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Performance Criteria for Restoration Coatings for Porcelain Enamel Surfaces

U.S.DEPARTMENT OF COMMERCE
National Bureau of Standards
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Department of Housing and Urban Development
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PERFORMANCE CRITERIA FOR RESTORATION COATINGS FOR PORCELAIN ENAMEL SURFACES

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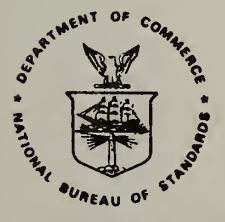

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
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ABSTRACT

In June 1982, the results of a laboratory-based study to develop interim performance criteria for restoration coatings for porcelain enamel surfaces were reported in NBSIR 82-2553, "Development of Interim Performance Criteria for Restoration Coatings for Porcelain Enamel Surfaces." Additional studies, consisting of a one-year field test of three of the five restoration coatings studied in the laboratory, were performed to assess the effectiveness of the interim performance criteria. The field test included periodic evaluation of the three restoration coatings applied to a total of nine bathtubs in public housing units in Alexandria, Virginia.

The results of the field tests were compared to the previous laboratory results and showed that the interim performance criteria were effective in selecting durable restoration coatings. This report presents the findings of the field test and includes the final performance criteria.

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1. INTRODUCTION

1.1 BACKGROUND

Within the last 15 years, processes have been developed for restoring, in place, damaged or worn porcelain enamel fixtures such as bathtubs and wash basins. These processes involve a thorough cleaning (usually by acid etching) of the porcelain enamel substrate followed by application of an organic coating. Costwise, these restoration techniques may represent considerable savings when compared to complete replacement of a damaged or worn porcelain enamel fixture. In the maintenance of public housing, a continuing problem exists with regard to porcelain enamel coatings on steel and cast iron fixtures in need of repair. Performance criteria are needed to aid in ensuring the performance and durability of restoration coatings.

Previously, a laboratory test study provided the technical bases of interim performance criteria for restoration coatings for porcelain enamel surfaces[1].[1] However, data on the performance and durability of restoration coatings applied to actual porcelain enamelled fixtures are needed to confirm, or serve as the bases for modification of, the interim performance criteria.

1.2 OBJECTIVES

The objectives of the research discussed in this report were 1) to assess the effectiveness of the previously developed interim performance criteria for restoration coatings for porcelain enamel surfaces using data obtained on coatings applied to actual bathtubs in public housing units and 2) to present modified performance criteria (if modification was needed).

1.3 SCOPE

In order to meet the stated objectives, a study was performed which involved: 1) the application, by three selected commercial companies, of restoration coatings to degraded bathtubs in public housing units; 2) periodic evaluation of the restoration coatings over about a one year period; 3) comparison of the field study results with the laboratory test results that formed the bases for the interim performance criteria; and 4) development of performance criteria based upon both field and laboratory studies.

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[1] Numbers in brackets refer to references in the Bibliography.

2. FIELD TEST SITES

The field sites to study the performance of the restoration coatings on bathtubs were established after consultation with representatives from the Department of Housing and Urban Development (HUD) and the Alexandria, Virginia Public Housing Authority. Two sites were selected: the first included three dwelling units in Cameron Valley, Alexandria, Virginia, and the second included six dwelling units in Alexandria, Virginia near the Housing Authority Headquarters. Criteria used in selecting specific dwelling units for use in the study were: 1) the units must be located in the Metropolitan Washington, D.C. area to permit convenient inspection by National Bureau of Standards (NBS) personnel, 2) the units must be among those already identified by the Public Housing Authority for restoration (this would ensure that the units would be vacant when initial work was done and would, therefore, not cause disruption to occupants), 3) the bathtubs of the units must be coated with porcelain enamel and be in need of refinishing and 4) the units must be occupied following the restoration and during the evaluation period to permit evaluation of the effect of in-use conditions on the coatings. The porcelain enamel bathtubs used in the study were generally cast iron, of various designs and ages. All were basically sound, but exhibited porcelain coatings that were chipped, worn or otherwise degraded. The information on restoration coatings, dwelling unit location and address, date of refinishing, date of occupancy and occupancy data are given in table 1.

3. APPLICATION PROCEDURES AND INITIAL TESTING FOR RESTORATION COATINGS

The three restoration finish companies were selected for participation in the field test study because of their previous participation in the laboratory study [1]. Also, they represented a cross-section of performance based upon previous accelerated laboratory testing results. Company representatives applied the restoration coatings using their own equipment, materials, and techniques. Generally, the restoration procedure involved: 1) cleaning the porcelain enamel coating by etching with a dilute solution of hydrofluoric acid followed by thorough rinsing (the cleaning was also, in some cases, supplemented by hand abrasive cleaning); 2) repairing, as needed, chipped areas using a filler; 3) masking the areas not to be coated; 4) thoroughly cleaning the bathroom to remove dust particles; 5) applying the prime and finish coats to the dry surface with an air sprayer; 6) curing the coating; and 7) cleaning up.

The restoration coatings used in the field study were numbered 3, 4, and 5 as described in reference 1. The generic descriptions of the finish coat, as given by the restoration finish companies, were as follows: 3, urethane; 4, enamel; 5, urethane. Curing times for the coatings were as follows: 24 hour cure using infrared heat lamps for restoration coating 3; 2 days at ambient conditions for restoration coating 4; and 7 days at ambient conditions for restoration coating 5.

Figures 1 and 2 illustrate typical examples of the bathtubs before repair. Figure 1 shows delamination around the drain area and extensive rusting. Figure 2 shows a bathtub with non-slip decals which have to be removed in the repair process; also shown are dirt, delamination and loss of gloss.

Only one of the companies used an exhaust system to control dust or to vent chemical fumes. However, respirators were used by all applicators during coating application. All companies' workers used protective gloves during the etching process. As part of the cleaning operation, all companies used special care to see that fixtures were removed and that the areas around the drain were clean and dry. All companies took precautions to ensure that the cleaned and etched porcelain enamel surface was dry and free of dust particles. In addition, plastic covers were used to seal the water outlets to prevent water back up.

After completion of the restoration process described above, three pull-off adhesion tests of the restoration coatings were made in each tub. The pneumatic adhesion test apparatus used was developed at NBS and is described in reference 2. The adhesion tests were made for two reasons: 1) to determine the mode of failure of the newly applied restoration coatings as discussed in Section 4.1 of this report (the modes of faiure prior to occupancy were later compared to those after occupancy) and 2) to induce three damaged areas similar to chipped porcelain [approximately 19 mm (0.75 in) diameter] in each tub and 76 mm (3 in) apart. Company representatives then repaired the damaged areas of each tub using their their own materials and techniques. This provided an opportunity to assess the effectiveness of the processes that would be used to repair chipped porcelain prior to recoating with an organic coating.

Epoxy fillers were used to repair the chipped areas before application of restoration coatings 3 and 5; fillers were not used in chipped areas of tubs restored with coating 4.

4. FIELD EVALUATION TEST PROCEDURES

Field evaluation tests on the restored bathtubs were performed before and after occupancy to assess performance attributes described in the interim performance criteria [1]. Data obtained during occupancy were used to assess degradation with increased time of exposure under in-service conditions. Adhesion and stain tests, as well as visual examinations, were used to evaluate performance. Impact resistance, one of the tests carried out in the laboratory study [1,3] and included in the interim performance criteria, was not used as an evaluation method in the field tests because the laboratory data showed that all the organic coatings tested had greater impact resistance than porcelain enamel. Initial (before occupancy) adhesion tests were made on July 30, August 13 and September 3, 1981 and adhesion tests after occupancy were made between August 31 and September 2, 1982. Adhesion tests were not made during intermediate inspections because the test is destructive to the coated surface and repairs were planned only at the completion of the annual inspection to minimize disruption to occupants. Stain tests were performed prior to occupancy. Visual inspections were made periodically after occupancy, i.e., November 1981 (inspection no. 1); March 29, 1982 (inspection no. 2), and August 30, 1982 (inspection no. 3).

4.1 ADHESION TESTS

Adhesion tests were performed near the middle of the bottom of the bathtubs using the portable pneumatic test apparatus described in reference 2. The primary elements of the portable test apparatus are a piston assembly, a loading fixture (stainless steel "button"), a rate of load device to provide a constant rate of load and a compressed air handling system. A 101.6 mm (4 in) piston and a 19 mm (0.75 in) load fixture were used. Loading fixtures were bonded to the coated substrate with an epoxy adhesive. The piston assembly was placed over the loading fixture and, after attachment, compressed air was steadily added to the apparatus until rupture occurred. The tensile force required to induce rupture can be used to provide a measure of coating adhesion if the rigidity of the substrate is known. As shown in reference 2, the tensile force at rupture varies with substrate thickness and rigidity. Since the substrate for the restoration coatings in the bathtubs was more rigid than the steel panel substrates used in the laboratory tests, the tensile forces obtained in the field would not be comparable to those obtained on laboratory test specimens. However, the locus of failure would be expected to be the same in both tests and provide information on the strength of the restoration coating/porcelain enamel bond.

After testing, the faces of the 19 mm (0.75 in) diameter loading fixtures (buttons) and the area of the restoration coating beneath the loading fixtures were visually examined to determine the dominant failure mode. The failure modes were defined as follows:

1. At the interface of porcelain and metal substrate
2. In the porcelain
3. At the interface of the primer and porcelain surface
4. At the interface of the primer and finish coat

5. At the interface of the loading fixture and adhesive
6. At the interface of the adhesive and the coating surface.

4.2 STAIN TESTS

The refinished bathtubs were rated visually for effectiveness of stain removal prior to occupancy. Tests were not repeated during or after occupancy because the laboratory data indicated that stain resistance is not affected by exposure. The test apparatus, procedures and staining materials, i.e., purple Tintex, black hair dye, black shoe polish, lipstick, and acetone, were those as described in reference 1. The staining materials selected were those thought to be in common usage in bathroom areas. The stains were placed upon the restored bathtub surface using the chambered holders previously described; these holders prevented stain evaporation or removal during the 16 hour test exposure. After 16 hours exposure, the stains were removed from the restoration coating using the following sequence:

method 1 - wipe with soft, dry paper towel
method 2 - wipe with soft, wet paper towel
method 3 - wipe with soft, wet paper towel and mild soap
method 4 - scrub with mild abrasive cleaner

4.3 VISUAL INSPECTIONS

Visual inspections of the restoration coatings on the bathtubs were carried out to assess the appearance; the data were recorded on an inspection sheet which contained an individual map of the bathtub, inspection date, code of coatings defects, and recommendations. The "Pictorial Standards of Coating Defects" [4] was used for guidance for estimating coating defects. While instrumental measurements of color and gloss changes were not taken of the white bathtubs, any visual color and gloss changes were noted since they would affect the overall appearance.

5. RESULTS OF FIELD TESTS

5.1 ADHESION

As mentioned in Section 4.1, one reason for performing adhesion tests was to obtain data on the failure modes. In particular, data were sought on whether or not the failure mode changed between the time the restoration coatings were applied and the time of the final evaluation, approximately 12 months later. In the laboratory tests [1], for example, it was observed that, in some cases, the failure mode gradually changed with increasing time of accelerated exposure, thus indicating the bond strength between the primer and finish coat to be degrading.

The adhesion tests prior to occupancy of bathtubs with restoration coating 3 produced rupture primarily either at the interface of the porcelain/metal substrate or in the porcelain. This indicated that the bond strength of the newly applied primer and restoration coating was greater than that of the original porcelain coating. After the 12 month field exposure, the primary failure mode continued to be either at the interface of the porcelain/metal substrate or in the porcelain. Thus, after exposure, the adhesion of the restoration coating system was greater than that of the original porcelain system.

For bathtubs with restoration coating 4, the adhesion tests prior to occupancy produced rupture primarily at the interface of the primer and finish coat. After twelve months, the failure mode was primarily at the interface of the porcelain and metal substrate. The tests prior to occupancy were performed three days after application of the restoration coating, even though the restoration company recommended seven days for curing. Testing before the end of the recommended curing period was required in order to meet the schedule of occupancy. It is likely that the failures at the interface of the primer and finish coat were the result of an incomplete curing of the coating system at the time of testing. It is significant, however, that the tests after occupancy produced a failure mode primarily at the interface of the porcelain and metal substrate, indicating that adhesion within the restoration coating system remained at least as strong as that of the original porcelain system during the field test.

The adhesion tests, both prior to occupancy and after twelve months, of bathtubs with restoration coating 5 produced rupture primarily at the interface between the primer and finish coat.

In the initial tests (prior to occupancy), all three loading fixtures were bonded to each bathtub at the same time. In retrospect, this may not have been the best procedure, since the energy required to remove a loading fixture may adversely affect the adhesive bond of the remaining adjacent loading fixtures. In fact, during testing of bathtub number 9 (restoration coating 3), as the first loading fixture ruptured, the adjacent fixture ruptured even though it was not under load or impacted by the loading fixture under test. For the measurements of the bathtubs after occupancy, adhesion tests were performed one at a time.

5.2 STAIN TESTS

The results of the stain test procedures are given in table 2. The wiping and scrubbing sequence described in Section 4.2 was continued until the stains were either removed completely or were only very lightly visible. The stain test data obtained on the newly restored bathtubs indicated that the stain resistance of the field applied coatings was comparable to that measured in previous laboratory tests [1]. Ordinarily, the hard-to-remove stains would not be allowed to stand for as long as 16 hours before the occupant would try to remove the stain; thus, the test procedure is thought to represent a condition more severe than would actually be encountered in service. Despite this, stains were generally removed after use of a mild abrasive.

5.3 VISUAL INSPECTIONS

Visual inspections of the restored bathtubs were made prior to occupancy and periodically after the housing units were occupied. Three examinations (inspection nos. 1, 2, and 3) were made after occupancy and the results documented using inspection sheets as well as photographs to record changes in the restoration coatings. The results of the inspections are compiled in table 3.

As illustrated in figure 3, tub number 7 had blisters of size 4 to 6, as defined in ASTM D 714 [5], covering the entire bottom of the bathtub. Isolated small blisters were found in at least one tub of each restoration coating. For tub numbers 3 and 4, blisters greater than 25 mm (1 in) diameter were found in the repaired areas. The blistering did not appear to increase in number or size after inspection no. 2. The formation of blisters can lead to delamination as illustrated in figure 4. Pinholing (see figure 5) was observed in inspection nos. 1 and 2 and was prevalent around the drain area. The pinholing may have been caused by a number of factors including insufficient coating thickness, leaking faucets, or insufficient surface preparation prior to coating application which was often enhanced by the poor initial surface conditions (see figure 2). Cigarette stains (burns) were found on the rims of three of the tubs (see figure 6). Two occupants had added decorative non-slip decals to their bathtubs (see figure 7). However, most of the restoration coating companies do not recommend their use. It was observed that some of the decals were delaminated and appeared to be causing minor delamination of the restoration coating.

Despite the visually detectable problems noted above, the restoration coatings performed well on all tubs except number 7. Prior to the restoration, tub number 7 was more heavily corroded than any of the other tubs and it is likely that the poor initial surface conditions contributed to the observed blistering.

In three instances, the surface of the restoration coating was noted to have lost some gloss in localized areas. This was likely due to the use of abrasive cleaning materials.

6. COMPARISON WITH LABORATORY TEST RESULTS

In order to develop a final performance criteria document for restoration coatings for porcelain enamel surfaces from the interim criteria previously developed [1], an in-service study was essential. Therefore, the laboratory-based performance criteria of appearance, adhesion, impact resistance, stain resistance and fungal resistance are discussed in the following paragraphs with regard to their relevance based upon data obtained from the field study.

All the restoration coatings used in the field study met the interim performance criteria for appearance, which were based upon laboratory test results. Appearance was estimated in the field study by visual examination and documented using inspection sheets and photographs. Instrumental gloss, reflectance, and color measurements were not made because of the bulk of the instruments involved, the lack of flat surfaces required for the measurements, and the lack of uniformity of cleaning methods used by the occupant. In general, the bathtubs of the field study retained their color and gloss. However, where highly abrasive cleaning materials were used, gloss decreased noticeably in the abraded areas. The loss of gloss appeared to be more dependent on the occupant's cleaning methods than upon the individual restoration coatings. Except for tub number 7, the appearance of the coatings was good throughout the field study. As noted in section 5.3, the blistering and delaminations on tub number 7 may have resulted from particularly poor surface conditions prior to restoration.

The modes of failure, as determined by the adhesion tests, were found to be similar for both field and laboratory tests and the failure modes of two of the three coating systems indicated the adhesion within the restoration coating system to be greater than that in the porcelain coating system.

The impact resistance was not measured in the field test for reasons presented in section 4.0. Only one instance was observed in the field study of chipping due to impact.

The stain resistances of the coatings in the field study and in the laboratory study were similar in that typical household staining materials could be removed nearly completely even though left in contact with the coatings for 16 hours. The field test was modified slightly from the laboratory test in that a mild abrasive cleaner was used to aid stain removal. There were cigarette stains (burns) on the rims of three of the bathtubs. The extent and presence of many cigarette stains to a bathtub indicated that the stains could not be removed easily.

In the laboratory fungus resistance test, all restoration coatings met the requirements of a rating of 10 according to ASTM D 3274 [6]. In the field test, none of the restoration coatings showed signs of fungal growth after one year exposure. This result was encouraging, as many bathrooms had continually leaking water fixtures, there were instances of deteriorating plaster adjacent to the bathtubs, and the cleaning methods of the occupants varied widely. Thus, the interim performance criterion for fungus resistance appears relevant to actual field usage of restoration coatings.

7. PERFORMANCE CRITERIA FOR RESTORATION COATINGS

The comparison of field test performance with test results according to the interim performance criteria formed the bases for the final performance criteria for restoration coatings which are presented in appendix A. The relevance of the interim criteria is discussed in the following paragraphs.

In our opinion, the criterion for appearance should remain unchanged. The availability of test instrumentation and standard test panels (both planar substrate and coatings applied under standard conditions) as well as the adequacy of the interim requirements make changes unnecessary. As reinforcement, the restoration coatings involved in the field test retained their appearance after a year's exposure, unless the surfaces were abused or unless the surface of the tub was badly deteriorated before restoration.

The adhesion tests of the restoration coatings in the field study, both initial and after exposure, indicated that the adhesion within the restoration coating systems was generally good despite visual observation of some blistering. The blistering was typically localized and may have resulted from inadequate preparation and badly degraded tub surfaces. Since the failure mode data from the field test indicated that the adhesion within two of the three restoration coating systems was at least as great as that of the porcelain/metal substrate, the interim performance criterion for adhesion appears to be appropriate.

The restoration coatings in the laboratory tests had impact resistance values higher than unrestored porcelain. The requirement of 0.53 Nm impact resistance should be adequate for quality assurance.

The stain resistance tests of the restoration coatings in the field study confirmed their resistance to common household stains as found in the laboratory tests. This indicates that the interim performance criterion for staining is relevant to field performance and should remain in the final performance criteria. However, the restoration coatings were not resistant to cigarette stains (burns). The combination of high temperatures of a burning cigarette and accumulation of tar residues appears to facilitate penetration into the organic coating. Because staining by cigarettes can be considered an instance of abuse and because it is unlikely any organic coating would resist such stains, a stain resistance requirement for cigarette burns has not been incorporated into the performance requirements.

The fungal resistance of the restoration coatings used in the field study was excellent in spite of often favorable conditions for fungal growth. Thus, the test requirement of the interim criteria document appears to be adequate.

8. CONCLUSIONS

Conclusions based upon the field study are as follows:

1. Data obtained from the field study indicate that the interim performance criteria provide an effective assessment tool for restoration coatings. The restoration coatings that met most or all of the interim performance requirements also performed well in service on eight of the nine bathtubs studied.

2. The performance of the restoration coatings after a year of in-service use was, in general, good. Only one bathtub would have needed complete restoration because of extensive blistering and delamination and the degradation is believed to have stemmed from the poor condition of the tub prior to restoration. Other bathtubs needed only spot repairs, if repairs were needed at all.

3. Surface preparation is a critical factor for the restoration coating process. For the restoration coating to be applied successfully, not only do the personnel performing the application need to be skilled, but the areas where the bathtubs are to be coated have to be free of water, dust, dirt, or other foreign material. Also, adequate working space is required. Unfortunately, the bathrooms used in the study were cramped, water intrusion was sometimes impossible to control, and it was always extremely difficult to control dust and dirt because the whole housing unit was being restored at the same time. The blistering and delaminating that were likely associated with poor surface conditions prior to restoration indicate the need for additional information on surface preparation for badly degraded substrates.

4. The adhesion test apparatus used for the field test proved to be useful in assessing the failure mode of restoration coatings.

5. The gloss of restoration coatings is likely to be affected by the use of abrasive cleaning materials. The types of cleansers used were not controlled in the field tests and, in three instances, cleaning in localized areas of the bathtub left an uneven appearance. The problem of surface dulling by use an abrasive cleaner had been noted in the previous report. This points out the need to use mild abrasives in cleaning restoration coatings.

9. ACKNOWLEDGMENTS

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Table 1. Data on Field Test Sites

Restoration Coating*	Tub Number	Location	Date Refinished	Date Occupied	Occupants Adults	Occupants Children
		Cameron Valley				
3	7	129 Williams St.	07/27/81	09/15/81	1	3
3	8	139 Williams St.	07/27/81	09/25/81	1	1
3	9	156 Maiden Lane	07/27/81	09/25/81	1	3
		Downtown Alexandria				
4	1	411 N. Pitt St.	08/07/81	09/11/81	1	1
4	2	509 N. Pitt St.	08/07/81	08/21/81	1	2
4	3	417 Oronoco St.	08/07/81	08/27/81	1	2
		Downtown Alexandria				
5	4	418 N. Pendleton St.	08/31/81	09/22/81	1	2
5	5	512 N. Royal St.	08/31/81	09/28/81	1	2
5	6	318 Tancil Ct.	08/31/81	09/17/81	1	2

* Described in 'Development of Interim Performance Criteria for Restoration Coatings for Porcelain Enamel Surfaces', NBSIR 82-2553.

Table 2. Stain Resistance of Restoration Coatings Using Four Removal Methods[1]

Company Code Restoration Coating	Purple Tintex	Black Hair Dye	Acetone	Black Shoe Polish	Lipstick
Method 1					
3	L	D	SDS	L	L
4	L	L	NE	L	L
5	VL	L	SDS	VL	L
Method 2					
3	L	D	2/	L	L
4	L	L	2/	L	L
5	VL	L	2/	VL	L
Method 3					
3	VL	L	2/	VL	VL
4	L	L	2/	VL	VL
5	VL	VL	2/	VL	VL
Method 4					
3	VL	VL	2/	VL	VL
4	VL	VL	2/	R	R
5	VL	VL	2/	VL	VL

1/ Method 1 - Wipe with soft, dry paper towel
2 - Wipe with soft, wet paper towel
3 - Wipe with soft, wet paper towel and mild soap
4 - Scrub with mild abrasive cleaner

2/ No further treatment

Description of Abbreviations

R - stain removal
NR - stain not removed
VL - very light stain remained
L - light stain remained
D - dark stain remained
DC - discolored surface
DS - dissolved surface
SDC - slightly discolored surface
SDS - slightly dissolved surface
NE - no effect

Table 3. Results of Field Test Visual Examinations of Restoration Coatings

estoration Coating and Tub No.	Comments		
	Inspection No. 1	Inspection No. 2	Inspection No. 3
3-7	Slight blistering in bottom of tub; small pinholes	Extensive blistering; delamination of blisters; rust observed beneath ruptured blisters along rim of tub	Same as No. 2
3-8	Slight pinhole rusting around drain (during application water backed up into clean work area and it was difficult to dry properly around drain area)	Slight blistering and delamination of blisters around drain; pinhold rusting radiating to ca. 20 cm around drain; chip in rim to metal by impact; slight dulling of gloss	Same as No. 2
3-9	Slight rust appearance around drain area	Slight localized blistering	Same as No. 2
4-1	No defects	Decals added to bottom of tub; pinhole rusting near drain; two slight cracks along rim	Same as No. 2
4-2	No defects	Dulling of gloss and scratches at bottom of tub; slight cracks in bottom of tub; cigarette stains on rim	Same as No. 2
4-3	Slight pinholing	Blistering ca. 30 mm over previous repairs; slight rusting (near drain)	Same as No. 2
5-4	Slight cracking and rusting around drain	Decals added to bottom of tub; slight dulling of gloss on bottom of tub; scratches; also 30 mm blister over repaired area	Same as No. 2
5-5	No defects	Slight blistering and delamination; cigarette staining on rim	Cigarette staining on rim; small area of pinholes near drain
5-6	No defects	ca. 2 mm ruptured blister	Cigarette staining on rim

Figure 1. Typical bathtub with extensive delamination and rusting before restoration

Figure 2. Typical bathtub with decals, dirt and delamination before restoration

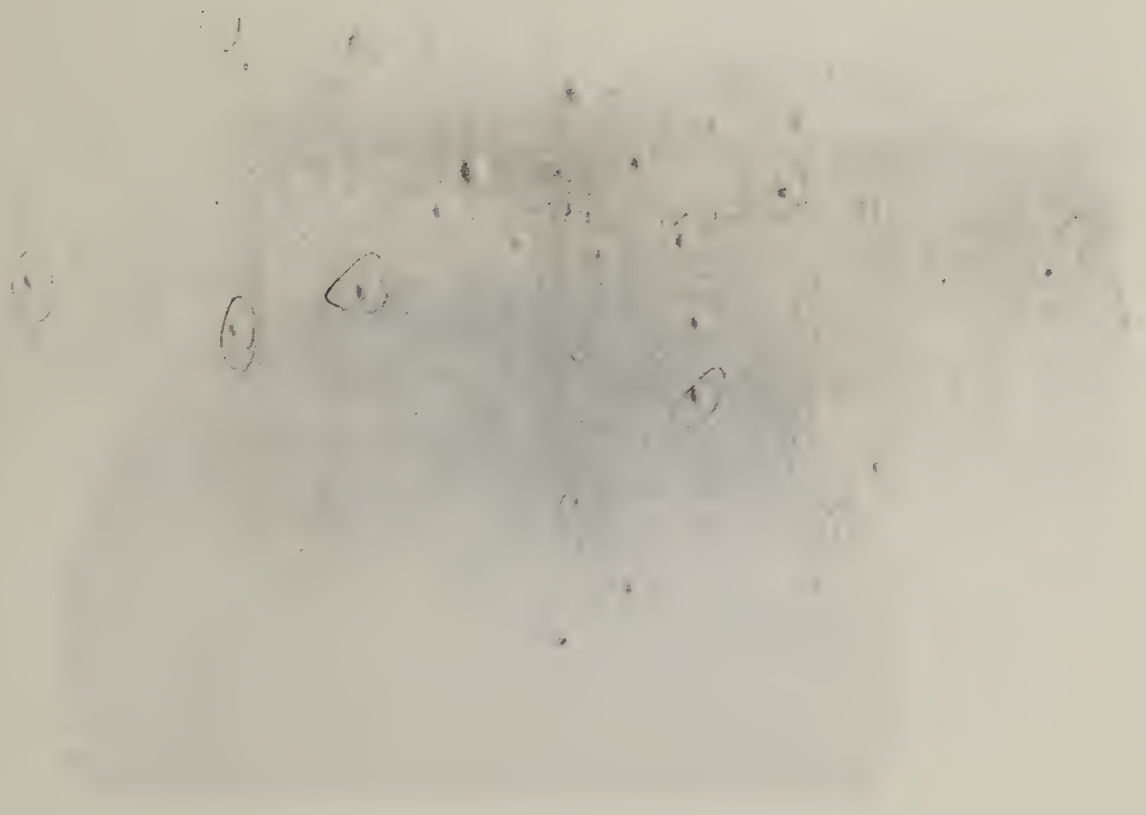

Figure 3. Blisters in the bottom of bathtub number 7[1/]

[1/] The figure shows an area of approximately 65 cm^2 (10 in^2).

Figure 4. Typical delaminated blister of restoration coatings

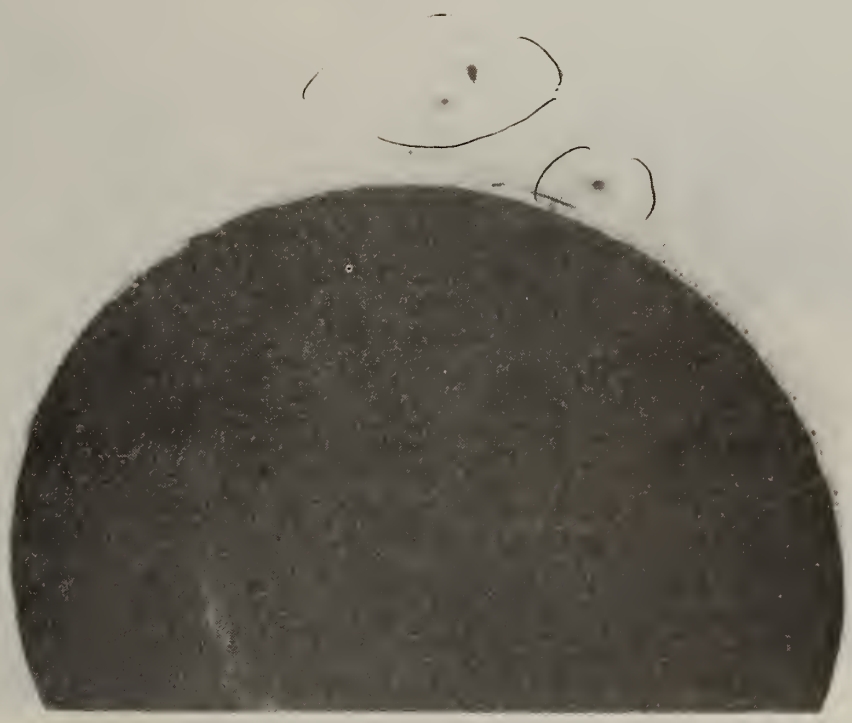

Figure 5. Typical pinholing near drain of restoration coatings

Figure 6. Typical cigarette stains on restoration coatings

Figure 7. Bathtub with non-slip decals

APPENDIX A

PERFORMANCE CRITERIA FOR RESTORATION COATINGS FOR PORCELAIN ENAMEL SURFACES

APPENDIX A. PERFORMANCE CRITERIA FOR RESTORATION COATINGS FOR PORCELAIN ENAMEL SURFACES

A.1 INTRODUCTION

These performance criteria are applicable to organic coatings used in the restoration of porcelain enamel surfaces. They are based upon 1) the results of laboratory tests conducted on five restoration coatings and on specimens of unrestored porcelain enamel test panels and 2) the results obtained after approximately one year of actual in-service use of restoration coatings. The tests and criteria are intended to provide the data needed to assess the expected in-service performance of restoration coatings from laboratory tests. The criteria reflect performance characteristics which restoration coatings would be expected to show in-service; they include appearance, adhesion, impact resistance, stain resistance, and fungal resistance. Abrasion resistance is included as part of the cyclic exposure test.

The criteria refer to exposure of porcelain enamel test panels to accelerated bathtub exposure cycling (ABEC). The cycling includes wet and dry cycling, elevated water temperature and surface abrasion. In the laboratory study [1], an automatic dishwasher was modified for continuous cycling using water temperatures of 43°C (110°F), air drying temperatures of 77°C (170°F), and detergent injection at each bath cycle. At the end of 28 bath cycles (24 hours), the cooled panels were abraded on a Porcelain Enamel Institute (PEI) abrasion tester for 56 machine counts where the abrasive used was feldspar-containing cleanser (modified ASTM C 448 test) before repeating the cyle. Thus, one accelerated bathtub exposure cycle (ABEC) included 28 bath cycles and one abrasion cycle.

A.2 PERFORMANCE CRITERIA

A.2.1 Appearance

Requirement

When applied at the restoration coating company's designated rate and method, the restoration coating shall provide a smooth, uniform gloss appearance under ordinary conditions of illumination and viewing, both initially and after in-service exposure.

Criterion

When applied to a porcelain enamel test panel using the designated rate and method, the initial (before exposure) 60° gloss measurements, as described in ASTM D 523, shall be 75 or greater. The initial apparent reflectivity (white only) [Directional Reflectance, 45°, 0°] shall be at least 85 as described in ASTM D 2244. After exposure to 25 ABECs, the 60° gloss in the unabraded area shall be 70 or greater, and the color difference (E) shall be less than two NBS units (ASTM D 2244).

Commentary

Materials for the restoration of porcelain enamel substrates should have initial gloss and reflectance characteristics similar to those of porcelain enamel.

After exposure to accelerated bathroom exposure cycling, the restoration coatings should retain both color and gloss.

A.2.2 Adhesion

Requirement

The restoration coating shall adhere to a porcelain enamel substrate both initially and after in-service exposure.

Criterion

The mean stress at rupture value of a minimum of five measurements of the restoration coating shall be at least 3.1 MPa (450 psi) before exposure, and shall be at least 1.4 MPa (200 psi) after exposure to 25 ABECs when the adhesion is measured by a pull-off technique, as described in NBSIR 82-2535.

Commentary

The degree to which restoration coatings adhere to porcelain enamel substrates is very important, especially after exposure to in-use conditions such as wet and dry cycling, elevated water temperatures and abrasion.

A.2.3 Impact Resistance

Requirement

The restoration coating shall have an impact resistance equal to or greater than that of the porcelain enamel substrate.

Criterion

The mean impact resistance of a minimum of five measurements of the restoration coating shall be at least 0.53 Nm (4.7 in lbs) after exposure to 25 ABECs; impact resistance being measured according to a modified ASTM D 2794 procedure with a 0.45 kg (1 lb) aluminum cylinder.

Commentary

The minimum impact resistance of 0.53 Nm stated above is the mean value obtained during testing of unrestored porcelain enamel test panels. All of the restoration coatings evaluated in generating the data needed as the technical basis for these criteria had impact resistance values higher than that of the unrestored porcelain because they were elastomeric.

A.2.4 Stain Resistance

Requirement

The restoration coatings shall be resistant to household stains common to bathroom areas.

Criterion

When Tintex, black hair dye, black shoe polish and lipstick are applied for a 16 hour period to restoration coating panels which had been exposed for 25 ABECs, only a very light stain residue shall remain after scrubbing gently with warm soapy water (modified ASTM D 1308).

Commentary

These staining materials are among those which would likely be used in a bathroom area. In order to maintain an attractive appearance, the restoration coating should be easily cleaned if staining materials are spilled on the coating's surface.

A.2.5 Fungal Resistance

Requirement

The restoration finishes shall be resistant to fungal attack when exposed to in-use conditions.

Criterion

No fungus growth shall appear on the restoration finish after the 30 day exposure to the conditions of test method ASTM D 3273 (i.e., a rating of 10 according to ASTM D 3274).

Commentary

It is important that an organic coating used in warm, moist environments be resistant to fungal growth.

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5. AUTHOR(S)

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6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

In June 1982, the results of a laboratory-based study to develop interim performance criteria for restoration coatings for porcelain enamel surfaces were reported in NBSIR 82-2553, "Development of Interim Performance Criteria for Restoration Coatings for Porcelain Enamel Surfaces". Additional studies, consisting of a one-year field test of three of the five restoration coatings studied in the laboratory, were performed to assess the effectiveness of the interim performance criteria. The field test included periodic evaluation of the three restoration coatings applied to a total of nine bathtubs in public housing units in Alexandria, Virginia.

The results of the field tests were compared to the previous laboratory results and showed that the interim performance criteria were effective in selecting durable restoration coatings. This report presents the findings of the field test and includes the final performance criteria.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Organic coatings; performance criteria; porcelain enamel restoration; restoration coatings; test methods

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