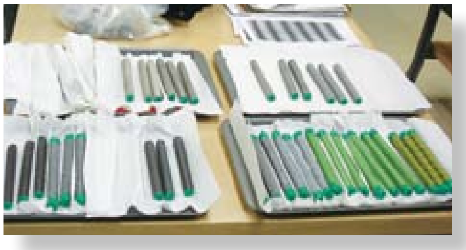
EPOXY INTEREST GROUP

CORROSION-RESISTANCE OF REINFORCING BARS:

An Accelerated Test

Epoxy-coated bars have shown good corrosion protection in concrete structures since 1973. Recently, interest in other corrosion-resistant bar systems has resulted in new products being supplied to the marketplace. Tests were conducted by Wiss, Janney, Elstner Associates using a wide range of products including 15-year old epoxy-coated reinforcing bars that had been removed from salt-contaminated concrete. Results from the tests show that even old coated bars perform significantly better than other products. This work supports conclusions of other longer-term research, that epoxy-coated bars provide cost-effective corrosion protection.

The detailed report with before and after photos of each product is available at www.epoxyinterestgroup.com



The bars met the following ASTM Standards:

Carbon steel (black)	A615
Low-Carbon, Chromium, Steel (LCC, MMFX)	A1035
Galvanized	A767
Stainless steel 3CR12	A995
Stainless steel 2201	A995
Stainless steel 2205	A995
Stainless steel 316LN	A995
Epoxy-coated reinforcing	A775

TEST METHOD

The salt spray test is the oldest and most widely used test for the evaluation of corrosion resistance of finished surfaces or parts. While it is known that this test does not reproduce any specific environment, the test generates a defined, high-corrosive and reproducible environment. The test is commonly used for ranking the corrosion properties of various stainless and coated steel.

The testing is conducted in a closed chamber, where a salted solution is sprayed by means of a nozzle. This produces a corrosive environment in the chamber and thus, parts in it are attacked under this severe corroding atmosphere.

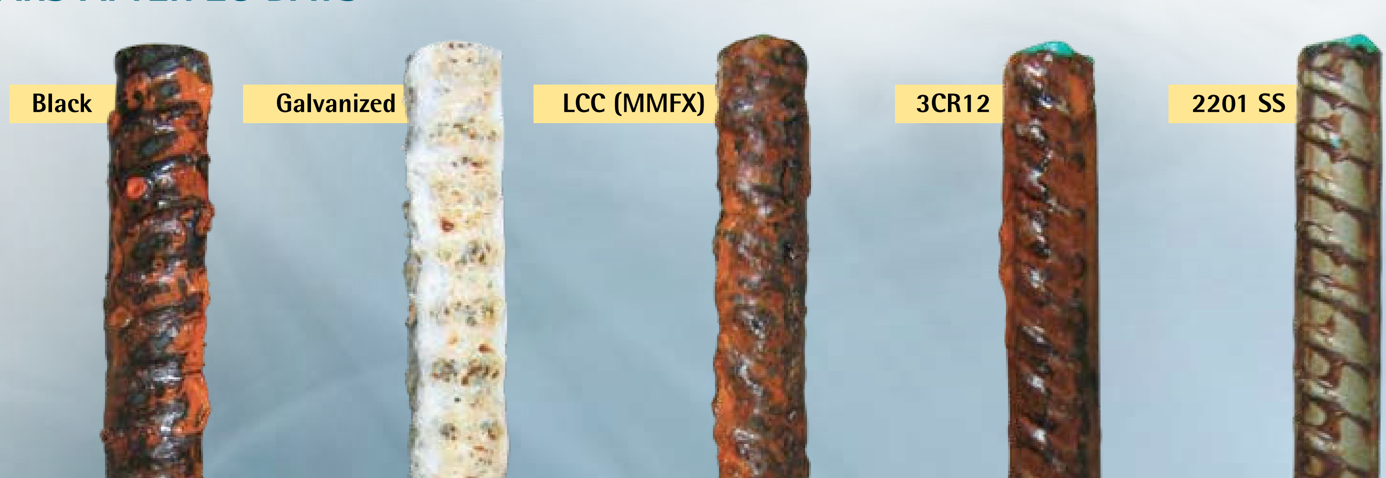
Reinforcing bar samples were tested in a fog cabinet for a period of 28 days. During this period they were exposed to a 5% sodium chloride fog at 35°C following the ASTM B117 protocol.

The carbon steel and LCC bars were tested in both an "as-received" and a sandblasted condition. The 3CR12 and 2201 stainless bars were tested in sandblasted conditions. Old epoxy-coated bars were extracted from a 15-year old bridge deck in Chicago and used in the tests as some researchers have expressed concerns that epoxy-coated bars may exhibit distress after embedment in concrete. Chloride analysis of the concrete surrounding these bars showed that the chloride concentration at the bar depth was approximately 600 ppm, twice the typical chloride threshold for conventional black steel. Despite the high chloride level, all the extracted bars had no signs of corrosion and the deck had no delaminations.

The epoxy-coated and galvanized bars were tested in two conditions; as-received specimens and with intentional small damaged areas. This damage was introduced with a single 1/16 inch drill hole, resulting in a damaged area of approximately 0.064 percent.

Prior to placing into the fog chamber, all bars were degreased with solvent, rinsed with deionized water and air-dried. After 7, 18 and 28 days of testing, one bar per test condition was removed from the chamber and cleaned following ASTM G1 test method for weight analysis.

BARS AFTER 28 DAYS



OBSERVATIONS

Carbon Steel

All bars corroded extensively during the test period, and the corrosion aggressively progressed with time. Weight analysis shows that the bars experienced significant corrosion.

LCC (MMFX)

Both as-received and sandblasted bars corroded significantly and the corrosion aggressively progressed with time.

Galvanized

All galvanized bars experienced extensive corrosion. The zinc coating corroded first, producing a white-color corrosion product, and then the underlying carbon steel started to corrode, producing a rusty color. The rust color was prominent after 2 weeks of exposure. For the samples with drill holes, the exposed carbon steel at drilled holes was protected until the adjacent zinc coating was consumed. Weight loss analysis showed that these galvanized bars experienced extensive corrosion with very high corrosion rates. Average corrosion weight loss of the undamaged galvanized bars was about 30 percent higher than that of the as-received carbon steel bars.

Stainless Grade 3CR12

The sandblasted bars corroded extensively. These experienced general corrosion attack at most areas and some deep pitting corrosion near the ribs. While corrosion of 3CR12 appeared to be extensive, its average corrosion was about half of the LCC (MMFX) and about one third the rate of the as-received carbon steel bars.

Stainless Grade 2201

After 12 hours of exposure, corrosion products were visible on most of the bar surfaces and corrosion appeared to progress with time. However, the cleaned bar showed that corrosion was rather superficial and no obvious pits were observed. Weight loss analysis yielded a very low average corrosion of about 3% of as-received carbon steel bars.

Stainless Grades: 2205 & 316LN

These stainless steel bars experienced some localized corrosion and this corrosion apparently progressed with time. The total amount of corrosion was superficial and such corrosion was speculated to have been induced by local contamination or crevices generated by the coating used to seal cut ends.

Epoxy-coated, New

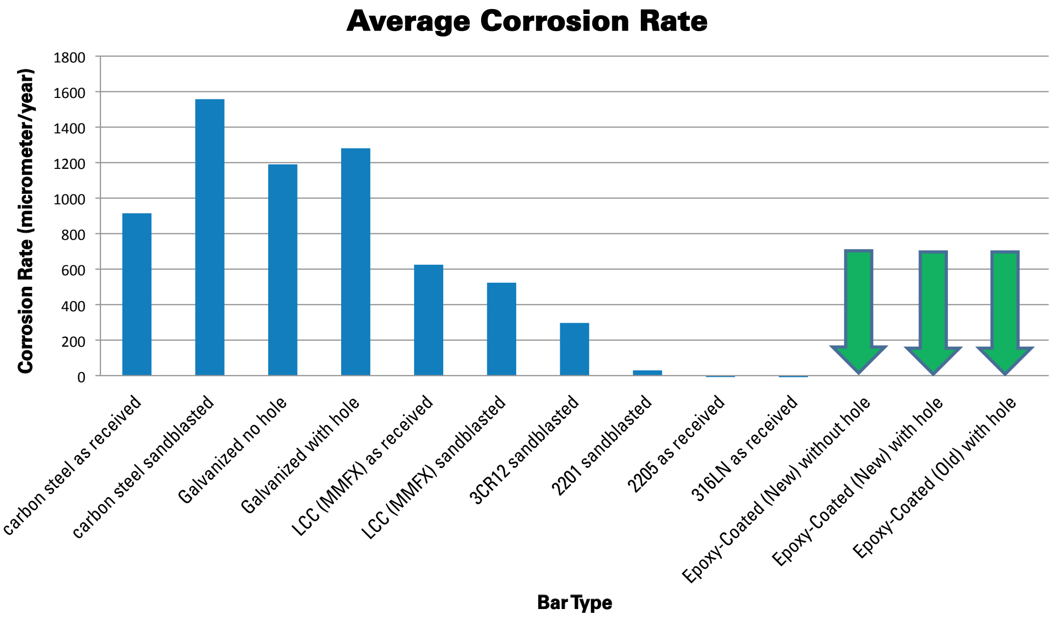
The new ECR bars with no defects had no corrosion throughout the testing program. The specimens with a drilled hole only corroded at the holes.

Epoxy-coated, Old

The bars extracted from a 15-year-old bridge deck performed very well with little corrosion. For the first seven days of exposure, corrosion only occurred at the drilled holes where carbon steel was exposed. Visual observation indicated that corrosion of the bars was minor. For all the ECR specimens, weight loss was so minor that it was not possible to effectively estimate actual corrosion rates. The epoxy coating adhesion did not affect the corrosion performance. Even bars with poor coating adhesion performed well in the test, which does not support conclusions of some researchers who have indicated that old coatings will provide little or no benefit.

Bar Type	Condition	Average Corrosion Rate Micrometer/Year
Carbon Steel	as received	914.7
Carbon Steel	sandblasted	1557.6
Galvanized	no hole	1190.2
Galvanized	with hole	1281.0
LCC (MMFX)	as received	625.0
LCC (MMFX)	sandblasted	523.6
Stainless steel 3CR12	sandblasted	296.8
Stainless steel 2201	sandblasted	29.7
Stainless steel 2205	as received	1.9
Stainless steel 316LN	as received	1.2
Epoxy-Coated (New)	without hole	*
Epoxy-Coated (New)	with hole	*
Epoxy-Coated (Old)	with hole	*

**The method using weight loss data to determine corrosion rate was not applicable to epoxy-coated rebar (ECR). Corrosion rate of ECR, however, was minor and estimated to be in the same order as stainless steel 316LN and 2205.*



The method using weight loss data to determine corrosion rate was not applicable to epoxy-coated rebar (ECR). Corrosion rate of ECR, however, was minor and estimated to be in the same order as stainless steel 316LN and 2205.

RESULTS

1. Both as-received and sandblasted carbon steel reinforcing bars corroded at high corrosion rates. The sandblasted bars had corrosion rates higher than the as-received bars. Pitting corrosion was also noted.
2. The LCC (MMFX) bars meeting ASTM A1036 and stainless steel 3CR12 reinforcing bars meeting ASTM A955 offered some improvement in corrosion protection and yet still corroded rapidly in this test environment.
3. While the zinc offered protection to the underlying steel, the galvanized reinforcing bars meeting ASTM A767 corroded extensively. Within 2 weeks, the zinc layer was essentially consumed and underlying steel corrosion was observed.
4. Stainless steel 2201 reinforcing bars meeting ASTM A995 exhibited significant surface corrosion; however, only moderate corrosion was measured in this test.
5. Stainless steel 316LN and 2205 stainless reinforcing bars meeting ASTM A995 had very high corrosion resistance and only experienced minor corrosion likely due to presence of crevices or steel contamination.
6. The new epoxy-coated reinforcing bars meeting ASTM A775 performed very well and corrosion was only observed at drilled holes.
7. The epoxy-coated reinforcing bars removed from a 15-year old deck performed well during the test. Corrosion was regarded as being minor and only took place at the drilled holes and at existing defects in the coating.

The salt spray tests used for this evaluation were very aggressive to some steels and measured corrosion rates were much higher than that expected for bars embedded in concrete. Nevertheless, the observed corrosion performance provides a simple and useful comparison of the corrosion resistance of the various bar types.

These results are consistent with other published research, including one of the most recently released extended laboratory tests titled "Long-Term Performance of Epoxy-Coated Reinforcing Steel in Heavy Salt Contaminated Concrete", (FHWA Publication No. FHWA-HRT-04-090). This report ranked carbon steel reinforcing at a very high corrosion rate and epoxy-coated and stainless reinforcing bars at a minor corrosion rate.

REFERENCED STANDARDS

ASTM B117-07a *Standard Practice for Operating Salt Spray (Fog) Apparatus*

ASTM A615/A615M-08b *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 A1035/A1035M-07 *Standard Specification for Deformed and Plain, Low-carbon, Chromium, Steel Bars for Concrete Reinforcement*

ASTM A767/A767M-05 *Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement*

ASTM A955/A955M-07a *Standard Specification for Deformed and Plain Stainless-Steel Bars for Concrete Reinforcement*

ASTM G1-03 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*

The full report titled *"Corrosion Resistance of Alternative Reinforcing Bars; An Accelerated Test"* is available from www.epoxyinterestgroup.com

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