Evaluation of Underwater-Curing Coating Materials

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An evaluation of underwater - repair coating materials was based on the premise that defective areas of the existent epoxy coating such as blistering and cracking will be repaired on spot under submerged condition. Tests include the clarification as to whether they are compatible between as-built coating and new repair coating on each concrete specimen. Candidate coating materials for repair were tested in a laboratory to scrutinize their suitability to perform the needed function satisfactorily. The qualification tests performed are as a minimum as follows: Integrated radiation tolerance test, chemical resistance test (submerged condition in deionized water), hardness test and adhesion test of the repair materials. The proper repair coating materials were selected and approved from this test results.

Keywords *: underwater, epoxy coating, compatibility, radiation, qualification*

1. Introduction

This paper is related to the performance evaluation of compatibility between the existent epoxy coating and the new repair coating in submerged condition. The basic coating system for these tests was a fiber glass-reinforced epoxy-coating system applied to concrete surfaces in underwater condition. The underwater coating was designed to perform the specially intended function. So, the test plan of new coating material is based on the premise that defective areas such as blistering and cracking will be repaired under submerged condition. To evaluate the quality of the new underwater repair coating, three tests were performed subsequently as follows: Radiation tolerance test, chemical resistance test, and physical properties test.

2. Test plan for underwater coating

2.1 Preparation of concrete specimens

Concrete specimens were prepared, placed and cured under the same conditions as those expected for the concrete in the designated area. Quality control and documentation records were maintained as the formal procedures. According to ASTM D 5139,[1)] typical test concrete specimens, 2" by 2" by 4", were manufactured at laboratory in advance.

2.2 Base coating system

The basic coating systems applied to concrete specimens were made as specified in the specifications[2)] of 'Fiber-Glass Reinforced Epoxy, Liner Containment Quality'. The as-built coating system in a special pool consists of Amercoat Nu-Klad 110AA Sand Filled Epoxy Grout, Amercoat 90, and Fiber-Glass Weave Cloth No. 173, supplied by Ameron Co., U.S.A. The original coating system was applied as follows: Firstly the sand filled epoxy grout was applied to maintain 9 mils dry film thickness, in order to have a good adhesion between concrete surface and coating layer. Then the fiberglass weave cloth was applied to make 9 mils thick film thickness. Thirdly, dry film coating in thickness of 20 to 24 mils(0.5 to 0.6mm) was applied per four times. The total dry film thickness of the coating system including fiber glass was maintained at 42 mils. To evaluate the compatibility between the existent coating and new repair coating, the base coating systems were classified into two cases; BCS-1 was an original base coating system, and the other was an original base coating system without fiber glass, defined as BCS-2. The BCS is shown in Fig. 1.

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Fig. 1. Completion of base Coating

Fig. 2. Repair coat in water

2.3 Repair coating system

Candidate underwater repair coating materials were selected according to the result of prior successful testing such as Radiation Tolerance Test to 1×10^9 rads, Dynamic Elevated Temperature and Pressure Testing, and successful long-term case histories in submerged areas. All Candidate underwater repair coating materials were 100% solid epoxy materials, to minimize the potential for osmotic blistering. Candidate underwater repair coating materials were applied to the test specimens by divers in water to simulate actual repair conditions as shown in Fig. 2. Candidate coating materials for underwater repair were applied to the bare concrete, and then overlapped on the base coating, as shown in Fig. 3. Underwater-cured epoxy was applied by two coats, to a thickness equivalent to that of the base coating system. However any fiber-glass weave cloth was not used for the repair work. Candidate coating systems for repair, RCS-1, RCS-2 were looked for the bases of application experiences of similar circumstances. These candidate coating materials for underwater repair were selected by two manufacturers in the U.S.A.

Fig. 3. overlapping of repair coating

2.4 Control samples

One of the prepared six test specimens for each candidate repair coating material was maintained as a control sample, and not subjected to radiation exposure and physical properties tests.

Table 1. List of Test Specimens

Specimen I.D (Quantity)	Bare Coating System	Repair Coating System	Radiation Tolerance Test	Immersion Test	Physical Properties Test
WSFP-1.1.1 to WSFP-1.1.5 (5)	BCS-1	RCS-1	Yes (No.1,3,5 Only)	Yes	Yes
WSFP-1.1.6 (for control) (1)	BCS-1	RCS-1	No	No	Yes
WSFP-1.1.7 to WSFP-1.1.11 (5)	BCS-1	RCS-2	Yes (No.7,9,11 Only)	Yes	Yes
WSFP-1.1.12 (for control) (1)	BCS-1	RCS-2	No	No	Yes
WSFP-2.1.13 to WSFP-2.1.17 (5)	BCS-2	RCS-1	Yes (No.13,15 Only)	Yes	Yes
WSFP-2.1.18 (for control) (1)	BCS-2	RCS-1	No	No	Yes
WSFP-2.1.19 to WSFP-2.1.23 (5)	BCS-2	RCS-2	Yes (No.19,21 Only)	Yes	Yes
WSFP-2.1.24 (for control) (1)	BCS-2	RCS-2	No	No	Yes

2.5 Documentation

The preparation of all test specimens were witnessed, evaluated and accepted by an ANSI Level III Certified Nuclear Coatings Specialist, who is also fully certified under the National Association of Corrosion Engineers (NACE) International Coating Inspector training and Certification Program. All test panel preparation steps were documented on a Test Specimen Inspection Report, provided as in this test plan.

3. Description of the qualification tests

3.1 Radiation tolerance test

Radiation tolerance test was performed at Tustin Gamma Facility of Sterigenics International in Tustin, California. Radiation was irradiated to test panels in the submerged "Co 60 Irradiator" located within the Radiation Laboratory. The radiation test was conducted in accordance with ASTM D 4082.[3] The radiation exposure was measured by instruments having certified accuracy and calibration traceable to the National Institute of Standards and Technology (NIST). The gamma-ray intensity at the specimen position was 1×10^6 rads/hr specified on ASTM D4082 and should be uniformly distributed within 10% from one position of the specimen to another. Provisions were made so that all areas could receive the same average exposure and dose, if the specimens were irradiated by a non-uniform dose. The accumulative dose to irradiated panels was reached up to 1.0×10^9 rads. Maximum temperature during irradiation did not exceed 140º F[4].

Test specimens were taken photographs and examined for coating defects within 2 hours after the prescribed cumulative radiation dose. All evaluations were performed by an ANSI Level III Certified Nuclear Coatings Specialist, who was also fully certified under the National Association of Corrosion Engineers (NACE) International Coating Inspector training and Certification Program. Panel grading was documented on a Post - Radiation Tolerance Test Grading Report.

Any other changes such as discoloration, in coating properties which were not associated with the separation or the release of coating from the substrate, were not regarded as a cause for rejection. The condition of the edges and plane areas within 1/4" (6.4 mm) from the edges of the test surfaces were disregarded in the evaluation process.

3.2 Chemical resistance tests

Upon the completion of radiation tolerance test, test samples were subjected to long-term (180 days) immersion in 32-36 ℃ deionized water in accordance with ASTM D3912[5] and NACE Standard TM0174-91, "Laboratory Methods for the Evaluation of Protective Coatings and Lining Materials in Immersion Service". Immersion testing was conducted at Corrosion Control Consultants and Laboratories (CCC&L) test facilities in Michigan, USA. This test includes a chemical resistant test to a nitric acid solution, after immersion.[6] Test specimens were photographed and examined for coating defects weekly for the first month, then monthly thereafter. All defects, such as blistering, cracking, peeling, and/or flaking had been documented.

3.3 Material property tests

Upon completion of radiation tolerance and long-term immersion tests, the repair areas on test samples were subjected to physical property tests to evaluate the cumulative effects of these exposures. Each of the five test specimens for all candidate repair coating materials will be tested for physical properties. Physical property tests were performed on the repair areas only. All tests were performed by an ANSI Level III Certified Nuclear Coatings Specialist, who was also fully certified under the National Association of Corrosion Engineers (NACE) International Coating Inspector Training and Certification Program.

3.3.1 Adhesion test

The repair areas on each side of test sample were tested for tensile adhesion in accordance with ASTM D 4541,[7] Test Method for Pull-Off Strength of Coatings Using

Table 2. Criteria for Test Approval

Coating Defect	Accept/ Reject Criteria
Flaking (ASTM D 772)	• Flaking shall not be permitted
De-lamination and peeling	• Peeling shall not be permitted • De-lamination shall not be permitted
Blistering (Evaluate and document size and distribution in accordance with ASTM D 714)	Blistering shall be limited to a few intact blisters which are completely surrounded by sound coating bonded to the surface.
Chalking (ASTM D 659)	Heavy chalking shall not be permitted.

Portable Adhesion Testers.

3.3.2 Hardness test

The repair areas on each side of test sample were tested for hardness using a portable hardness meter in accordance with ASTM D2240.[8] All test specimens were tested both before and after radiation tolerance and long-term immersion test to scrutinize any change results from these exposures.

4. Test rults

4.1 Radiation tolerance test result

After the exposure of accumulated radiation, 1.01~ 1.25×10^{9} rads., which was actually 2.7~3.4×10^{6} rads/hr more than the specified regulation, visual inspection was performed on four kinds of coating system as described in Table 3. The RCS-1 series show discoloration to light brown, but any decisive defects led to degradation was not investigated on the each side of four surfaces shown in Fig. 4. However, the RCS-2 series show excessive burst blistering, extreme distress, flaking on the four sides of specimens shown in Fig. 5. This test result of RCS-2 series is an unexpected outcome, because this candidate material had already experienced of having been applied on the surface of steel under the same environmental conditions.

4.2 Chemical resistance test / material property test

The specimens of RCS-2 series degraded severely in the process of radiation tolerance test, therefore, they were not proceeded to immersion test. The rest specimens were placed subsequently under submerged condition for six months, but no defective occurrence after radiation was observed.

Upon completion of chemical resistance test, hardness test was conducted on each side of specimens by using both type A durometer and type D durometer. As for type A hardness test records, these were recorded above 100.

Fig. 4. RCS-1, Before and After Radiation

Fig. 5. RCS-2, Before and After Radiation

Table 3. Visual Inspection Results after Radiation

Specimen Identification	BCS	RCS	A Surface	B Surface	C Surface	D Surface	Description
WSFP-1.1.1	BCS-1	RCS-1	Pass	Pass	Pass	Pass	Repair coating discoloration to light brown (Pass)
WSFP-1.1.3	BCS-1	RCS-1	Pass	Pass	Pass	Pass	Repair coating discoloration to light brown (Pass)
WSFP-1.1.5	BCS-1	RCS-1	Pass	Pass	Pass	Pass	Repair coating discoloration to light brown (Pass)
WSFP-1.2.7	BCS-1	RCS-2	Fail	Fail	Fail	Fail	Excessive burst blistering, extreme distress, flaking
WSFP-1.2.9	BCS-1	RCS-2	Fail	Fail	Fail	Fail	Excessive burst blistering, extreme distress, flaking
WSFP-1.2.11	BCS-1	RCS-2	Fail	Fail	Fail	Fail	Excessive burst blistering, extreme distress, flaking
WSFP-2.1.13	BCS-2	RCS-1	Pass	Pass	Pass	Pass	Repair coating discoloration to light brown (Pass)
WSFP-2.1.15	BCS-2	RCS-1	Pass	Pass	Pass	Pass	Repair coating discoloration to light brown (Pass)
WSFP-2.2.19	BCS-2	RCS-2	Fail	Fail	Fail	Fail	Excessive burst blistering, extreme distress, flaking
WSFP-2.2.21	BCS-2	RCS-2	Fail	Fail	Fail	Fail	Excessive burst blistering, extreme distress, flaking

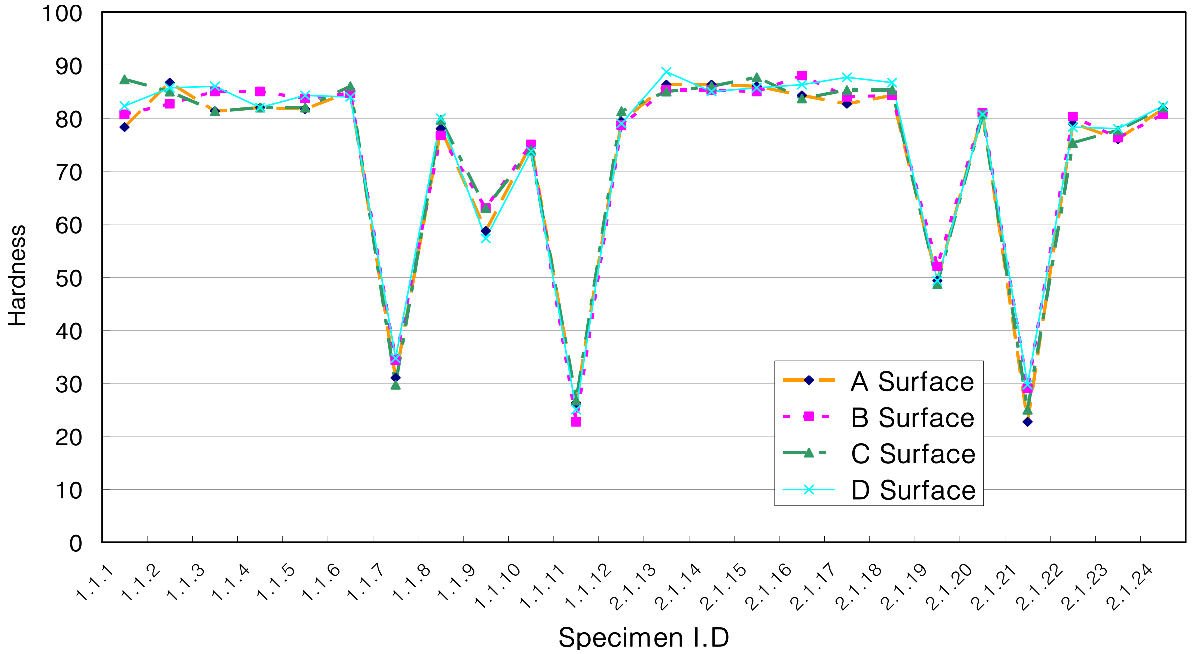

Fig. 6. Type 'D' Hardness Test Record

However, based on ASTM D2240 9.3, it was not acknowledged because durometer readings below 20 or above 90 are not considered reliable. ASTM type D values are best suited to epoxy coating. Based on type D hardness test records, all of them except failed specimens by radiation test show satisfactory value, 59.8, that is above the limit of the regulation as shown in Fig. 6.

After completing the hardness test, adhesion test was conducted and the acceptance criteria are specified to meet the requirement of at least 200 lbs/in^2. Like the hardness test results, adhesion values except failed specimens on radiation test showed the range from 350 to 450 lbs/in^2.

5. Conclusion

It was not easy to select the appropriate repair coating materials suitable to underwater condition. Moreover, even if the selected candidate material had passed the qualification test requested by the prescribed specifications, it would have been necessary to remove an uncertainty on the compatibility between the existent coats and overlapped areas new coating under immersion state. In order to prove a good quality both the old and the new, the three kinds of qualification test were conducted in sequence.

One of the two candidate coatings, RCS-1 passed radiation tolerance test, immersion test and physical property test, but RCS-2 did not meet the requirement of radiation test conducted at first. It is, therefore, concluded that the RCS-1 can be applied under submerged condition for repair work.

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