NBSIR 82-2553

Development of Interim Performance Criteria for Restoration Coatings for Porcelain Enamel Surfaces

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
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June 1982

Prepared for
Division of Energy, Building Technology and Standards
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

A study was performed to develop interim performance criteria for restoration coatings for porcelain enamel surfaces. The laboratory study consisted of evaluating five restoration coatings which had been applied to porcelain enamel test panels with various surface conditions. Performance characteristics of the coatings examined included appearance, adhesion, impact resistance, stain resistance and fungal resistance. Existing test methods were used in the study if appropriate methods were available. However, the laboratory studies led to the development of a new cyclic exposure test and the use of a newly developed method for measuring adhesion. Adhesion of the coatings was the performance characteristic most sensitive to change with time of exposure to the newly developed cyclic exposure test. Interim performance criteria for restoration coatings for porcelain enamel surfaces were developed, based upon the results of the laboratory study.

Additional studies are being conducted to assess the performance and durability of selected restoration coatings applied to bath tubs in public housing units. Since the field studies are not yet completed, they are not addressed in this report.

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1. INTRODUCTION

1.1 BACKGROUND

Within the last 15 years, processes have been developed for restoring in place chipped or worn porcelain enamel fixtures, such as bathtubs and wash basins, by application of an organic coating. Newer restoration techniques have been developed which may cost only one-quarter as much as replacement of the enamel-coated fixture. In the maintenance of public housing, a continuing problem exists with regards to porcelain enamel coatings on steel and cast iron fixtures which have been damaged by wear or abuse. The potential economic savings could make these new restoration techniques attractive, provided that they perform well. For example, one major problem has been that of adhesion of the organic coating to the damaged or degraded porcelain enamel surfaces. Performance criteria are needed to aid in ensuring the performance and durability of restoration coatings. Laboratory and field data, as well as accelerated test methods, are needed to serve as the technical bases for the performance criteria.

1.2 OBJECTIVE

The objective of the research discussed in this report was to develop interim performance criteria for restoration coatings for porcelain enamel surfaces.

1.3 SCOPE

In order to meet the stated objective, tasks were performed to 1) identify the available commercial restoration coatings for the repair of porcelain enamel surfaces, 2) identify performance requirements and available test methods for evaluating restoration coatings and, where appropriate existing tests were not available, to develop new methods, 3) select and evaluate several commercial coatings in the laboratory to identify factors which affect adhesion and durability and 4) develop interim performance criteria based upon laboratory studies. The results of the above tasks are given in this report.

Field studies are currently being conducted to obtain performance and durability data on selected coatings applied to bathtubs in public housing units. These data will be used to assess the effectiveness of the interim performance criteria. Since the field studies are not yet completed, they are not addressed in this report.

2. IDENTIFICATION OF COMMERCIALLY AVAILABLE RESTORATION COATINGS

Thirty five renovation firms were identified throughout the country. Eleven firms were contacted by telephone although contacts were sought with all firms. It may be noted that many of these firms also franchised other firms or were distributorships for other firms. Information sought was as follows: 1) the type of enamelled metal renovated and whether spot repairs were also made to porcelain enamel surfaces, 2) the type of surface preparation used, 3) generic coatings used, and 4) costs for renovation/repair.

The list of identified companies and information obtained from the telephone contacts are included in appendix A. To summarize the telephone responses, it was found that 1) bathtubs were the most frequently repaired units, 2) surface preparation almost always included acid, solvent and sand treatment, 3) the generic coatings most commonly used were urethanes and epoxies, and 4) the renovation costs for a bathtub were $175 to $250 versus the replacement costs estimated to be $600 to $1000.

3. PERFORMANCE REQUIREMENTS

In order for the restoration coating to perform satisfactorily, the coating must adhere to the substrate under elevated temperature exposure and wet/dry cycling. Also, the coating should be resistant to color and gloss changes (particularly after repeated scrubbing), resistant to impact, and resistant to fungal attack and to stains when exposed to in-service use conditions.

Standard test methods were determined to be available for measuring impact resistance, color, gloss, stain resistance and fungal resistance. A modified standard method was used for measuring adhesion of coatings and a cyclic exposure test was developed to accelerate the exposure conditions experienced by a porcelain bathtub or wash basin finish. These methods are described in section 4.2 of this report.

4. LABORATORY EVALUATIONS

4.1 MATERIALS

The surfaces of porcelain enamel-coated steel panels, obtained through the Porcelain Enamel Institute (PEI), were treated at the National Bureau of Standards to simulate four potential surface conditions that could be encountered by a restoration coating company during a restoration operation. These conditions included 1) glaze intact, 2) glaze eroded but no metal exposed, 3) glaze eroded and metal exposed and 4)glaze chipped, metal exposed with damaged substrate. Following the surface treatment, test panels were sent to five different restoration companies for restoration. The following paragraphs describe the surface treatment performed at NBS and the restoration by the five companies.

4.1.1 Treatment of Test Panels Prior to Restoration

The porcelain enamel coated steel panels, obtained through the PEI, were 130 x 150 mm (4 x 6 in) in size. These panels were considered to be representative of a "typical" new porcelain enamelled steel bathtub or wash basin. The surfaces of the test panels were subjected to one of the following four pretreatments in order to simulate various surface conditions that could be encountered prior to an actual field restoration:

Surface Condition 1. Porcelain enamel surface glaze retained intact, i.e., as received from PEI.

Surface Condition 2. Porcelain enamel surface lightly sandblasted to remove surface glaze (but metal not exposed).

Surface Condition 3. Porcelain enamel surface lightly sandblasted and then chipped with an impact tester in three locations (see pattern* in figure 1) to expose, approximately, a 19 mm (0.75 in) diameter area of the metal substrate. Prior to shipping for restoration, these panels were placed in distilled water until rust appeared.

Surface Condition 4. Porcelain enamel surface lightly sandblasted and then sandblasted to white metal in three locations (see figure 1) using a metal mask to expose 19 mm (0.75 in) diameter areas. Prior to shipping for restoration,

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* The three locations for chipping and sandblasting were within the circular abrasion pattern created by the PEI abrasion tester1/ as described in ASTM C 448 [1].

1/ Certain commercial equipment, instruments or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

these panels were placed in distilled water until rust appeared.

4.1.2 Restoration Coatings

Five restoration finish companies were selected for participation in this study to provide a cross-section of the generic coatings typically used by restoration companies. The code for the companies and the generic types of restoration coatings are as follows:

Company Code for Restoration Coatings	Generic Description of Coating Used
1	Phenolic
2	Epoxy
3	Urethane
4	Enamel
5	Urethane

Each company received 77 test panels as described in 4.1.1 and was asked to recoat or repair them in a manner consistent with procedures used in field restorations. Thirty-five of the test panels sent to each company were pretreated using Surface Condition 1; 14 panels were sent for each of the Surface Conditions 2, 3, and 4. The test panels were coated at the factory using the companies' individual restoration techniques and then returned to the National Bureau of Standards for laboratory testing.

4.2 TEST METHODS

Laboratory tests of the restored panels were performed to assess resistance to degradation using an accelerated bathtub exposure and resistance to fungal growth. Tests of adhesion, impact resistance, color, gloss, and stain resistance were performed at various exposure time increments to assess degradation. Duplicate test panels for each coating and each surface condition were kept in the laboratory as control specimens. The methods used in the laboratory tests are described below.

4.2.1 Accelerated Bathtub Exposure

An accelerated bathtub exposure test was developed to simulate in-service usage. It was designed to include the elements of wet and dry cycling, elevated water temperatures and surface abrasion. One accelerated bathtub exposure cycle (ABEC) included 28 bath cycles and one abrasion cycle (56 counts on the PEI abrasion tester).

The bath portion of the exposure test, which provided wet and dry cycling and elevated water temperature exposure to the panels, utilized a modified Maytag[1/] dishwasher (Model WC201). The control knob on the dishwasher was automated to provide the desired bath cycle. The electrical circuit diagram is given in figure 2 and shown in the photograph of figure 3. The bath cycle began at the setpoint on the control knob where the rinse cycle started and stopped at the drying period end point. The control knob automatically rotated from the end point (completion of drying period) to the set point (start of rinse period). During this 30 second interval, a solenoid operated valve automatically allowed liquid detergent to enter the machine. One complete bath cycle required approximately 40 minutes and the conditions are illustrated in the following table:

Time Period	Dry Air Temp. °C(°F)	Water Temp.[4/] °C(°F)	Time min.
End point[2/] to set point[3/]	N.A.	N.A.	0.5
Set point to end of wash	N.A.	43 (110)	4.0
Start to end of first rinse	N.A.	43 (110)	5.0
Start to end of second rinse	N.A.	43 (110)	6.0
Start to end of drying period	77 (170)	N.A.	23.5

Twenty-eight bath cycles were completed in each 24 hour period and the procedure is illustrated in figures 4-6. Following each 28 cycles, the panels were cooled to room temperature and visually examined for any surface defects. The abrasion portion of the exposure test was carried out at the end of each 28 bath cycles using a modification of the ASTM procedure C 448 [1] and using the PEI tester. The PEI abrasion tester was selected because it produces an

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1/ Certain commercial equipment, instruments or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

2/ Internal timer stops, turning motor starts.

3/ Turning motor stops, internal timer begins.

4/ A previous study [2] of vitreous enamel and plastic sanitary fixtures used tests for hot water resistance and thermal shock resistance at 93.3-100°C to 0°C (200-212°F to 32°F). Frechette, et al. [3] used a water temperature of 93.3°C (200°F) in studies of patch kits applied to poreclain enamel. A water temperature of 43°C was selected for this study because the water temperature from most residential water heaters currently is not believed to exceed 43°C (110°F).

oscillating motion which simulates hand scrubbing of a porcelain fixture. The ASTM C 448 procedure was modified so that the panels were abraded for 56 machine machine counts and the abrasive used was a mild cleanser containing feldspar.[1/] The abrasion test procedure is illustrated in figures 7-15.

The panels were visually examined after 2, 5, 10, 15, 20, and 25 ABECs and tested for changes in color, gloss, impact resistance and adhesion. The panels were rinsed with dilute hydrochloric acid and water to remove traces of salt deposits before testing. The stain and fungus tests were conducted after 25 ABECs.

4.2.2 Adhesion

Adhesion tests were performed to determine the level of adhesion of the restoration coatings with increasing time of accelerated exposure. The test method to determine the stress at rupture of the restoration coatings was a newly developed modification of the International Standards (ISO) method No. 4624 [4] which utilizes a pull-off technique. The adhesive used for bonding the metallic button was an industrial strength epoxy and the yoke apparatus was was especially designed for use with a testing machine. Figures 16-21 illustrate special apparatus and test procedure. Prior to bonding the metallic buttons to the panels, the panels were allowed to stabilize at 21°C (70°F) and 50 percent RH for at least 24 hours. A 19 mm (0.75 in) diameter, 19 mm (0.75 in) high stainless steel cylinder was glued, plane face down, with the epoxy adhesive and cured at 70°C (158°F) for 40 minutes. Four small spacers were machined on the outer edges of the planar surface of the stainless steel cylinder in order to produce a bond line of 0.203 mm + 0.002 mm thickness. Three cylinders were attached at uniform intervals to duplicate coated panels having porcelain enamel Surface Condition 1. Thus, the reported stress at rupture values were an average of 6 pull-off tests. Two cylinders were attached at uniform intervals on duplicate coated panels having Surface Conditions 2, 3, and 4. Thus, stress at rupture values were an average of 4 pull-off tests for these surface conditions. For Surface Conditions 3 and 4, the cylinders were attached directly over the repaired areas that had been chipped or sandblasted. The adhesion tests were conducted using the 300 kg (661 lb) range of the testing machine with a chart drive of 50 mm/min (2 in/min) and a console speed (movement rate of the screw drive) of 1 mm/min (0.04 in/min).

[1/] Preliminary studies with the PEI abrasion tester indicated that the alloy balls did not affect the color or gloss of the restoration finishes, but that the Pennsylvania glass sand abrasive used in the test was much too abrasive on the organic coatings. Preliminary studies indicated that the mild abrasive cleanser recommended by the restoration coating companies along with the alloy balls would produce moderate abrasion on the organic coatings while having little or no effect on porcelain enamel itself.

4.2.3 Impact Resistance

The test method to determine the impact resistance of the restoration coatings after exposure to the accelerated exposure described in 4.2.1 was modified from ASTM D 2794 [5]. To provide improved sensitivity, a 0.45 kg (1 lb) aluminum impactor cylinder was used instead of the 0.9 kg (2 lb) steel cylinder of the variable light duty impact tester. The aluminum cylinder was dropped in 25 mm (1 in) height increments, starting at 25 mm (1 in), until a visible dent or chip occurred on the surface. The coated panels used for the test were those having Surface Condition 1, (see 4.1.1). Figures 22-25 illustrate the impact resistance procedure.

4.2.4 Color

ASTM test method D 2244 [6] was used to measure color differences (ΔE) on the coated panels after exposure to the ABECs. Using a colorimeter, measurements were made in both the abraded and unabraded areas.

4.2.5 Gloss

ASTM test method D 523 [7] was used to measure 60° gloss differences on the coated panels after exposure to ABECs. Gloss measurements were made in both the abraded and unabraded areas. Preliminary gloss measurements revealed the necessity of removing traces of minerals or other deposits from the tap water and detergents used in the bath cycle. Consequently, a dilute hydrochloric acid wash and distilled water rinse was an essential part of panel preparation before gloss measurements were made.

4.2.6 Stain Resistance

Test panels were rated visually for effectiveness of stain removal. The measurement of stain resistance involved modification of the test method ASTM D 1308 [8]. The test apparatus was the same as that used in a previous study [2]. In particular, the procedures were modified to ensure that the staining materials would not evaporate during the 16 hour exposure. The staining materials selected were those thought to be in common usage in bathroom areas and those which had proved troublesome on other organic substrate such as fiber glass reinforced polyester bathtubs [2] and plastic wall covering materials [9]. These staining materials were purple Tintex, black hair dye, black shoe polish, lipstick and acetone. The test apparatus and its use is illustrated in figures 26 to 31. The stains were removed after 16 hours exposure on the restoration coating using the following three methods:

Method 1 - wipe with soft dry paper towel,

Method 2 - scrub gently with warm soapy water and brush, and

Method 3 - scrub on PEI abrasion tester for 28 cycles.

The panels used for this test were Surface Conditions 1 and 2, (see 4.1.1) which had been exposed to the ABECs. Surface Conditions 3 and 4 panels were not used for this test because staining is a surface related phenomena and the restoration coating surfaces of Surface Condition 3 and 4 panels were comparable to those of Surface Condition 1 and 2 panels.

4.2.7 Fungal Resistance

Measurement of fungal resistance was by test method ASTM D 3273 [10]. The coated test panels were examined in accordance with test method ASTM D 3274 [11] after 30 days exposure in the incubation chamber.

5. RESULTS AND DISCUSSION

5.1 ADHESION

The change in measured stress at rupture of the test panels with ABECs is given in figures 32-36 for Restoration Coatings 1, 2, 3, 4, and 5. Prior to exposure, to range of measured stress at rupture values for all surface conditions of each Restoration Coating were as follows: Restoration Coating 1: 3.0 MPa 1/ (430 psi) the 1.7 MPa (250 psi); Restoration Coating 2: 2.6 MPa (375 psi) to 1.4 MPa (200 psi); Restoration Coating 3: 2.8 MPa (400 psi) to 1.8 MPa (260 psi); Restoration Coating 4: 5.2 MPa (750 psi) to 1.7 MPa (250 psi); and Restoration Coating 5: 4.3 MPa (630 psi) to 1.9 MPa (275 psi). The surface condition of the panels prior to restoration/repair had an influence on the stress at rupture of the restored/repaired panels. The stress at rupture of panels of Surface Conditions 1 and 2 would have been expected to have been nearly equal. The lower stress at rupture values of Surface Condition 2 panels may have been the result of the sandblasting treatment treatment causing micro-cracking which weakened the cohesive bonding of the porcelain enamel. The stress at rupture values of Surface Condition 3 and 4 panels were usually lower than the others. Also, the values were more erratic for Surface Conditions 3 and 4 than for Surface Conditions 1 and 2, which may reflect the influences of the epoxy fillers used for the repair and the stresses imposed on the panels during impact and sandblasting treatment. The stress at rupture of all the restoration coatings decreased with increasing number of exposure cycles. However, the rate of decreasing stress at rupture with ABECs was noticeably different for the different restoration coatings. As examples, 1) the stress at rupture of Restoration Coating 5, Surface Condition 1, decreased rapidly from 4.3 MPa (630 psi) to 1.9 MPa (275 psi) after 2 ABECs before stabilization, and 2) the stress at rupture of Restoration Coating 4, Surface Condition 1, decreased from 5.2 MPa (750 psi) initially to 3.7 MPa (537 psi) after 25 ABECs. For each of the coatings, the general shape of the ABEC curve for Surface Conditions 2, 3, and 4 was similar to that of the Surface Condition 1 curve. This implies that the properties of each of the restoration coatings were a more important factor in the degradation process than the individual surface condition treatments.

When the average stress at rupture was greater than 4.1 MPa (600 psi), failures occurred in the porcelain enamel-metal interface. For example, all of the panels of Restoration Coating 4, Surface Condition 1, delaminated in the porcelain enamel for up to 20 ABECs, while none of the panels of Restoration Coating 1, Surface Condition 1, delaminated in the porcelain enamel following accelerated exposure. Also of interest, the mode of adhesion failure changed with a decrease in average stress at rupture as exposure cycles increased. This is illustrated in figure 37 for Restoration Coating 5, Surface Condition 1; the initial failure was in the porcelain enamel substrate; after two ABECs, failure was observed at the primer to organic top coat interface; and after three ABECs, cohesive failure occurred within the organic top coat. The mode

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1/ MPa = mega pascal.

of failure in order of decreasing frequency was 1) failure in the enamel, 2) primer-to-top coat failure, and 3) cohesive failure in the top coat. The latter failure mode was primarily observed as the stress at rupture values decreased with increasing exposures. In general, stress at rupture values of the restoration coatings over repaired areas (Surface Conditions 3 and 4) were not as high as those for Surface Conditions 1 and 2. Influences other than the test exposure on the adhesion of the restoration coatings may have been the thickness of coating and/or filler surface treatment, stress concentrations from bonding to the relatively thin steel substrate, and the air and water temperatures used in the bath cycles which may have accelerated polymer degradation.

5.2 IMPACT RESISTANCE

The average impact resistance of the restoration coatings was determined by a modification of ASTM D 2794 [5] after exposure to ABECs. The results are shown in table 1. For comparison purposes, the impact resistance test was also performed on unrestored porcelain enamel panels, Surface Condition 1. The average impact resistance of six of these panels was 0.53 Nm.

All the restoration coatings had better initial impact resistance than the unrestored porcelain enamel panel. The change in impact resistance of the restoration coatings after exposure was small and considered insignificant.

5.3 COLOR

Color difference measurements were made on both the abraded and unabraded areas of the restoration coatings after exposure to ABECs. The results of coatings, Surface Condition 1, are illustrated in table 2. For comparison purposes, color measurements were performed on unrestored porcelain enamel panels, Surface Condition 1. These data are included at the bottom of table 2. The color differences of Restoration Coatings, Surfaces Conditions 2, 3 and 4, are illustrated in table 3 after 25 ABECs.

The color changes for the restoration coatings after accelerated exposures were generally 2 NBS color difference units or less and thus, color changes are considered insignificant. Restoration Coating 2 (table 3), was an exception in that color changes were visible. Varying panel surface conditions did not affect the color changes after accelerated exposures except for possible minor effects due to surface differences (defects).

5.4 GLOSS

The 60° gloss measurements were made on both the abraded and unabraded areas of the restoration coatings after exposures. The test results of coatings, Surface Condition 1, are illustrated in table 4. For comparison purposes, gloss measurement was also performed on unrestored porcelain enamel panels, Surface Condition 1. These data are shown at the bottom of table 4. The gloss measurements of restoration coatings, for Surface Conditions 2, 3, and 4, after 25 ABECs are illustrated in table 5.

Gloss changes for the restoration coatings after accelerated exposures, i.e., 25 ABECs, in the unabraded areas were minor. However, large gloss changes were found in the abraded areas for all restoration coatings. The unrestored porcelain enamel panel, Surface Condition 1, had a 21 percent loss in gloss in the abraded area after 25 ABECs. While the abrasive used in the tests is of a type recommended for restoration coating and fiber glass reinforced polyester bathtubs, its use in this study proved to be devastating on the gloss of the finishes. The abrasive medium for organic coatings should be a softer inorganic material or an organic fibrous material, e.g., Nylon mats, in order to retain gloss.

5.5 STAIN RESISTANCE

The stain test results are given in table 6 for the restoration coatings, Surface Condition 2, which had been exposed to 25 ABECs. In preliminary experiments, unrestored porcelain enamel coatings were completely resistant to all of the stain materials. With the exceptions of the effects of the black hair dye on Restoration Coatings 2 and 3, and the effects of acetone in dissolving Restoration Coatings 1, 3, and 5, the stains were readily removed from the coatings.

5.6 FUNGAL RESISTANCE

Since restoration coatings would often be exposed to fungi growth in a hot, humid bathroom environment, the procedure in test method ASTM D 3273 was used to examine the fungi resistance of these materials. After 30 days test exposure of the five restoration coatings, and an unrestored porcelain enamel panel, which had previously been exposed to 25 ABECs, no fungal growth was observed on any of the panels.

6. INTERIM PERFORMANCE CRITERIA

Interim performance criteria for restoration coatings for porcelain enamel surfaces are presented in appendix B and are based upon the laboratory test results described in chapter 5 of this report. These performance criteria are termed "interim" because they may be modified after the completion of the field studies.

The key to the development of the performance criteria was exposure of the test panels to accelerated bathtub exposure cycling (ABEC) which included wet and dry cycling, elevated water temperatures and surface abrasion. All panels were exposed to 25 ABECs (each cycle included 28 bath cycles with detergent injection at each bath cycle, then cooling and abrading the panels on the PEI abrasion tester for 56 machine counts using feldspar-containing cleanser and the alloy balls as abrasive before evaluation). The criteria selected were chosen to reflect performance characteristics which these materials would be expected to exhibit in service; they included appearance, abrasion resistance, adhesion, impact resistance, stain resistance and fungal resistance.

Based upon the laboratory test results, all of the five restoration coatings had good performance with regard to appearance, impact resistance, stain resistance, and fungal resistance which is reflected in the respective proposed test requirements. The proposed test requirements are as follows:

- Appearance: 60° gloss: Before exposure - $\geq$ 75
  After 25 ABECs - $\geq$ 70
  45° reflectance: Before exposure - $\geq$ 85
  color change: After 25 ABECs - < 2 NBS units

- Impact resistance: $\geq$ 0.53 Nm (4.7 inch pounds) after exposure to 25 ABECs

- Stain resistance: very light stain residue after scrubbing with warm soapy water on specimens exposed to 25 ABECs

- Fungal resistance: no fungus after 30 days exposure to conditions of ASTM D 3273 (i.e., rating 10, ASTM D 3274).

Test data indicated differences in stress at rupture for adhesion tests in both the initial and exposed restoration coatings. The adhesion test requirement is proposed of a 3.1 MPa (450 psi), initial, and 1.4 MPa (200 psi), after exposure to 25 ABECs. This is thought to represent the criteria for heavy use areas, e.g., children, transient tenants, whereas the adhesion criteria may well be modified for use in light use areas, e.g., elderly occupants. At this time, the interim performance criteria do not differentiate between various use conditions. The additional field test study should aid in the validation of the interim criteria and provide guidance in differentiating criteria for different use areas.

7. SUMMARY AND CONCLUSIONS

An accelerated bathtub exposure cycle (ABEC) was developed to study the performance of restoration coatings for porcelain enamel surfaces. The exposure test contained the elements of elevated water tempertures, wet and dry cycling and surface abrasion. Five companies applied restoration coatings to porcelain enamel panels which had been treated to simulate various conditions of surfaces in need of repair. The restored panels were exposed to the accelerated exposures for selected time periods prior to evaluation. Performance characteristics of the restoration coatings examined included appearance, adhesion, impact resistance, stain resistance and fungal resistance. Interim performance criteria were developed based upon these characteristics of the five restoration coatings.

General conclusions based upon the laboratory results are as follows:

1. Adhesion was the performance characteristic most sensitive to change with the length of time of accelerated exposure. Damage to the porcelain enamel surface during sandblast surface preparation and prior to restoration coating application appeared to have had a noticeable deleterious effect on stress at rupture. This could be of concern in future restoration procedures.

2. The restoration coatings examined had good performance with regards to appearance, impact resistance, stain resistance, and fungal resistance.

3. The use of the feldspar-containing cleanser in the PEI abrasion tester was judged to be too severe for the restoration coatings tested. This conclusion is based upon the large changes in gloss in abraded areas of test specimens. While a housewife cleaning a bathtub with a feldspar-containing cleanser ordinarily would not abrade a bathtub under the severe conditions used in the PEI abrasion test, consideration should be given to the development of an even milder abrasive for use with restoration coatings. Also, modification of test procedures for measuring abrasion resistance and resultant gloss changes will require milder abrasives for more sensitive detection of changes.

8. FUTURE RESEARCH

The interim performance criteria presented in appendix B for restoration coatings for porcelain enamel are based only upon accelerated exposure tests and require field testing to validate the interim criteria. As pointed out in previous sections of the report, field tests are currently underway. The effectiveness of the adhesion test in assessing changes in coatings performance necessitates the use of adhesion tests in the field test study. The development of a portable pneumatic adhesion tester is needed to permit these tests to be carried out; research is currently underway to develop a portable tester. Research is also needed to determine the effects of surface preparation treatments prior to restoration coating application. The development of non-abrasive cleansers for use with restoration coatings is needed.

9. ACKNOWLEDGMENTS

The authors thank Mr. Larry Masters, Dr. Mary McKnight and Mr. Harvey Berger of NBS for their helpful guidance and assistance in preparing this report, Mr. Jack Lee of NBS for his dedicated laboratory work and collation of data and Mr. Ronald Morony and Ms. Dorothy Allen of HUD and Mr. Richard Moss, PEI, for their helpful guidance and assistance. Also, we wish to thank the Department of Housing and Urban Development for supporting this research and the manufacturers and suppliers who provided materials and assistance in this project.

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Table 1. Average Impact Resistance of Restoration Coatings, Surface Condition 1, After ABECs

Company Code for Restoration Coating	Impact Resistance (Nm)* ABECs 0	2	5	10	15	20	25
1	0.87	0.82	0.84	0.84	0.79	0.82	0.84
2	0.59	0.62	0.56	0.67	0.56		0.67
3	0.82		0.79	0.67	0.79		0.84
4	0.87	0.79	0.82	0.79	0.81	0.73	0.80
5	0.79	0.65	0.76	0.67	0.67	0.67	0.64

* Each value is an average in Newton meters of four measurements.

Table 2. Color Differences of Restoration Coatings, Surface Condition 1, After ABECs

Company Code for Restoration Coating	Color Difference ABECs 2		5		10		15		20		25	
	A*	U*	A	U	A	U	A	U	A	U	A	U
1**	0.93	0.41	1.28	0.59	1.33	0.48	1.70	0.80	1.64	0.98	1.77	1.00
4	1.37	0.40	1.58	0.50	1.39	0.34	1.16	0.54	1.4	0.70	1.37	0.74
5	2.43	0.34	1.87	0.24	2.42	0.49	2.47	0.33	2.51	0.47	2.54	0.32
Unrestored Porcelain Enamel***	0.35	0.59	0.52	0.56	0.71	0.74	0.50	0.53	0.95	1.22	0.55	0.36

*A = abraded area, i.e., PEI abrasion test area; *U = unabraded area

** Restoration coatings 2 and 3 were not included because of insufficient specimens

*** The unrestored porcelain enamel specimens, Surface Condition 1, were included as a basis for comparison of restoration coatings with porcelain enamel.

Table 3. Color Differences of Restoration Coatings, Surface Conditions 2, 3, and 4, After 25 ABECs

Company Code for Restoration Coating	Surface Condition	Color Difference A*	U*
1	2	1.16	0.34
	3	0.75	0.74
	4	0.63	0.62
2	2	3.01	3.24
	3	5.52	3.17
	4	4.51	3.23
3	2	1.10	1.44
	3	0.69	0.98
	4	0.88	0.92
4	2	1.77	1.16
	3	1.87	1.25
	4	1.83	1.33
5	2	0.94	0.59
	3	1.05	0.52
	4	1.40	0.80

*A = abraded area, i.e., PEI abrasion test; *U = unabraded area

Table 4. 60° Gloss of Restoration Coatings, Surface Condition 1, After ABECs

Company Code for Restoration Coating	Gloss ABECs 0	2		5		10		15		20		25	
		A*	U*	A	U	A	U	A	U	A	U	A	U
1	53	47	67	36	58	22	63	16	65	12	54	9	50
2	94	59	93	45	92	29	91	–	–	–	–	18	78
3	92	–	–	55	92	28	88	18	88	–	–	7	81
4	92	42	92	32	78	15	87	9	92	7	84	5	90
5	76	66	79	45	71	23	81	16	82	11	70	11	70
Unrestored porcelain enamel	98	99	99	100	100	93	96	89	97	82	96	75	95

Table 5. 60° Gloss of Restoration Coatings, Surface Conditions 2, 3, and 4, After 25 ABECs

Company code for Restoration Coating	Surface Condition	60° Gloss A*	60° Gloss U*
1	2	7	79
	3	13	74
	4	11	72
2	2	42	89
	3	36	89
	4	34	89
3	2	10	83
	3	10	87
	4	8	82
4	2	6	91
	3	6	93
	4	5	89
5	2	25	84
	3	24	76
	4	28	81

*A = abraded area, i.e., PEI abrasion test area; *U = unabraded area

Table 6. Stain Resistance of Restoration Coatings Using Three Removal Methods[1/]

Method 1

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

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

[1/] Method 1 - Wipe with soft dry paper towel
2 - Scrub gently with warm soapy water and brush
3 - Scrub on PEI tester 28 cycles

Description of Abbreviations

R - Stain removed
NR - Stain not removed
VL - Very light strain 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

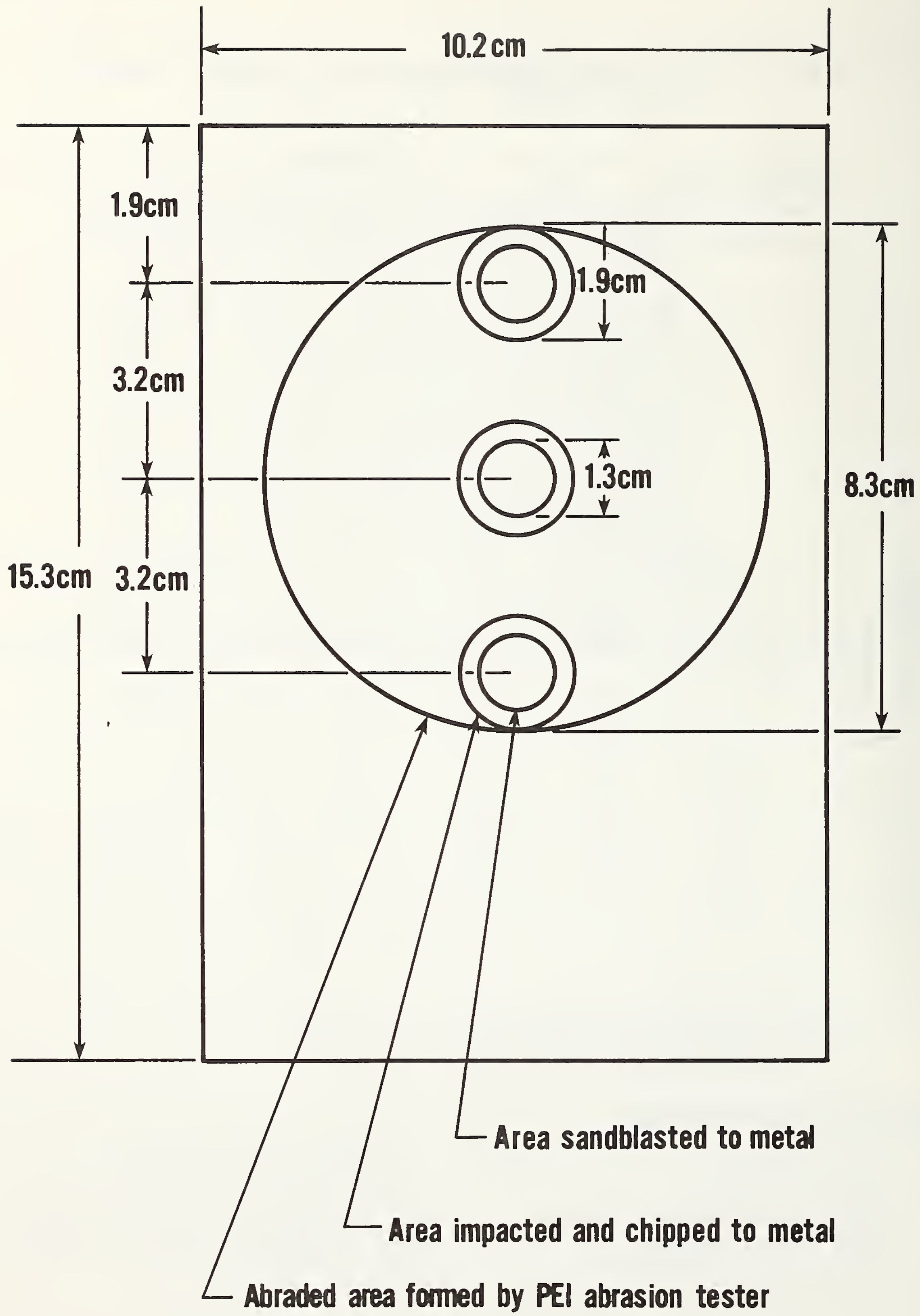

Figure 1. Pattern for preconditioning test panels

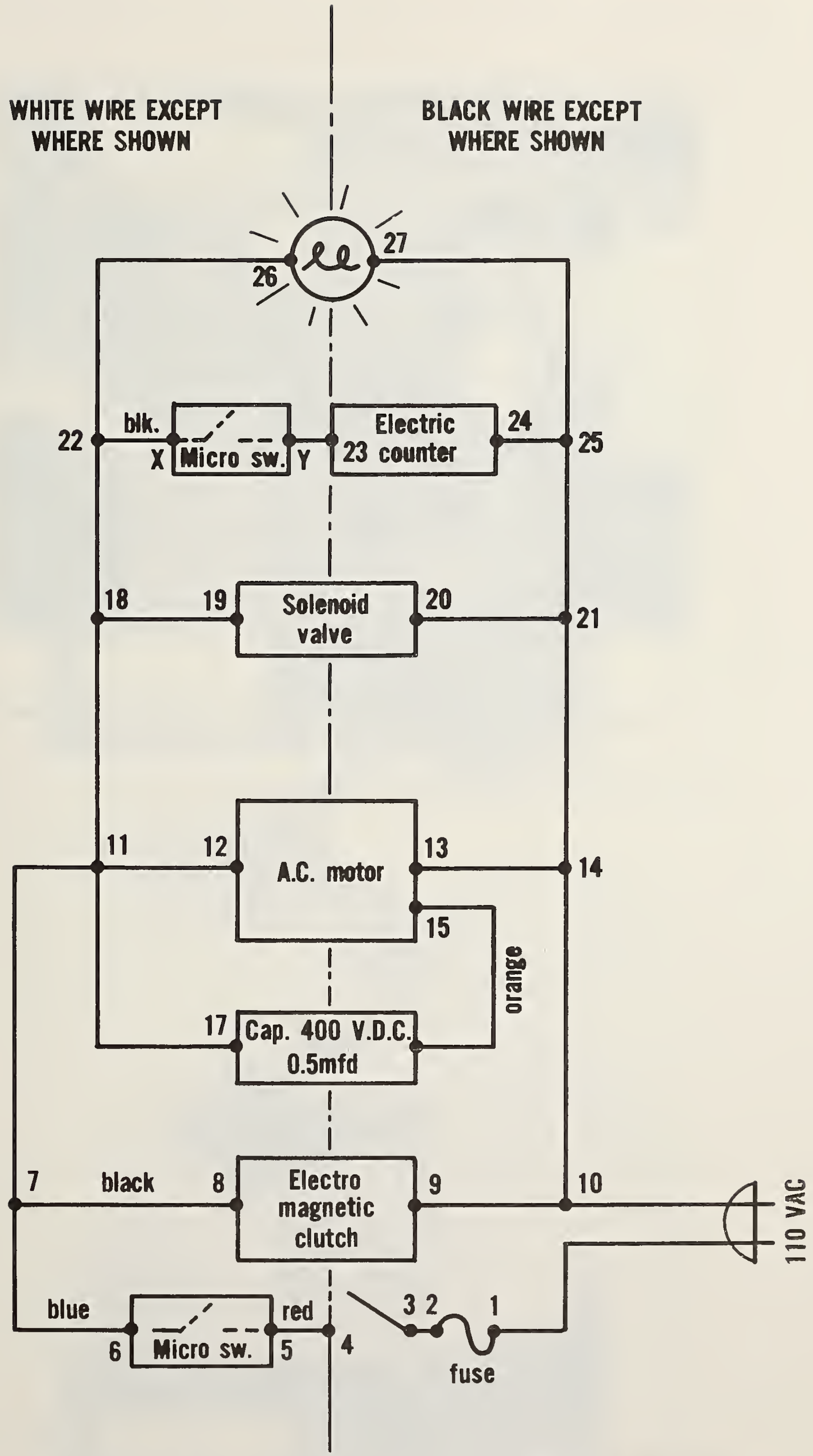

Figure 2. Circuit diagram for recycling controls on modified dishwasher

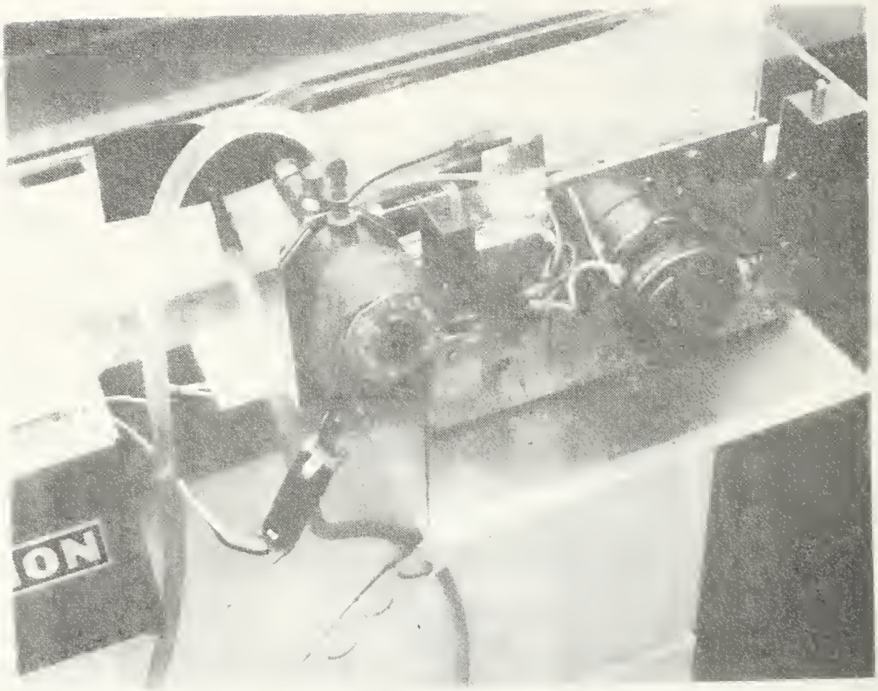

Figure 3. Recycling controls on modified dishwasher

Figure 4. Accelerated bath cycle apparatus - overall view

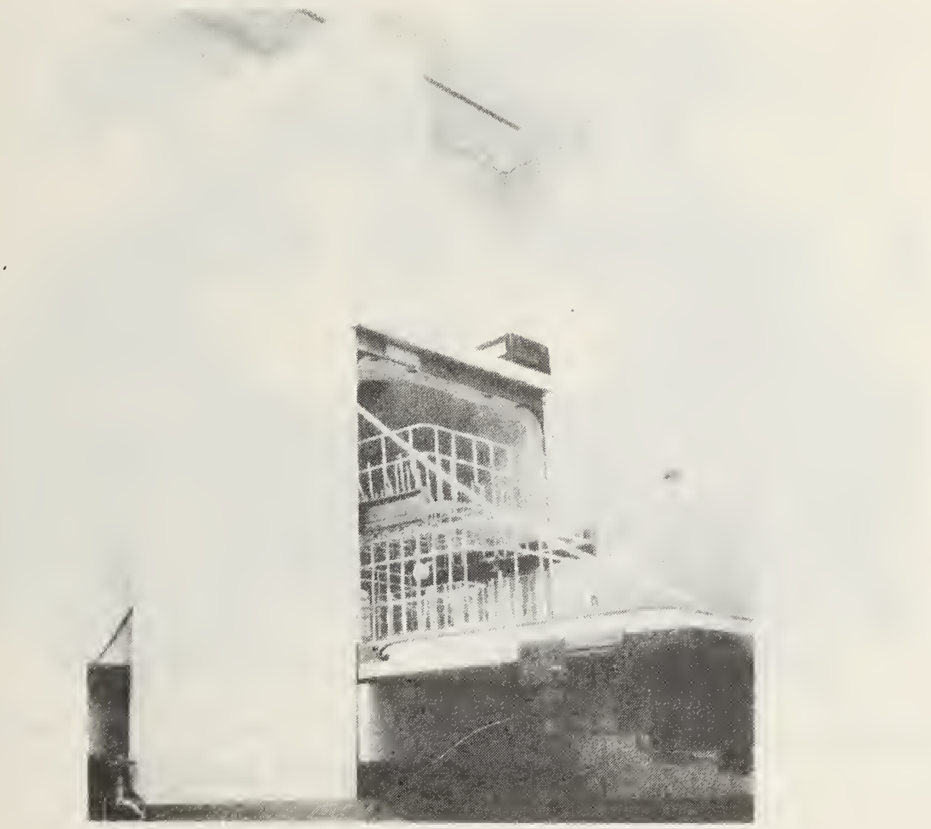

Figure 5. Accelerated bath cycle apparatus - machine unloaded

Figure 6. Accelerated bath cycle apparatus - panels loaded in rack

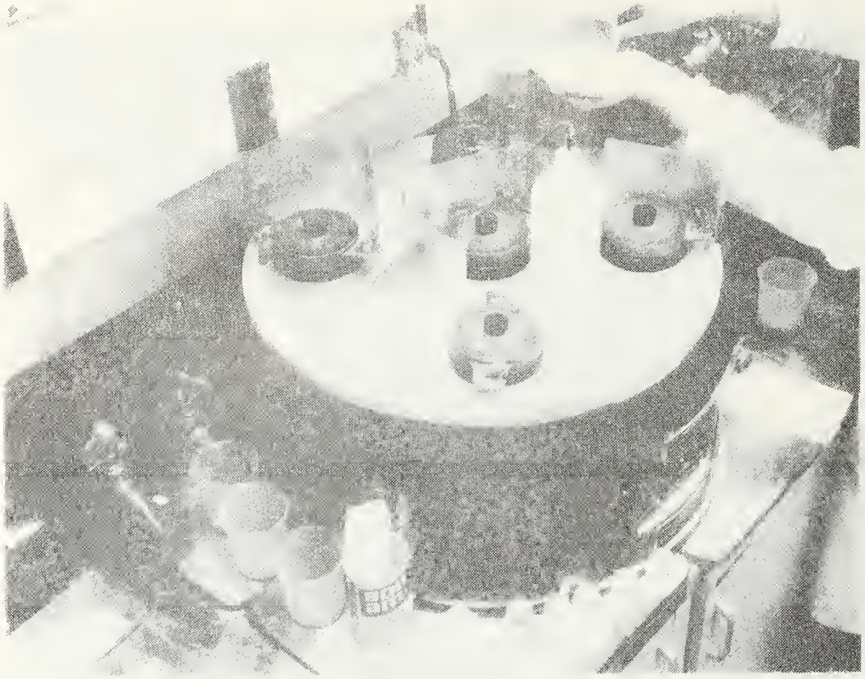

Figure 7. Modified abrasion procedure using PEI abrasion tester and alloy balls

Figure 8. Modified abrasion procedure - placing test panels on apparatus

Figure 9. Modified abrasion procedure - placing containers for holding alloy balls and abrasive on test panels

Figure 10. Modified abrasion procedure - addition of alloy balls

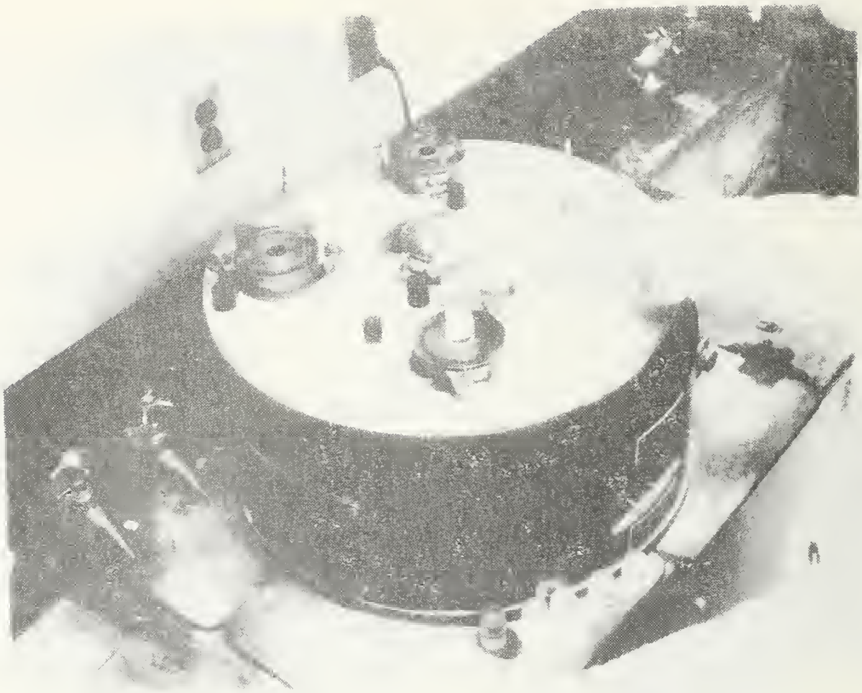

Figure 11. Modified abrasion procedure - addition of abrasive

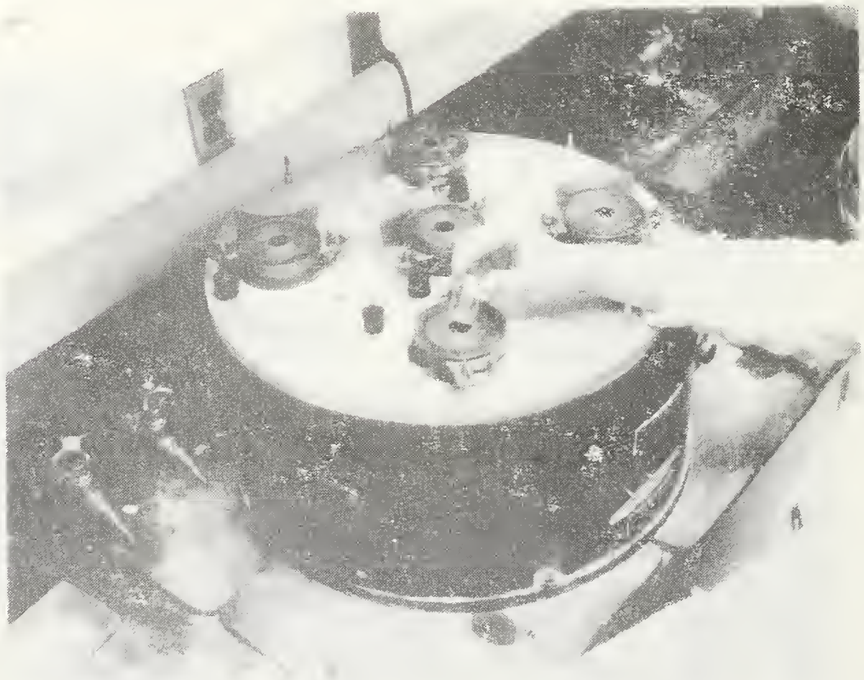

Figure 12. Modified abrasion procedure - addition of water

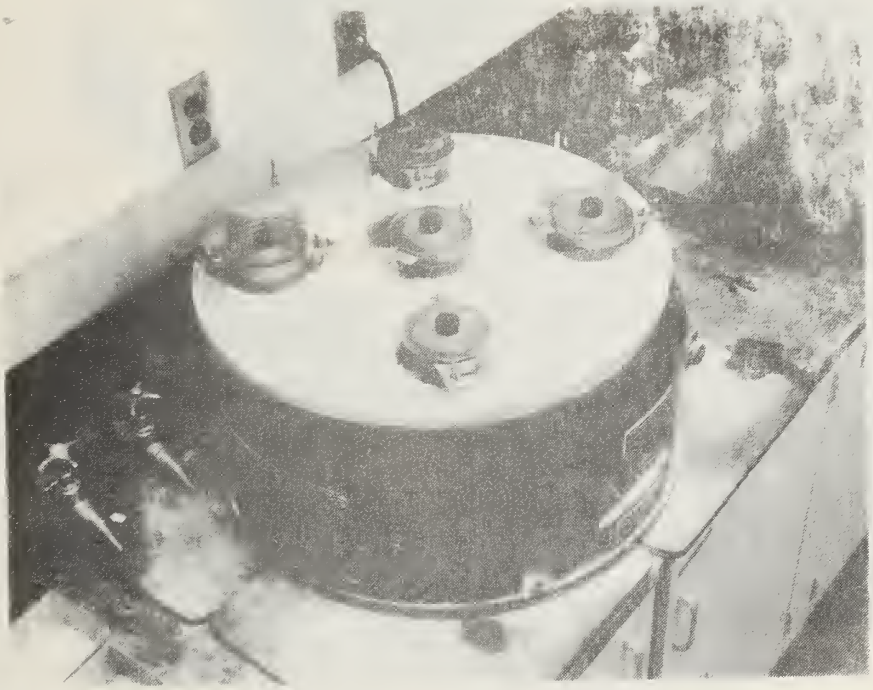

Figure 13. Modified abrasion procedure - abrasion test commences

Figure 14. Modified abrasion procedure - removal of test panels and alloy balls after test

Figure 15. Modified abrasion procedure - rinsing alloy balls and test panels

Figure 16. Adhesion procedure - yoke apparatus mounted in testing machine

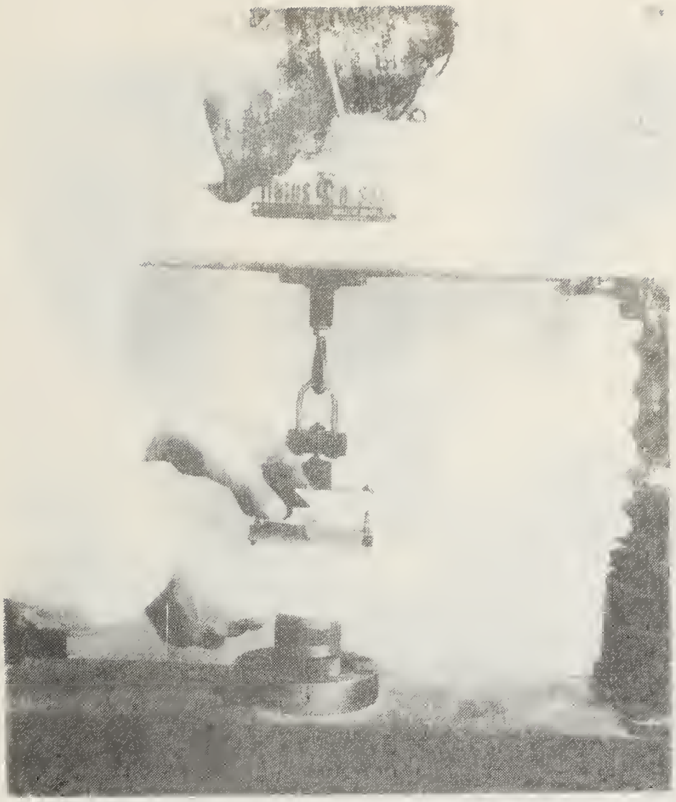

Figure 17. Adhesion procedure - insertion of test panel with buttons attached

Figure 18. Adhesion procedure - joining upper and lower portions of yoke apparatus

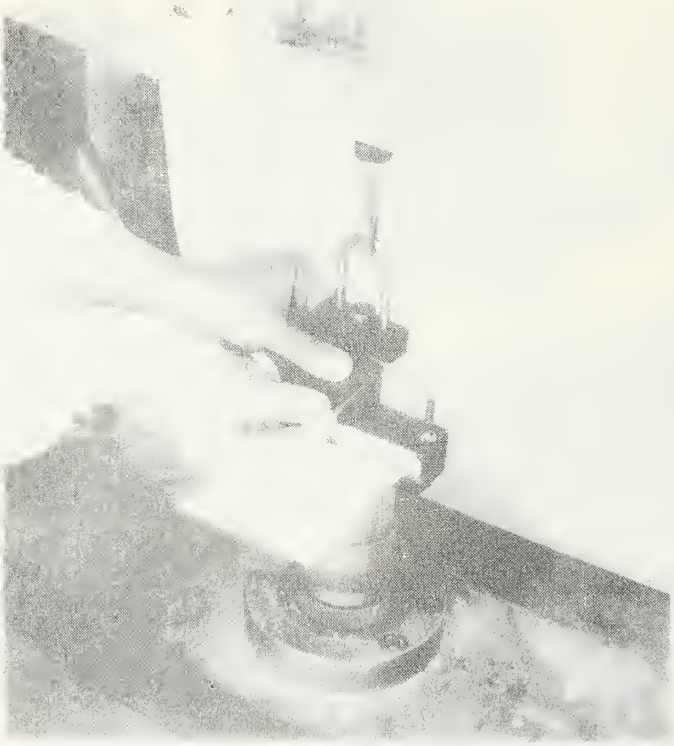

Figure 19. Adhesion procedure - joining upper and lower portions of yoke apparatus

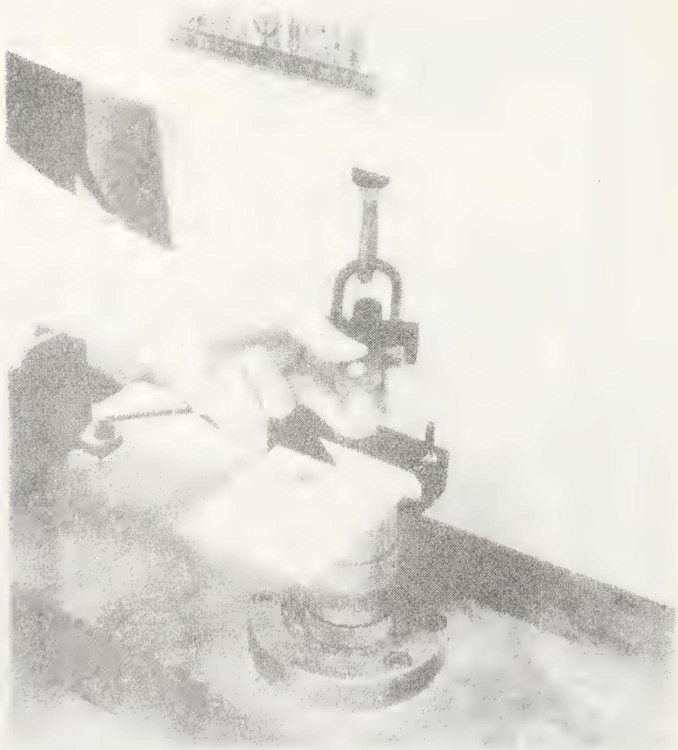

Figure 20. Adhesion procedure - after test, bottom of button showing delaminated coating

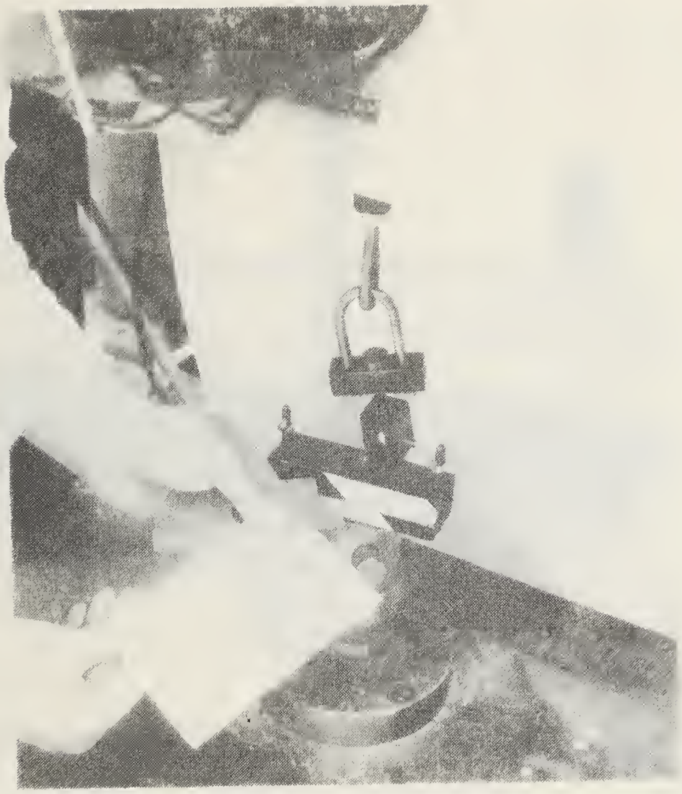

Figure 21. Adhesion procedure - coated area pulled off after testing

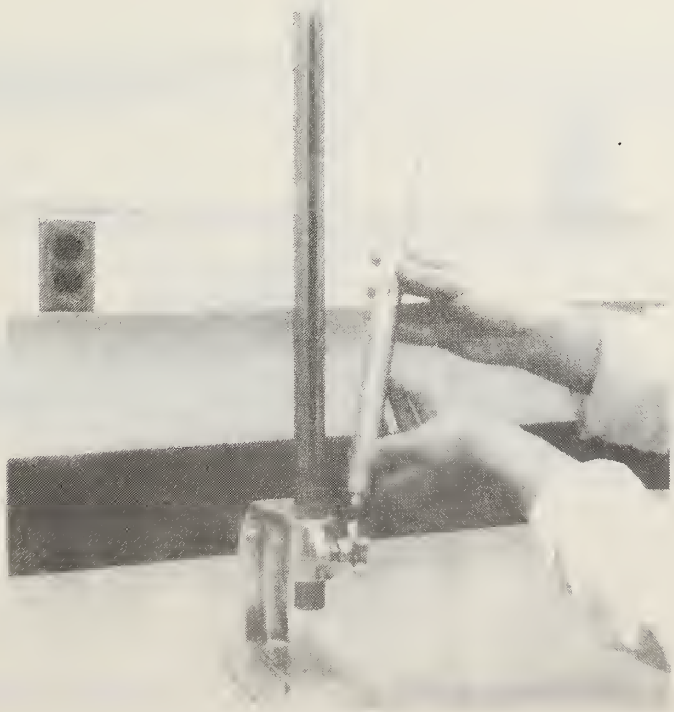

Figure 22. Impact resistance procedure - apparatus with aluminum impactor cylinder

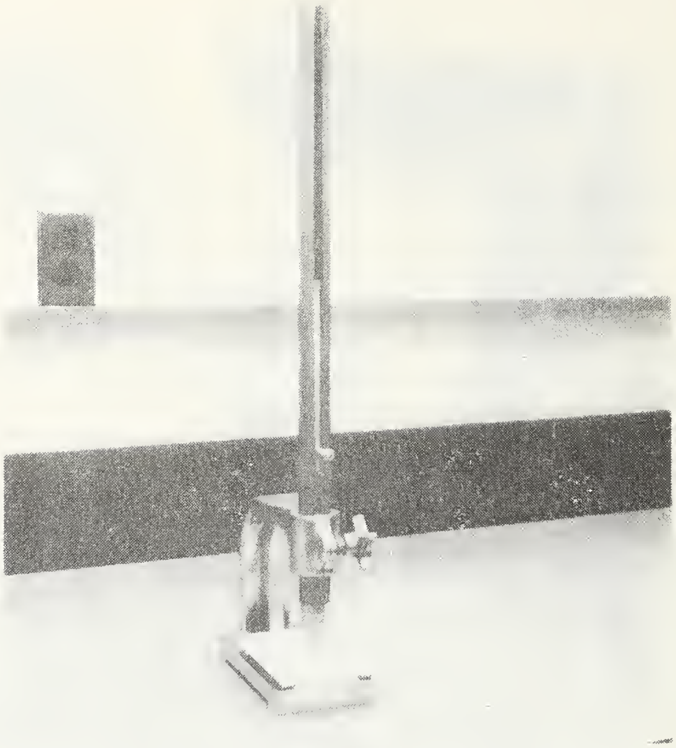

Figure 23. Impact resistance procedure - apparatus with test panel in place

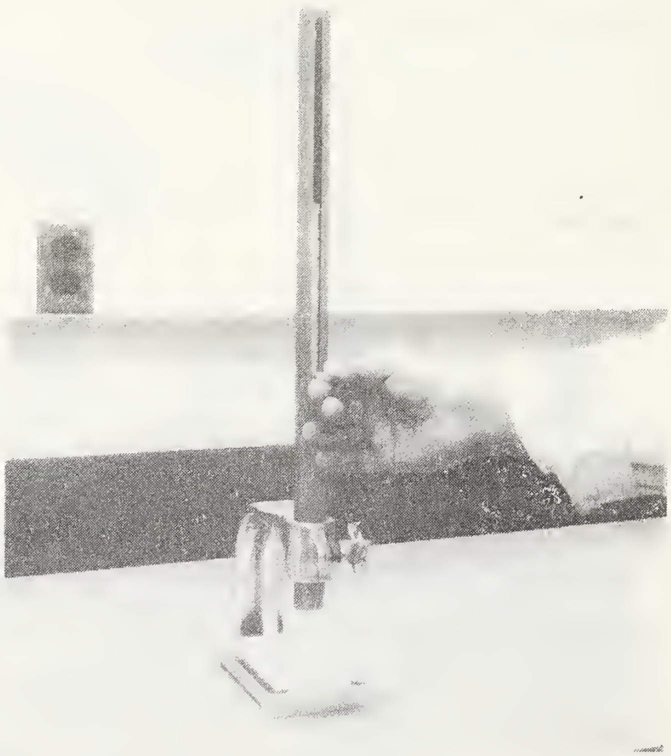

Figure 24. Impact resistance procedure - raising impactor cylinder

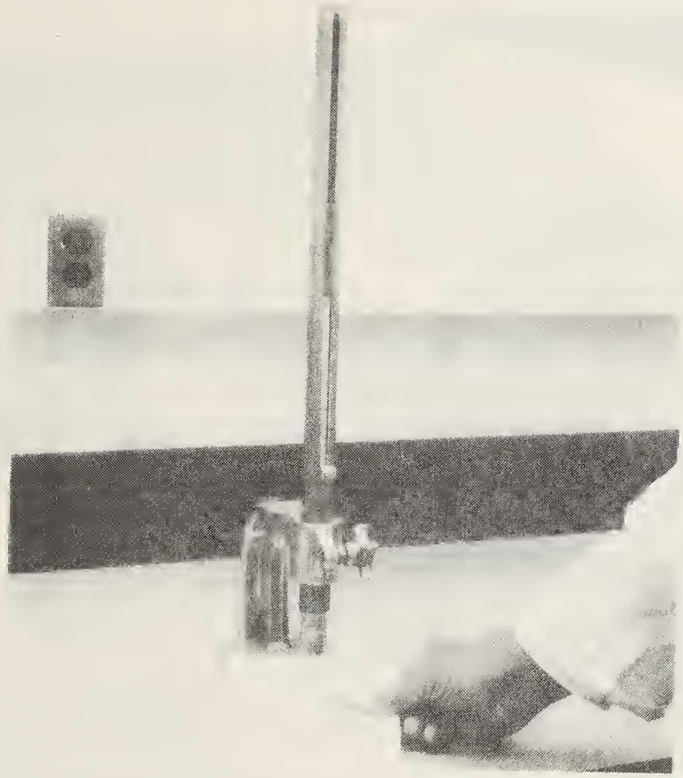

Figure 25. Impact resistance procedure - test panel after impact

Figure 26. Stain resistance test procedure - chambers with rubber seals

Figure 27. Stain resistance test procedure - chambers inserted in upper section of holder

Figure 28. Stain resistance test procedure - upper holder prior to clamping

Figure 29. Stain resistance test procedure - application of liquid stain

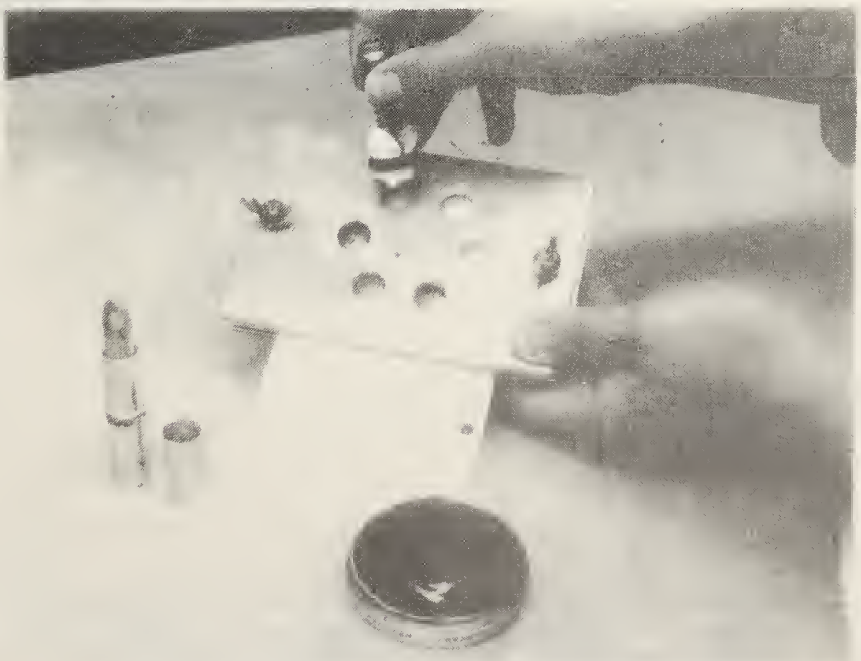

Figure 30. Stain resistance test procedure - application of solid stain

Figure 31. Stain resistance test procedure - test complete, removal of rubber seals

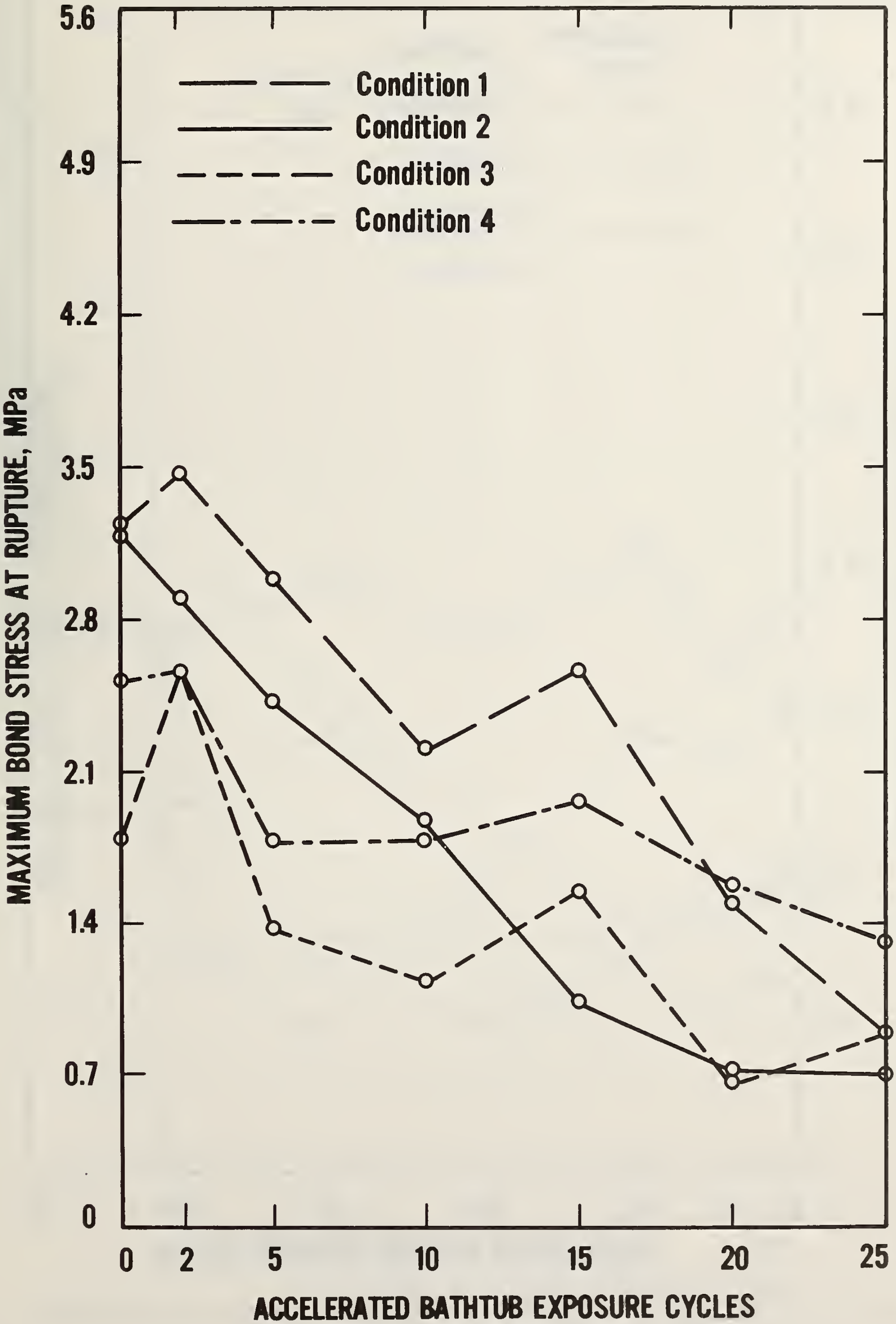

Figure 32. Average stress at rupture for various accelerated bathtub exposure cycles (Restoration Coating 1)

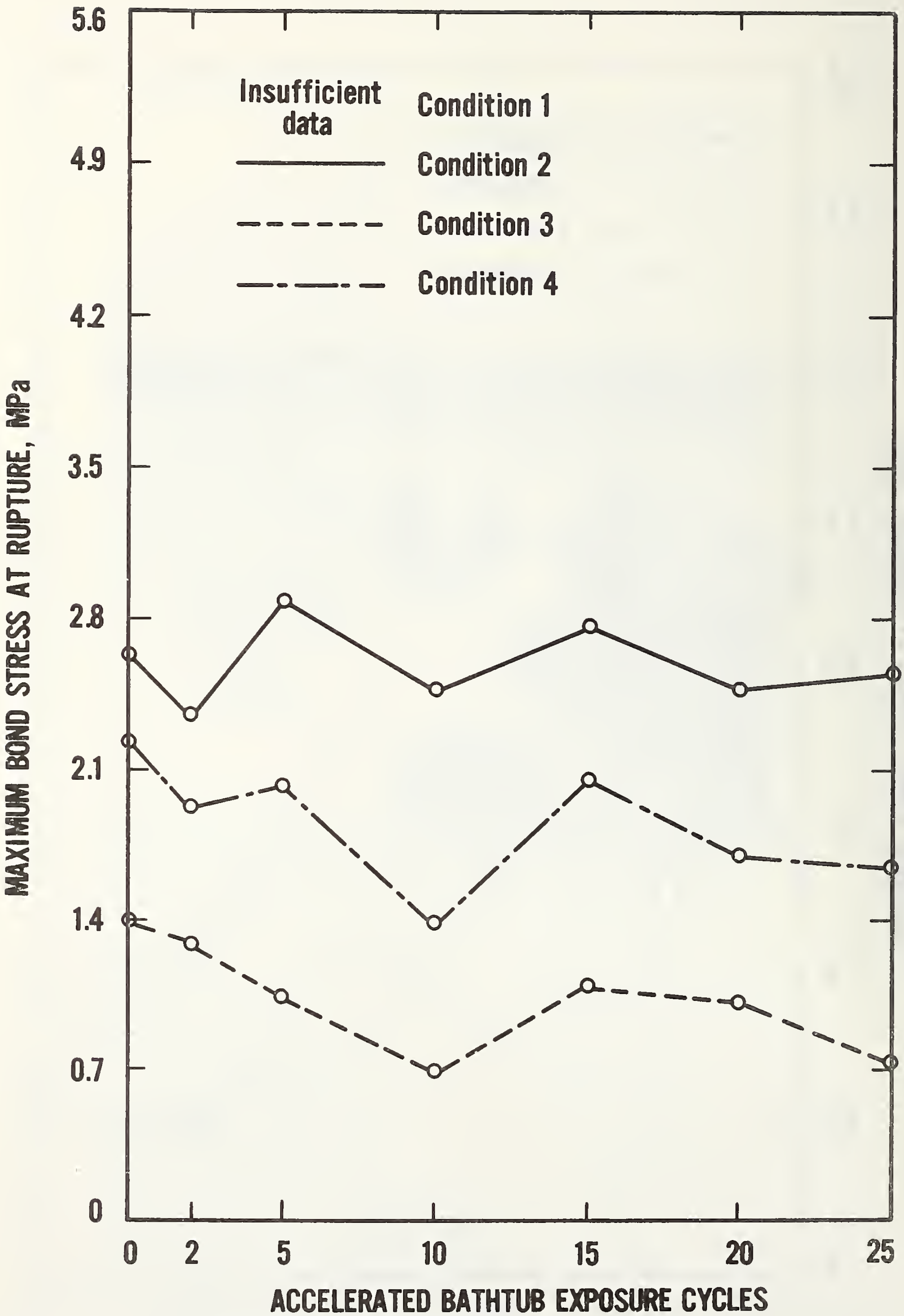

Figure 33. Average stress at rupture for various accelerated bathtub exposure cycles (Restoration Coating 2)

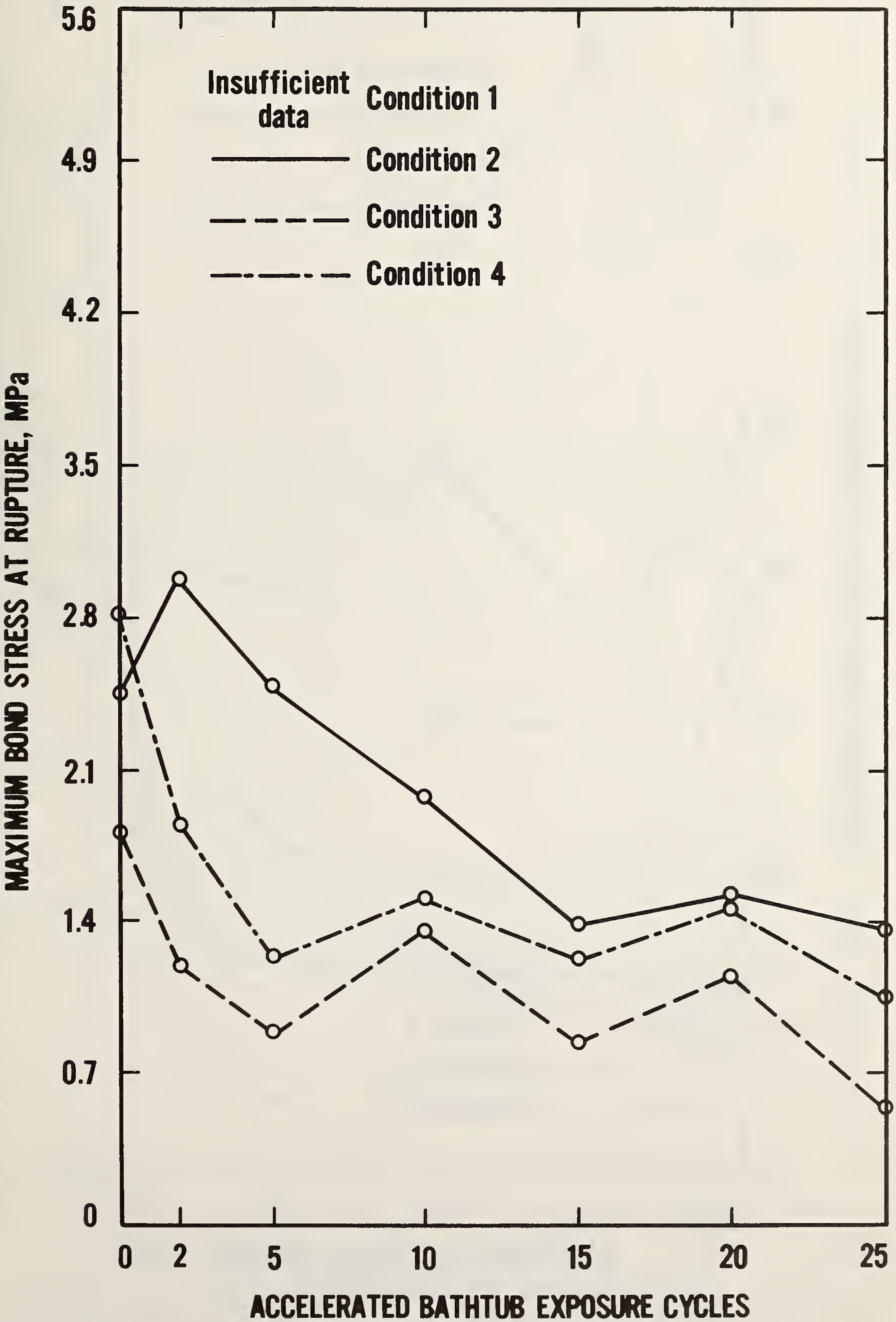

Figure 34. Average stress at rupture for various accelerated bathtub exposure cycles (Restoration Coating 3)

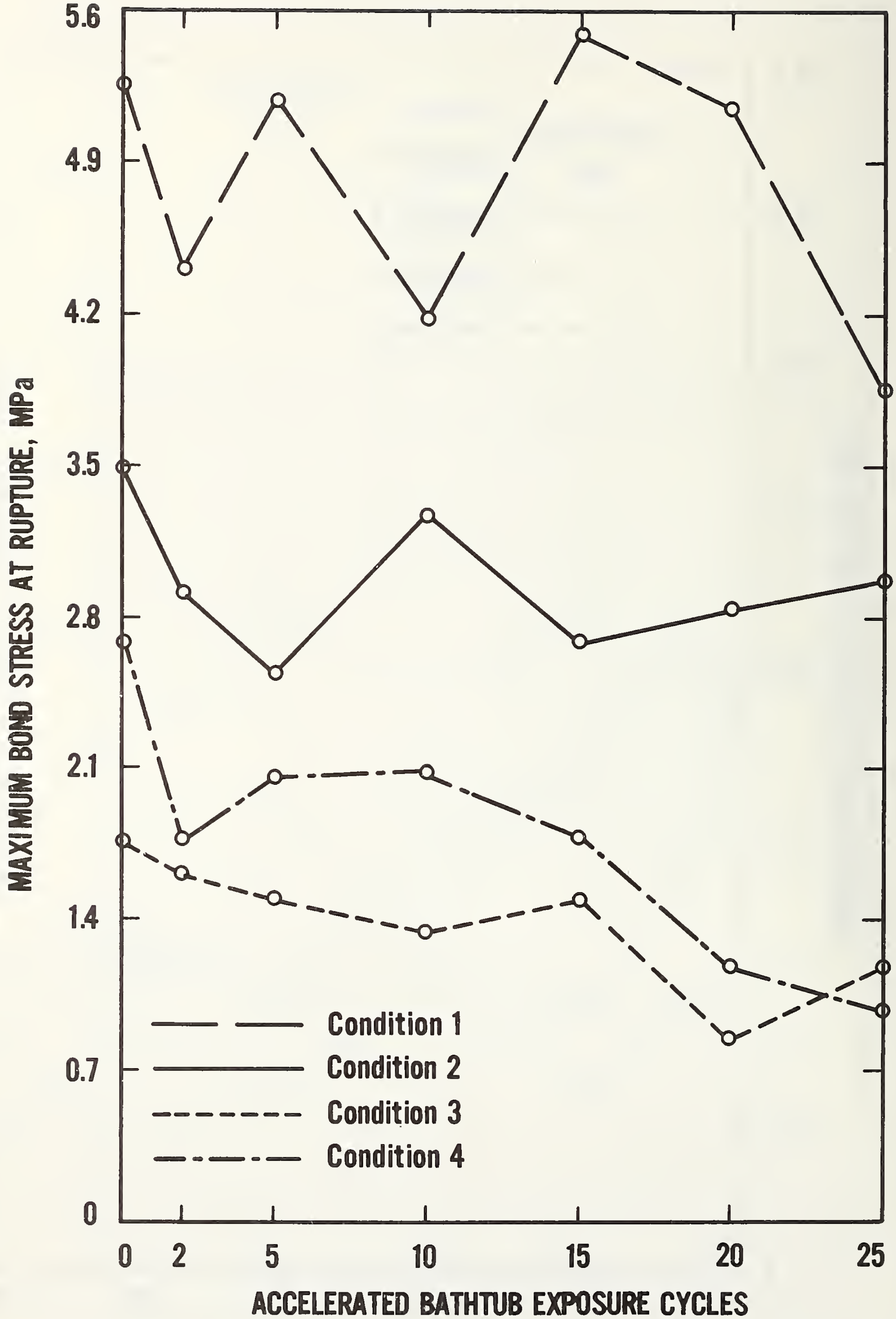

Figure 35. Average stress at rupture for various accelerated bathtub exposure cycles (Restoration Coating 4)

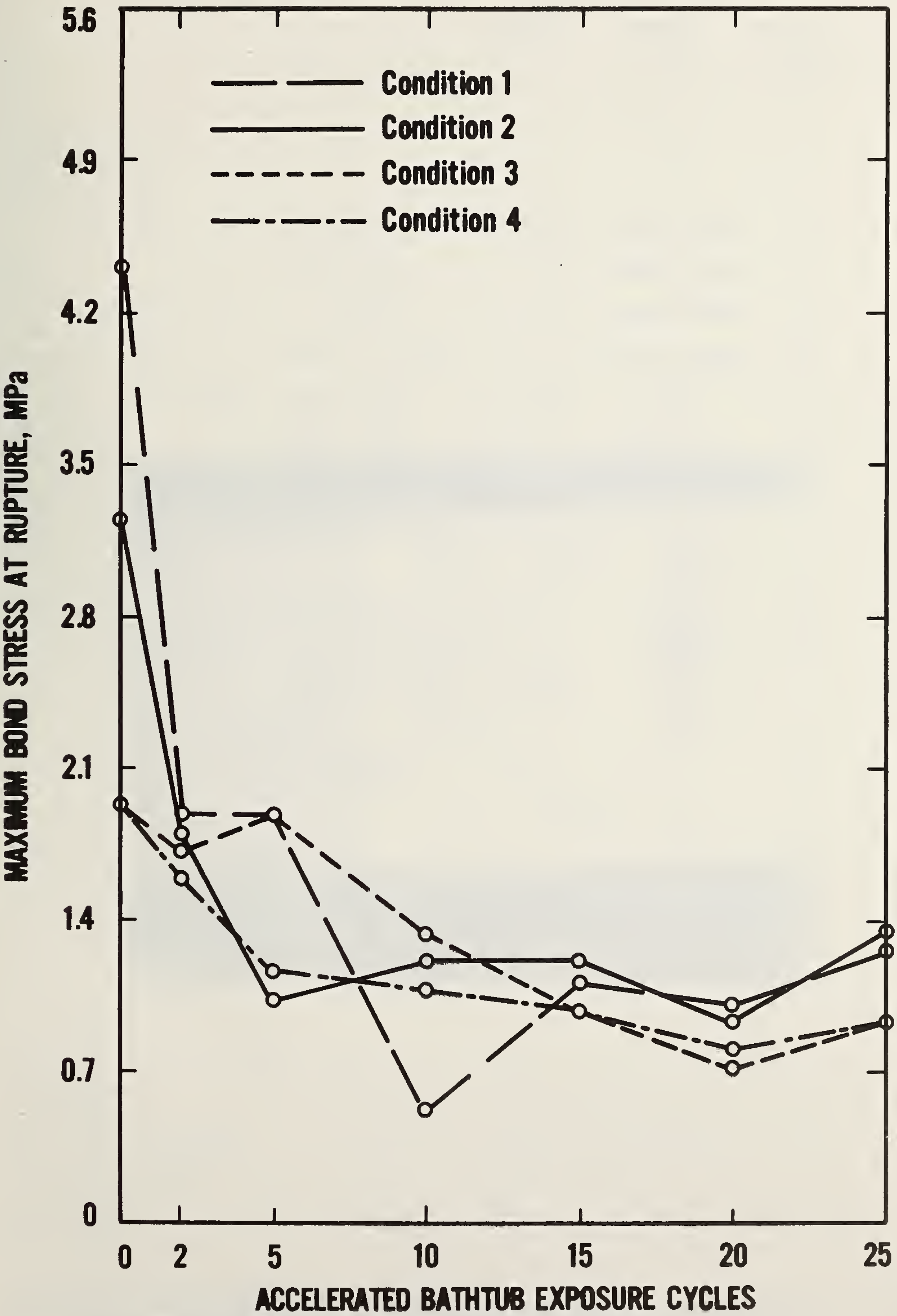

Figure 36. Average stress at rupture for various accelerated bathtub exposure cycles (Restoration Coating 5)

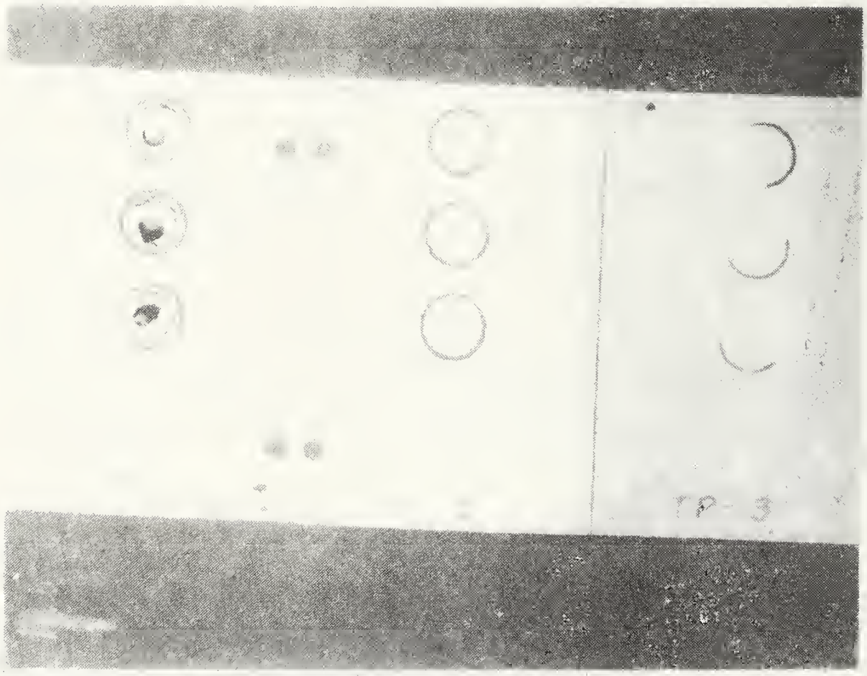

Figure 37. Restoration coating 5 after adhesion tests; left panel unexposed, center panel after two ABECs; right panel after three ABECs

Appendix A. Commercially Available Restoration Coatings[1/]

Company Name	Types of Repairs	Surface Preparation	Generic Finishes	Cost of Refinishing[3/] ($)
Nu-Glaze	--	--	--	--
Perma-Patch Inc.	--	--	--	--
Lik-Nu Porcelain Inc.	--	--	--	--
Dyna-Glaze Co.	--	--	--	--
Authorized SPR Tub Reglazing	Tubs, Commodes, sinks	A.S.S.[2/]	Polyurethane	225
Porcelite Enterprises, Inc.	Tubs, sinks	A.S.S.	Polyurethane	--
City Porcelain Refinishing Co. Inc.	Tubs only	A.S.S.	Polyurethane	175
Porcelain Repair Company, Inc.	Tubs, some sinks	A.S.S.	Epoxy urethane	200
New Life Electro Glaze Process	Tubs, sinks	A.S.S.	Ester	175
Regal House (Bathmasters Intl.)	Tubs, sinks	A.S.S.	Phenolic	250
Uni-Tub Co.	--	--	--	--
ACME Porcelain Resurfacing Co.	--	--	--	--
JEVCO Co.	--	--	--	--
Thermo Bond, Inc.	--	--	--	--
New Gloss, Inc.	--	--	--	--
Dura Glaze Porcelain Refinishing Service	Tubs only	A.S.S.	Enamel	225
Perma-Brite of Northern Illinois, Inc.	Tubs, sinks, commodes outside	Acid, solvent	Epoxy	225
Ark Porcelain Refinishers	--	--	--	--
Lectro Glaze of Chicago	Tubs, sinks, commodes	A.S.S.	--	215
K.R.T. Porcelain Refinishing	Tubs	--	Epoxy	175
Active Porcelain Refinishing	--	--	--	--
Custom Coating	--	--	--	--
California Bathtub Refinishing	Tubs only	A.S.S.	Polyurethane	200
J.C. Blending Serv.	--	--	--	--
V.C.S. Vinyl Repair	--	--	--	--
Permaceram of South California	--	--	--	--
Valley Porcelain Refinishing	--	--	--	--
Seismore's Fiberglass	--	--	--	--
Cerma Glaze	--	--	--	--
ACME Perfect Patch Co.	--	--	--	--
RM Bathtub Refinishing	--	--	--	--
Bathtubs and Sinks Refinishing, Inc	--	--	--	--
Dokan Pierri	--	--	--	--
Kott Koatings	--	--	--	--
Gnu-Services Corp.	--	--	--	--

[1/] The information presented in this table was provided by the restoration companies.

[2/] A.S.S. = Acid, solvent, sand.

[3/] Cost of refinishing one bathtub

APPENDIX B. INTERIM PERFORMANCE CRITERIA FOR RESTORATION COATINGS FOR PORCELAIN ENAMEL SURFACES

B.1 INTRODUCTION

These interim performance criteria are based upon the results of laboratory tests conducted on five restoration coatings and on specimens of unrestored porcelain enamel test panels. The tests and criteria are intended to be used in evaluating the performance of restoration coatings and they may be more severe than in-service situations. The criteria selected were chosen to reflect performance characteristics which these materials 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 key to the development of performance criteria was exposure of the panels to accelerated bathtub exposure cycling (ABEC) which includes wet and dry cycling, elevated water temperatures and surface abrasion. 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 P.E.I. abrasion tester for 56 machine counts where the abrasive used is feldspar-containing cleanser (modified ASTM C 448 test) before repeating the cycle. Thus, one accelerated bathtub exposure cycle (ABEC) included 28 bath cycles and one abrasion cycle.

B.2 PERFORMANCE CRITERIA

B.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 shall be 75 or greater as described in ASTM D 523. 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 bathtub exposure cycling, the restoration coatings should retain both color and gloss.

B.2.2 Adhesion

Requirement

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

Criterion

The restoration coating shall have a stress at rupture value of at least 3.1 MPa (450 psi) before exposure, and of 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 section 4.2.2 of this report.

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.

B.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 restoration coating shall have an impact resistance of at least 0.53 Nm (4.7 in pounds) after exposure to 25 ABECs, when using a modified ASTM D 2794 procedure with a one pound 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 had impact resistance values higher than that of the unrestored porcelain because they were elastomeric.

B.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.

B.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.

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 82-2553	2. Performing Organ. Report No.	3. Publication Date July 1982

4. TITLE AND SUBTITLE

Development of Interim Performance Criteria for Restoration Coatings for Porcelain Enamel Surfaces

5. AUTHOR(S)

James F. Seiler and Paul G. Campbell

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

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Department of Housing and Urban Development
Washington, DC

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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)

A study was performed to develop interim performance criteria for restoration coatings for porcelain enamel surfaces. The laboratory study consisted of evaluating five restoration coatings which had been applied to porcelain enamel test panels with various surface conditions. Performance characteristics of the coatings examined included appearance, adhesion, impact resistance, stain resistance and fungal resistance. Existing test methods were used in the study if appropriate methods were available. However, the laboratory studies led to the development of a new cyclic exposure test and the use of a newly developed method for measuring adhesion. Adhesion of the coatings was the performance characteristic most sensitive to change with time of exposure to the newly developed cyclic exposure test. Interim performance criteria for restoration coatings for porcelain enamel surfaces were developed, based upon the results of the laboratory study.

Additional studies are being conducted to assess the performance and durability of selected restoration coatings applied to bath tubs in public housing units. Since the field studies are not yet completed, they are not addressed in this report.

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

Accelerated bathtub exposure cycle; performance criteria for restoration coatings; porcelain enamel restoration; restoration coatings

13. AVAILABILITY

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[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

56

15. Price

$9.00

USCOMM-DC 6043-P80