LINCORE Ni2 LOW ALLOY SUBMERGED ARC WELDING WIRE

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

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The Lincoln Electric Company introduced a new low alloy tubular electrode called 'Lincore Ni2,' to be used in the automatic submerged arc welding of ASTM A588 steel for unpainted exposures. This electrode has an alloy powder contained in its core that gives a nickel content ranging between 2.00 and 2.90 percent by weight in the deposited weld. They also offer a new flux, 'Lincolnweld 880,' which is more neutral than the standard neutral flux and is designed specifically for use with their Lincore Ni2 electrode. This electrode/flux combination is designated in accordance with AWS A5.23-76, "Specification for Bare Steel Electrodes and Fluxes for Submerged Arc Low Alloy Steel Weld Metal" and has an AWS classification of F710-ECNi2-Ni2. This classification is allowed for welding done on exposed, unpainted applications of ASTM A588 steel in Table 4.1.4 of AWS D1.1-Rev. 76, Structural Welding Code. This type of electrode depends on a high nickel content to give the weld metal its 'enhanced corrosion resistance' when exposed in the unpainted condition. A588 weathering type steels have a combination of elements--usually nickel, chromium, copper, and silicon--which likewise give them an enhanced corrosion resistance. In using an electrode such as Lincore Ni2 an overmatch of the weld metal chemistry occurs which actually renders it more corrosion resistant than the base metal.

This electrode/flux combination was submitted to the Department for evaluation and approval for use on our welding of unpainted A588 steel bridge structures. This report summarizes our findings in evaluating the product and our recommendations.

The first series of experimental welds made with the Lincore Ni2 wire and Lincolnweld 880 flux combination were in conformance with the requirements of AWS A5.23-76 to verify the wire/flux combination's conformance to the F71-ECNi2-Ni2 classification. Lincoln advertises the wire/flux combination as F710-ECNi2-Ni2 which requires the weld metal to possess a minimum average Charpy V-notch impact strength of 20 ft-lb at -100 F. Since our interest is in wire flux combinations that meet a minimum average impact strength of 20 ft-lb at 0 F we decided to test the welds for the F71 classification only. Two test weldments were made in 1-in. thick A36 steel plate in strict conformance to the requirements of AWS A5.23-76. These welds were made by Raymond Fayer, District Manager of the Lincoln Electric Co. in Grand Rapids, Michigan and the welding was witnessed by Research Laboratory personnel. The specifications call for stress relieving the weld at 1150 F for one hour before machining and mechanical testing. Since our application of the welding will not include stress relieving we ran two plates, one was stress relieved and one was tested in the 'as welded' state. Table 1 gives the results of the mechanical tests run on these weldments.

TABLE 1
TEST RESULTS OF STRESS RELIEVED AND 'AS WELDED' PLATES, MADE IN CONFORMANCE TO AWS A5.23-76

Weld Sample	Yield Strength, psi	Tensile Strength, psi	Elongation in 2-in., percent	Reduction in Area, percent	Charpy V-notch at 0 F, ft-lb
Stress Relieved	68,500	83,200	33	69	103
As Welded	68,000	83,200	28	57	96
Specification Requirements for F71-ECNi2-Ni2	60,000 min	70,000-90,000	22 min	None	20 min

These results show a good conformance to the specification requirements for strength, and exceptionally high ductility and impact values. Note that the stress-relieved weld had slightly higher ductility and impact strength than the 'as welded' plate. This is the expected influence of the residual stresses, but the difference here is not significant since the 'as welded' properties are very good. The results of chemical analyses run on the experimental weldments are given in Table 2. The samples noted as 'surface' were removed from within 1/4 in. of the surface of the welded plate and the samples noted as 'tensile' were removed from the fractured region of the all-weld-metal tension specimen which comes from the mid-thickness of the weldment.

These results show good conformance to the required chemistry range. The stress relieving has no effect on the chemistry of the weld metal, the sample is included mainly to show the repeatability of the chemistry produced by the wire/flux combination. Note that there is very little variation in the weld metal analysis between the surface of the plate and the tensile specimen, which is located almost exactly at the mid-thickness. The column called 'Balance' in the tables gives the total percentage of unaccounted-for elements in the weld metal. This balance percentage is quite low in all cases and the elements that compose this column apparently had no adverse effect on the weld metal properties. The nickel content of each analysis is near to mid-range on the requirement of 2.00 to 2.90, which shows promise of being able to consistently produce a weld metal deposit in shop welding that will exceed the minimum. The high nickel content of these welds is a major cause of the high impact strengths produced, nickel being a good element for elevating weld metal notch toughness.

TABLE 2
CHEMICAL ANALYSIS OF TEST WELDMENTS MADE IN CONFORMANCE TO AWS A5.23-76

Weld Sample	Composition, percent weight								
	C	Mn	P	S	Si	Ni	Cu	Fe	Balance
Stress Relieved 'surface'	0.07	0.99	0.010	0.012	0.36	2.50	0.04	95.97	0.048
Stress Relieved 'tensile'	0.07	1.00	0.009	0.012	0.37	2.50	0.03	95.90	0.109
As Welded 'surface'	0.07	0.97	0.010	0.010	0.32	2.41	0.05	96.06	0.100
As Welded 'tensile'	0.06	0.99	0.012	0.012	0.36	2.47	0.03	95.91	0.156
Specification* Requirements Ni2 Class	0.12	1.60	0.030	0.030	0.80	2.00-2.90	0.30	None	None

* Single values shown are a maximum.

The second series of evaluations conducted on the Lincore Ni2 wire were procedure qualification tests for butt joint welding and were performed by two different fabricators. Fabricator I ran two 24-in. long welds in A588 steel plate, one 1-in. thick and one 3-1/8 in. thick. Fabricator II ran one 24-in. long weld in 2-1/4 in. thick A588 plate. The welding variables used in each weld are given in Table 3. All welding was done with 5/32-in. diameter electrode which is the only size of this product currently available. The electrical stick-out was 2-3/4 in. for Fabricator I as recommended by the manufacturer and was not noted by Fabricator II.

TABLE 3
WELDING PARAMETERS USED IN BUTT WELDING PROCEDURE QUALIFICATION PLATE PREPARATION WITH LINCORE Ni2 WELDING WIRE

Weld Identification[1]	Plate Thickness, in.	Current Type and Polarity	Current, amps	Voltage, volts	Carriage Travel Speed, in./min	Wire Consumption Speed, in./min	Preheat Temp, F	Interpass Temp, F
F1-A	1	D.C., Rev.	500	30	17	72	200	650 max
F1-B	3-1/8	D.C., Rev.	500	30	17	72	300	650 max
F2-A	2-1/4	D.C., +	500	30	16	Unknown	300	300 min to 400 max

[1] F1 denotes Fabricator I, F2 denotes Fabricator II.

Fabricator I used a double V joint preparation similar to the AWS prequalified joint B-U3B-S. Fabricator II used a double U type joint similar to AWS B-U7-S. Fabricator I made several root passes on each side with the manual shielded arc electrode Jet-LH 8018-C3 as recommended by the manufacturer to minimize the chance of hot cracking which the high alloy weld metal is sensitive to. Fabricator II did not include this in his procedure. No hot cracking problems were encountered in either of the welding procedures. A complete series of mechanical tests were run on the procedure qualification welds in accordance with the requirements of Michigan's "Supplemental Specifications for Welding Structural Steel." The results of these tests are summarized in Table 4.

TABLE 4
RESULTS OF MECHANICAL TESTS ON PROCEDURE QUALIFICATION BUTT WELDMENTS

Weld Identification	Yield[1] Strength, psi	Tensile[1] Strength, psi	Elongation[1] in 2-in., percent	Reduction[1] in Area, percent	Side Bend Test	Tensile[2] Strength, psi	Charpy V-notch at 0 F, ft-lb
F1-A	70,250	85,900	28	70	Pass	75,500	56
F1-B	72,100[3] 88,800[4]	86,800 98,300	28 16	70 31	Pass	81,800	80
F2-A	76,500	86,400	30	66	Pass	85,000	62
MDSHT Specification Requirements	60,000 min	70,000-90,000	22 min	--	Pass	70,000 min	20 min

[1] Properties measured on a 0.5 in. diameter all-weld-metal tensile specimen.

[2] Tensile strength as measured by the full thickness, transverse reduced section tensile specimen. Values given are the average of two specimens.

[3] All-weld tensile specimen located at the quarter thickness position.

[4] All-weld tensile specimen located at the mid-thickness position.

As given in Table 4, all the test requirements were met except for one all-weld-metal tensile specimen that was taken at the mid-thickness of the 3-1/8-in. thick weld F1-B. This specimen gave an excessively high yield and tensile strength with very low ductility. The fractured surface of the specimen revealed an inclusion which was not detected on the X-ray of the test plate. It appeared as though this specimen came from the location where several root passes were made on both sides of the joint with an 8018-C3 manual shielded arc electrode. This procedure apparently had an adverse effect on the tensile properties and trapped inclusions in the weld.

Consequently this procedure would not be considered as acceptable. Fabricator II had no apparent difficulties with weld soundness or hot cracking by omitting the use of the manual root passes. Note that the weldments all exhibit very high impact toughness as was the case in the previous tests. Again this is mainly due to the high nickel content of the weld metal.

Chemistry samples were taken from within 1/4 in. of each weld surface on all the weldments to check the conformance of the weld metal to the specification range. Results of these analyses are shown in Table 5.

TABLE 5
CHEMICAL ANALYSIS OF PROCEDURE QUALIFICATION TEST WELDMENTS

Weld Sample		Composition, percent weight								
		C	Mn	P	S	Si	Ni	Cu	Fe	Balance
F1-A,	Surface 1	0.08	0.92	0.014	0.014	0.30	1.97	0.06	96.60	0.042
	Surface 2	0.09	0.96	0.014	0.010	0.25	1.63	0.09	96.88	0.076
F1-B,	Surface 1	0.07	1.03	0.014	0.012	0.30	2.45	0.03	96.00	0.094
	Surface 2	0.08	1.04	0.012	0.011	0.28	2.02	0.07	95.79	0.697
F2-A,	Surface 1	0.07	0.90	0.012	0.010	0.28	2.29	0.04	96.30	0.098
	Surface 2	0.07	0.90	0.012	0.010	0.28	2.35	0.02	96.32	0.038
Specification* Requirements Ni2 Class		0.12	1.60	0.030	0.030	0.80	2.00-2.90	0.30	None	None

* Single values shown are a maximum.

All of the weld deposits meet the requirements of the Ni2 class with the exception of the nickel content of weld F1-A which was made in the 1-in. thick plate. The reason for the nickel being below the 2.00 percent minimum is undoubtably due to the dilution factor in this thinner weld. The weld profile was quite narrow at the surface in comparison to the other welds made and the increased dilution with base metal resulted in a lower nickel content. On all the weldments produced a chemical analysis taken in the weld metal immediately adjacent to the fusion line would likewise give a low nickel content due to a similar dilution with base metal. However, since the nickel content of the weld is several times higher than that of the base metal, such results are acceptable. As noted before the alloy composition of the weld metal is quite consistent comparing one surface to the other.

In conclusion the Lincore Ni2 and Lincolnweld 880, electrode/flux combination appear to be quite well suited to the butt welding of A588 steel plates used in unpainted exposures. The mechanical properties produced in the welds are superior to those typically seen in other 'weathering steel' type of electrodes and the chemistry of the deposited weld is seen to be quite consistent. The manufacturer claims that deposition rates can be up to 70 percent higher with this cored electrode than the rates possible with a similar solid electrode, without any adverse effects due to high heat input. No evaluation of the deposition rate was done in this study but the heat input was observed to be quite low in comparison to our experience with solid electrode welding of similar joints. This high deposition rate would be very attractive to potential users from an economic point of view. However, the heat input would need to be carefully monitored and maximum interpass temperatures held to below some reasonable maximum such as 600 to 700 F. Note in Table 3 that Fabricator II held his interpass temperature between 300 to 400 F. This range of variation may be unreasonably tight for production work and would not be practically applied. A procedure qualification test should be run more like actual production welding where the maximum interpass may run to 700 F or higher. The effects of high heat inputs and high interpass temperatures are especially critical on low alloy weld deposits such as the one being considered here.

A possible serious disadvantage to using the Ni2 welding wire on unpainted exposures of A588 steel is the potential for accelerating the corrosion in the base metal along the weld fusion line where the average nickel content will run around 0.25 percent or lower compared to the 2.00 percent and above in the weld. This sets up a potential difference between the two metals and could actually accelerate corrosion in the base metal by galvanic action. Preliminary findings of test specimens we have exposed in a salt spray weatherometer do indicate that this occurs. We have no way of quantifying the results, however, and can only speculate on how long-term performance in a bridge structure would be effected. The most logical conservative approach would be to maintain as close a match between base metal and weld metal chemistry and still get adequate mechanical properties. This line of reasoning would exclude the high nickel deposit from use on unpainted exposures and would continue to allow the use of materials with considerably poorer physical properties. Therefore, since the Ni2 weld appears to be superior in respect to its mechanical properties we would recommend that it be allowed in such structures and that the weld area be painted to provide the needed protection.

From a cost point of view the Lincore Ni2 wire is essentially the same per pound as the other weathering steel wires on the market. The economic advantage in using the process would be from the increased deposition rate possible with the cored wire which could add up to a considerable labor savings for the fabricator.

Based on the facts to date we would recommend the approval of the use of the Lincore Ni2 and Lincolnweld 880 electrode/flux combination for welding on A588 steel but would not advise its use in unpainted exposures on critical structures. We have documented that in certain adverse combinations of industrial and highway atmospheres the unpainted A588 steel performs very poorly, and that salt water leakage through joints increases the problem drastically. The addition of the high nickel weld deposit to such bridges undoubtably would compound a perplexing problem area.

No change would be required in our specification to allow the use of this electrode/flux combination since we currently permit combinations that produce a 8018-C3 type of deposit.