TECHBRIEF

The Structures research and technology program aims to foster increased durability of new bridges and observable increases in the service life of existing structures, placing an emphasis on increasing highway safety while preserving the environment. The program focuses on researching nondestructive evaluation technologies to identify structural deficiencies and support bridge management systems. It also uses high-performance materials to repair and rehabilitate the existing inventory of deficient bridges. This find-it-and-fix-it program is supplemented by research, which examines all aspects of bridges and foundations, including planning, design, construction, management, maintenance, inspection, and demolition.

Specific expertise areas include bridge coatings, bridge infrastructure, bridge management, nondestructive evaluation, corrosion protection, foundations, scour, geotechnical research, high-performance materials, aerodynamics, seismic research, and structures instrumentation.

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

Inorganic Zinc Coatings and Their Topcoats for Steel

Publication No. FHWA-RD-98-I 70
FHWA Contact: Shuang-Ling Chong, HRDI, (202) 493-3081

This TechBrief announces the key findings of a Federal Highway Administration (FHWA) study that is fully documented in a separate report with the same title (FHWA-RD-98-170).

Water-based inorganic zinc (WBIOZ) coatings are capable of providing excellent long-term corrosion protection in both mild environments and highly corrosive marine environments. This result has been demonstrated by several investigators and in many field applications. In a 7-year low volatile organic compound (VOC) coating study conducted by FHWA (Report No. FHWA-RD-96-0581, a high-ratio water-based inorganic zinc single-coat system performed among the best of all coatings tested over an SSPC SP-10 near-white metal-blasted surface. In addition, WBIOZ coatings with zero VOC provide an environmentally compliant option for many high-volume fabrication shops and for field painting operations that are subject to limitations on VOC emissions. However, these materials have decreased in popularity within the past few years because of concern over several field failures that have occurred shortly after application of the systems in both shop and field applications. In these failures, two distinct scenarios have been observed-early pinpoint rusting (sometimes called freckle rusting) and severe disbondment of water-based topcoats applied over WBIOZ. If the cause of WBIOZ failures was understood and could be controlled, these materials could be effectively used to meet the VOC regulations. FHWA sponsored a pooled-fund study (FHWA and 12 States provided funding) to better understand the failures of WBIOZ.

The report consists of four sections-literature review, technical approach, results of testing, and guidelines for use of water-based inorganic zinc.

Environmental Variables

The testing conducted included a core test matrix evaluating the effect of environmental variables on WBIOZ cure and performance.

As results were obtained from this core matrix, three side issues were examined in preliminary testing. Each of these side issues gave rise to separate test matrices.

The environmental variables testing included two phases—Dry Rate Testing and Accelerated Exposure Testing. The Dry Rate Testing was designed to obtain a rather basic understanding of how the self-cure coatings dry in various environments. This fundamental knowledge then served as the basis for selecting specific conditions to apply coatings for the accelerated testing. On the basis of dry time results, eight curing conditions were selected to apply the zinc primers.

One set of duplicate panels for each coating system/cure combination was exposed at a marine exposure site for 1 year. Spraying the panels daily with natural seawater accelerated corrosion in the marine atmosphere exposure. Visual panel evaluations were initially made daily to determine the time to produce pinpoint rusting or topcoat blistering. A cyclic accelerated test using another set of duplicate panels was used to evaluate coating system performance under conditions of cyclic salt-fog, ultraviolet light exposure, and freeze/thaw temperature exposure. Each accelerated test cycle was approximately 15 days long and was completed twice for a total exposure of approximately 30 days.

All panels subjected to the cyclic accelerated test and marine atmosphere exposure were evaluated for surface rusting, cracking, blistering, and scribe cutback. Evaluations were performed following each cycle of the cyclic accelerated test and included panel photographs. Evaluations of the marine atmosphere exposure panels were conducted frequently during the first month of exposure and approximately monthly thereafter, up to 1 year. At 60 days of marine atmosphere exposure, a topcoat adhesion survey was conducted.

Application Variables

Three additional issues included: the effects of surface salt contamination, the effects of varied zinc content, and the effect of various primer washing techniques.

A test matrix was designed to investigate salt contamination as a factor influencing freckle rusting of WBIOZ coatings that occurs when left untopcoated or in the short time before topcoating. Both WBIOZ and ethyl silicate inorganic zinc were evaluated over a blasted surface with salt contamination varying between < 2 μg/cm^2 and 30 μg/cm^2.

Additional panel testing was conducted to confirm the effects of off-ratio (i.e., zinc-to-binder mixing ratios) mixing of WBIOZ. Two WBIOZ coatings were each applied to abrasive-blasted steel panels (SSPC SP-10). Five mix ratios varying between 66 percent and 133 percent of specified zinc were tested.

Primer wash testing was performed to investigate potential surface cleaning methods to eliminate blistering of acrylic topcoats. Experimental variables included different surface treatments after primer application, but before topcoat application. Primer surface pH was measured prior to topcoating. Topcoat blistering was observed after exposure in either a marine atmosphere or in condensing humidity.

Each test matrix produced test results related to the failure modes of interest (i.e., freckle rusting and blistering). The following table summarizes the test results as they relate to each failure mode.

Table 1. Summary of Test Results

TEST	FRECKLE RUSTING	TOPCOAT ADHESION
Environmental Effects	None of the test panels prepared under the eight environmental conditions exhibited significant (greater than 0.03 percent) freckle rusting after either marine exposure or accelerated testing. There was not any correlation of the minor pinpoint rust occurrence with any of the environmental conditions.	No strong relationships between environmental conditions and topcoat adhesion were observed. There were interesting trends related to the primer and topcoat material, which are discussed below.
Topcoat Material Effects	No freckle rusting was observed on the topcoated panels prepared under the varying environmental conditions.	Epoxy topcoats adhere better over WBIOZ primers than acrylic topcoats. Average topcoat adhesion values for all cure conditions were 6.06 MPa (879 psi) for the epoxy versus 3.77 MPa (547 psi) for acrylic. Less than 5 percent of the epoxy-topcoated test panels in the accelerated and marine exposure tests showed blistering, while more than 60 percent of the acrylic-topcoated test panels showed blistering.
WBIOZ Primer Cure (Self-cure versus post-cure)	Insignificant differences in freckle rusting were observed between the self-cure panels and post-cure panels.	Acrylic topcoats have a lower propensity for blistering over the post-cure inorganic zinc primer than over the self-cure WBIOZ. Unfortunately, the propensity for blistering did not correspond with any of the cure conditions. Interestingly, there was no significant difference in acrylic-topcoat adhesion data for the post-cure and self-cure primers.
Zinc Content Effects	There is a very clear trend between zinc content and degree of freckle rusting. It is particularly interesting to note that slightly more than the specified amount of zinc was required to eliminate freckle rusting in these tests.	Acrylic-topcoat adhesion data did not demonstrate a clear correlation between topcoat adhesion and zinc content. Blister ratings on panels exposed in the marine atmosphere did not demonstrate a clear trend either.
Salt Contamination Effects	The test results showed that salt contamination as low as 8 $\mu g/cm^2$ can influence freckle rusting on the WBIOZ primers. By contrast, the ethyl silicate inorganic zinc did not show freckle rusting with chloride contamination levels as high as 29 $\mu g/cm^2$. The data also suggest that higher humidity increases the effects of salts at the test temperature (21°C [70°F]).	The effect of substrate salt contamination on topcoat blistering was not evaluated.
Primer Rinsing and Aging Effects	The effect of primer rinsing on freckle rusting was not evaluated.	Test panels with alkaline pH showed significant blistering after 2 days of marine atmosphere exposure. A strong relationship between those conditions resulting in an alkaline pH and blistering was also observed after 8 days of humidity exposure. This suggests that a WBIOZ surface pH below neutral is necessary to minimize topcoat blistering.

Researcher—This study was performed by Ocean City Research Corporation, Ocean City, NJ. Contract No. DTFH61-95-C-00004.

Distribution—This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to the Resource Centers and Divisions.

Availability—The publication will be available in April 1999. Copies will be available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. A limited number of copies will be available from the R&T Report Center, HRTS, FHWA, 9701 Philadelphia Court, Unit Q, Lanham, MD 20706, Telephone: (301) 577-0818, Fax: (301) 577-1421.

Key Words—Water-based, inorganic zinc, curing, coatings, corrosion protection, topcoat, adhesion, blistering, rusting.