EIG CRSI
EPOXY INTEREST GROUP

CORROSION RATES
Of Select Reinforcing Bars In Macrocell Tests

A comparison of ASTM A775 epoxy-coated and ASTM A1035 low-carbon, chromium reinforcing bars with requirements for ASTM A955 stainless-steel reinforcing bars

ASTM A955 provides a method for corrosion testing of stainless-steel reinforcing bars and this test is used to determine if a particular alloy is suitable for use in concrete under corrosive conditions. Epoxy-coated steel reinforcing bars meeting ASTM A775 and low-carbon, chromium reinforcing bars, meeting ASTM A1035 were tested using this method at the University of Kansas. The work shows that epoxy-coated reinforcing bars can meet the requirements of this test, whereas the low-carbon, chromium bars cannot and have corrosion rates that are approximately ⅔ that of uncoated bars. The data supports continued use of epoxy-coated reinforcement and suggests that low-carbon chromium bars may not provide adequate corrosion resistance for long-term protection.

INTRODUCTION

The repair of concrete due to corrosion of reinforcing steel causes significant distress. Repairs frequently disrupt traffic, and inconvenience the public. For this reason, engineers seek methods to reduce the rate of corrosion damage. Frequently, solutions involve the use of alternate reinforcing steels, including epoxy-coated reinforcing bars.

Many different test methods have been used to evaluate the corrosion-resistance of reinforcing steel materials; however, few have been developed under an open, consensus process and are part of a product specification. ASTM A955 contains a rapid macrocell test that is used to qualify corrosion-resistance of stainless-steel reinforcing bars. Within this specification, the corrosion rate of the stainless-steel bars must remain below a particular rate in order for the product to qualify under this specification. The performance of other reinforcing steel bars under this test is of interest. The manufacturer of a product meeting ASTM A1035 claims that this product "offers corrosion resistance similar to stainless-steel." It was of interest to calculate these products using the requirements of ASTM A955.

Tests were conducted at the University of Kansas using six types of reinforcing bars:

ASTM A615 – uncoated carbon-steel

ASTM A775 – fusion-bonded epoxy-coated A615 bars (0, 0.04 & 0.8% damage)

ASTM A1035 – low-carbon, chromium (as-received and pickled)

ASTM A615
Uncoated
Carbon-Steel

ASTM A775
Fusion-Bonded
Epoxy-Coated
A615 Bars

ASTM A1035
Low-Carbon,
Chromium
(As Received)

ASTM A1035
Low-Carbon,
Chromium
(Pickled)

TEST METHOD

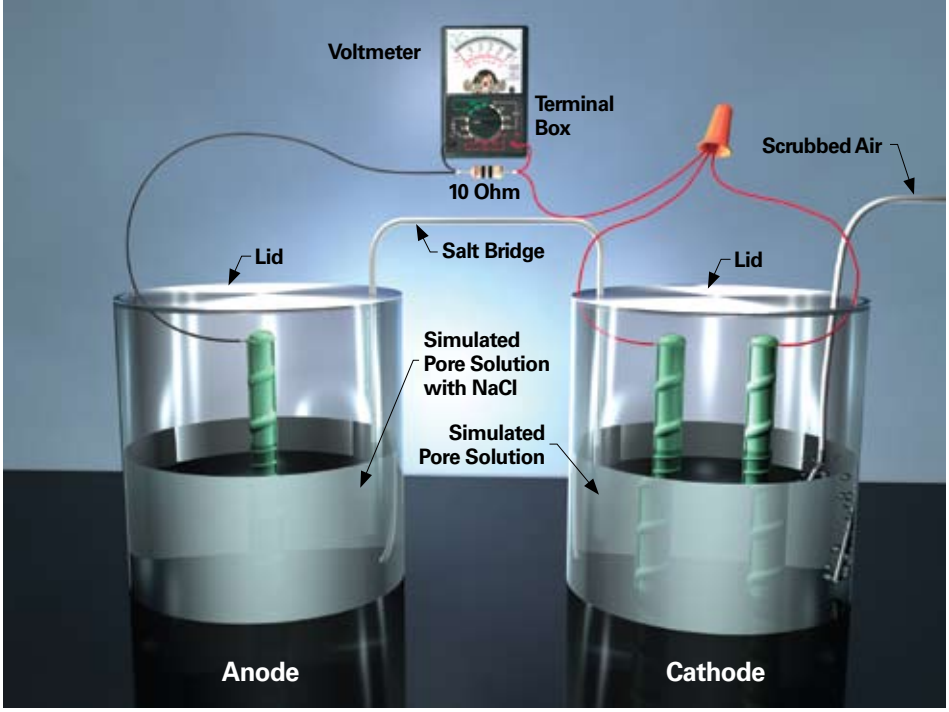
Appendix A2 of ASTM A955 has been used to determine appropriate stainless-steel alloys for use in reinforcing concrete. The test consists of two containers, each containing one or two reinforcing bars. One container holds two bars, suspended in a solution of simulated concrete pore water, while the other container holds a single bar suspended in a solution of simulated pore water with additional sodium chloride. A salt bridge is connected between the two containers to enable ionic flow to occur. The bars are connected using a resistor, which enables any electrical current between the two sets of bars to be measured. From the measurements, the amount of steel corrosion during the 15-week test can be readily determined.

The ASTM A955 specification requires that over the 15 week period, the average corrosion rate during the test program remains less than 0.25 µm/year and that no single specimen has a corrosion rate exceeding 0.50 µm/year.

Bars meeting ASTM A775 and ASTM A1035 were submitted from a commercial source. Along with the ASTM A775 bars, the base steel used in manufacture of the ASTM A775 bars, meeting ASTM A615, was also provided.

When received, the bars meeting ASTM A1035 exhibited significant surface corrosion. Concern was raised regarding how such corrosion may affect test results. Thus, tests were conducted on both as-received and bars pickled using a solution of nitric and hydrofluoric acid.

Epoxy-coated bars were tested under three conditions. These were: undamaged or with 0.04 and 0.83 percent exposed steel area. Generally, specifications for epoxy-coated bars require all damage to be repaired prior to concrete placement. Thus, high damage levels of 0.83 percent would not be expected in the field. Simulated damage was obtained by drilling four holes through the coating to the base metal using 0.028 in. (0.7 mm) and 1/8 in. (3.2 mm) drill bits, respectively.



Schematic Diagram showing the test configuration.

RESULTS

Corrosion rates for the various bars during the 15-week study are summarized below.

Material	Condition	Range µm/year	Average µm/year	Meets ASTM A955
ASTM A615	As received	10 – 80	30	No
ASTM A775	As received	~ 0	0	Yes
	0.04% damage	–0.3 - 0.3	0	Yes
	0.83% damage	0 - 4	1.5	No
ASTM A1035	As received	10 – 40	20	No
	Pickled	0 – 25	?	No

The uncoated bars meeting ASTM A615 had corrosion rates ranging from 10 to 80 µm/year with an average of around 30 µm/year, which was typical of prior tests for uncoated bars conducted using this test method.

When results of the ASTM A775 as-received bars were reviewed, it was found that the corrosion rates were "nearly zero" and bars with 0.04 percent damage exhibited corrosion rates between -0.3 and 0.3 µm/year. The average corrosion rate during the test remained less than 0.5 µm/year for the entire 15 week testing program. These values met the requirements of ASTM A955.

Where 0.83 percent damage was introduced into the A775 bars, the corrosion rates increased, with a range from 0 to 4 percent; averaging 1 to 1.5 µm/year. While not meeting the requirements for ASTM A955, these provided over an order of magnitude reduction in corrosion rate compared with the uncoated bar meeting ASTM A615.

The corrosion rates for the as-received bars meeting ASTM A1035 ranged from 10 to 40 µm/year, with an average of around 20 µm/year. This value was 2/3 that of the uncoated A615 bars. When pickled, the corrosion rates of the ASTM A1035 bars dropped during initial stages of the test; however, as the test progressed, the corrosion rates approached that of the as-received bars. These values were significantly greater than that required to meet ASTM A955.

VISUAL INSPECTION

At the end of the testing program, the specimens were visually examined for corrosion. This visual examination found substantial corrosion on the ASTM A615 and A1035 bars, with minimum corrosion on the ASTM A775 bars.

ASTM A615
Uncoated
Carbon-Steel

ASTM A775
Fusion-Bonded
Epoxy-Coated
A615 Bars
0.83% damage

ASTM A1035
Low-Carbon,
Chromium
(As Received)

ASTM A1035
Low-Carbon,
Chromium
(Pickled)

Figure 5: Visual condition of bars at the end of the testing program. Note the minimal corrosion of the epoxy-coated bars compared with those of the ASTM A615 and A1035 bars.

CONCLUSIONS

Conclusions reached from the test program are as follows:

1. The uncoated A615 bars exhibited significant corrosion with average corrosion rates of 30 µm/yr.
2. The ASTM A1035 low-carbon, chromium bars exhibited significant corrosion upon receipt. For this reason, samples were tested in an as-received and pickled condition.
3. Bars meeting ASTM A1035 exhibited corrosion rates of approximately 20 µm/yr. This corrosion rate is only $^2/_3$ that of the uncoated A615 bars.
4. While pickling initially reduced the corrosion rate of bars meeting ASTM A1035, corrosion rates during the 15 week program approached those of the as-received bars.
5. Significant visual corrosion was observed on the ASTM A1035 samples and this corrosion appeared to be similar to that of the uncoated A615 bars.
6. Claims that ASTM A1035 bars perform like stainless-steel cannot be supported.
7. Epoxy-coated bars with no or low damage met the requirements of ASTM A955 and had average corrosion rates less than 0.25 µm/yr.
8. Epoxy-coated bars with 0.83 percent damage exhibited corrosion rates substantially less than that of the black bars with a rate of around 1.5 µm/yr. These rates are at least 1 order of magnitude lower than that of the uncoated A615 bars.
9. Minimal visual corrosion was observed on the bars meeting ASTM A775.

A copy of the report titled "Rapid Macrocell Tests of ASTM A775, A615 and A1035 Reinforcing Bars" by W.J. Surgeon, M. O'Reilly, D. Darwin and J. Browning can be obtained from the Epoxy Interest Group of CRSI.

REFERENCES

Surgeon, W.J., O'Reilly, M., Darwin D., and Browning J.: **"Rapid Macrocell Tests of ASTM A775, A615 and A1035 Reinforcing Bars"** Structural Engineering and Engineering Materials SL Report 10-4, University of Kansas Center for Research Inc., Lawrence Kansas, 2010.

ASTM A615/A615M - 09b Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

ASTM A775/A775M - 07b Standard Specification for Epoxy-Coated Steel Reinforcing Bars

ASTM A955/A955M - 10a Standard Specification for Deformed and Plain Stainless-Steel Bars for Concrete Reinforcement

ASTM A1035/A1035M - 09 Standard Specification for Deformed and Plain, Low-carbon, Chromium, Steel Bars for Concrete Reinforcement

EPOXY INTEREST GROUP

933 N Plum Grove Road ■ Schaumburg, IL 60173
Tel: 847.517.1200 ■ email: info@epoxy.crsi.org ■ www.epoxyinterestgroup.org

02/11