6.40	0.02	0.18	61.0	Martensite	56.8	49.1	53.0
309 100 4	0.29	0	34	0.101	1.78	0.018	0.008	0.42	12.48	7.30	0.03	0.18	6.3	Martensite	48.1	42.0	45.0
309 100 3	0.21	0	34	0.078	1.94	0.023	0.011	0.53	16.58	9.12	0.04	0.24	0.7	Ok Tie-in	31.0	27.5	29.3
W164	0.18	0	34	0.075	2.52	0.031	0.015	0.63	19.90	10.78	0.05	0.31	7.0	Slight Roll	17.2	14.3	15.8
309 100 2	0.14	0	34	0.022	2.56	0.032	0.011	0.75	24.04	12.58	0.05	0.37	17.9	No Tie-in	0.0	0.0	0.0
309 100 33	0.21	30	34	0.070	1.93	0.023	0.011	0.54	17.10	9.49	0.04	0.25	0.6	Ok Tie-in	28.9	24.6	26.7
W165	0.18	30	34	0.119	2.47	0.031	0.014	0.64	19.12	10.29	0.05	0.29	4.6	Slight Roll	20.5	18.2	19.3
309 100 32	0.14	30	34	0.035	2.16	0.025	0.009	0.61	21.22	11.24	0.03	0.28	7.5	Slight Roll	11.7	10.7	11.2
45P3	0.21	45	34	0.074	1.74	0.019	0.006	0.37	15.97	7.67	0.01	0.20	0.8	Ok Tie-in	3.6	39.0	36.3
45P2	0.14	45	34	0.048	2.30	0.027	0.010	0.66	22.66	11.72	0.04	0.32	11.1	Slight Roll	5.7	6.8	6.3
90 309 100 38 5	0.36	0	38	0.137	1.74	0.017	0.008	0.38	10.56	6.14	0.02	0.18	54.5	Martensite	56.1	50.4	53.2
90 309 100 38 4	0.29	0	38	0.107	1.85	0.018	0.008	0.42	12.57	6.80	0.03	0.20	13.1	Martensite	47.7	45.1	46.4
90 309 100 38 3	0.21	0	38	0.086	1.97	0.024	0.012	0.56	16.74	8.74	0.04	0.26	0.8	Slight Roll	30.4	29.4	29.9
90 309 100 38 2	0.14	0	38	0.029	2.50	0.034	0.011	0.74	24.04	12.38	0.05	0.33	15.3	No Tie in	0.0	0.0	0.0
30 309 100 38 3	0.21	30	38	0.091	1.95	0.023	0.012	0.54	17.08	9.05	0.05	0.25	0.5	Ok Tie-in	29.0	26.9	27.9
30 309 100 38 2	0.14	30	38	0.050	2.25	0.029	0.009	0.63	22.08	11.08	0.04	0.27	11.5	Slight Roll	8.2	10.5	9.3

Made with 1/8 in. ER309L, 80 in./min wire feed speed (approximately 480 A, 16.7 lb/h deposition rate), 1-3/4 in. Electrical extension, 20 in./min travel speed, ST-100 chromium-compensating flux.

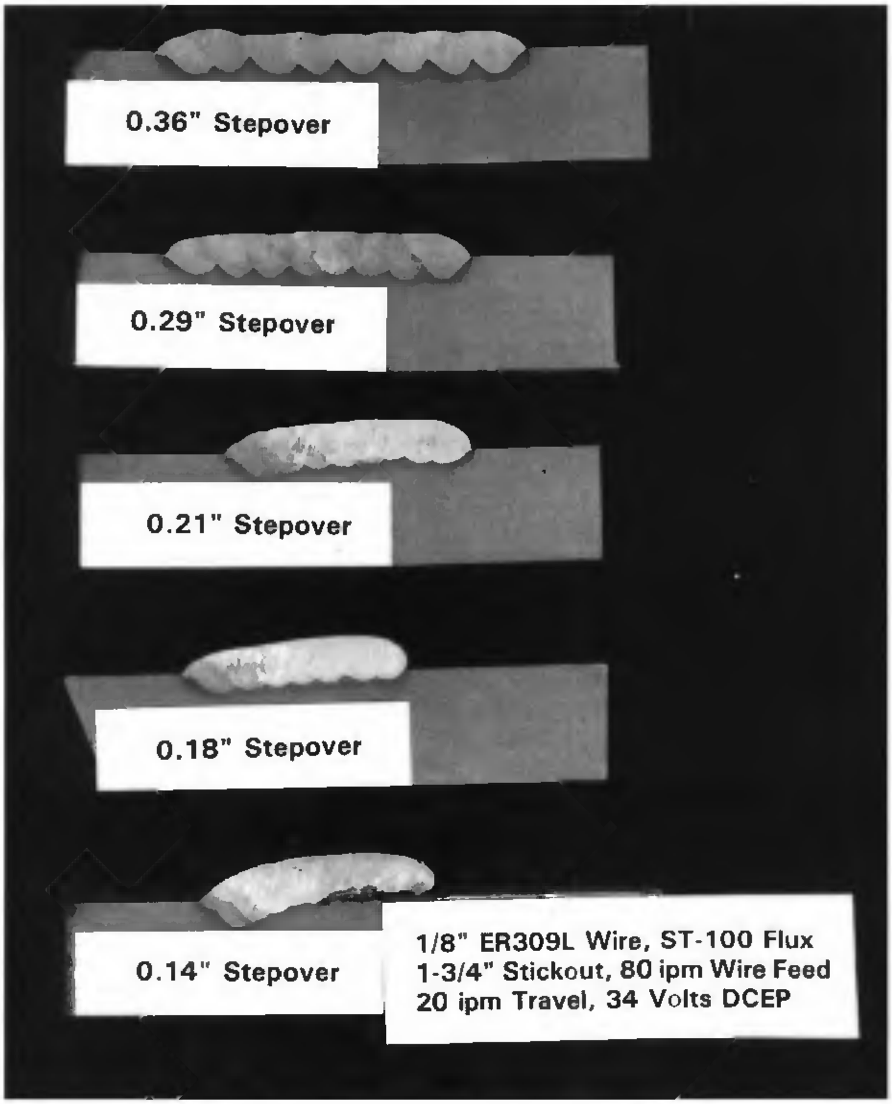

Fig. 2 — Cross-sections of 1/8-in. (3.2-mm) ER309L single-layer cladding with ST-100 flux at various stepovers, successive beads from left to right.

tension, polarity, and factors not always under control. Current values reported herein are only approximate. It was always the wire feed speed that was actually set. All welding was done on ASTM A36 mild steel plates. A nominal composition of 0.17% C, 1% Mn, 0.1% Si is quite representative of A36 steel, and any departure from this composition in a given test plate within the A36 steel specification is very unlikely to affect the results. Unless otherwise specified, the plate thickness was 1 in. (25 mm). The interpass temperature employed was 300°F (150°C) maximum.

Experimental Results

Chromium-Compensating Flux — DCEP

A numher of claddings were made with 1/8-in. (3.2-mm) welding wire at 80 in./min (2.03 m/min) wire feed speed, which deposited about 16.6 lb/h (7.6 kg/h) on DC electrode positive (DCEP) polarity, with a chromium-compensating flux, ST-100. Table 1 lists the test conditions, cladding compositions and Ferrite Numbers, and calculated dilutions. Voltage, tilt of the electrode hack toward the previous bead, and stepover were principal variables. Of these, only stepover had a major effect on dilution. With stepover of 0.36 in. (9.1 mm), over 50% dilution was observed, and the cladding was highly magnetic due to martensite formation. 5ince martensite is ferromagnetic, as is ferrite, some interpretation of measured Ferrite Number is always necessary in cladding. Martensite presence can be determined metallographically by its hardness, by its brittleness in a bend test, or by the chemical composition of the metal with reference to the 5chaeffler diagram (Ref. 4). In the present work, most martensite determinations were made from chemical composition and the Schaeffler diagram.

With stepover of 0.21 in. (5.4 mm), the deposit was virtually nonmagnetic (0.7 FN), indicating that it is almost fully austenitic. With stepover of 0.14 in. (3.6 mm), 0% dilution was observed (no tie-in to the base metal). With stepover of 0.18 in. (4.5 mm), dilution of about 16% was obtained with 7 FN, and the steady-state deposit cumpositiun matches exactly with a 308 composition. This last result would be optimum for crack resistance, mechanical properties, and corrosion resistance in a single layer of cladding.

Figure 1 presents these results graphically and shows that voltage has virtually no effect on dilution under these conditions, but stepover has a very large effect. Figure 2 shows cross-sections of the 34-V claddings of Fig. 1 and Table 1. With 0.36-in. (9.1-mm) stepover, the depth of fusion for each successive bead is scarcely changed from that of the first bead. 8ut as the stepover is reduced, it can be seen that the beads after the first one have successively less penetration into the mild steel. The cladding at 0.18 in. (4.5 mm) stepover, which produced the most desirable result of 7 FN and a deposit composition that looks exactly like that of a 308 weld metal, exhibits a slight tendency toward rollover at the edge of the deposit, which could be considered undesirable, though no incomplete fusion was found. Tilting the electrode back toward the previous bead at 30 and 45 deg from vertical was used to see if this electrode tilt could lessen the tendency toward rollover, but it was not very helpful (Table 1) and did not in general reduce dilution.

A series of claddings was made also with 3/32-in. (2.4-mm) and 5/64-in. (2.0-mm) electrodes with similar results. These are given in Table 2. Figure 3 compares the 3/32-in. wire results with those from the 1/8-in. wire. It can be seen that the smaller welding wire produces somewhat less dilution at larger stepovers, but at 0.18-in. stepover, where there is ferrite in the cladding, the two wire sizes produce equivalent results, with lower deposition rate for the smaller wire. As with the 1/8-in. electrode described above, when the stepover was reduced to the point where about 5 to 8 FN was observed in the deposit, there was a tendency for roll-over at the bead edge. Table 2, as Table 1, shows that titling the electrode 30 deg back toward the previous bead did not reduce dilution. With 5/64-in. welding wire, both a low and a high wire feed speed were used to make claddings at various stepovers. The same general trends were seen with the larger wires. The higher wire feed speed in general produced higher dilution at a given stepover. These results are

Table 2 — Comparison of Claddings

Sample Number	Step-over, in.	Angle Towards Previous Bead Degrees	Arc Volts, DCEP (in.)	Composition of Last Beads in First Layer, % C	Mn	P	S	Si	Cr	Ni	Mo	Cu	FN	Comments	Percent Dilution Based on: Cr	Ni	Avg.
3/32 Wire Lot 309W				0.025	2.10	0.02	0.012	0.54	23.96	13.38	0.04	0.38	13.0	N=0.049			
Claddings made at 120 in./min Wire Feed Speed (325 A 14.1 lb/h Deposition Rate), 1½ Electrical extension 20 in./min Travel Speed																	
SW221	0.36	0	34	0.098	1.81	0.026	0.012	0.41	12.84	7.25	0.03	0.19	16.5	Martensite	42.4	41.3	41.9
W166	0.29	0	34	0.099	1.72	0.025	0.014	0.44	14.37	8.01	0.25	0.28	0.3	Ok Tie-in	35.6	35.2	35.4
W167	0.21	0	34	0.082	1.97	0.025	0.014	0.59	17.35	9.30	0.10	0.33	1.1	Ok Tie-in	22.2	24.8	23.5
SW222	0.18	0	34	0.064	2.24	0.030	0.015	0.61	19.36	10.33	0.05	0.28	5.5	Ok Tie-in	13.2	16.4	14.8
W168	0.14	0	34	0.057	2.78	0.037	0.018	0.78	22.31	12.36	0.07	0.36	16.1	No Tie-in	0.0	0.0	0.0
SW223	0.36	30	34	0.121	1.51	0.023	0.010	0.31	12.14	6.99	0.02	0.18	13.9	Martensite	45.6	43.4	44.5
W169	0.29	30	34	0.111	1.80	0.027	0.010	0.41	13.39	7.59	0.03	0.21	6.6	Martensite	40.0	38.6	39.3
W170	0.21	30	34	0.088	2.00	0.030	0.009	0.56	17.49	9.40	0.04	0.26	0.2	Ok Tie-in	21.6	23.9	22.8
SW224	0.18	30	34	0.070	2.56	0.029	0.016	0.65	20.10	10.54	0.06	0.29	5.9	Roll	9.9	14.7	12.3
W171	0.14	30	34	0.055	2.62	0.035	0.009	0.69	20.71	11.39	0.06	0.31	9.9	Roll	7.2	7.8	7.5
2.0 mm Wire Lot PN2817				0.020	2.08	0.021	0.007	0.44	23.90	13.73	0.05	0.53	12.5	N = 0.045			
Claddings made at 150 in./min Wire Feed Speed (300 A, 12.3 lb/h Deposition Rate), 1¼ Elelctrical extension 20 in./min Travel Speed																	
W174	0.29	0	34	0.146	1.77	0.021	0.009	0.32	13.42	7.81	0.03	0.29	0.3	Ok Tie-in	41.0	38.4	39.7
W175	0.21	0	34	0.128	1.87	0.024	0.012	0.43	15.23	8.82	0.04	0.31	0.0	Ok Tie-in	33.1	30.4	31.7
W176	0.14	0	34	0.073	2.62	0.029	0.016	0.63	19.98	11.25	0.09	0.45	6.7	Slight Roll	12.2	11.2	11.7
Claddings made at 100 in./min Wire Feed Speed (210 A, 8.2 lb/h Deposition Rate), 1¼ Electrical extension, 14 in./min Travel Speed																	
W177	0.29	0	34	0.102	1.99	0.026	0.013	0.47	16.68	9.35	0.04	0.35	0.7	Ok Tie-in	26.7	26.2	26.5
W178	0.21	0	34	0.060	2.82	0.031	0.015	0.61	20.14	11.27	0.06	0.42	8.0	Slight Roll	11.5	11.0	11.3
W179	0.14	0	34	0.059	2.89	0.037	0.016	0.74	22.76	12.67	0.08	0.46	17.4	No Tie-in	0.0	0.0	0.0

Made with 3/32 in. and 5/64 in., ST-100 chromium-compensating flux.

Table 3 — Comparison of Claddings

Sample Number	Step-over, in.	Angle Towards Previous Bead Degrees	Arc Volts, DCEP (in.)	Composition of Last Beads in First Layer, % C	Mn	P	S	Si	Cr	Ni	Mo	Cu	FN	Comments	Percent Dilution Based on: Cr	Ni	Avg.
Claddings made at 120 in./min Wire Feed Speed (325 A, 14.1 lb/h Deposition Rate, 20 in./min Travel Speed																	
SW225	0.36	30	34	0.075	1.68	0.022	0.012	0.55	17.00	9.95	0.04	0.26	0.2	Too Much Step	23.5	24.2	23.8
SW226	0.29	30	34	0.072	1.74	0.022	0.013	0.59	17.95	10.39	0.04	0.27	0.0	Ok Tie-in	19.2	20.8	20.0
W173	0.21	30	34	0.062	2.38	0.022	0.015	0.75	19.83	11.80	0.05	0.34	5.4	Ok Tie-in	10.7	10.1	10.4
SW227	0.18	30	34	0.023	2.30	0.024	0.016	0.74	21.54	12.87	0.06	0.35	9.3	Slag Spots	3.0	1.9	2.5
SW228	0.14	30	34	0.014	2.47	0.026	0.015	0.83	22.21	13.12	0.06	0.37	12.1	No Tie-in	0.0	0.0	0.0
Claddings made at 150 in./min Wire Feed Speed (380 A, 17.6 lb/h Deposition Rate), 25 in./min Travel Speed																	
SW229	0.36	30	34	0.099	1.50	0.020	0.011	0.42	14.59	8.77	0.03	0.22	0.2	Too Much Step	35.0	33.2	34.1
SW230	0.29	30	34	0.096	1.59	0.021	0.012	0.48	16.25	9.48	0.03	0.25	0.1	Fair Tie-in	27.6	27.8	27.7
W198	0.21	30	34	0.027	1.68	0.017	0.009	0.59	19.30	10.71	0.17	0.31	4.0	Fair Tie-in	14.0	18.4	16.2
SW231	0.18	30	34	0.041	2.26	0.023	0.015	0.67	20.92	12.26	0.06	0.34	8.1	Slag Spots	6.8	6.6	6.7
SW232	0.14	30	34	0.025	2.42	0.025	0.016	0.75	22.44	13.13	0.07	0.35	12.3	No Tie-in	0.0	0.0	0.0
Claddings made at 180 in./min Wire Feed Speed (450 A, 21.2 lb/h Deposition Rate), 30 in./min Travel Speed																	
SW233	0.36	30	34	0.119	1.42	0.018	0.010	0.35	14.05	8.31	0.02	0.21	0.7	Too Much Step	37.4	36.7	37.0
SW234	0.29	30	34	0.149	1.54	0.019	0.013	0.45	15.08	8.92	0.03	0.24	0.1	Slag Spots	32.8	32.1	32.4
W199	0.21	30	34	0.036	1.59	0.015	0.008	0.58	16.70	9.81	0.20	0.30	1.5	Fair Tie-in	25.6	25.3	25.4
SW235	0.18	30	34	0.042	1.82	0.022	0.014	0.62	20.21	11.66	0.05	0.32	5.6	Ok Tie-in	9.9	11.2	10.6
SW236	0.14	30	34	0.030	2.30	0.023	0.016	0.70	21.85	12.71	0.06	0.35	10.0	No Tie-in	0.0	0.0	0.0

Made with 3/32 in. ER309L Lot 309W, 1½ in. Electrical extension, 882 basic chromium-free flux.

also included in Fig. 3.

Basic Chromium-Free Flux — DCEN

DC electrode negative (DCEN) polarity was used for a series of claddings with 3/32-in. (2.4-mm) welding wire. The chromium-compensating flux did not perform well using DCEN (poor bead shape) so a high basicity chromium-free flux (882), which welds better on DCEN, was chosen for this series. Even with this flux, beads tended to be narrower and higher when using DCEN than when using DCEP at otherwise identical settings. The 0.36-in. (9.1-mm) stepover turned out to be too much to obtain consistent tie-in between beads. The results are given in Table 3. For a given stepover, less dilution was obtained on DCEN than was obtained on DCEP, as can be seen by comparing the results for otherwise similar welding conditions in Table 2. This comparison is made graphically in Fig. 4. Ferrite was not as high as with the chromium-compensating flux at a given dilution due to lower chromium, but 5

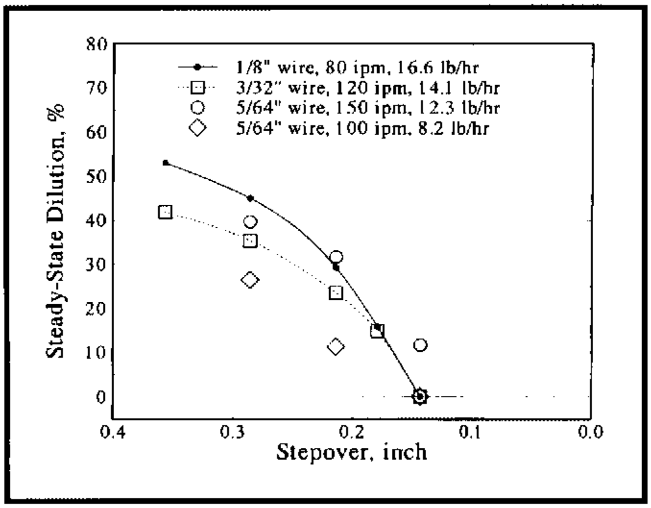

Fig. 3 — Effect of wire size on dilution in single-wire submerged arc cladding.

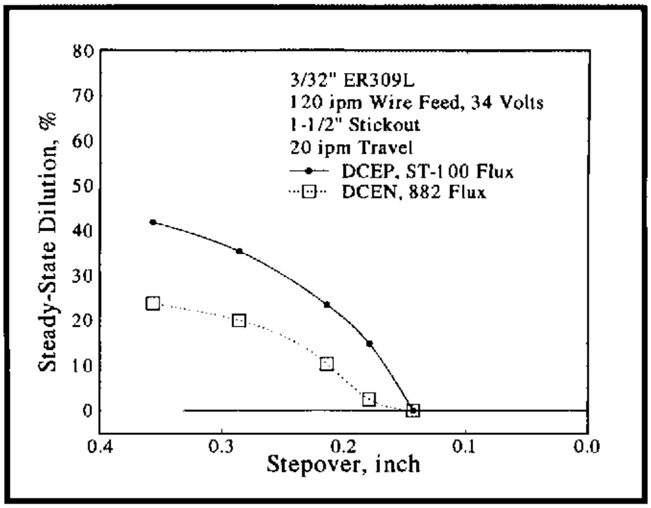

Fig. 4 — Effect of polarity on dilution in single-wire submerged arc cladding.

FN was obtained at about 10% dilution with 0.21-in. (5.4-mm) stepover, at a deposition rate of about 14.1 lb/h (6.4 kg/h). The bead shape obtained under the 120 in./min (3.05 m/min) wire feed speed condition at 0.21-in. (5.4-mm) stepover (Sample W173 in Table 3) was very attractive with no tendency toward rollover.

With this same flux and welding wire, additional claddings were made on DCEN at higher wire feed speeds to determine if a higher deposition rate could be made with similar results. Claddings made at 150 in./min (3.81 m/min) wire feed speed (17.6 lb/h; 8.02 kg/h) deposition rate) and at 180 in./min (4.57 m/min) wire feed speed (21.2 lb/h; 9.62 kg/h deposition rate) were made at various stepovers, with the travel speed adjusted to keep a constant bead cross-section or constant ratio of wire feed speed to travel speed. These results are also detailed in Table 3. Higher wire feed speed combined with higher travel speed produced higher dilution at any given stepover. This is best seen in Fig. 5. The tendency for inconsistent tie-in between beads at large stepover became greater, and slag spots between beads were sometimes found in cross-sections of the claddings, as noted in Table 3. While good tie-in and Ferrite Number were obtained at 180 in./min (4.57 m/min) wire feed speed and 0.18-in. (4.5-mm) stepover, it appeared that this condition is rather sensitive to small fluctuations in wire positioning, and it is not recommended.

Chromium-Adding Flux — DCEP

As noted earlier, Lefebvre (Ref. 3) recommends a minimum of 4 FN for maximum hot cracking resistance. It is apparent from the data of Tables 1 and 2 that dilution must be limited to something on the order of 15% with the chromium-compensating flux if this Ferrite Number is to be achieved. To permit more freedom in selection of welding conditions for single-wire submerged arc cladding, a chromium-adding flux can be considered. The A-100 chromium-adding flux was originally designed to produce a Type 410 stainless steel deposit (12% chromium) using a mild steel electrode and DCEN polarity. This flux can be used with DCEP as well, but DCEN at high voltage is recommended to obtain the 12% Cr deposit with a mild steel wire.

With the chromium-adding flux using DCEP, a series of six-layer deposits was made with the 3/32-in. (2.4-mm) ER309L wire to examine all-weld-metal deposit composition and Ferrite Number. The results from a series of deposits at increasing voltage are given in the upper portion of Table 4. With all other conditions held constant, the deposit chromium content rises with increasing voltage, as expected. This effect is caused by increasing arc length with increasing voltage, thereby melting more flux for the same amount of wire melted, other things being equal. Since the flux contains metallic chromium (in the form of low-carbon ferro-chromium), melting more flux results in more chromium gain in the weld deposit. At the same time, it can be seen from the upper part of Table 4 that the nickel content of the deposit is decreasing with increasing voltage. This is not caused by loss of nickel due to oxidation, but to mixing and diluting the nickel from the wire with the nickel-free metal (ferro-chromium) from the flux. Then, as a result of both increasing chromium and decreasing nickel in the deposit, the deposit's Ferrite Number increases markedly with increasing voltage. It can also be seen that the Ferrite Number calculated from the deposit's composition using the WRC-1992 diagram (Ref. 5) agrees reasonably well with the measured Ferrite Numbers. It is noteworthy that the deposits' Ferrite Numbers are considerably higher with this flux

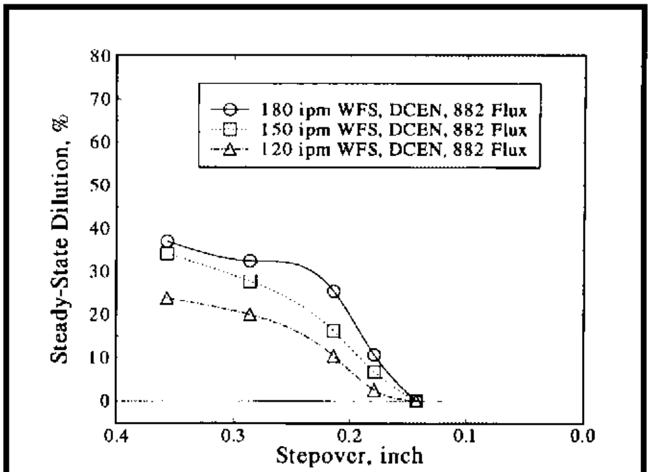

Fig. 5 — Effect of 3/32-in. (2.4-mm) wire feed speed on dilution in DCEN cladding with 882 flux.

Table 4 — DCEP Welds

Sample Number	Wire Feed Speed, ipm	Approx. Current, Amps	Deposit Rate lb/hr	Travel Speed, ipm	Volts, DCEP	Six-Layer Deposit Composition, % C	Mn	Si	Cr	Ni	N	Magne Gage FN	WRC 1992 Diagram FN	Percent Dilution Based on: Cr	Ni	Avg.
Wire	—					0.025	2.10	0.54	23.96	13.38	0.05	—	13.0	—	—	—
6P8	110	315	12.9	18.0	30	0.028	2.02	0.73	25.88	12.93	0.05	28	24.1	—		—
6P9	110	315	12.9	18.0	32	0.030	1.96	0.74	26.24	12.89	0.05	25	25.8	—	—	—
6P10	110	315	12.9	18.0	34	0.038	2.03	0.76	26.99	12.40	0.05	29	32.6	—	—	—
6P11	110	315	12.9	18.0	36	0.036	2.05	0.78	27.73	12.26	0.05	37	42.8	—	—	—
6P12	110	315	12.9	18.0	38	0.032	2.07	0.79	27.78	11.75	0.05	42	49.8	—	—	—
6P13	110	315	12.9	18.0	40	0.034	2.00	0.80	29.47	11.68	0.05	66	66.8	—	—	—
6P14	120	340	14.1	20.0	34	0.030	1.92	0.76	27.17	12.41	0.05	32	37.7	—	—	—
6P10	110	315	12.9	18.0	34	0.038	2.03	0.76	26.99	12.40	0.05	29	32.6	—	—	—
6P15	100	290	11.8	16.5	34	0.036	1.97	0.79	28.34	12.31	0.05	38	47.5	—	—	—
6P16	90	265	10.6	15.0	34	0.035	1.95	0.84	28.65	12.20	0.05	51	51.9	—	—	—
6P17	80	240	9.4	13.0	34	0.034	1.97	0.84	29.51	12.07	0.05	67	62.6	—	—	—
6P18	70	215	8.2	11.5	34	0.035	1.99	0.85	29.41	12.36	0.05	70	57.7	—	—	—
6P19	60	190	7.1	10.0	34	0.041	2.09	0.84	29.99	11.80	0.05	70	66.9		—	—
						Single-Layer Deposit Composition, %										
SW265	120	340	14.1	20.0	34	0.102	1.62	0.52	15.10	6.56	—	0.2	—	44.42	47.13	45.78
SW264	110	315	12.9	18.0	34	0.110	1.62	0.49	16.06	6.62	—	0.6	—	40.49	46.61	43.55
SW263	100	290	11.8	16.5	34	0.086	1.65	0.51	18.75	7.66	—	6.3	—	33.83	37.77	35.80
SW262	90	265	10.6	15.0	34	0.079	1.68	0.53	20.32	8.17	—	15.1		29.07	33.03	31.05
SW261	80	240	9.4	13.0	34	0.074	1.80	0.57	23.00	9.12	—	25.0	—	22.06	24.44	23.25

Made with ⅛ in. ER309L wire Lot 309W and A-100 chromium adding flux 1¼ in. Electrical extension, 0.29 in. Stepover

than with the chromium-compensating flux considered earlier.

A second series of six-layer weld deposits was prepared with this same flux and wire, but varying only wire feed speed at 34 V DCEP. The travel speed of this series was varied in proportion to the wire feed speed to maintain a nearly constant weld bead cross-section. The test results from this series are given in the middle of Table 4. It can be seen that, as the wire feed speed increases, other things being equal, the deposit of chromium decreases. Since the voltage (arc length) is constant, increasing the wire feed speed sends more wire through the arc column for the same amount of metal from the flux, which causes the chromium to decrease in the deposit with increasing wire feed speed. At the same time, the nickel content of the deposit increases slightly with wire feed speed. As a result of both decreasing chromium and increasing nickel with increasing wire feed speed, the measured and calculated deposit Ferrite Numbers decrease with increasing wire feed speed. Again, the deposits' Ferrite Numbers are considerably higher than with the chromium-compensating flux considered earlier. And the measured Ferrite Numbers agree reasonably well with those calculated from the WRC-1992 diagram.

In cladding, deposition rate (wire feed speed) determines how quickly a given job can be completed. So it was of most interest to examine single-layer cladding composition with the chromium-adding flux as a function of wire feed speed. For this series, a relatively large stepover, 0.29 in. (7.3 mm), was selected, as this results in no tendency for rollover at the edge of the bead. The results are given in the lower part of Table 4. Dilutions were calculated using the six-layer deposit compositions from the middle of Table 4. It can be seen that, at 100 in./min (2.54 m/min) wire feed speed (11.7 lb/h; 5.3 kg/h deposition rate), 35% dilution and a near-308 deposit composition, with 6.3

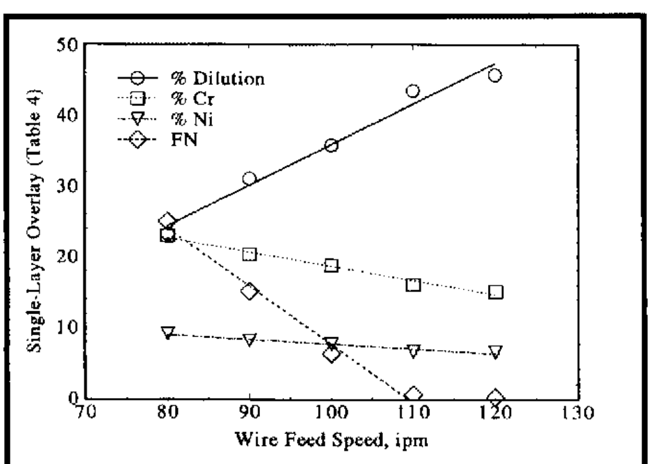

Fig. 6 — Effect of 3/32-in. (2.4-mm) wire feed speed on dilution (%), cladding composition (%), and ferrite number in DCEP cladding with A-100 flux.

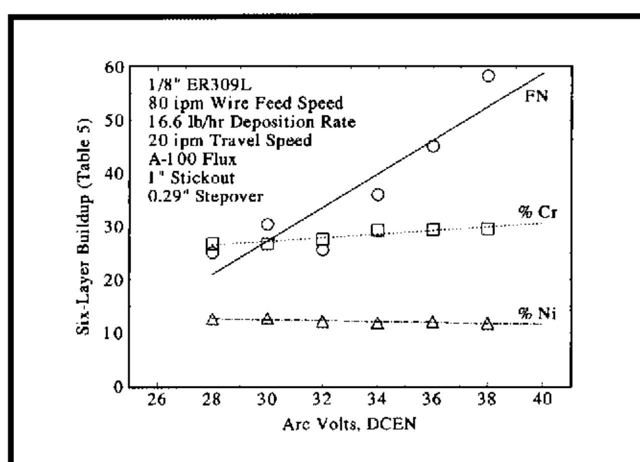

Fig. 7 — Effect of voltage on all-weld-metal composition with A-100 flux.

Table 5 — Cladding Compositions

Sample Number	Step-over, in.	Angle Towards Previous Bead, Degrees	Arc Volts, DCEN	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	WRC 1992 FN	Comments	Percent dilution based Cr	Ni	Avg.
wire Lot 309N	—	—	—	0.022	2.12	0.024	0.011	0.55	23.84	13.43	0.04	0.41	12.7	N = 0.051			
				Six-Layer Deposit Composition, %									Measured FN				
SW266P	0.29	0	28	0.027	1.69	0.024	0.009	0.68	26.77	12.64	0.03	0.32	25.1				
SW267P	0.29	0	30	0.027	1.69	0.025	0.009	0.68	26.76	12.73	0.03	0.32	30.4				
SW268P	0.29	0	32	0.037	1.68	0.025	0.009	0.71	27.61	12.17	0.03	0.32	25.6				
SW269P	0.29	0	34	0.027	1.61	0.025	0.009	0.76	29.27	11.90	0.03	0.31	36.0				
SW270P	0.29	0	36	0.031	1.58	0.026	0.008	0.79	29.40	12.06	0.03	0.31	45.1				
SW271P	0.29	0	38	0.035	1.61	0.029	0.009	0.83	29.55	11.82	0.03	0.30	58.3				
				Composition of Last Beads in First Layer, %										Comments	Cr	Ni	Avg.
SW266	0.29	0	28	—	—	—	—	—	—	—	—	—	—	No Tie-in	—	—	—
SW267	0.29	0	30	0.067	1.41	0.022	0.009	0.51	20.01	9.15	0.02	0.22	5.4	Poor Tie-in Spots	25.22	28.12	26.67
SW268	0.29	0	32	0.066	1.42	0.023	0.008	0.53	20.40	9.18	0.02	0.22	7.3	Poor Tie-in Spots	26.11	24.57	25.34
SW269	0.29	0	34	0.073	1.29	0.025	0.009	0.46	21.15	9.21	0.02	0.22	10.1	Poor Tie-in Spots	27.74	22.61	25.17
SW270	0.29	0	36	0.071	1.31	0.026	0.009	0.52	21.15	8.45	0.02	0.22	11.9	Good Tie-in	28.06	29.93	29.00
SW271	0.29	0	38	0.063	1.29	0.027	0.009	0.54	21.66	8.25	0.02	0.21	15.0	Good Tie-in	26.70	30.20	28.45

Made with ⅛ in. ER309L, 80 in./min wire feed speed (approximately 410 A, 16.7 lb/h deposition rate), 1 in. Electrical extension, 20 in./min travel speed, A-100 chromium-adding flux.

Table 6 — Cladding Compositions

Sample Number	Step-over, in.	Angle Towards Previous Bead, Degrees	Arc Volts, DCEN	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	WRC 1992 FN	Comments	Percent Dilution Based on: Cr	Ni	Avg.
Wire Lot 309N	—	—	—	0.022	2.12	0.024	0.011	0.55	23.84	13.43	0.04	0.41	12.7	N = 0.051			
				Six-Layer Deposit Composition, %									Measured FN				
SW272P	0.29	0	30	0.025	1.78	0.022	0.009	0.69	26.36	12.92	0.03	0.32	27.2				
SW273P	0.29	0	32	0.026	1.75	0.023	0.009	0.70	26.55	12.91	0.03	0.32	28.6				
SW274P	0.29	0	34	0.024	1.73	0.026	0.009	0.75	27.06	12.15	0.03	0.32	24.7				
SW275P	0.29	0	36	0.038	1.69	0.026	0.009	0.76	27.29	12.08	0.03	0.32	26.3				
SW276P	0.29	0	38	0.035	1.64	0.026	0.009	0.76	27.70	11.72	0.03	0.31	29.8				
SW277P	0.29	0	40	0.030	1.61	0.028	0.008	0.81	27.50	11.65	0.03	0.30	33.6				
				Composition of Last Beads in First Layer, %										Comments	Cr	Ni	Avg.
SW272	0.29	0	30	0.080	1.41	0.023	0.008	0.47	19.52	9.30	0.02	0.23	4.4	Poor Tie-in Spots	25.95	28.02	26.98
SW273	0.29	0	32	0.083	1.41	0.024	0.008	0.50	19.08	8.80	0.02	0.22	4.6	Good Tie-in	28.14	31.84	29.99
SW274	0.29	0	34	0.077	1.31	0.025	0.008	0.46	19.18	8.72	0.02	0.21	3.2	Good Tie-in	29.12	28.23	28.68
SW275	0.29	0	36	0.075	1.33	0.025	0.008	0.52	19.05	8.79	0.02	0.21	4.0	Good Tie-in	30.19	27.24	28.71
SW276	0.29	0	38	0.086	1.29	0.027	0.008	0.52	19.48	7.67	0.02	0.21	4.3	Good Tie-in	29.68	34.56	32.12
SW277	0.29	0	40	0.088	1.29	0.028	0.007	0.55	20.20	8.42	0.02	0.21	4.7	Poor Tie-in Spots	26.55	27.73	27.14

Made with ⅛ in. ER409L, 100 in/min wire feed speed (approximately 500 A, 20.9 lb/h deposition rate), 1¼ in. Electrical extension, 25 in./min travel speed, A-100 chromium adding flux.

FN, are obtained. Except for the relatively modest deposition rate, this is a very desirable result, and bead shape is very good. The lower dilution claddings (lower deposition rates) resulted in still higher deposit ferrite. But the highest deposition rates produced higher dilutions (over 40%) and resulted in virtually ferrite-free weld claddings. In the lower part of Table 4, cladding Ferrite Numbers were calculated using the WRC-1992 diagram, not from the cladding composition, but from the all-weld-metal composition, base metal composition, and measured dilution, using the method of tie-lines and the FERRITEPREDICTOR® computer software (Ref. 6). Again, the measured FNs agree reasonably well with the FNs calculated by the WRC-1992 diagram. Figure 6 summarizes graphically the single-layer dilution, chromium content, nickel content, and measured FN results.

Chromium-Adding Flux — DCEN

In order to increase deposition rate,

Table 7 — Longitudinal Face Bend Tests

			C	Mn	P	S	Si	Cr	Ni	N	WRC 1992 FN				
ER309L Lot 309N			0.022	2.12	0.024	0.011	0.55	23.84	13.43	0.051	12.7				
Sample Number	Bead Number	Polarity	Six-Layer Deposit Composition, % C	MN	P	S	Si	Cr	Ni	N	Magne Gage FN	Comments	Percent dilution based on: Cr	Ni	Avg.
SW239 Six-Layer		DCEP	0.028	2.03	0.030	0.008	0.77	26.40	12.43	—	24.9	All-Weld-metal	—	—	—
SW280	1	DCEP	0.101	0.96	0.017	0.016	0.35	12.98	4.27	—	65.7	Martensite	50.8	65.6	58.2
SW280	2	DCEP	0.134	1.01	0.018	0.014	0.39	14.77	5.22	—	41.6	Martensite	44.1	58.0	51.0
SW280	3	DCEP	0.088	1.02	0.018	0.014	0.39	15.48	5.41	—	8.9	Martensite	41.4	56.5	48.9
SW280	4	DCEP	0.085	1.04	0.018	0.014	0.42	15.67	5.54		6.8	Martensite	40.6	55.4	48.0
SW280	6	DCEP	0.104	0.99	0.018	0.017	0.37	13.51	4.90	—	63.2	Martensite	48.8	60.6	54.7
SW270P Six-Layer		DCEN	0.031	1.58	0.026	0.008	0.79	29.40	12.06	—	45.1	All-Weld-Metal	—	—	—
SW281	1	DCEN	0.075	1.12	0.022	0.014	0.47	18.51	6.20	—	3.3	Ferrite	37.0	48.6	42.8
SW281	2	DCEN	0.059	1.23	0.024	0.012	0.54	20.74	9.07	—	10.9	Ferrite	29.5	24.8	27.1
SW281	3	DCEN	0.065	1.25	0.024	0.012	0.54	21.41	9.41	—	12.7	Ferrite	27.2	22.0	24.6
SW281	4	DCEN	0.057	1.24	0.023	0.012	0.54	20.94	9.40	—	10.0	Ferrite	28.8	22.1	25.4
SW281	6	DCEN	0.080	1.14	0.024	0.015	0.49	19.85	8.14	—	8.2	Ferrite	32.5	32.5	32.5

Using ⅛ in. ER309L at 80 in./min wire feed speed (16.7 lb/h deposition rate), A-100 chromium-adding flux, 1¼ in. electrical extension, 0.29 in. stepover, 20 in./min travel speed, 36 V, ½ in. thick mild steel base metal.

while limiting dilution, further welding with the chromium-adding flux was done with 1/8-in. (3.2-mm) wire and DCEN. At 80 in./min (2.03 m/min) wire feed speed (16.7 lb/h; 7.6 kg/h deposition rate), a series of varying voltage welds was made. The upper part of Table 5 describes the all-weld-metal composition and Ferrite Numbers obtained. As with the DCEP results noted in Table 4, the deposit chromium content, and therefore the Ferrite Number, rises with increasing voltage, and the nickel content drops slightly. Figure 7 shows these trends also. These data provide the basis for dilution calculations for the single-layer claddings given in the lower half of Table 5 For the lowest voltage cladding in Table 5. (Sample SW266), there was very little tie-in between beads. The 30-, 32-, and 34-V claddings all showed occasional spots of poor tie-in between beads also, which looked much like undercut. But the two highest voltage claddings showed good tie-in with no roll-over tendency (due to the rather comfortable 0.29-in. (7.3-mm) stepover, and rather high Ferrite Numbers. The trends are shown in Fig. 8.

It is noteworthy that the percent dilution increases slightly with increasing voltage, at the same time that the deposit FN rises. This occurs because the higher voltage promotes more chromium pickup from the flux. All of the claddings of Table 5 have a satisfactory composition.

A still higher deposition rate condition was then examined with this wire and flux, as detailed in Table 6. The upper part of Table 6 lists all-weld-metal deposit composition and Ferrite Number as a function of voltage at 100 in./min (2.54 m/min) wire feed speed (20.9 lb/h; 9.5 kg/h deposition rate). The travel speed in these tests was increased proportionally to the increased wire feed speed as compared to the tests of Table 5. The increase in deposit chromium content and resulting ferrite with increasing voltage is not as great as at the lower wire feed speed of Table 5. The trends in chromium, nickel, and FN are shown graphically in Fig. 9. The scale of Fig. 9 is exactly the same as of Fig. 7, permitting direct comparison.

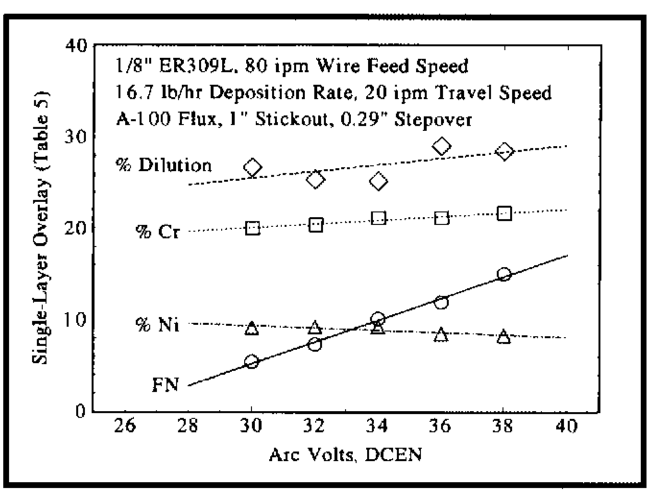

Fig. 8 — Effect of voltage on DCEN single-layer cladding with A-100 flux.

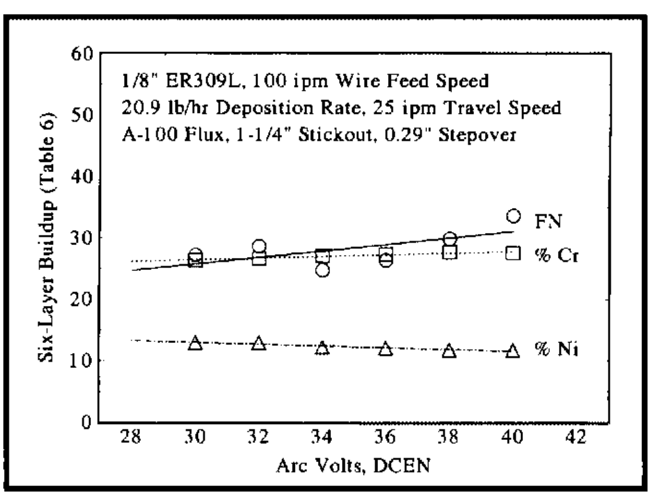

Fig. 9 — Effect of DCEN voltage on all-weld-metal with A-100 flux, 100 in./min (2.54 m/min) wire feed speed.

The data in the upper portion of Table 6 are used in computing the percent dilution in the lower portion of this table, where the corresponding single-layer claddings are detailed. In these claddings, only the lowest and highest voltages produced poor tie-in spots (undercut) between beads. The claddings at 32 through 38 V had good tie-in, with absence of any hint of rollover at the edge of the last bead, again due to the rather comfortable 0.29-in. stepover used. The dilutions observed are very similar to those observed at the lower wire feed speed of Table 5, but the resulting Ferrite Numbers are lower in general, because the all-weld-metal chromium content is lower under the higher wire feed speed conditions. The trends are shown in Fig. 10. In contrast to the trend for increasing FN with increasing voltage in Fig. 8 for the 80 in./min wire feed speed tests, the Ferrite Numbers are nearly unchanged with increasing voltage. These Ferrite Numbers, all about 4 FN, are just adequate for assurance of freedom from hot cracking, according to Lefebvre (Ref. 4). These, therefore, would be satisfactory conditions for stainless steel cladding.

Longitudinal Face Bend Tests

It must be recognized that, in a cladding of stainless steel on mild steel, the first bead will not benefit from the arc impinging partly on previously deposited weld metal. This means that the first bead, and possibly the second, will have a composition reflecting higher base metal dilution than the steady-state dilution of a series of beads as were considered above.

To examine this effect, claddings were made on 1/2-in.- (12.7-mm) thick A36 mild steel plate using 1/8-in. (3.2-mm) ER309L wire and A-100 chromium-adding flux. One set of claddings was made DCEP and the other DCEN, under otherwise identical welding conditions. Details are given in Table 7. In each set, two plates were welded. On one plate, four beads were deposited using 0.29-in. stepover, with the first bead about 16 in. (400 mm) long, the second 14 in. (350 mm) long, the third 12 in. (300 mm) long, and the fourth 10 in. (250 mm) long, all starting at the same distance from one end of the plate. This provided convenient samples for chemically analyzing each bead just outside the crater. The second plate in each set consisted of six beads deposited using 0.29-in. stepover, each about 12 in. (300 mm) long. This plate, without any preparation of the weld face, was bent around a 2-in. (50-mm) diameter. Then chemical analysis was performed on the sixth bead. These chemical analysis results are given in Table 7, along with six-layer compositions produced under the same welding conditions for dilution calculations.

The six-layer deposit on DCEN contains higher chromium, lower nickel, and higher ferrite than does the six-layer deposit on DCEP. For both the DCEP and DCEN claddings of Table 7, only the first bead of each is significantly leaner in alloy content than the other beads. The composition of the first bead in each case reflects higher dilution than in the other beads. The DCEP condition produces about 50% dilution in steady-state, while the DCEN condition produces just over half of the dilution of the DCEP condition. All of the DCEP beads contain martensite, some more than others. But not even the first DCEN bead contains martensite. All of the DCEN beads, even the first, contain some ferrite.

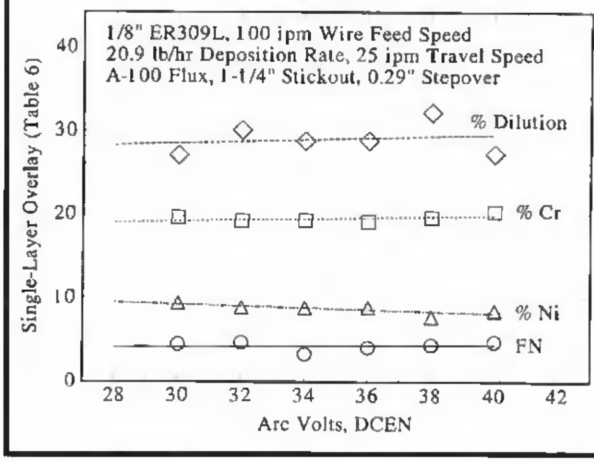

Fig. 10 — Effect of DCEN voltage on single-layer cladding with A-100 flux, 100 in./min (2.54 m/min) wire feed speed.

The six-bead-wide DCEN cladding bent without cracking. But the DCEP cladding fractured completely across the cladding in several places. This illustrates the difficulty with having martensite in the cladding. Figure 11 shows cross-sections of the two bend samples. It can be seen that the penetration into the mild steel plate is much greater with DCEP than with DCEN, again illustrating the high dilution, which leads to martensite formation and causes the cladding to fracture during bending.

Discussiun of Results

A number of claddings have been produced in this study, under a variety of conditions. While the conditions which produce the most desirable results can be useful to any fabricator directly, the data developed can also provide some direction for modifications of the conditions used herein, for particular applications. The two concerns addressed are avoiding martensite and obtaining 4 FN minimum in the deposit.

The Schaeffler diagram (Ref. 4) is quite useful for considering the tendency to form martensite. It does not present predictions in terms of Ferrite Numbers, so it is not especially suitable for ferrite predictions. The WRC-1992 diagram (Ref. 5) is more suitable for ferrite predictions in terms of Ferrite Numbers, but does not consider martensite.

Figure 12 presents the Schaeffler diagram generated from the FERRITEPREDICTOR computer software (Ref. 6). On it are located the nominal A36 mild steel base metal composition and the all-weld-metal composition obtained with ER309L and ST-100 chromium-compensating flux (Sample Number 309 100 2 in Table 1). A tie-line is constructed between these two compositions, and all possible mixtures of this all-weld-metal composition with the A36 base metal

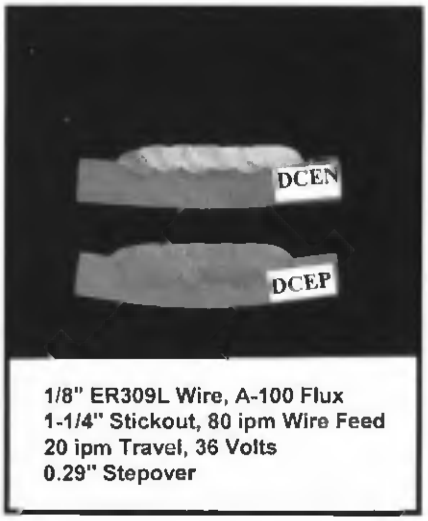

Fig. 11 — Cross-sections of 1/2-in. (12.7-mm)-thick A36 steel with 1/8-in. (3.2-mm) ER309L cladding using A-100 flux DCEN (top) and DCEP (bottom) at 0.29-in. (7.3-mm) stepover.

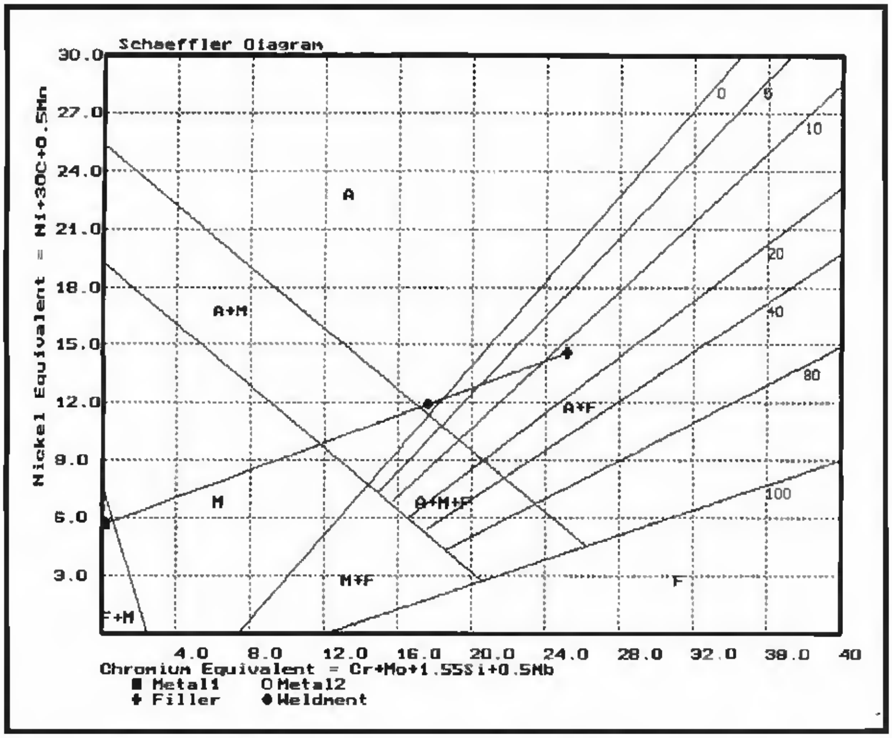

Fig. 12 — Dilution tie-line on Schaeffler diagram for single-layer cladding of A36 steel with ER309L and ST-100 flux (all-weld-metal composition 309 100 2 in Table 1). The 30% dilution point is expected to contain no martensite and no ferrite. This figure is a direct printout of the FERRITEPREDICTOR® software (Ref. 6). In the legend below the figure, "□Metal2" is included, but it does not exist in the figure.

must lie along the tie-line. The weld metal microstructure for a given dilution is then estimated by moving along the tie-line, from the all-weld-metal composition toward the base metal composition, a distance equal to the percent dilution. Then a dilution of 30% would be located by proceeding 30% of the distance from the all-weld-metal composition to the base metal composition on the diagram, which is indicated by the weld metal point included in the diagram shown in Fig. 12. It is of interest to note that, as dilution increases, the weld metal composition reaches zero ferrite just before reaching the two-phase martensite-austenite region of the diagram. This indicates that, if ferrite is obtained in a deposit made using this filler metal, there will be no martensite. Then satisfying the requirement for 4 FN minimum also takes care of avoiding martensite.

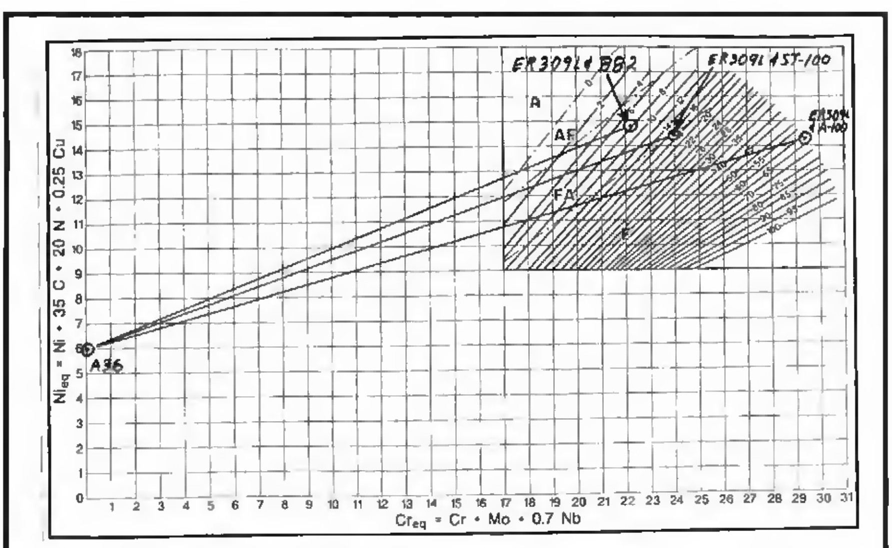

Fig. 13 — WRC-1992 diagram showing ER309L deposit composition with 882, ST-100, and A-100 fluxes, with dilution tie-lines connected to the nominal A36 steel base metal composition.

The FERRITEPREDICTOR® software is also very convenient for calculating dilution effects on estimated weld cladding FN using the WRC-1992 diagram, although it does not graphically extend the axes to zero chromium equivalent and zero nickel equivalent as was done by Kotecki and Siewert (Ref. 5). Dilution effects were calculated with this software using the rather low-chromium all-weld-metal composition obtained with the DCEN deposit of ER309L and 882 basic chromium-free flux (Sample Number SW228 in Table 3), with the higher-chromium all-weld-metal composition obtained with the DCEP deposit of ER309L and ST-100 chromium-compensating flux (Sample Number 309 100 2 in Table 1), and with the very high-chromium all-weld-metal composition obtained with the DCEN deposit of ER309L and A-100 chromium-adding flux (Sample Number SW270P in Table 7). These three compositions are shown in Fig. 13, with tie-lines connected to the nominal A36 composition. From Fig. 13, it is easy to see that the ER309L wire with A-100 flux permits greater dilution than does the same wire with ST-100 flux or 882 flux. For each of these three all-weld-metal compositions and the nominal A36 mild steel base metal composition, the FN of the weld cladding at various dilutions was estimated. One might vary the stepover with each of these all-weld-metal compositions, for example, to adjust the dilution. These results are then plotted in Fig. 14. This figure allows consideration of the range of dilutions over which 4 FN can be exceeded (and over which martensite will also be avoided).

From Fig. 14, it can be seen that the cladding from the basic chromium-free flux 882 with ER309L can only be expected to exceed 4 FN when the dilution is less than about 8%. This is very difficult to maintain without incomplete fusion defects. It can also be seen that the cladding from the chromium-compensating flux ST-100 with ER309L can only be expected to exceed 4 FN when the dilution is less than about 20%. This is possible with limited stepover, although the conditions are necessarily close to bead rollover. And it can be seen from Fig. 13 that the cladding from the chromium-adding flux A-100 with ER309L can be expected to exceed 4 FN when the dilu-

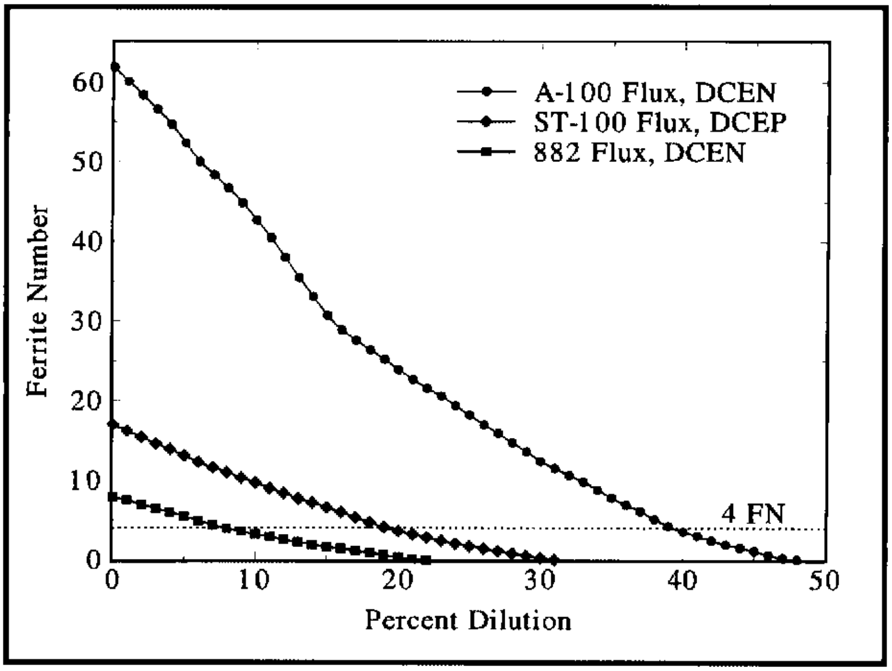

Fig. 14 Ferrite numbers calculated by the WRC-1992 diagram for single-layer submerged arc cladding of A36 mild steel using chromium-free 882 flux DCEN, chromium-compensating ST-100 flux DCEP, and chromium-adding A-100 Flux DCEN assuming all-weld-metal compositions.

tion is less than about 40%. The chromium recoveries using the other two fluxes do not vary greatly with voltage, but with the A-100 flux, as can be seen from the upper portion of Tables 4 and 5, chromium recovery varies strongly with voltage (and with wire feed speed).

It should be clear from the above that, before an acceptable level of dilution can be determined, it is necessary to know what the all-weld-metal composition is for a given set of welding conditions. Then the WRC-1992 diagram can be used to estimate ferrite content of the cladding.

Conclusions

In single-wire submerged arc cladding with ER309L, stepover is a very important variable in determining dilution and ferrite. Decreasing stepover decreases dilution. However, if too little stepover is used, incomplete fusion of the cladding with the base metal results. Use of DCEN can be helpful in limiting dilution and obtaining ferrite, but many fluxes do not perform well on DCEN. A chromium-adding flux designed for DCEN can be of some assistance in limiting dilution, and can permit ferrite to be obtained over a broader range of dilutions.

Quantitative dilution and Ferrite Number data are presented for a variety of single-layer cladding conditions. These data show that increasing wire feed speed tends to increase dilution. Increasing voltage has a small tendency to increase dilution. But increasing voltage can also be used to increase the chromium content of the all-weld-metal deposit when using a chromium-adding flux, which in turn can provide some ferrite at higher dilution.

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