GALVANIC CORROSION POTENTIAL OF CHROMX REINFORCEMENT

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ABSTRACT

The corrosion potential of ChromX 9100 and 4100 steel (ASTM A1035 Type CS and CM), Type 2205 and 2304 stainless steels, and ASTM A1094 galvanized reinforcement was evaluated in this study. Reinforcement was evaluated in moving simulated seawater prepared in accordance with ASTM D1141at temperatures of 50 °F, 65 °F, and 80 °F for a period of one week. A1035 reinforcement was evaluated both before and after removal of the mill scale on the bars.

The corrosion potentials of 2205 and 2304 stainless steels were the least negative of those evaluated in this study, approximately –0.2 vs a copper sulfate electrode (CSE). A1035 Type CS and CM reinforcement exhibited potentials of approximately –0.5 V and –0.6 V vs. CSE, respectively. With the exception of A1035 Type CS reinforcement at 50 °F, the removal of mill scale did not alter the corrosion potential of A1035 reinforcement. A1094 reinforcement exhibited the most negative potential, around –1.05 V vs. CSE.

KEYWORDS: ChromX reinforcement, corrosion, galvanic corrosion, galvanized reinforcement, stainless steel

INTRODCUTION

This report describes tests performed to establish the corrosion potential of ChromX 9100 and 4100 steel (ASTM A1035 Type CS and CM), as well as Type 2205 and 2304 stainless steels and ASTM A1094 galvanized reinforcement. Allowing metals with significant differences in corrosion potential to come into electrical contact with each other can result in accelerated corrosion of the more active metal, a process known as galvanic corrosion or dissimilar metal corrosion. The use of different types of reinforcement in a given concrete structure is sometimes considered as a means of reducing construction costs, therefore, it is critical to establish corrosion potentials for commonly used reinforcement prior to allowing it to be mixed in the field.

EXPERIMENTAL WORK

Five types of reinforcing steel were investigated as part of this study. Two types of ChromX reinforcing steel were investigated, ChromX 9100 and 4100 (ASTM A1035 Type CS and CM, respectively), along with 2205 and 2304 stainless steel reinforcement and ASTM A1094 galvanized reinforcement. The A1035 reinforcement consisted of No. 4 reinforcing bars; all other reinforcement was No. 5. Bars were tested in the as-received condition; A1035 reinforcement was also evaluated after removal of mill scale. The preparation of the reinforcement proceeded as follows:

1. Bars were cut to a length of 5 in.
2. One end of the bar was drilled to a depth of 0.75 in and threaded to accept a 10-24 screw. Selected A1035 bars were wire brushed to remove mill scale.
3. Bars were cleaned with acetone to remove any oil or surface contamination from machining.
4. A 0.5-in. long 10-24 stainless steel machine screw and washer were used to attach a 16-gauge stranded copper wire to the reinforcement; this electrical connection was covered with two coats of Scotchkote 323 Epoxy to protect the electrical connection from corrosion.

The bottom end of A1094 bars were covered in Scotchkote 323 Epoxy and a rubber cap to protect the exposed steel core from corrosion; solid bars were evaluated without the cap.

The reinforcement was evaluated for galvanic corrosion potential in moving simulated seawater prepared in accordance with ASTM D 1141. Testing was performed at three temperatures; 50 °F, 65 °F, and 80 °F. Two bars from each type of steel were evaluated at each temperature, with the exception of A1035 bars with the mill scale removed, which were not evaluated at 65 °F due to limited material. Bars were secured in a saltwater tank with approximately 1 in. of bar above the surface of the water to prevent submersion of the electrical connection. Bars were placed randomly throughout the tank to minimize the impact of any variation of environment within the tank.

Corrosion potentials were measured on each bar a minimum of twice a day with respect to a silver chloride electrode; potential values have been converted to equivalent readings with respect to a copper sulfate electrode (CSE) for presentation. The temperature of the tank was also recorded at each reading to ensure a proper environment was being maintained. Bars were exposed for one week, after which they were removed from solution and photographed.

RESULTS

Figure 1 shows the corrosion potential (vs. CSE) versus time for bars evaluated at 50 °F. A1035 bars are labeled as CS and CM to indicate their type; bars that were wire brushed to remove mill scale have an additional “S” modifier after the type. As seen in the figure, the two stainless steels, 2205 and 2304, exhibited the least negative corrosion potential; after starting the test with potentials in the –0.3 to –0.4 V range, potentials quickly rose to approximately –0.2 V and remained there throughout the duration of the test. Some variation was seen between individual specimens, particularly for the 2304 stainless steel. A1035-CS reinforcement exhibited a consistent potential near –0.5 V throughout testing; the removal of mill scale resulted in a slightly less negative potential, but also a more erratic potential, with values ranging from –0.35 to –0.6 V for

A1035-CS-S. This behavior was not seen on A1035-CM reinforcement, where specimens both with and without mill scale exhibited potentials near –0.6 V vs. CSE throughout testing. A1094 reinforcement exhibited the most negative potential, with both specimens exhibiting potentials around –1.05 V throughout testing.

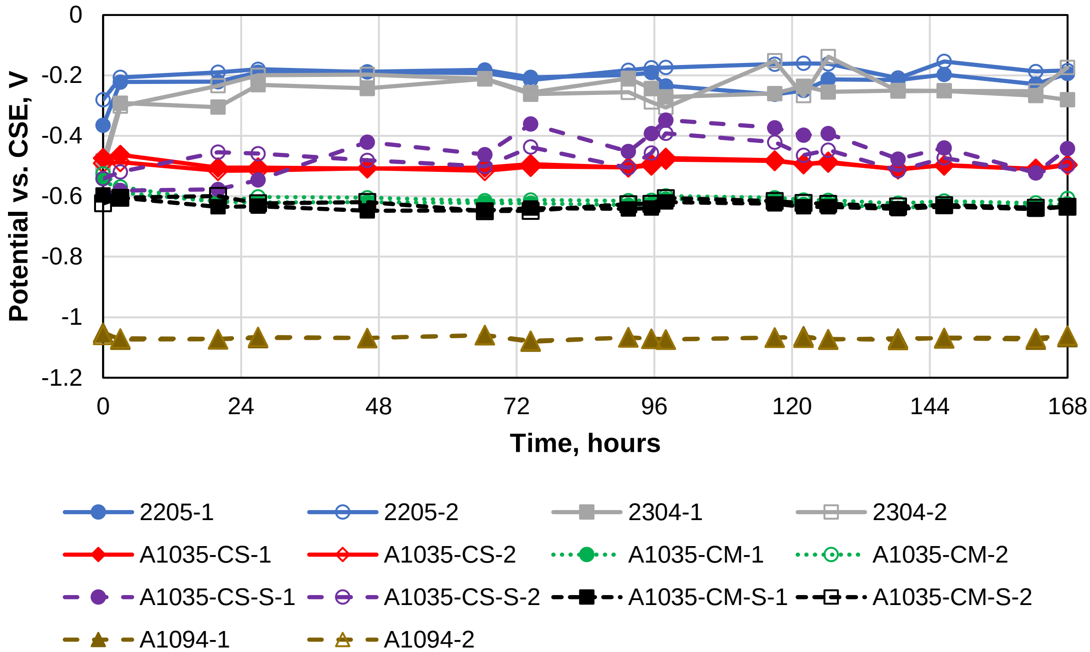

Figure 1: Corrosion potential (vs. CSE) for specimens evaluated at 50 °F.

Figure 2 shows the corrosion potential (vs. CSE) versus time for bars evaluated at 65 °F. As was the case at 50 °F, the 2205 and 2304 stainless steels, exhibited potentials in the –0.3 to –0.4 V range at the start of testing before rising to approximately –0.2 V. Specimen 2304-2 exhibited two drops in potential to below –0.3 V before returning gradually to approximately –0.2 V; other stainless steel specimens did not exhibit this behavior. A1035-CS and A1035-CM reinforcement exhibited consistent potentials near –0.5 V and –0.6 V respectively, comparable to the results at 50 °F. (A1035 reinforcement was not evaluated after wire brushing at this temperature). A1094 reinforcement again exhibited the most negative potential, with both specimens exhibiting potentials around –1.05 V throughout testing.

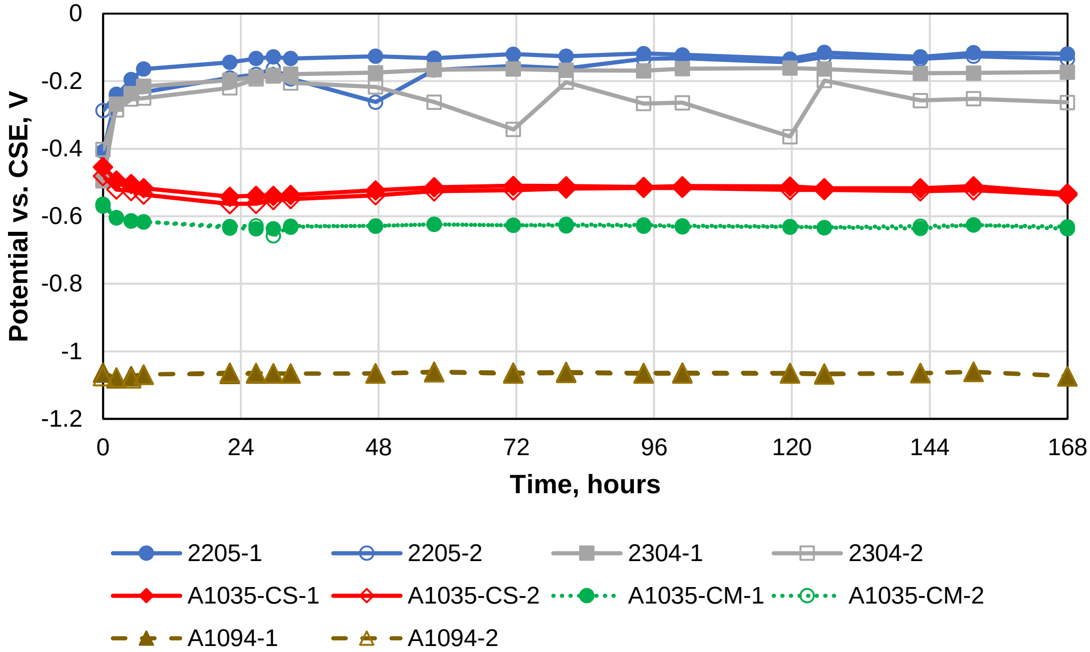

Figure 2: Corrosion potential (vs. CSE) for specimens evaluated at 65 °F.

Figure 3 shows the corrosion potential (vs. CSE) versus time for bars evaluated at 80 °F. The trends observed here match what was seen at lower temperatures, with potentials similar to those observed in Figures 1 and 2. The one exception of note is that the wire brushed A1035-CS-S reinforcement, which exhibited erratic potentials at 50 °F, showed no difference from A1035-CS bars with the mill scale intact.

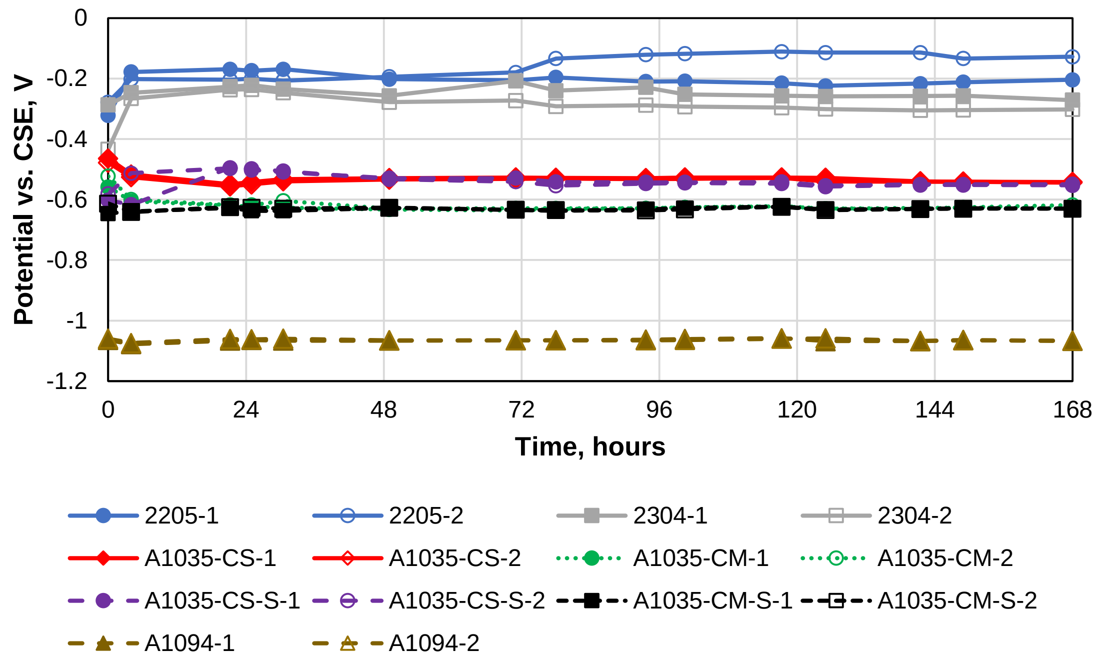

Figure 3: Corrosion potential (vs. CSE) for specimens evaluated at 80 °F.

Figures 4 and 5 show 2205 reinforcement after one week at 65 °F, and is representative of all the 2205 reinforcement in this study. Minimal corrosion is observed on the bars, with corrosion limited to a small region above the waterline (Figure 5).

Figure 4: 2205 stainless steel reinforcement after one week of exposure to simulated seawater at 65 °F.

Figure 5: Closeup of corrosion on 2205 stainless steel reinforcement after one week of exposure to simulated seawater at 65 °F.

Figure 6 shows 2304 reinforcement after one week at 80 °F, and is representative of all the 2304 reinforcement in this study. As was the case with 2205 reinforcement, corrosion minimal on the bars and is limited to a small region above the waterline.

Figure 6: 2304 stainless steel reinforcement after one week of exposure to simulated seawater at 80 °F.

Figure 7 shows A1035-CS reinforcement after one week at 65 °F, and is representative of all the A1035-CS reinforcement in this study. On A1035-CS bars both with and without mill scale, moderate corrosion products were observed along the entire length of the bar.

Figure 7: A1035-CS reinforcement after one week of exposure to simulated seawater at 65 °F.

Figure 8 shows A1035-CM reinforcement after one week at 50 °F, and is representative of all the A1035-CM reinforcement in this study. Corrosion products were much heavier than was observed on A1035-CS reinforcement, with significant portions of the bar covered with rust.

Figure 8: A1035-CM reinforcement after one week of exposure to simulated seawater at 50 °F.

Figure 9 shows A1094 reinforcement after one week at 65 °F, and is representative of all the A1094 reinforcement in this study. White zinc corrosion products were visible over the entire length of the bar, but were more pronounced above the waterline. No signs of iron corrosion products were visible either on the bar or under the protective cap.

Figure 9: A1094 reinforcement after one week of exposure to simulated seawater at 65 °F.

Table 1 shows the average, range, and COV of corrosion potentials for each type of reinforcement investigated in the study over the full duration of testing. As previously described, the potential of most types of reinforcement changed rapidly during the first 12 to 24 hours of testing before stabilizing. Table 2 shows the average, range, and COV of corrosion potentials for each type of reinforcement investigated in the study excluding the first 24 hours of testing and is more representative of long-term performance. As seen in the tables, the stainless steel reinforcement evaluated had the least negative potentials, but also the highest coefficients of variation among reinforcement types in this study. Part of the reason for the high COV is due to the low average potentials; however, the stainless steel reinforcement also exhibited several drops in potential over the duration of testing. A1035-CS and A1035-CM reinforcement exhibited average potentials of approximately –0.5 V and –0.6 V, respectively, and A1094 reinforcement exhibited the most negative potential, –1.07 V. In all cases, excluding the first 24 hours of testing resulted in a decrease in COV.

Table 1: Corrosion Potentials Over Entire Duration of Testing

Reinforcement Type	Potential vs. CSE			
	Average	COV	Min	Max
2205	-0.184	0.289	-0.408	-0.111
2304	-0.250	0.265	-0.503	-0.138
A1035-CS	-0.516	0.044	-0.564	-0.454
A1035-CM	-0.618	0.035	-0.658	-0.523
A1035-CS-S	-0.502	0.124	-0.617	-0.348
A1035-CM-S	-0.630	0.018	-0.649	-0.595
A1094	-1.067	0.005	-1.081	-1.051

Table 2: Corrosion Potentials Over Testing (Excluding First 24 Hours)

Reinforcement Type	Potential vs. CSE			
	Average	COV	Min	Max
2205	-0.170	0.232	-0.263	-0.111
2304	-0.236	0.201	-0.364	-0.138
A1035-CS	-0.519	0.037	-0.563	-0.473
A1035-CM	-0.625	0.015	-0.658	-0.599
A1035-CS-S	-0.491	0.122	-0.557	-0.348
A1035-CM-S	-0.632	0.013	-0.649	-0.606
A1094	-1.066	0.004	-1.081	-1.058

GALVANIC SERIES CHART

Figure 10 presents the galvanic series chart recreated from ASTM G82 with the bars evaluated in this study added (highlighted in yellow). The potential ranges for the reinforcement in this study represent the range of those observed excluding the first 24 hours of testing to allow the bars time to reach a stable potential. As seen in the figure, both A1035-CS (ChromX 9100) and A1035-CM (ChromX 4100) exhibit potentials comparable to mild and low alloy steel (representative of A615 reinforcement), with a potential difference less than –0.1 V. The 2205 and 2304 stainless steels exhibit potentials in the approximately 0.4 V more positive than mild and low alloy steel and 0.25 to 0.3 V more positive than A1035-CS steel. As expected, these duplex alloys of stainless steel exhibit potentials between that of the martensitic Type 410 and the austenitic Type 304, 316, and others. No attempt to depassivate the 2304 or 2205 was made, so the results are presented in the passive state only. Also as expected, the A1094 reinforcement exhibited a potential comparable to existing tests on pure zinc, approximately 0.5 V more negative than mild and low alloy steel.

Previous work by Kuster and Bielman (1973) recommended a maximum potential difference of 0.25 V for dissimilar metals in contact; more recent work by Darwin et al. (2013) found that 2304 and conventional reinforcement (with a potential difference of 0.40 V, as found in this study) exhibited limited galvanic activity in simulated pore solution and no galvanic activity in concrete, suggesting a slightly higher upper bound than that found by Kuster and Bielman. Based on these studies, it is unlikely that A1035 reinforcement will result in increased galvanic corrosion when paired with either conventional reinforcement or with 2304 reinforcement. The galvanic potential difference between both types of A1035 reinforcement and 2205 reinforcement is comparable to that between 2304 and conventional reinforcement investigated by Darwin et al.; thus, acceptable performance is also expected.

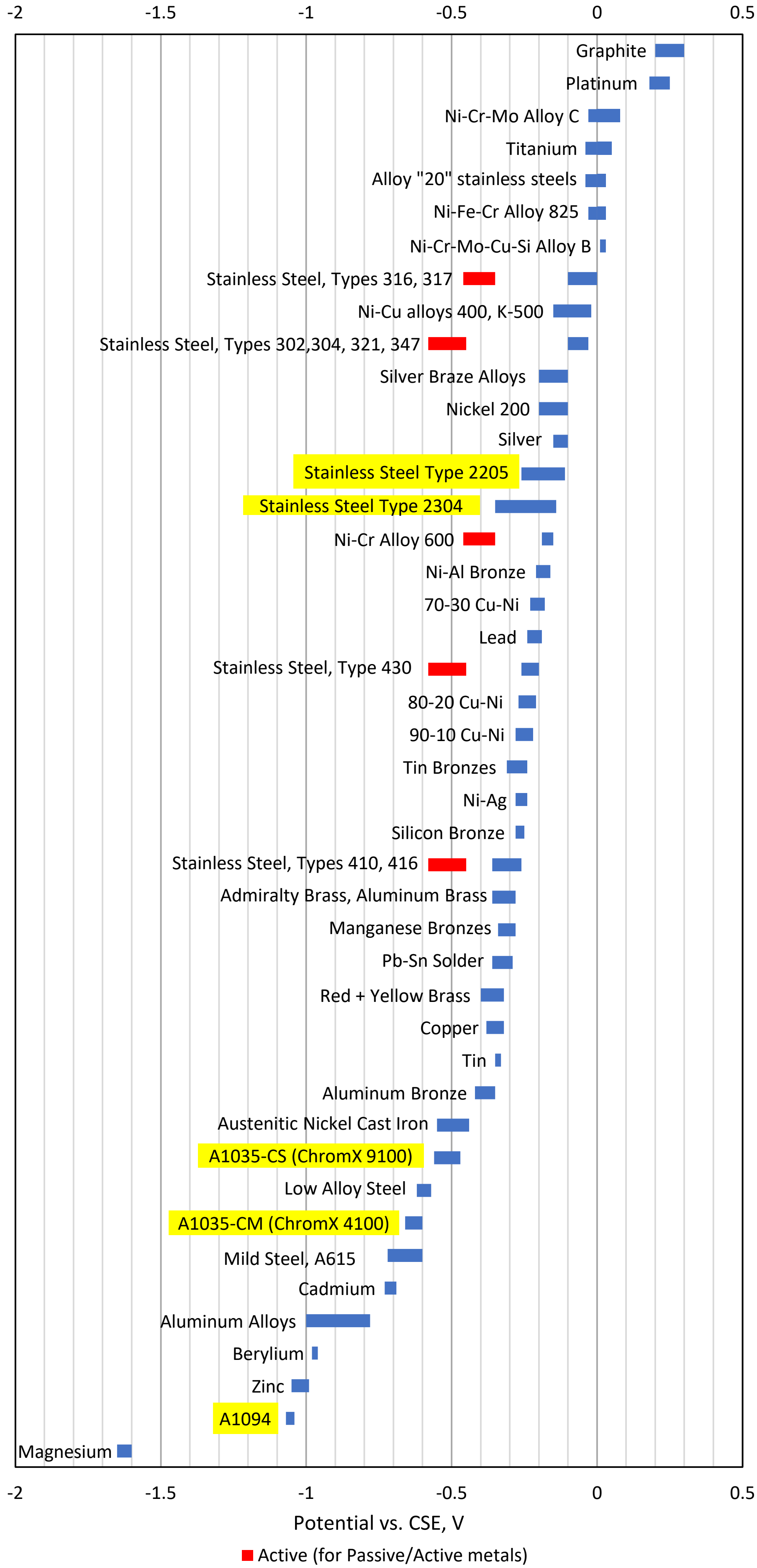

Figure 10: Galvanic Series in moving seawater

SUMMARY AND CONCLUSIONS

This report presents the corrosion potential of ChromX 9100 and 4100 steel (ASTM A1035 Type CS and CM), as well as Type 2205 and 2304 stainless steels and ASTM A1094 galvanized reinforcement. Reinforcement was evaluated in moving simulated seawater at temperatures of 50 °F, 65 °F, and 80 °F for a period of one week. A1035 reinforcement was evaluated both before and after removal of the mill scale on the bars.

The following conclusions are based on the results presented in this report:

1. A1035 Type CS and CM reinforcement exhibits corrosion potentials approximately 0.1 V more positive than conventional reinforcement.
2. The removal of mill scale did not significantly alter the corrosion potential of A1035 Type CM reinforcement. The removal of mill scale produced inconsistent results with A1035 Type CS reinforcement, resulting in a less negative potential at 50 °F and having no effect at 80 °F. These results are within the scatter of the data, however, and appear unlikely to affect performance in the field.
3. Based on prior research, A1035 Type CS and CM reinforcement is unlikely to result in increased galvanic corrosion activity when coupled with either conventional, 2205, or 2304 stainless steel reinforcement.
4. 2205 and 2304 duplex stainless steel reinforcement exhibit potentials approximately 0.4 V more positive than conventional reinforcement, a difference in potential slightly less than that between conventional reinforcement and austenitic stainless steel reinforcement.
5. A1094 reinforcement exhibits a corrosion potential comparable to that of other zinc products, approximately 0.5 V more negative than conventional reinforcement.

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