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IDEA *Innovations Deserving Exploratory Analysis Project*

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Report of Investigation

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STRATEGY FOR COATING STRUCTURAL STEEL WITHOUT STRINGENT BLASTING REQUIREMENTS

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS
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EXECUTIVE SUMMARY

The general goal of this project was to examine new technology, particularly penetrating primer sealers, glass microspheres and thermal spray plastic flamecoats. The project also investigated the application of this new technology to the painting of bridges coated with lead based alkyd paint. The project was broken into two phases:

- Phase 1 - Determine process reliability.
- Phase 2 - Explore performance of reliable systems in short term testing.

This project had four main objectives and several secondary objectives.

MAIN OBJECTIVES

Objective 1. To examine the use of zero VOC penetrating sealers to secure aged alkyd bridge coatings - (lead pigment containing);

Result: The accelerated laboratory tests indicated that the two penetrating primer sealers performed very well over the aged alkyd coatings. There was no evidence of any incompatibility between the sealer and either the substrate or the topcoats. Over the aged alkyd substrate, the systems using the penetrating primers and the epoxy mastic system performed best. These systems performed better than the alkyd control system, which performed better than the latex control system.

Objective 2. To examine performance of zero VOC thermal spray thermoplastic topcoats used over the penetrating sealer;

Result: Both thermal spray topcoats performed very well over the aged alkyd coatings when either penetrating primer was used. These thermal spray topcoats exhibited much better impact resistance than the liquid applied coatings.

Objective 3. To examine performance of low or zero VOC liquid applied coatings applied to the penetrating sealer;

Result: The project plan only allowed for testing of one zero VOC liquid applied topcoat and this particular topcoat performed well.

Objective 4. To examine the utility of a special glass microsphere additive to the penetrating sealer.

Result: Addition of the glass microspheres to the primer was not determined to be detrimental but the laboratory tests conducted in this project were unable to prove that the spheres were beneficial.

ADDITIONAL OBJECTIVES

Objective 5. To provide a method of utilizing high performance coating systems with minimal surface preparation;

Result: The thermal spray coatings and the zero VOC liquid applied coating all performed well over the aged alkyd substrate when the penetrating primers were used. These systems and the epoxy mastic system were better over the aged alkyd than the alkyd control system, which was better than the latex control system.

Objective 6. To eliminate the need for costly surface preparation;

Result: The performance of the thermal spray coatings was not dependent on the use of spheres in the primer. Thus, the envisioned task of breaking the spheres by sweep blasting or other labor intensive method is not really necessary. This further simplifies the use of these high performance systems.

Objective 7. To provide a system capable of surviving freeze/thaw cycles.

Result: Thermal spray coatings have a tendency to disbond when subjected to freeze/ thaw. The two thermal spray topcoats tested in this project showed no signs of disbonding or other catastrophic failure when used in conjunction with the penetrating primers.

Further testing is necessary to determine the effectiveness of the glass microsphere additive. Outdoor exposure tests or other field exposures would be the next step in determining the viability of these innovative systems.

STRATEGY FOR COATING STEEL WITHOUT STRINGENT BLASTING REGULATIONS

NCHRP-IDEA Project 93-1D007

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INTRODUCTION

Thorough blast cleaning is generally required when applying protective coatings to structural steel by painting or thermal spraying. This is undesirable in terms of costs, environmental contamination, and coating quality control when existing steel has lead-based paint present. Where applicable, the technology envisioned in this project would drastically reduce surface preparation requirements and offer economical, long term protection by combining three recent innovations:

- Surface tolerant, high penetration primers;
- Interlocking of primer and topcoat by embedding hollow glass fly-ash microspheres in the primer, which are then fractured to key-in the topcoat; and
- Use of advanced thermal spray and liquid applied zero volatile organic content (VOC) polymers to provide the primary environmental barrier.

This strategy would effectively deal with the critical environmental problem of blast residues contaminated with old lead paint. It would involve no volatile organic compounds and would make use of recycled materials.

OBJECTIVE AND APPROACH

This project had four main objectives:

1. To examine the use of zero VOC penetrating sealers to secure aged alkyd bridge coatings - (lead pigment containing);
2. To examine performance of zero VOC thermal spray thermoplastic topcoats used over the penetrating sealer;
3. To examine performance of low or zero VOC liquid applied coatings applied to the penetrating sealer; and
4. To examine the utility of a special glass microsphere additive to the penetrating sealer.

A reasonable approach to attacking the problem was to break the research into two phases:

- Phase 1 - Determine process reliability.
- Phase 2 - Explore performance of reliable systems in short term testing.

PHASE 1, DETERMINE PROCESS RELIABILITY

DETERMINE SPHERE LOADINGS FOR THE PENETRATING SEALERS

The first goal was to find the optimum loading level for glass spheres used for promoting adhesion in the penetrating sealer-primer material.

Three manufacturers were requested to submit samples of penetrating sealers previously specified for use on surfaces with mixed rust/aged coatings. The three materials requested were: a) a 98% solids, thin film epoxy sealer; b) a 100% solids, thin film epoxy; and c) a new 100% solids urethane material. This urethane was not received from the supplier who cited concerns that the technology was not yet commercially available. In addition to these materials, SSPC also provided existing samples of high solids direct to rust epoxy primers and a moisture curing urethane for evaluation in the sphere loading tests.

The primers were shipped to Copperlok, Inc. where tests were run to determine the best sphere loading factors with each product. The following parameters were assessed:

- Optimum sphere size;
- Optimum sphere loading, percent of liquid primer by volume/weight; and
- Optimum primer application characteristics.

The following criteria were used to assess the effects of different sphere loading and size combinations:

- Visual film integrity;
- Ability to withstand cracking of the spheres to create a keying surface; and
- Adhesion to the aged alkyd surface.

Three levels of filler were tested with the 100% solids epoxy penetrating primers, they were:

- 4:2 Epoxy:Filler
- 4:3 Epoxy:Filler
- 4:4 Epoxy:Filler

The optimum filler loading was 4:4 or 50% by volume. At this level the penetrating primer met the following criteria:

- Provided a dense tightly packed loading of spheres - see attached micrographs
- Withstood typical secondary surface preparation to create a keyed surface - without removing penetrating primer - see attached micrographs.

Similar results were obtained if a loading level of 4:5 Epoxy:Filler was used. Adhesion to the surface was also determined to be quite acceptable - see Table 1. As a consequence it was decided to run all future penetrating primer applications using a minimum loading of 4:4 Epoxy:Filler. Appendix 1 shows photomicrographs of three sealers with spheres before and after sweep blasting.

DETERMINE FILM CHARACTERISTICS - THICKNESS - HOMOGENEITY - ADHESION

Having determined optimum sphere loading for the penetrating primer, the next step involved examining the integrity of zero VOC liquid and thermal spray coatings applied to these surfaces. The factors used in the experimental design of Phase 1 are summarized in Table 1.

For the purpose of this phase of the experimental work, several distinct types of sample were made. All samples used one of the penetrating primer candidates. The primary divisions among types of samples are given below:

- Samples prepared on aged coated surfaces.
- Samples prepared on abrasive blast cleaned steel.

Each of these sets of samples was further subdivided to reflect the following factors:

- Secondary surface preparation (e.g. sweep blasting);
- No secondary surface preparation (liquid coated samples only).

Finally, for the thermal spray polymer coated samples, a subdivision was made between samples with a "clear" thermal spray coating and samples with pigmented thermal spray co-polymers.

The prepared samples were examined to assess film integrity, film thickness and adhesion.

Film integrity was examined by use of both photomicrographic and holiday detection equipment.

The photomicrographs and discussion of film integrity are included in Appendix 2. Certain voids were noted in the films of the thermal spray copolymer. As discussed below these did not affect the physical performance of the applied penetrating primer or either type of topcoat.

A simple "Bird Dog" holiday detector was used to assess film integrity and homogeneity. In no instance was a set of voids penetrating to the metal surface observed with any of the prepared samples matching the matrix in Table 1. This indicates that the suggested method of film preparation is entirely suitable for creating highly uniform films, free of obvious defects. Table 2 shows the results of holiday detection conducted on a second set of panels. These include panels only with a sphere loaded penetrating primer placed on bare steel. In this instance, all samples with only the primer/sealer "failed" the holiday detection test. This is not surprising as the penetrating sealer forms a very thin film. The surprise was that 50% of the plastic flame sprayed panels using the TSC-3 topcoat also exhibited this failure. These panels came from an earlier production run at SUNY. We believe our later positive results verify our contention that the film system has sufficient homogeneity.

Film thickness was assessed only on abrasive blast cleaned samples. Samples placed on aged alkyd surfaces may give false readings of film thickness. This affects records for the thermal spray copolymer samples. All samples of this type were prepared in exactly the same manner as those placed on abrasive blast cleaned surfaces. Film thickness numbers are given in Table 1.

Adhesion was assessed using both ASTM D 4541 pull-off adhesion measurements and ASTM D 3325 X-cut adhesion by tape pull-off. Adhesion data are given in Table 1. No meaningful data was obtained from the ASTM D 3325 runs as no failures of any type occurred.

The ASTM D 4541 adhesion data was quite interesting yet difficult to interpret. An aluminum dolly is attached to the coated surface using epoxy glue. This is then pulled off using a portable instrom like machine. The pull-off value is read from a scale accurate within about 0.34 Mpa (50 psi). The absence of any strong trend is an

indicator that adhesion is not negatively affected by any of the process or system variables examined at this Phase. The most noticeable trend was in the type of failure observed. All of the samples to which a thermal spray copolymer coating was applied failed at the glue layer. In no instance did any failure of the thermal spray copolymer itself occur, nor at the alkyd layer for those samples placed over aged alkyd coatings. Curiously the actual failure values are lower than those typically observed with epoxy glued aluminum dollies. This implies that there was insufficient adhesion between the thermal spray copolymer topcoat and the aluminum dolly. This occurred despite all attempts to prepare the thermal copolymer surface by abrading the surface with fine emery paper before gluing on the dollies. Some of the readings in this set do approach the limiting value of the strength of the epoxy glue, specifically samples "F," "G," "H," and "O". An examination of the characteristics of these samples reveals no common thread between them. We attribute this result to a normal statistical distribution.

More revealing and informative were the results from the samples applied to simple steel surfaces, finished using liquid applied, zero VOC epoxy topcoats, designated TC-1 and TC-2. The majority of these samples do not show some failure points involving the primer. This would normally be taken as a warning sign; however, the pull-off value associated with each such failure is as high or higher than that found for failure in the topcoat alone. Furthermore, only three samples, all prepared using the penetrating sealer, PP-1, showed pull-off at the primer/metal interface.

Lastly, in relation to the use of spheres as an adhesion promoter, no significant diminution in adhesion was observed in our testing between samples without spheres in the penetrating primer layer and those with spheres present. Given the successful application of the adhesion promoting sphere concept in marine coating applications, we conclude it is too early to dismiss this part of the process as unneeded. Further evaluation of longer term performance using accelerated test methods is the preferred next step.

DETERMINE FILM COMPATIBILITY WITH AGED ALKYD COATINGS

As part of the work involving the use of thermal spray copolymer topcoats, samples were prepared in which the initial surface was an aged alkyd coating. As discussed above, no detrimental film integrity, no detrimental adhesion characteristics, nor any significant incompatibility between the thermal spray copolymers and aged alkyd coatings was observed in our results. We conclude that the process as examined in these tests is viable for application evaluation in accelerated short term testing.

DETERMINE PENETRATING PRIMER COMPATIBILITY WITH TOPCOATS

As part of the work involving the use of penetrating primer, samples were prepared to which either a thermal spray copolymer or a liquid applied zero VOC topcoat was applied. As discussed above, no detrimental film integrity, no detrimental adhesion characteristics, nor any significant incompatibility between these topcoats and the penetrating primer was observed in our results. We concluded that the process as examined in these tests was viable for application evaluation in accelerated short term testing.

PHASE 2, EXPLORE PERFORMANCE OF RELIABLE SYSTEMS IN SHORT TERM TESTING

PHASE 2 TEST PLAN

The test plan for Phase 2 is outlined in Table 3. Two penetrating sealers, two thermal sprayed topcoats, one liquid applied topcoat and three conventional controls were used. There were two surfaces, aged alkyd and blast cleaned. Penetrating primers were applied with and without spheres. All test panels were 4 x 12 x 1/4" and were prepared in triplicate. Because of financial and test cabinet constraints, the test plan is not a full factorial design.

Coating Systems

The particular coating systems used in Phase 2 are listed in Table 4. The two penetrating sealers used in Phase 1 were also used in Phase 2. The ratio of spheres to liquid paint was 1:1, by volume, as determined in Phase 1.

Two of the thermal spray coatings used in Phase 1 were also used in Phase 2. A zero VOC liquid applied topcoat was included in the test as a comparison with the thermal sprayed topcoats. This particular liquid topcoat was applied by brush in this phase of the project. However, with suitable equipment, this two component solvent free amine cured epoxy topcoat is able to be spray

applied.

Three conventional painting systems were included as controls: a two coat alkyd system; a three coat latex system; and a two coat epoxy mastic system.

Test Surfaces

Aged Alkyd (Containing Lead)

SSPC had a set of 10 cm x 30 cm (4 in x 12 in) aged alkyd panels that had been on exposure at Neville Island since 1977. Neville Island is an industrial area near Pittsburgh. The panels were coated with a red lead alkyd primer. The top half of each panel had been given another coat of lead-free alkyd. The overall condition of the panels was very similar. The tops had rust ratings from 4 to 6 and the bottoms rated from 7 to 9. Before assigning the panels to a particular paint system, the aged alkyd panels were laid out on the table and shuffled around so that no triplicate set was better or worse (on average) than any other set. Once this was accomplished, the panels were ordered within each set from best to worst. If, for example, the set consisted (in order) of: FVW, FVU1 and FVV, then FVW was the least rusted and FVY was the most rusted.

Blast Cleaned

As a control, 10 cm x 30 cm x 0.6 cm (4 in x 12 in x 1/4 in) steel panels were blast cleaned to SSPC-SP 5, White Metal Blast Cleaning, with a steel grit / steel shot mix. The profile was 38 µm (1.5 mils).

Exposure Environment

The test cycle consisted of one week in the cyclic salt fog alternating with one week in the UV-condensation cabinet. Each weekend, Friday afternoon until Monday morning, the panels were in a freezer. Some panels from each replicate set were started in the cyclic salt fog and some were started in the UV-condensation cabinet. The exception was that the latex control panels all started the exposure in the UV- condensation cabinet. From experience, SSPC has found that latex paints will more closely mimic atmospheric exposure if started in the UV-condensation part of the cycle.

The cyclic salt fog was set for one hour of spray at 30° C (86° F) and one hour of forced air drying at 40° C (104° F). The spray is 3.5% ammonium sulfate and 0.5% sodium chloride in deionized water.

The parameters of the UV-condensation cabinets were four hours of condensation at 40° C (104° F) and four hours of UV exposure at 60° C (140° F). The lamps were UVA-340.

EXECUTION OF TEST PLAN

Coatings were applied to the aged alkyd panels and to the blast cleaned panels according to the test plan (Table 3).

Several methods to break the spheres were tried:

- Low pressure sweep blasting was ideal, but this method was deemed the least desirable for this project since one goal is to eliminate the need for blasting. One panel from each set was sweep blasted, nonetheless, to tie in with the work done in Phase 1 of this project.
- A tool was made by wrapping galvanized hardware cloth on a block of wood. This broke the spheres but zinc was deposited on the surface.
- Scraping a blunt metal object (concrete edging tool) across the surface did not work well.
- Sand paper was an adequate method to break the spheres.
- A surform shaver proved to be the tool of choice. A similar Surform tool of much larger dimensions could be used on large jobs, but the shaver worked fine for these test panels. It was estimated that 70% of the surface spheres were broken this way. In contrast, sweep blasting breaks 98% of the spheres.

On each replicate set with spheres, the first and the third panel had the spheres broken with the Surform tool and the middle panel was sweep blasted.

Those panels that were to be painted with thermal spray coatings were shipped to SUNY for topcoating and then returned to SSPC for exposure.

Panels were put on test March 20, 1995. The test was completed on May 30, 1995, which is 1704 hours (10 weeks + 1 day).

Pull-off adhesion tests were performed on all panels after the exposure was completed.

RESULTS OF PHASE 2

CORROSION PROTECTION (RUST AND BLISTER)

Panels in the accelerated laboratory test were rated for rust and blister six times during the course of the exposure: 168, 336, 672, 1008, 1344 and 1704 hours. Rust ratings were made according to SSPC-Vis 2 (ASTM D 610) and blister ratings followed ASTM D 714. Raw exposure data are given in Table 5.

In order to facilitate statistical analysis by computer, all raw data were converted to a numerical scale from 1 to 10, with 10 being the best.

The SSPC-Vis 2 (ASTM D 610) "rust ratings" were sometimes judged by the inspector to be 10- or 9+. These ratings with plus or minus were converted to a decimal number such that 10- became 9.7, 9+ became 9.3, 9- became 8.7, etc.

The ASTM D 714 blister ratings were converted to a numerical scale from 0 to 10 according to the scheme of Table 6. If a panel consisted of a mixture of blister sizes, the numerical conversion was based on the largest size blisters.

Table 7 gives the rust and blister data after numerical conversion and smoothing. Data smoothing occurred in a very few instances where a rating had to be adjusted to make it consistent with prior and subsequent ratings. To sum the effects of rust and blister, an average panel rating was computed. This rating is the average of the converted rust and blister ratings.

The final rust and blister data, Table 8, were analyzed statistically on the computer. Final exposure data for the aged alkyd substrate are shown separately in Table 9. One way ANOVA was performed for each variable: primer, topcoat, panel type and sphere loading. Only trends with a level of statistical significance greater than 95% according to Fisher PLSD are considered.

Primers: The ranking of the primers according to combined rust/blister ratings is from best to worst: epoxy mastic control; PP-2 sealer; PP-1 sealer; alkyd control; latex control. The epoxy mastic had better rust ratings than the other four primers. The statistically significant differences among primers in combined rust/blister ratings are:

Epoxy mastic > PP-1, alkyd, latex
PP-2, PP-1 > alkyd, latex
Alkyd > latex

Topcoats: The ranking of the topcoats according to combined rust/blister ratings is from best to worst: epoxy mastic control; thermal spray TSC-1; thermal spray TSC-2; zero VOC topcoat TC; alkyd control; latex control. The statistically significant differences among topcoats in combined rust/blister ratings are:

epoxy mastic, TSC-1 > TC, alkyd, latex
TSC-2 > alkyd, latex
TC, alkyd > Latex

The three control systems, as a group, had more blistering than the systems using a sealer. The two thermal spray coatings had no blisters.

With and without spheres: This experiment did not detect differences in rust or blister, whether or not the sealers were loaded with spheres. Analysis of variance of various sets of data revealed no significant difference between primers with spheres and primers without spheres. The most complete single set of data was with the thermal spray topcoat TSC-1 applied on the aged alkyd substrate. The analysis of variance for this data set, shown in Table 10, also indicated that the spheres have no statistically significant effect.

Type of Surface: There were no statistically significant differences in rust or blister ratings between aged alkyd surfaces and blast cleaned surfaces.

ADHESION

Adhesion measurements were taken on some of the panels after three weeks of exposure. After removing the panels from the freezer and allowing them to reach room temperature, three dollies were glued to the second and the third panel from each replicate set. The exact ID's are listed on the pull-off data sheet, Table 11. On the aged alkyd panels, one dolly was glued to the top half of the panel and 2 dollies to the bottom half. The top half of the aged alkyd panels had an extra coat of aged alkyd paint. On the blast cleaned panels, all three dollies were glued to the bottom half as that kept the top half free of defects.

After allowing the glue to cure for 24 hours, the pulls were performed. Two of the three defects left by the dollies were touched up with appropriate coating material and allowed to cure overnight. The defect nearest the bottom of the panel was not repaired. This was to act as a scribe. Unfortunately, this "scribe" proved to be of little value since very few of the dollies pulled off much paint. The three-week pull-off data are recorded in Table 11. Because of the extensive failure at the glue/topcoat interface, the pull-off data are inconclusive.

At the conclusion of the cyclic exposure test (1704

hours), pull-off adhesion tests were performed on all panels. As with the three week pull-off tests, the predominant mode of failure was at the glue/topcoat interface even though a different brand of epoxy glue was used. Several more pulls were done on selected panels using cyanoacrylate adhesive instead of epoxy. Pull-off data are given in Table 12. As with the three week data, glue failure predominated, especially on the thermal spray coatings. Table 13 gives final pull-off adhesion data for the aged alkyd substrate. Considering also the wide spread in the absolute pull-off numbers, no meaningful conclusions could be reached.

Krepski tried attaching the pull-off dollies with a low melting indium-bismuth solder. The modest heat from the molten alloy appeared to promote bonding to the thermoplastic without introducing damage to the topcoat or underlying layers. However, adhesion to the aluminum dolly was poor.

IMPACT-THRESHOLD TESTS

Another aspect of mechanical evaluation of tested panels has been an assessment of resistance to impact. The fragile nature of the aged alkyd primer is likely a dominant factor in controlling durability of overcoating approaches. Ability to absorb impact energy without spalling or cracking is a good indication of paint system integrity.

The test system employed is a modification of the impact test described in ASTM A 153, Specification for Zinc Coating (Hot Dip) on Iron and Steel Hardware, which is used to assess the adhesion of hot dipped galvanized coatings. The galvanized coating has brittle intermetallic layers between the steel and the zinc, so it resembles closely the situation of overcoating aged alkyd paint. The test apparatus is set up so that a falling weight impacts a 2.54 cm (1 in) chisel placed in contact with the coating surface. Impact energy is increased at 0.565 J (5 in-lb) increments to the system maximum of 7.91 J (70 in-lb). "Impact Threshold" is the lowest value at which noticeable flaking, buckling, and/or exposure of the underlying layers occurs. Table 14 summarizes impact test results for a group of panels representing all the coating types in the test program.

The thermal spray topcoats all performed remarkably well in the test, with no failures noted up to the 7.91 J (70 in-lb) test system limit. All the controls performed poorly, as did the liquid applied topcoat used in conjunction with the penetrating primers. The brittle flaked topcoats invariably had red primer on the underside of the flake, with primer also exposed on the panel. Thus, failure was within the aged alkyd layer. If the chisel impact does not penetrate through to the primer, it will not introduce as severe a shear stress in the primer. The chisel is perhaps not the best impact tool to use for this evaluation. The test machine can be easily adapted for a ball peen tool or a flat ended cylinder. Possibly, this kind of impact could be combined with a tensile pull-off or peel to give a more meaningful comparison of coating system integrity.

Some of the panels tested had exceedingly thick topcoats, over 750 μm (30 mils). This would obviously influence response to the impact test. Thicker coatings absorb more of the impact energy and prevent penetration of the stress field to the fragile underlying interfaces.

To gain further insight into the mechanical response of the thermal sprayed polymers, some of the panels were retested after carefully grinding away the thermal sprayed topcoat until the total coating thickness was comparable to that of the painted panels. First a 5 x 7.6 cm (2 x 3 in) section was cut from the top half of the panel using a low speed band saw. The polymer surface was then ground to 380 - 460 μm (15 - 18 mils) total coating thickness (old + new) using wet 60 and 240 grit silicon carbide papers. These samples were then subjected to the same impact test previously described. Results are given in the bottom section of Table 14.

Even after thinning the polymer topcoat, all these panels still had impact resistance superior to that of all the previously tested painted panels whose maximum threshold was 3.4 Joules (30 in-lb). The failure for the panel FVX1 occurred by fracture at the brittle old alkyd primer and tearing of the plastic topcoat. The inferior performance of this panel compared to the other polymer samples may relate to the thicker primer layer associated with penetrating primer, PP-2, and sweep blasting. The actual polymer topcoat thickness was likely thinner for this panel, decreasing its ability to absorb thick impact without damage.

Impact threshold was defined by visible flaking or rupture of the coating. Even though panels FWB1, FWD and FVZ did not show this damage, a "crackling" sound was noted when samples were pressed at the site of impact. This indicates that there was some fracturing of the underlying aged alkyd. The advantage of the polymer topcoat is that its high plasticity, even after environmental exposure, prevents flaking or spalling due to the impact.

Both of the thermal spray polymers appeared to retain their plasticity after ten weeks of the exposure cycle, whereas all the liquid applied topcoats (i.e. paints) appear to be fairly brittle after exposure.

The highly plastic behavior of these thermal spray topcoats is a distinct advantage in protecting the fragile aged alkyd underlayer from damage due to impact,

vibration and thermal stress. If the environmental barrier of the topcoat is breached, the polymer topcoat will act to retain flakes of the lead-containing primer such that they are not introduced into the environment.

CONCLUSIONS

This project had four main objectives and several secondary objectives.

Main Objectives

Objective 1. To examine the use of zero VOC penetrating sealers to secure aged alkyd bridge coatings - (lead pigment containing);

Result: The accelerated laboratory tests indicated that the two penetrating primer sealers performed very well over the aged alkyd coatings. There was no evidence of any incompatibility between the sealer and either the substrate or the topcoats. Over the aged alkyd substrate, the systems using the penetrating primers and the epoxy mastic system performed best. These systems performed better than the alkyd control system, which performed better than the latex control system.

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Result: Both thermal spray topcoats performed very well over the aged alkyd coatings when either penetrating primer was used. These thermal spray topcoats exhibited much better impact resistance than the liquid applied coatings.

Objective 3. To examine performance of low or zero VOC liquid applied coatings applied to the penetrating sealer;

Result: The project plan only allowed for testing of one zero VOC liquid applied topcoat and this particular topcoat performed well.

Objective 4. To examine the utility of a special glass microsphere additive to the penetrating sealer.

Result: Addition of the glass microspheres to the primer was not determined to be detrimental but the laboratory tests conducted in this project were unable to prove that the spheres were beneficial.

Additional Objectives

Objective 5. To provide a method of utilizing high performance coating systems with minimal surface preparation;

Result: The thermal spray coatings and the zero VOC liquid applied coating all performed well over the aged alkyd substrate when the penetrating primers were used. These systems and the epoxy mastic system were better over the aged alkyd than the alkyd control system, which was better than the latex control system.

Objective 6. To eliminate the need for costly surface preparation;

Result: The performance of the thermal spray coatings was not dependent on the use of spheres in the primer. Thus, the envisioned task of breaking the spheres by sweep blasting or other labor intensive method is not really necessary. This further simplifies the use of these high performance systems.

Objective 7. To provide a system capable of surviving freeze/thaw cycles.

Result: Thermal spray coatings have a tendency to disbond when subjected to freeze/ thaw. The two thermal spray topcoats tested in this project showed no signs of disbonding or other catastrophic failure when used in conjunction with the penetrating primers.

Based on the laboratory tests performed in this project, thermal spray coating systems employing a zero VOC penetrating sealer loaded with glass microspheres are a viable option for overcoating aged alkyd paint. The addition of glass microspheres to the penetrating primer had no measurable adverse effect on the performance of the thermal spray coating systems. Microscopic examination of the imbedded broken spheres indicates the potential for enhanced adhesion between the primer and the thermal spray topcoat. The liquid applied zero VOC topcoat with penetrating primer is also a viable option for overcoating aged alkyd systems. The epoxy mastic control system performed as well as or better than any of the other systems tested in this accelerated laboratory exposure.

The effectiveness of the glass microspheres could not be established from the laboratory test data.

RECOMMENDATIONS AND FUTURE WORK

Results of these laboratory tests have been encouraging

enough to warrant a more comprehensive field exposure study.

Improved laboratory test methods may become useful in screening thermal spray coating systems. A search for a better adhesive to attach the pull-off dollies to the thermal spray topcoats would enhance the value of the adhesion tests. The impact test could be modified to give more meaningful results. The panels could be scribed in future exposure tests to test resistance to undercutting if the coating is damaged.

Both penetrating primers used in this study were epoxy. Urethane penetrating primers are just coming on the market and should warrant examination.

ACKNOWLEDGMENTS

SSPC is grateful for the cooperation of those who have contributed to this project. Mr. Richard P. Krepski of Intermet Technology has performed microscopy on many samples, has conducted impact tests, and has overseen the application of the thermal spray coatings. Sections of the text were taken from Mr. Krepski's reports to SSPC. Dr. Christopher C. Berndt of the State University of New York at Stony Brook provided equipment, materials, and man power for the application of the thermal spray coatings. Mr. Al Bosna of Copperlok determined the optimal sphere loading for the primers. Mr. J. Henry Lauer, the SSPC lab technician, applied the liquid coatings and conducted other laboratory tests.

APPENDIX 1

This collection of photomicrographs compares sealers with spheres before and after sweep blasting.

Captions for the photographs of Appendix 1 which have been scanned electronically are:

FIGURE 1A Transition between as-applied (left) and sweep blasted (right) for penetrating primer, PP-1, on a Q-Test panel, with 50% loading by volume of microspheres. Magnification 40x.

FIGURE 1B As-applied. Magnification 100x.

FIGURE 1C Sweep blasted. Magnification 100x.

FIGURE 2A Penetrating primer, PP-2, as-applied on a Q-Test panel. Loading is 4 : 5 primer to spheres by volume. Magnification 40x.

FIGURE 2B Penetrating primer, PP-2, after sweep blasting. Loading is 4 : 5 primer to spheres by volume. Magnification 40x.

FIGURE 3A Urethane primer as-applied on a Q-Test panel. Loading of microspheres is 50% by volume. Magnification 40x.

FIGURE 3B Urethane primer after sweep blasting. Loading of microspheres is 50% by volume. Magnification 40x.

FIGURE 1A Transition between as-applied (left) and sweep blasted (right) for penetrating primer, PP-1, on a Q-Test panel, with 50% loading by volume of microspheres. Magnification 40x.

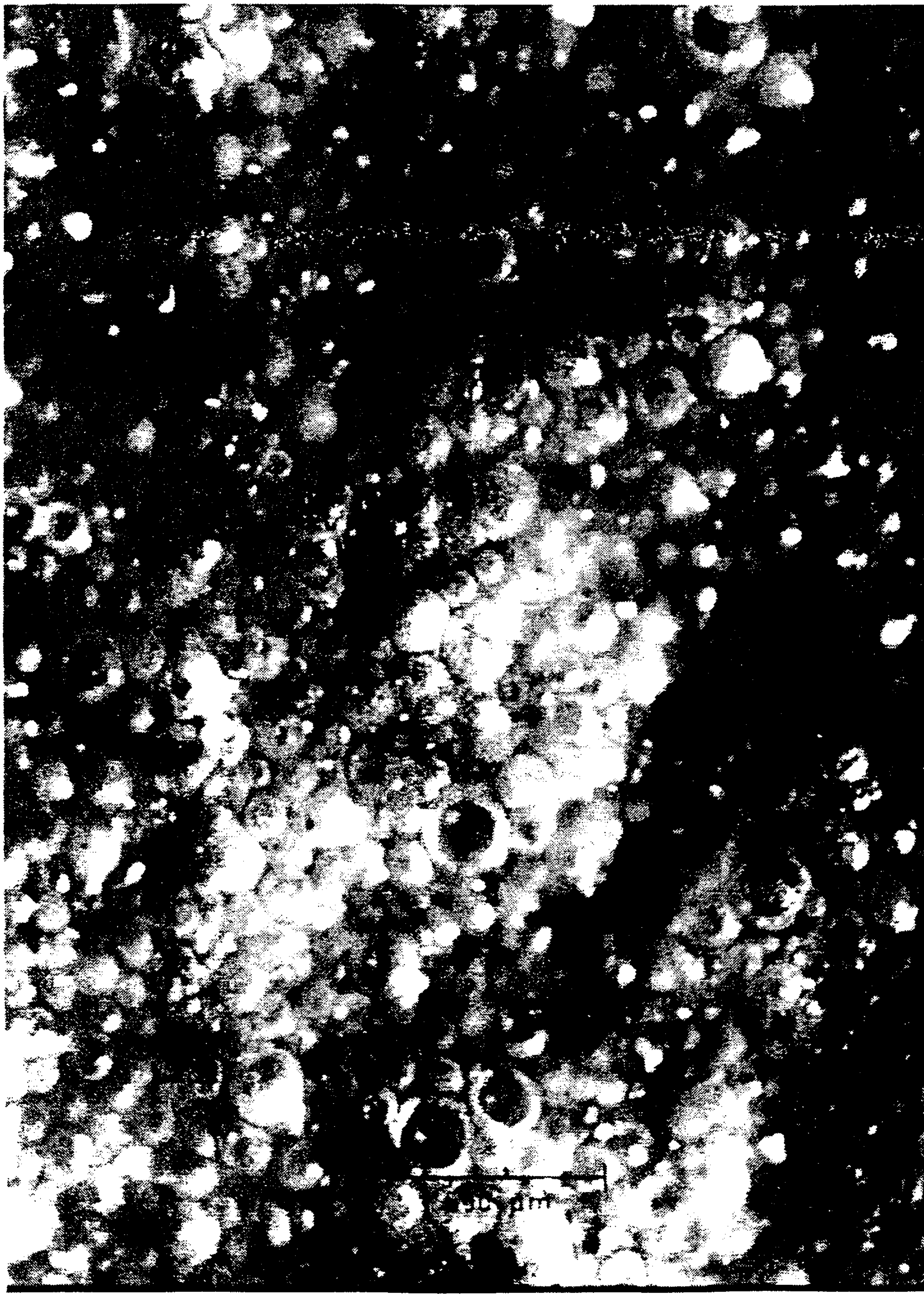


FIGURE 1B As-applied. Magnification 100x.

FIGURE 1C Sweep blasted. Magnification 100x.

FIGURE 2A Penetrating primer, PP-2, as-applied on a Q-Test panel. Loading is 4 : 5 primer to spheres by volume. Magnification 40x.

FIGURE 2B Penetrating primer, PP-2, after sweep blasting. Loading is 4 : 5 primer to spheres by volume. Magnification 40x.

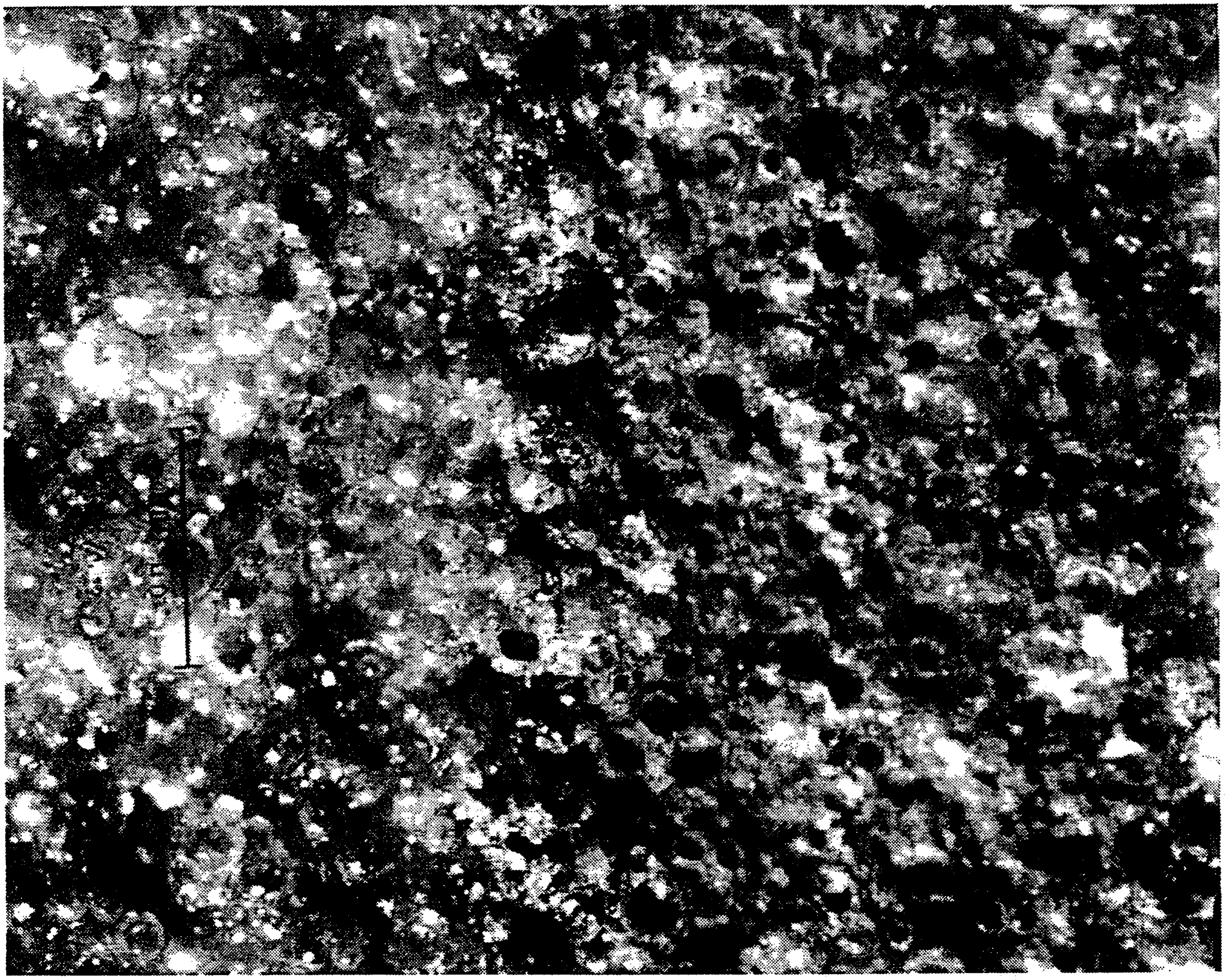


FIGURE 3A Urethane primer as-applied on a Q-Test panel. Loading of microspheres is 50% by volume. Magnification 40x.

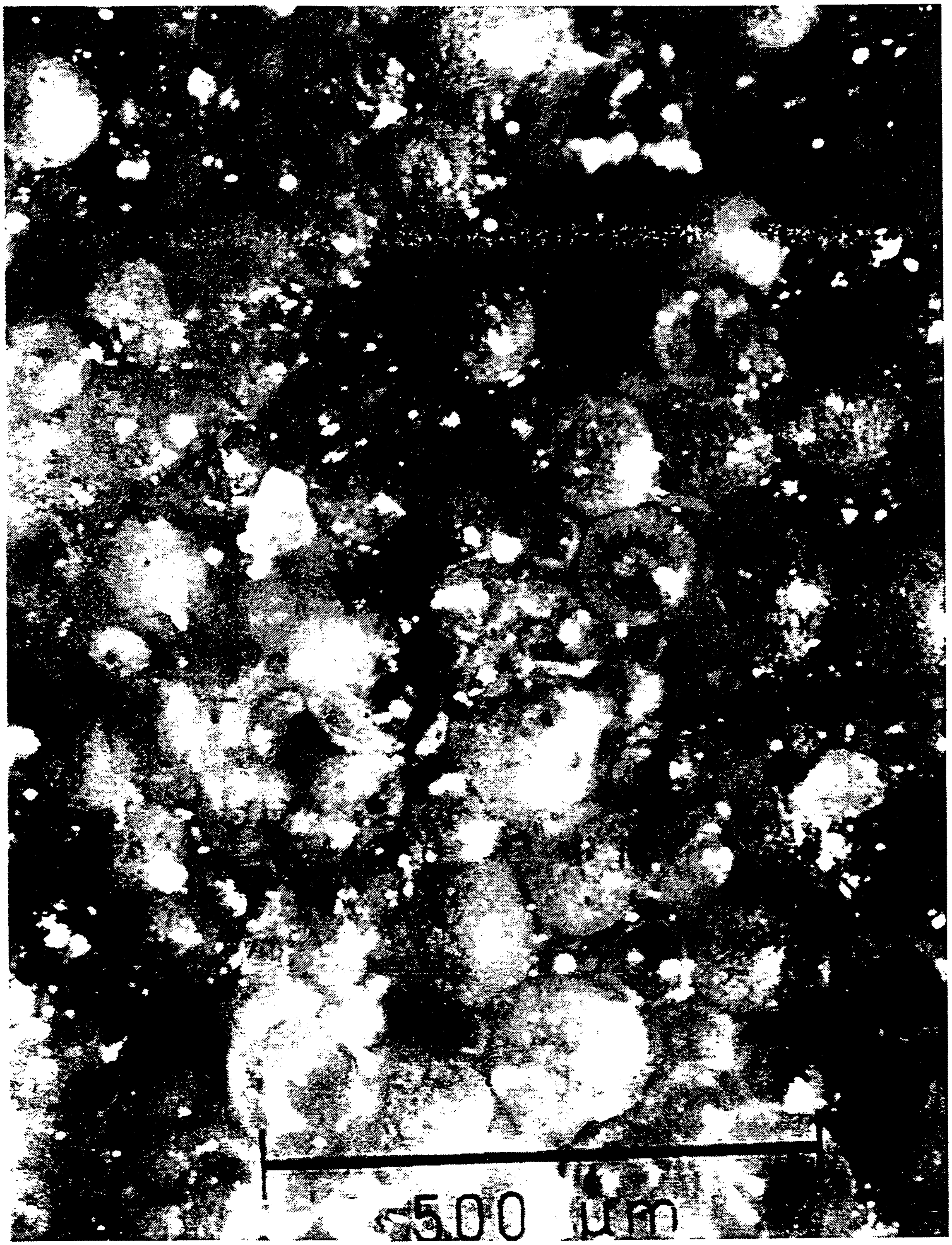
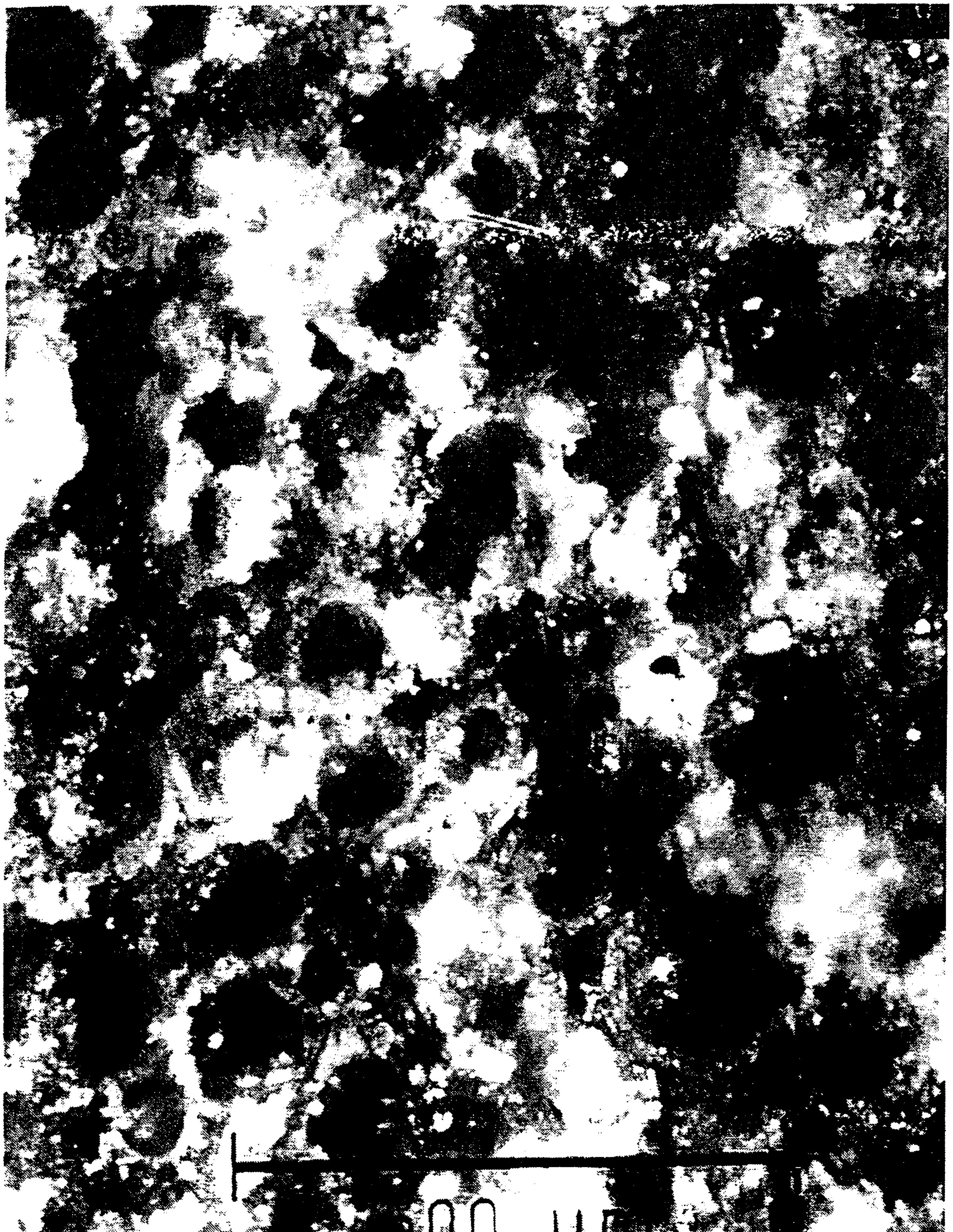


FIGURE 3B Urethane primer after sweep blasting. Loading of microspheres is 50% by volume. Magnification 40x.



APPENDIX 2 FILM INTEGRITY AND CROSS SECTION MICROGRAPHS

As part of Phase 1 of this project, microscopic examination was done on thermal sprayed systems. Sections cut from coated steel plates were mounted in Streuer's Epofix cold mount epoxy to avoid any heating problems. Mounts were coarse ground with 60 grit silicon carbide, SiC, paper to remove effects of the saw cut and then ground and polished using the grit sequence: 120, 320, 500, 800, 1000, 1200, 2400, 4000 SiC, 3 μ diamond, 1 μ diamond, 0.05 μ alumina. Samples were inspected using a Zeiss Axiomet metallograph. Selected micrographs are shown in Figures 4 to 10.

The microscopic inspection by R. Krepski yielded the following conclusions and recommendations:

1. The primer, PP-2, loaded with microspheres gave a thicker, more uniform priming layer, 100 μm (4 mils) than the primer, PP-1, 50 μm (2 mils).
2. All combinations of primers and thermal spray topcoats gave some indication of penetration of the sprayed polymer into the hollows of the broken spheres embedded in the primer. Inspection of partially peeled topcoats showed "necking" of the polymer at sites of the anchoring spheres, providing some verification of this enhanced performance. See Figure 8.
3. All thermal spray polymers showed entrapped gas bubble porosity. For the TSC-1 (Nucryl) feedstock, the bubbles appear to be air trapped during the spraying process, which coalesced into larger bubbles while the coating was still molten. Some of this air may gave been released from the broken spheres, although samples without spheres also showed trapped bubbles. For TSC-1, the bubbles were for the most part released from the primer/topcoat interface and were completely surrounded by the thermal spray coating. See Figure 9.

The TSC-3 (Surlyn) topcoats showed much larger pores, which were often attached to the primer/topcoat interface. See Figure 10. It appears that much of the trapped gas was generated by decomposition of the primer. This is consistent with the fact that coating with this thermal spray topcoat involves higher temperature, both in the spraying and the post-spray fusing of the topcoat. TSC-3 requires temperatures in excess of 150° C (300° F) while TSC-1 only requires temperatures of 120° C (250° F).

4. Such porosity has not been noted in metallic coatings sprayed by the Copperlok process since the coating solidifies rapidly and has "intersplat" porosity to release trapped air. The porosity present in the TSC-1 coating should not be a major problem in terms of adhesion or long term corrosion performance. There could be some difficulties in overhead spraying, where the bubbles might tend to accumulate at the interface with the primer.

On the other hand, the porosity in the TSC-3 coating is a major concern, as it could lead to degraded topcoat adhesion, coating appearance and long term corrosion performance. Although better temperature control during application could reduce the problem, TSC-3 was eliminated from the Phase 2 research. A modified Nucryl-based polymer with enhanced abrasion resistance, TSC-2, was used in Phase 2.

Captions for the photographs of Appendix 2 which have been scanned electronically are:

FIGURE 4 TSC-1 (Nucryl) on primer, PP-1, loaded with spheres. Magnification 160x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-1 topcoat; 5 = gas bubble; 6 = mounting material

FIGURE 5 TSC-1 (Nucryl) on primer, PP-2, loaded with spheres. Magnification 160x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-1 topcoat; 5 = gas bubble

FIGURE 6 TSC-3 (Surlyn) on primer, PP-1, loaded with spheres over alkyd. Magnification 100x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-3 topcoat; 5 = gas bubble; 6 = old alkyd paint

FIGURE 7 TSC-3 (Surlyn) on primer, PP-2, loaded with spheres over alkyd. Magnification 160x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-3 topcoat; 5 = gas bubble; 6 = old alkyd paint

FIGURE 8 TSC-1 (Nucryl) on primer, PP-2, loaded with spheres at peel. Magnification 100x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-1 topcoat; 5 = mounting plastic; 6 = old alkyd paint; 7 = "necks" of polymer formed during peel
Note necks of the polymer topcoat that formed during the peel. These appear to be located at sites of fractured spheres which anchor the topcoat and enhance adhesion.

FIGURE 9 TSC-1 (Nucryl) on primer, PP-2, without spheres. Magnification 80x.
1 = steel; 2 = primer; 3 = mounting plastic; 4 = TSC-1 topcoat; 5 = gas bubble
Note that trapped air bubbles are not attached to primer.

FIGURE 10 TSC-3 (Surlyn) on primer, PP-1, without spheres. Magnification 200x.
1 = steel; 2 = primer; 3 = local decomposition of primer; 4 = TSC-1 topcoat; 5 = gas bubble
Bubbles are attached to primer layer and appear to have formed by decomposition of the primer.

FIGURE 4 TSC-1 (Nucryl) on primer, PP-1, loaded with spheres. Magnification 160x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-1 topcoat; 5 = gas bubble; 6 = mounting material

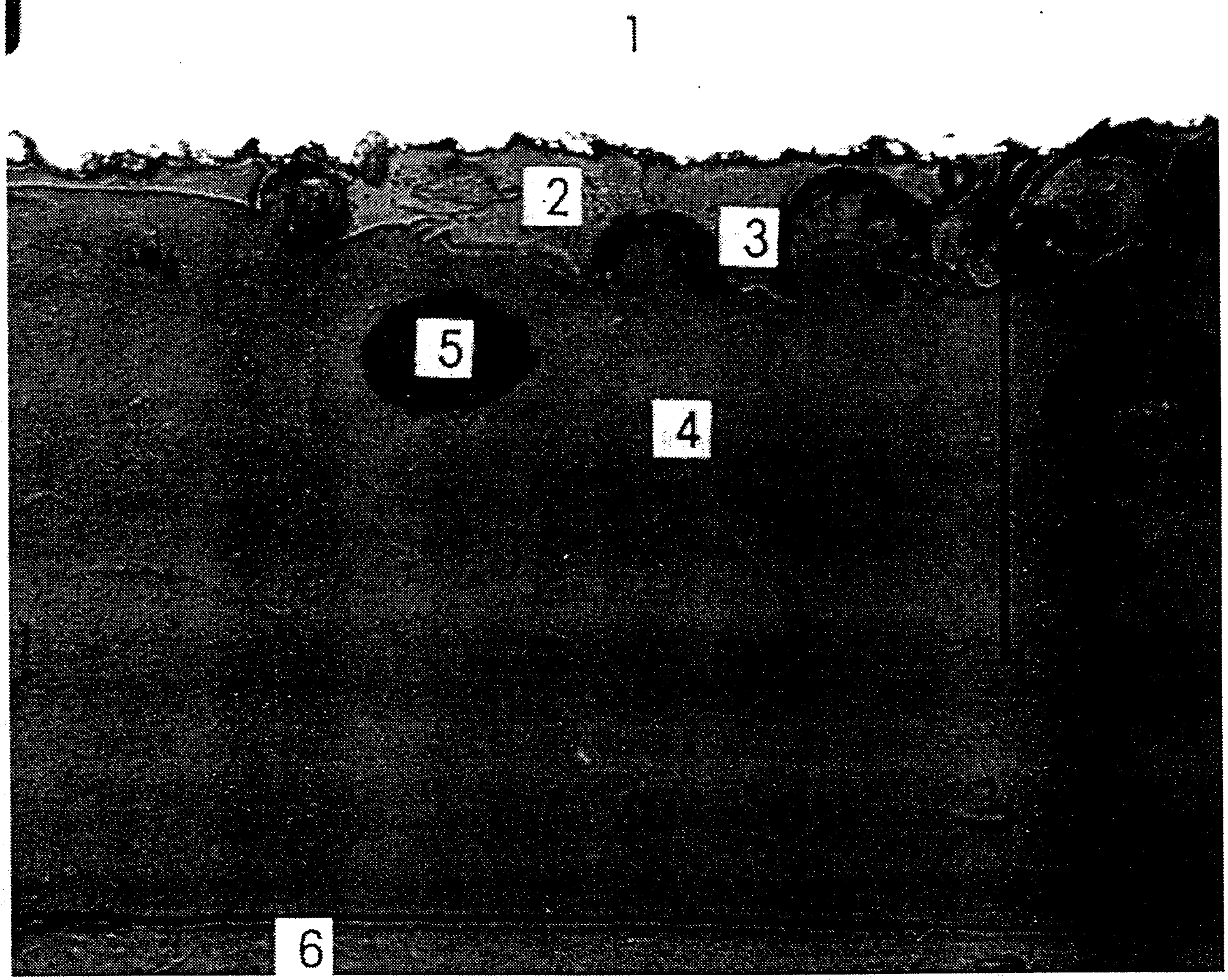


FIGURE 5 TSC-1 (Nucryl) on primer, PP-2, loaded with spheres. Magnification 160x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-1 topcoat; 5 = gas bubble

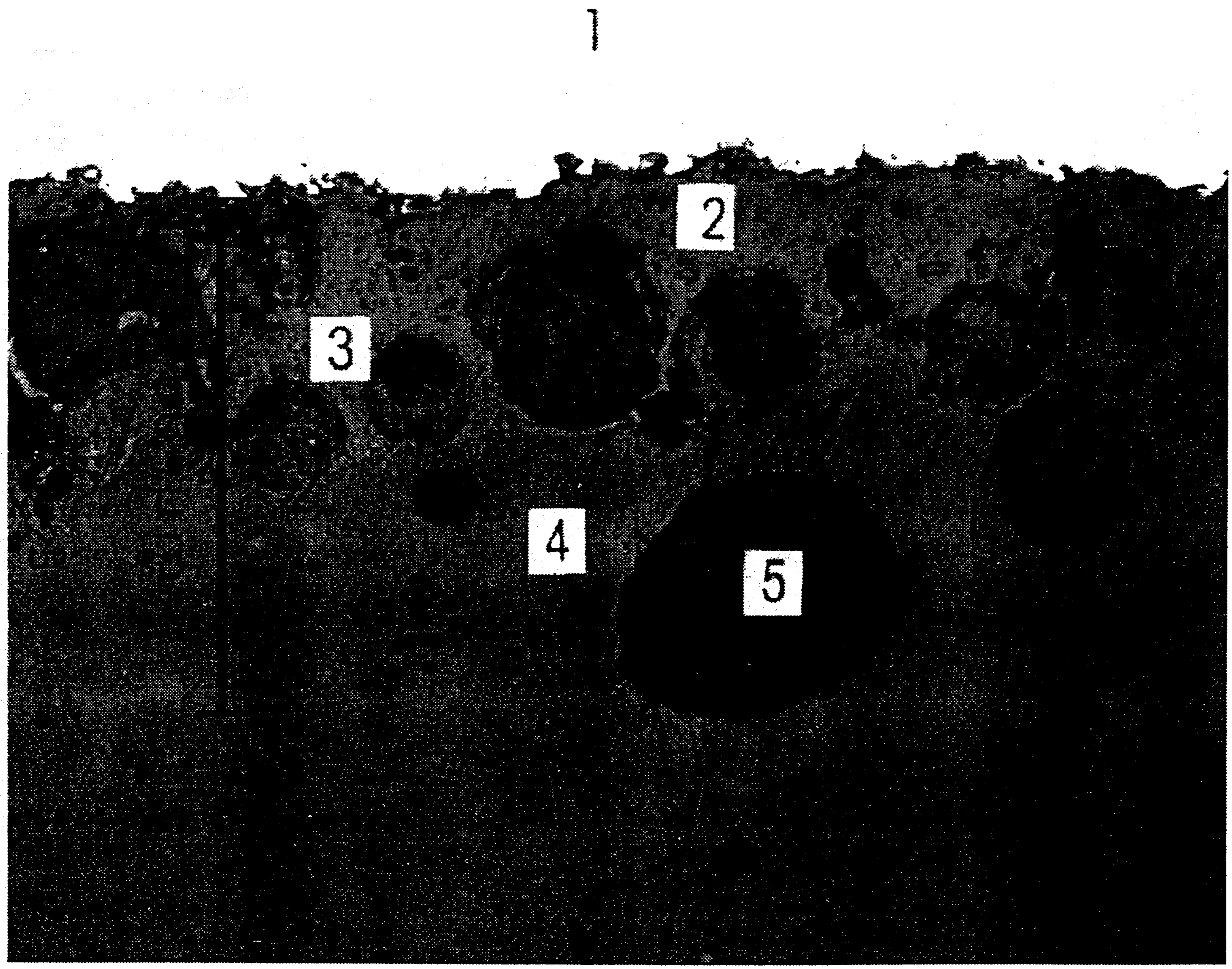


FIGURE 6 TSC-3 (Surlyn) on primer, PP-1, loaded with spheres over alkyd. Magnification 100x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-3 topcoat; 5 = gas bubble; 6 = old alkyd paint

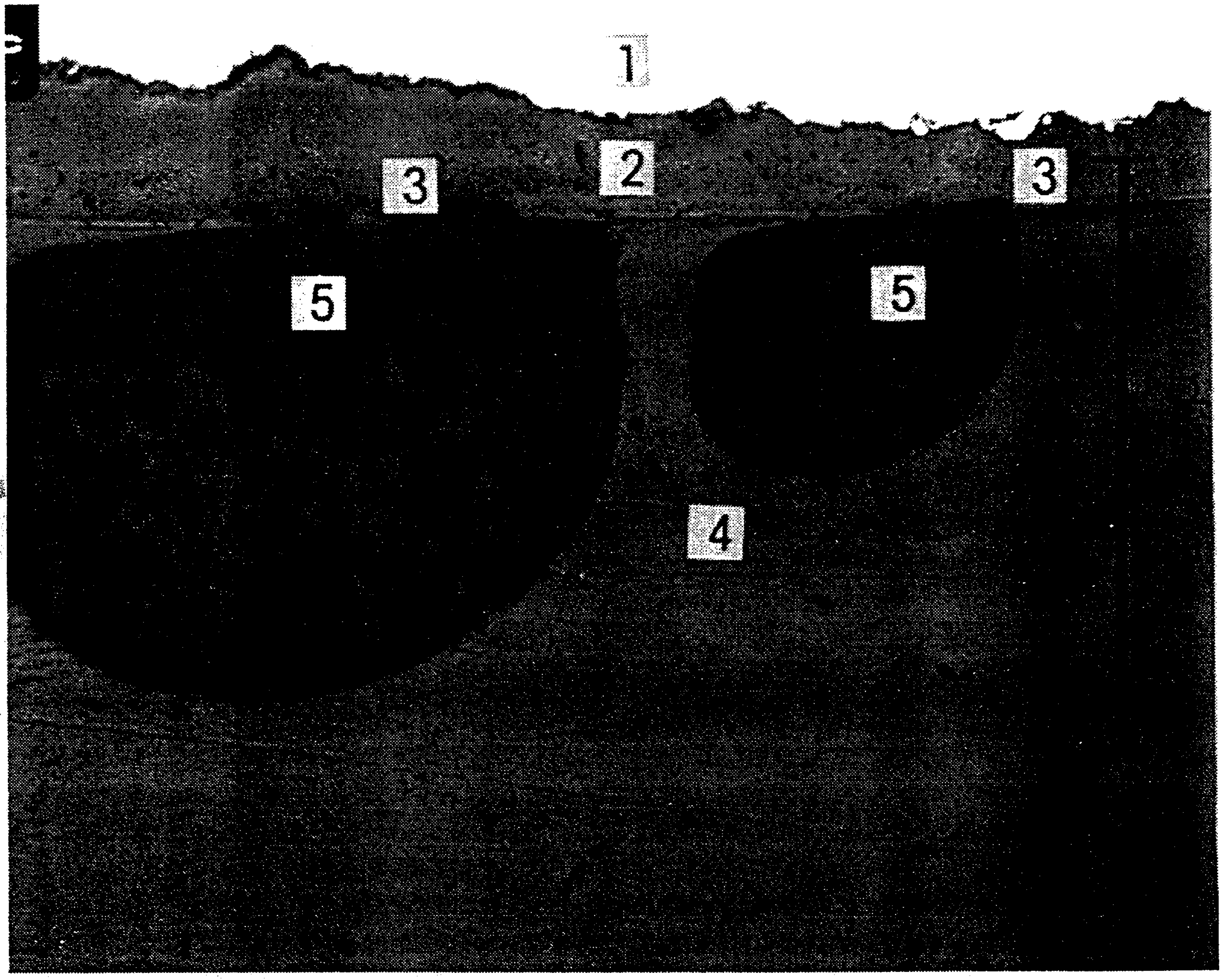


FIGURE 7 TSC-3 (Surlyn) on primer, PP-2, loaded with spheres over alkyd. Magnification 160x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-3 topcoat; 5 = gas bubble; 6 = old alkyd paint

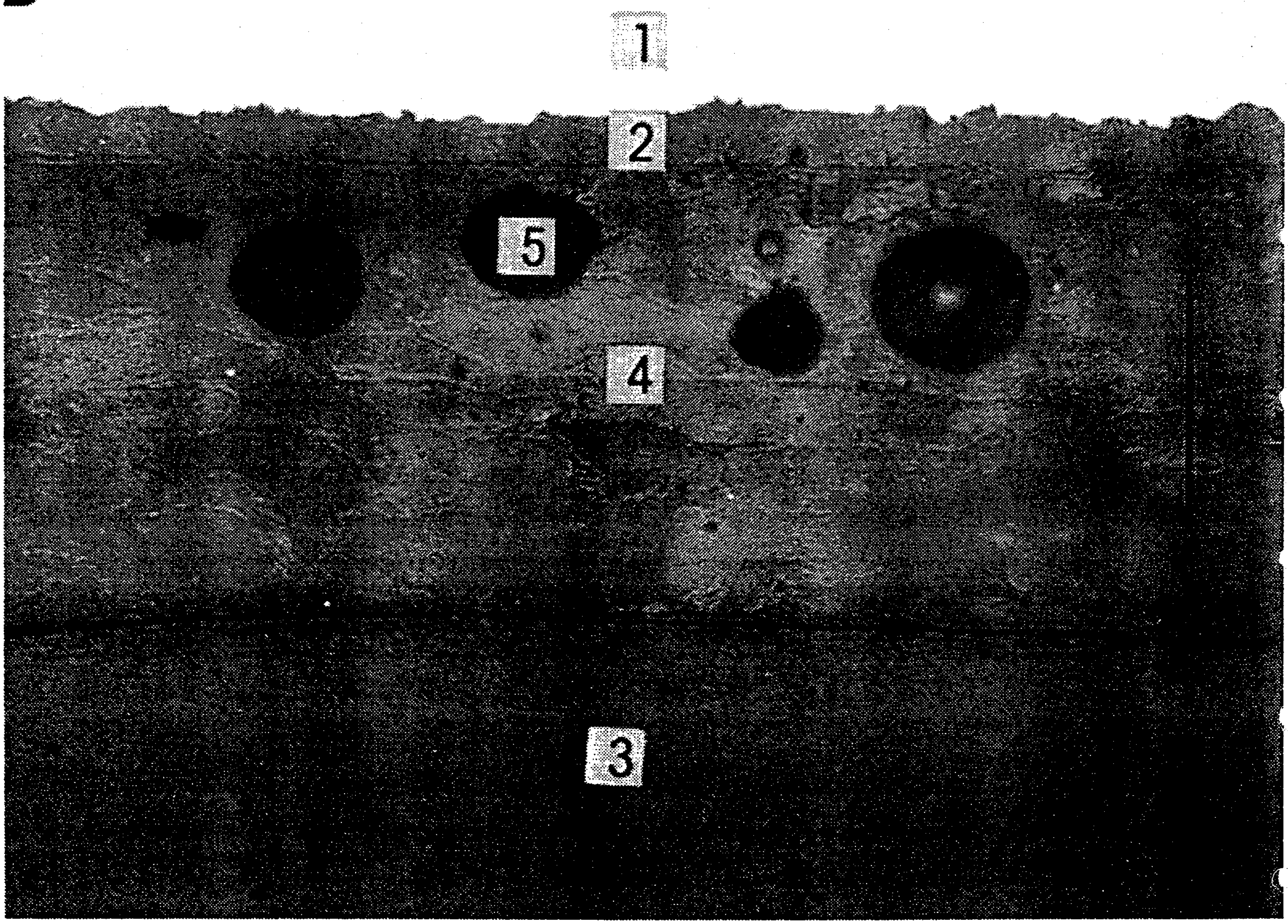


FIGURE 8 TSC-1 (Nucryl) on primer, PP-2, loaded with spheres at peel. Magnification 100x.
1 = steel; 2 = primer; 3 = broken spheres filled with polymer; 4 = TSC-1 topcoat; 5 = mounting plastic; 6 = old alkyd paint; 7 = "necks" of polymer formed during peel
Note necks of the polymer topcoat that formed during the peel. These appear to be located at sites of fractured spheres which anchor the topcoat and enhance adhesion.

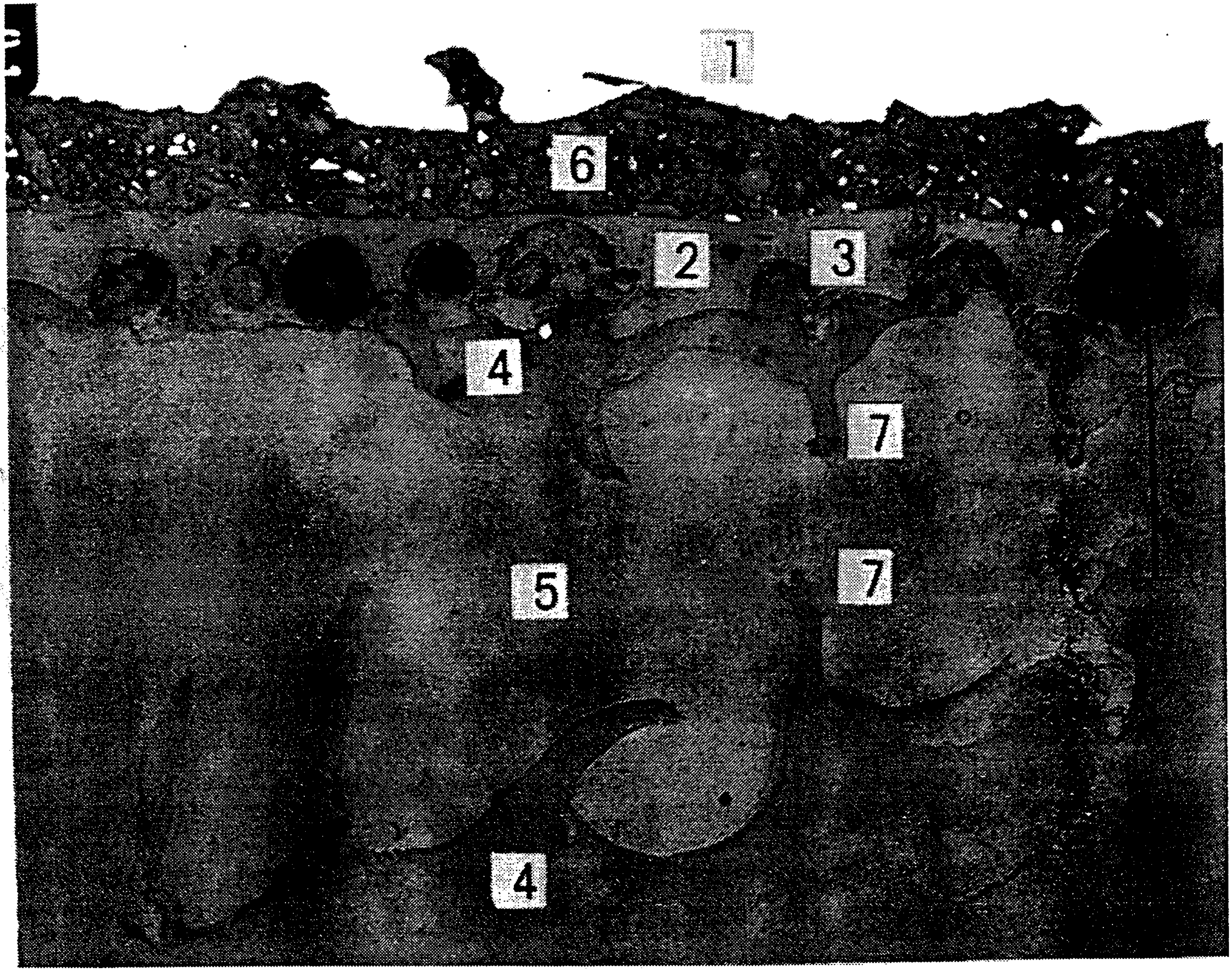


FIGURE 9 TSC-1 (Nucryl) on primer, PP-2, without spheres. Magnification 80x.
1 = steel; 2 = primer; 3 = mounting plastic; 4 = TSC-1 topcoat; 5 = gas bubble
Note that trapped air bubbles are not attached to primer.

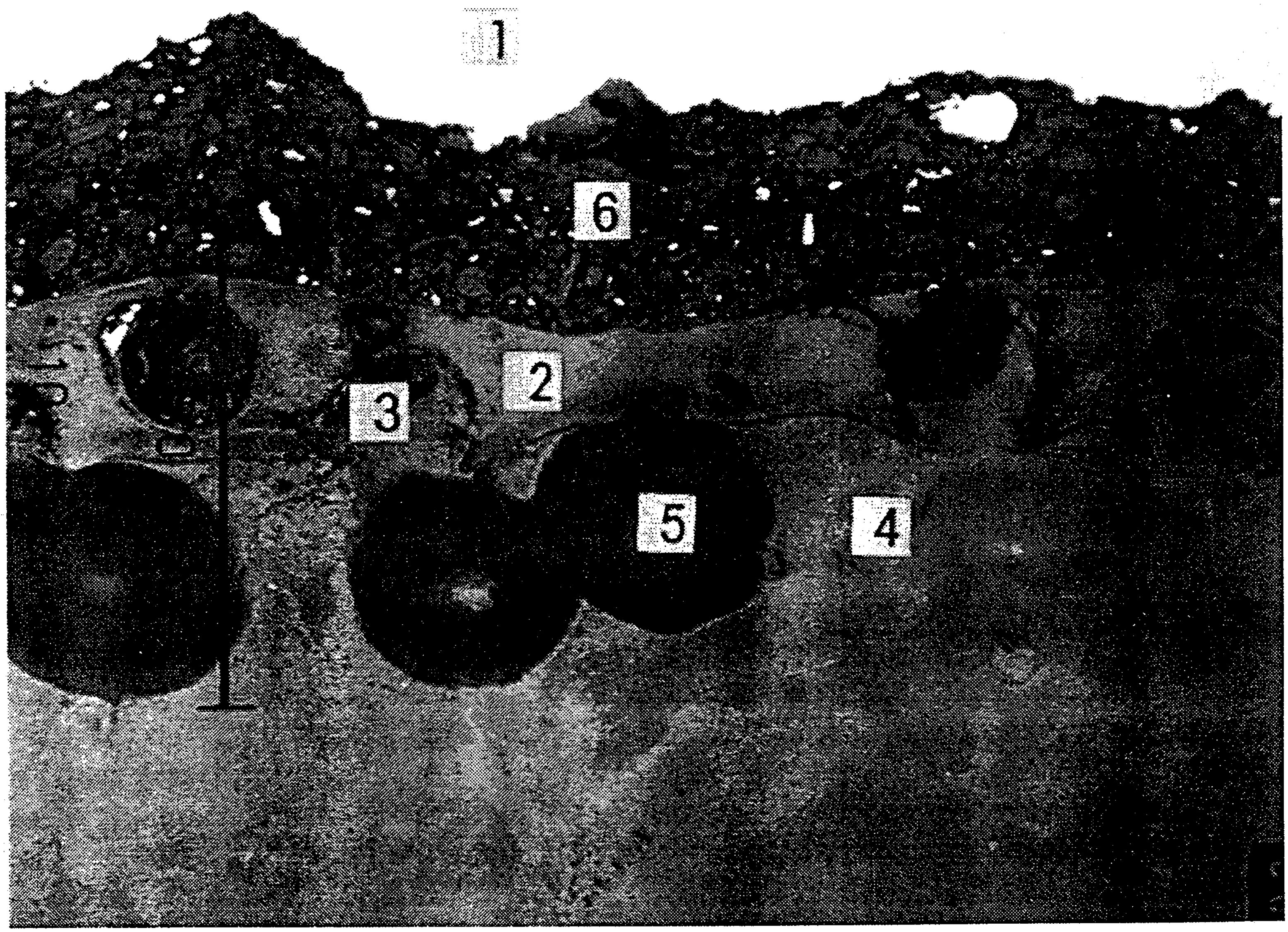
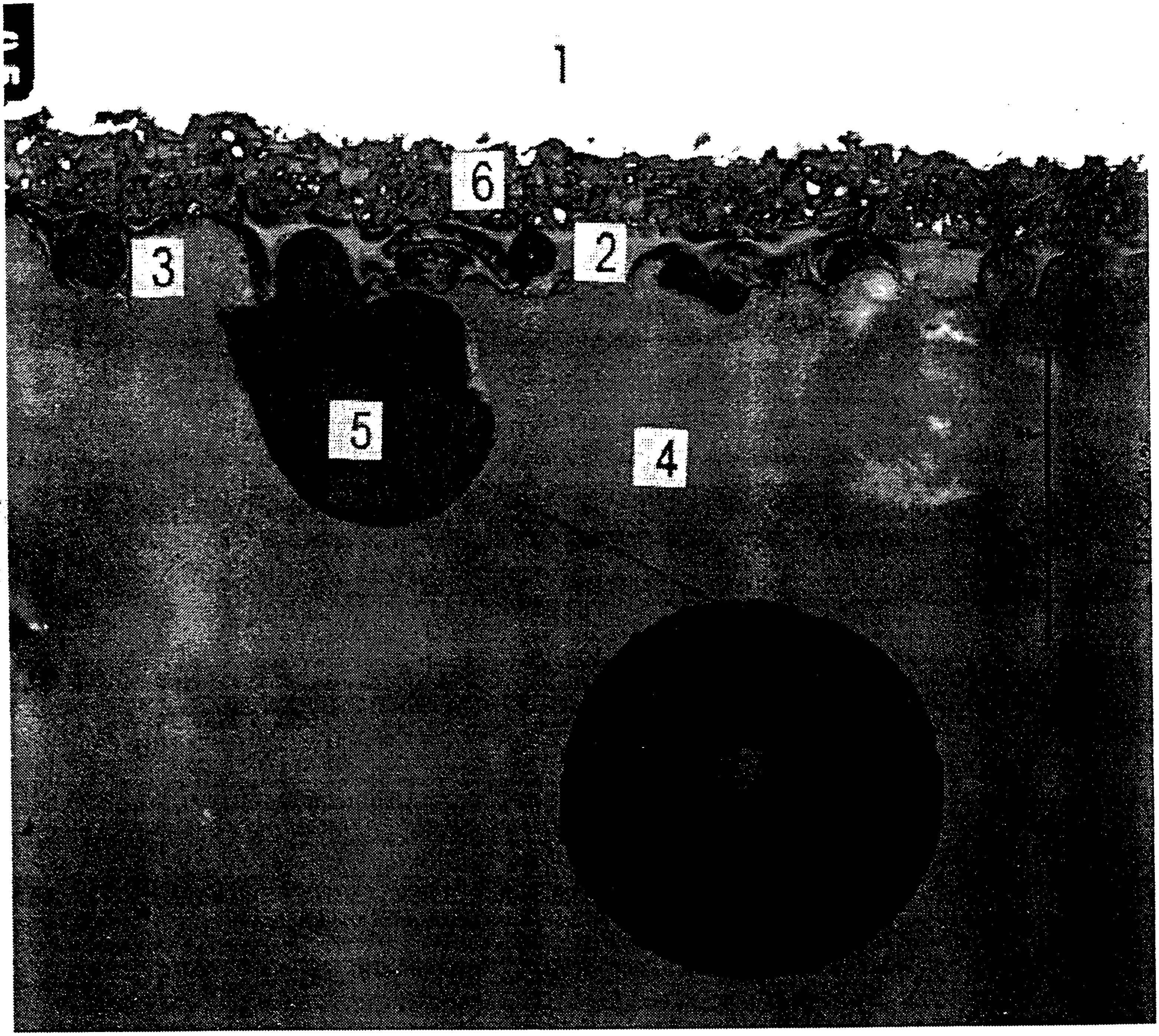


FIGURE 10 TSC-3 (Surlyn) on primer, PP-1, without spheres. Magnification 200x.
1 = steel; 2 = primer; 3 = local decomposition of primer; 4 = TSC-1 topcoat; 5 = gas bubble
Bubbles are attached to primer layer and appear to have formed by decomposition of the primer.



APPENDIX 3

Tables included in Appendix 3 are:

TABLE 1 Phase 1 Adhesion Data, Preliminary Work

Panel ID	Primer	Topcoat	Panel Type	Loading	DFT (µm)		Comments	Pull-Off Adhesion*				X-Cut Adhesion#
					Primer	System		MPa			Mode	
TOP	PP-1	TC-2	SP 5	No Spheres	61	317	No sweep blast	4.1	4.1	2.8	B	5A
TML	PP-1	TC-2	SP 5	Spheres	104	383	No sweep blast	2.1	2.1	2.8	B	5A
TOV	PP-1	TC-2	SP 5	Spheres	84	291	Sweep blast	2.1	1.4	1.7	B	5A
TPU	PP-2	TC-2	SP 5	No Spheres	28	314	No sweep blast	4.8	4.8	4.8	C	5A
TPY	PP-2	TC-2	SP 5	Spheres	67	328	No sweep blast	4.1	6.2	4.8	C/D	5A
TQB	PP-2	TC-2	SP 5	Spheres	71	301	Sweep blast	3.4	5.2	3.4	C/D	5A
TOS	PP-1	TC-1	SP 5	No Spheres	46	514	No sweep blast	2.1	1.7	2.8	C/D	5A
TMH	PP-1	TC-1	SP 5	Spheres	83	527	Sweep blast	2.4	1.4	2.8	C/D	5A
TOY	PP-1	TC-1	SP 5	Spheres	86	619	No sweep blast	2.1	2.8	1.4	C	5A
TPD	PP-2	TC-1	SP 5	No Spheres	38	559	No sweep blast	2.4	2.4	2.8	C	5A
TMR	PP-2	TC-1	SP 5	Spheres	71	601	Sweep blast	3.1	2.8	2.8	C	5A
TOZ	PP-2	TC-1	SP 5	Spheres	72	559	No sweep blast	2.8	2.1	2.4	C	5A
A	PP-1	TSC-1	SP 5	Spheres		541	Sweep blast	0.7	1.4	1.4	A	5A
B	PP-1	TSC-1	AA	Spheres		541	Sweep blast	1.4	1.4	1.4	A	5A
C	PP-1	TSC-1	SP 5	No Spheres		544	Sweep blast	1.4	1.4	1.0	A	5A
D	PP-1	TSC-3 clear	SP 5	Spheres		748	Sweep blast	2.1	4.1	3.4	A	5A
E	PP-1	TSC-3 clear	AA	Spheres		869	Sweep blast	0.7	2.8	0.7	A	5A
F	PP-1	TSC-3 clear	SP 5	No Spheres		639	Sweep blast	5.5	5.5	3.4	A	5A
G	PP-1	TSC-3 pig.	SP 5	Spheres		562	Sweep blast	6.2	6.2	4.8	A	5A
H	PP-1	TSC-3 pig.	AA	Spheres		687	Sweep blast	5.2	4.1	2.1	A	5A
I	PP-2	TSC-1	SP 5	Spheres		417	Sweep blast	2.1	1.0	1.0	A	5A
J	PP-2	TSC-1	AA	Spheres		425	Sweep blast	1.4	1.0	2.1	A	5A
K	PP-2	TSC-1	SP 5	No Spheres		439	Sweep blast	2.1	0.7	1.4	A	5A
L	PP-2	TSC-3 clear	SP 5	Spheres		635	Sweep blast	4.5	4.8	2.8	A	5A
M	PP-2	TSC-3 clear	AA	Spheres		743	Sweep blast	1.4	2.1	1.4	A	5A
N	PP-2	TSC-3 clear	SP 5	No Spheres		570	Sweep blast	3.4	2.8	2.8	A	5A
O	PP-2	TSC-3 pig.	SP 5	Spheres		632	Sweep blast	5.5	5.5	5.5	A	5A
P	PP-2	TSC-3 pig.	AA	Spheres		756	Sweep blast	2.1	1.4	2.1	A	5A

TABLE 1 Phase 1 Adhesion Data, Preliminary Work (continued)

Panel ID	Primer	Topcoat	Panel Type	Loading	DFT (µm) Primer	DFT (µm) System	Comments	Pull-Off Adhesion* MPa			Pull-Off Adhesion* Mode	X-Cut Adhesion#
Q	PP-1	TSC-2	SP 5	Spheres		769	Sweep blast	2.1	2.1	3.8	A	5A
R	PP-1	TSC-2	AA	Spheres		890	Sweep blast	2.8	2.1	0.7	A	5A
S	PP-1	TSC-2	SP 5	No Spheres		722	Sweep blast	1.4	1.4	2.1	A	5A
T	PP-2	TSC-2	SP 5	Spheres		1014	Sweep blast	2.1	1.4	1.4	A	5A
U	PP-2	TSC-2	AA	Spheres		1209	Sweep blast	1.4	0.7	0.7	A	5A
V	PP-2	TSC-2	SP 5	No Spheres		1180	Sweep blast	1.4	2.1	1.7	A	5A

* ASTM D 4541
\# ASTM D 3359
AA = Aged alkyd

1 mil = 25.4 µm
1000 lb/sq in = 6.895 MPa

Mode
- A = Glue failure
- B = Failed at metal/primer interface
- C = Failed in topcoat
- D = Failed in primer

C/D = Failed at primer/topcoat interface

PP-1 = Penetrating primer 1 (oxyrane)
PP-2 = Penetrating primer 2 (epoxy emidoamine)

TC-1 = Zero VOC topcoat 1 (liquid applied)
TC-2 = Zero VOC topcoat 2 (liquid applied)

TSC-1 = Thermal spray coating 1
TSC-2 = Thermal spray coating 2

TSC-3 = Thermal spray coating 3

TABLE 2 Phase 1 Holiday Test Data

All topcoated panels passed the holiday test without any holidays. However, three of the four panels which were not topcoated had many holidays. The untopcoated panels were never sent to SUNY but were primed at the same time as these topcoated panels. All panels were prepared in duplicate.

<u>UNTOPCOATED, WITH SPHERES, NO SWEEP BLAST</u>

PP-1	Both panels failed the holiday test.
PP-2	One panel passed and one panel failed the holiday test.

<u>TOPCOATED, SPHERES WERE BROKEN BY SWEEP BLASTING BEFORE TOPCOATING</u>

PRIMER	PANEL TYPE	TOPCOAT	HOLIDAY TEST
PP-1	SP 5 with spheres	TSC-1	2 panels passed
	alkyd w/ Spheres	TSC-1	2 panels passed
	SP 5 no spheres	TSC-1	2 panels passed
PP-2	SP 5 with spheres	TSC-3 clear	1 panel passed
	alkyd with Spheres	TSC-3 clear	1 panel passed
	SP 5 no spheres	TSC-3 clear	1 panel passed
	SP 5 with spheres	TSC-3 pigmented	1 panel passed
	alkyd with Spheres	TSC-3 pigmented	1 panel passed

Holiday testing on the new panels sent to SSPC from SUNY which had been sprayed with TSC-2 plastic flamecoat showed all 11 were free of holidays.

PP = Penetrating primer
TSC = Thermal spray coating

TABLE 3 Experimental Design, Phase 2

PP-1	WITH SPHERES	TSC-1	SP 5
			AA
		TSC-2	SP 5
			AA
		TC	SP 5
			AA
	WITHOUT SPHERES	TSC-1	SP 5
			AA
		TC	SP 5
			AA
PP-2	WITH SPHERES	TSC-1	SP 5
			AA
		TSC-2	SP 5
			AA
	WITHOUT SPHERES	TSC-1	SP 5
			AA
		TC	SP 5
			AA
Control System #1			SP 5
			AA
Control System #2			SP 5
			AA
Control System #3			SP 5
			AA

Replication: All panels prepared in triplicate

Panel size: 10 x 30 x 0.6 cm (4 x 12 x 1/4 in)

Exposure: prohesion/UV-condensation/freeze-thaw cycle.

AA = Aged Alkyd

PP-1 = Penetrating primer #1
PP-2 = Penetrating primer #2
TSC-1 = Thermal Spray Coating #1
TSC-2 = Thermal Spray Coating #2
TC = Zero VOC topcoat (liquid applied)

Control System #1 SSPC-Paint 25
SSPC-Paint 104
Control System #2 Latex (3 coats)
Control System #3 Epoxy mastic (2 coats)

TABLE 4 Phase 2 - List of Coatings

CODE	NAME	DESCRIPTION	VOC LEVEL (g/l)
PENETRATING PRIMERS (applied without spheres and with a loading of 50% spheres by volume)			
PP-1	Penetrating Primer #1	A 100% solids chelated polymeric oxirane with very low viscosity; two component; a rust penetrating sealer.	<10
PP-2	Penetrating Primer #2	A 98% solids polymeric epoxy emidoamine; two component; excellent wetting properties.	24
SPHERES			
	Copperlok P.Q.'s C.G.	Glass microspheres with silane coating.	
THERMAL SPRAY TOPCOATS			
TSC-1	Thermal Spray Topcoat #1	An ethylene-methacrylic acid copolymer based on DuPont's Nucrel resin; good compatibility with primers; good melt flow characteristics; low temperature of application; soft; inferior abrasion resistance.	<10
TSC-2	Thermal Spray Topcoat #2	A Nucryl based resin; better abrasion resistance than TSC-1; better melt flow than TSC-3 (used in Phase 1)	<10
LIQUID APPLIED TOPCOAT			
TC	Liquid Applied Topcoat	A two component solvent free amine cured epoxy; was applied by brush, but with suitable equipment it is able to be spray applied; identified in Phase 1 as TC-1	<10
CONTROL SYSTEMS			
Alkyd	SSPC-Paint 25	Red Iron Oxide, Zinc Oxide, Raw Linseed Oil and Alkyd Primer. Zinc oxide, French process (ASTM D 79, Type I); alkyd resin TT-R-266, Type II.	250
	SSPC-Paint 104	White or Tinted Alkyd Paint	320
Latex	Acrylic Latex Primer	Two coats of primer, one coat of topcoat; Meets Louisiana DOTD specification QPL-68.	60
	Acrylic Latex Topcoat		120
Epoxy	Aluminum Epoxy Mastic	Aluminum flake-filled surface tolerant epoxy mastic; two coats.	88 (as shipped) 231 (25% thinning)

TABLE 5 Raw Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	RUST RATINGS #					
FVY	PP-1	TSC-1	AA	NO Spheres	10-	10-	9	9	9	9
FVZ	PP-1	TSC-1	AA	NO Spheres	10	10-	10-	10-	10-	10-
FWA	PP-1	TSC-1	AA	NO Spheres	10-	10-	10-	10-	9	9
A1	PP-1	TSC-1	SP 5	NO Spheres	10-	10-	10-	10-	9	9
A2	PP-1	TSC-1	SP 5	NO Spheres	10	10-	10-	10-	10-	10-
A3	PP-1	TSC-1	SP 5	NO Spheres	10-	10-	10-	10-	9	9
FVY1	PP-1	TC	AA	NO Spheres	10-	10-	10-	10-	10-	10-
FWF1	PP-1	TC	AA	NO Spheres	10	10-	10-	10-	10-	10-
FVZ1	PP-1	TC	AA	NO Spheres	10-	10-	10-	10-	10-	10-
B1	PP-1	TC	SP 5	NO Spheres	10-	10-	10-	10-	10-	9-
B2	PP-1	TC	SP 5	NO Spheres	10	10-	10-	10-	10-	10-
B3	PP-1	TC	SP 5	NO Spheres	9	9	9	9	9	9
FVW1	PP-1	TSC-1	AA	Spheres	10	10-	10-	10-	10-	10-
FWB	PP-1	TSC-1	AA(sb)	Spheres	10-	9	9	9	9	9
FWB1	PP-1	TSC-1	AA	Spheres	10-	10-	10-	10-	9	9-
C1	PP-1	TSC-1	SP 5	Spheres	10	10-	10-	10-	10-	9
C2	PP-1	TSC-1	SP 5(sb)	Spheres	10-	10-	10-	10-	10-	10-
C3	PP-1	TSC-1	SP 5	Spheres	9	9	9	9	9	9
FWD1	PP-1	TSC-2	AA	Spheres	10	10-	10-	10-	10-	10-
FWC1	PP-1	TSC-2	AA(sb)	Spheres	10-	10-	10-	10-	10-	9
FWD	PP-1	TSC-2	AA	Spheres	10-	9	9	9	9	9-
D1	PP-1	TSC-2	SP 5	Spheres	10	9	8+	8	8	8
D2	PP-1	TSC-2	SP 5(sb)	Spheres	9	9	9	9	9	9
D3	PP-1	TSC-2	SP 5	Spheres	9	9	9	9	8	8
FVP	PP-1	TC	AA	Spheres	10	9	9	9	9	9
FVP1	PP-1	TC	AA(sb)	Spheres	10	10-	10-	10-	10-	10-
FVR	PP-1	TC	AA	Spheres	10	10	10-	10-	10-	10-
E1	PP-1	TC	SP 5	Spheres	10	10-	10-	10-	10-	10-
E2	PP-1	TC	SP 5(sb)	Spheres	10	9	9	9	9	9
E3	PP-1	TC	SP 5	Spheres	8	8	8	9	9	9
FVR1	PP-2	TSC-1	AA	NO Spheres	10-	10-	9	9	9	9
FVS1	PP-2	TSC-1	AA	NO Spheres	10	10-	10-	10-	10-	10-
FVS	PP-2	TSC-1	AA	NO Spheres	10-	9	9	9	9	9
F1	PP-2	TSC-1	SP 5	NO Spheres	10-	9	9	9	9	9
F2	PP-2	TSC-1	SP 5	NO Spheres	10	10-	10	10	10	10-
F3	PP-2	TSC-1	SP 5	NO Spheres	10-	10-	10-	10-	9	9
FWF	PP-2	TC	AA	NO Spheres	9	9	9	9	9-	9-
FVT1	PP-2	TC	AA	NO Spheres	10	10	10-	10-	10-	10-
FVT	PP-2	TC	AA	NO Spheres	9	9	9	9	9	9
G1	PP-2	TC	SP 5	NO Spheres	9	9	9	9-	9-	9-
G2	PP-2	TC	SP 5	NO Spheres	10	10-	10-	10-	10-	10-
G3	PP-2	TC	SP 5	NO Spheres	10-	10-	10-	10-	10-	10-
FVW	PP-2	TSC-1	AA	Spheres	10	10-	10	10	10	10-
FVU1	PP-2	TSC-1	AA(sb)	Spheres	10	10	10-	10-	10-	10-
FVV	PP-2	TSC-1	AA	Spheres	9	9	9	9	10-	9

TABLE 5 Raw Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw (continued)

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	RUST RATINGS #					
H1	PP-2	TSC-1	SP 5	Spheres	10	10-	10-	10-	10-	9
H2	PP-2	TSC-1	SP 5(sb)	Spheres	10	10	10	10	10-	10-
H3	PP-2	TSC-1	SP 5	Spheres	9	9	9	9	9-	9-
FVX	PP-2	TSC-2	AA	Spheres	10	10	10-	10-	10-	10-
FVX1	PP-2	TSC-2	AA(sb)	Spheres	10	10-	10-	10-	10-	10-
FWC	PP-2	TSC-2	AA	Spheres	10-	10-	10-	10-	10-	10-
I1	PP-2	TSC-2	SP 5	Spheres	10	10-	10-	10-	10-	10-
I2	PP-2	TSC-2	SP 5(sb)	Spheres	10	10	10	10	10-	10-
I3	PP-2	TSC-2	SP 5	Spheres	8	8	8	7	10-	7
FWE	Paint 25	Paint 104	AA	control	10-	10-	10-	10-	10-	10-
FWE1	Paint 25	Paint 104	AA	control	10	10-	10-	10-	10-	10-
FVU	Paint 25	Paint 104	AA	control	10-	9	9	9	9	9
J1	Paint 25	Paint 104	SP 5	control	10-	10-	10-	10-	10-	10-
J2	Paint 25	Paint 104	SP 5	control	10	10-	10-	10-	9	8
J3	Paint 25	Paint 104	SP 5	control	10-	9	9	9	9	9
FWG	latex	latex	AA	control	9	9-	9	9	9	8
FWG1	latex	latex	AA	control	10	10-	10-	10-	9	9
FWA1	latex	latex	AA	control	9	9	8	8	8	8
K1	latex	latex	SP 5	control	10	10-	10-	10-	10-	10-
K2	latex	latex	SP 5	control	10	10	10	10	10-	10-
K3	latex	latex	SP 5	control	10	10	10-	10-	10-	10-
FWI	epoxy	epoxy	AA	control	10	10	10	10	10-	10-
FWH1	epoxy	epoxy	AA	control	10	10	10	10	10	10
FVQ	epoxy	epoxy	AA	control	10	10-	10-	10-	10-	10-
L1	epoxy	epoxy	SP 5	control	10	10	10	10	10	10
L2	epoxy	epoxy	SP 5	control	10	10	10	10	10	10
L3	epoxy	epoxy	SP 5	control	10	10	10	10	10	10

TABLE 5 Raw Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw (continued)

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	BLISTER RATINGS*					
FVY	PP-1	TSC-1	AA	NO Spheres	10	10	10	10	10	10
FVZ	PP-1	TSC-1	AA	NO Spheres	10	10	10	10	10	10
FWA	PP-1	TSC-1	AA	NO Spheres	10	10	10	10	10	10
A1	PP-1	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
A2	PP-1	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
A3	PP-1	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
FVY1	PP-1	TC	AA	NO Spheres	10	10	10	10	10	10
FWF1	PP-1	TC	AA	NO Spheres	10	10	10	10	10	10
FVZ1	PP-1	TC	AA	NO Spheres	10	10	10	10	10	10
B1	PP-1	TC	SP 5	NO Spheres	10	10	10	10	10	10
B2	PP-1	TC	SP 5	NO Spheres	10	10	10	10	10	10
B3	PP-1	TC	SP 5	NO Spheres	10	10	10	10	10	10

TABLE 5 Raw Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw (continued)

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
PANEL ID	PRIMER	TOPCOAT	PANEL TYPE	LOADING	BLISTER RATINGS*					
FVW1	PP-1	TSC-1	AA	Spheres	10	10	10	10	10	10
FWB	PP-1	TSC-1	AA(sb)	Spheres	10	10	10	10	10	10
FWB1	PP-1	TSC-1	AA	Spheres	10	10	10	10	10	10
C1	PP-1	TSC-1	SP 5	Spheres	10	10	10	10	10	10
C2	PP-1	TSC-1	SP 5(sb)	Spheres	10	10	10	10	10	10
C3	PP-1	TSC-1	SP 5	Spheres	10	10	10	10	10	10
FWD1	PP-1	TSC-2	AA	Spheres	10	10	10	10	10	10
FWC1	PP-1	TSC-2	AA(sb)	Spheres	10	10	10	10	10	10
FWD	PP-1	TSC-2	AA	Spheres	10	10	10	10	10	10
D1	PP-1	TSC-2	SP 5	Spheres	10	10	10	10	10	10
D2	PP-1	TSC-2	SP 5(sb)	Spheres	10	10	10	10	10	10
D3	PP-1	TSC-2	SP 5	Spheres	10	10	10	10	10	10
FVP	PP-1	TC	AA	Spheres	10	10	10	10	10	10
FVP1	PP-1	TC	AA(sb)	Spheres	10	10	10	10	10	10
FVR	PP-1	TC	AA	Spheres	10	6M	6M	6M	6M	6M
E1	PP-1	TC	SP 5	Spheres	10	10	10	10	10	6F
E2	PP-1	TC	SP 5(sb)	Spheres	10	4VF	4VF	4VF	4VF	4VF
E3	PP-1	TC	SP 5	Spheres	10	6M	6M	6M	6M	6M
FVR1	PP-2	TSC-1	AA	NO Spheres	10	10	10	10	10	10
FVS1	PP-2	TSC-1	AA	NO Spheres	10	8D	10	10	10	10
FVS	PP-2	TSC-1	AA	NO Spheres	10	10	10	10	10	10
F1	PP-2	TSC-1	SP 5	NO Spheres	10	8MD	10	10	10	10
F2	PP-2	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
F3	PP-2	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
FWF	PP-2	TC	AA	NO Spheres	10	10	10	10	10	10
FVT1	PP-2	TC	AA	NO Spheres	10	10	10	10	10	10
FVT	PP-2	TC	AA	NO Spheres	10	10	10	10	10	10
G1	PP-2	TC	SP 5	NO Spheres	10	10	10	10	10	10
G2	PP-2	TC	SP 5	NO Spheres	10	10	10	10	10	10
G3	PP-2	TC	SP 5	NO Spheres	10	10	10	10	10	10
FVW	PP-2	TSC-1	AA	Spheres	10	10	10	10	10	10
FVU1	PP-2	TSC-1	AA(sb)	Spheres	10	10	10	10	10	10
FVV	PP-2	TSC-1	AA	Spheres	10	10	10	10	10	10
H1	PP-2	TSC-1	SP 5	Spheres	10	10	10	10	10	10
H2	PP-2	TSC-1	SP 5(sb)	Spheres	10	10	10	10	10	10
H3	PP-2	TSC-1	SP 5	Spheres	10	10	10	10	10	10
FVX	PP-2	TSC-2	AA	Spheres	10	10	10	10	10	10
FVX1	PP-2	TSC-2	AA(sb)	Spheres	10	10	10	10	10	10
FWC	PP-2	TSC-2	AA	Spheres	10	10	10	10	10	10
I1	PP-2	TSC-2	SP 5	Spheres	10	10	10	10	10	10
I2	PP-2	TSC-2	SP 5(sb)	Spheres	10	10	10	10	10	10
I3	PP-2	TSC-2	SP 5	Spheres	10	10	10	10	10	10
FWE	Paint 25	Paint 104	AA	control	10	8M	8M	8M	8M	8M
FWE1	Paint 25	Paint 104	AA	control	10	6M/6F	6M	6M	6M	6MD
FVU	Paint 25	Paint 104	AA	control	10	8D/8F	8MD/8F	8MD/8F	8MD/8F	8MD/8F

TABLE 5 Raw Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw (continued)

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	**BLISTER RATINGS***					
J1	Paint 25	Paint 104	SP 5	control	10	10	10	10	10	10
J2	Paint 25	Paint 104	SP 5	control	10	10	10	10	10	10
J3	Paint 25	Paint 104	SP 5	control	10	10	10	10	10	10
FWG	latex	latex	AA	control	10	8D	6D	6D	6D	6MD
FWG1	latex	latex	AA	control	10	8M	8MD/8M	8MD/8M	8D/6M	8D/6MD
FWA1	latex	latex	AA	control	10	8D	6D	6D	6D	6D
K1	latex	latex	SP 5	control	10	8D	10	10	8D	8D
K2	latex	latex	SP 5	control	10	6D/4M	6MD/4M	6MD/6M	6D	6D
K3	latex	latex	SP 5	control	10	6D/4MD	6M/4F	6M/6F	6MD/6F	6MD/6F
FWI	epoxy	epoxy	AA	control	10	10	10	10	10	10
FWH1	epoxy	epoxy	AA	control	10	10	10	10	10	10
FVQ	epoxy	epoxy	AA	control	10	10	10	10	10	10
L1	epoxy	epoxy	SP 5	control	10	10	10	8VF	8VF	8VF
L2	epoxy	epoxy	SP 5	control	10	10	10	10	10	10
L3	epoxy	epoxy	SP 5	control	10	10	10	10	10	10

top/bottom - the top and bottom of the aged alkyd panels may have different ratings.

AA = Aged alkyd
AA(sb) = Aged alkyd (spheres broken with sweep blast)
SP 5 (sb) = Spheres broken by sweep blast
SSPC-Vis 2 (ASTM D 610)
* ASTM D 714

PP-1 = Penetrating primer 1 (oxyrane)
PP-2 = Penetrating primer 2 (epoxy emidoamine)
TSC-1 = Thermal spray coating 1
TSC-2 = Thermal spray coating 2
TC = Zero VOC Topcoat (liquid applied)

CYCLE: 1 week in prohesion (1 hour spray at 30° C; 1 hour dry at 40° C) alternating with 1 week in UV-Condensation (4 h UV at 60° C; 4 h condensation at 40° C). Use UV-A-340 lamps. All panels are in a freezer each weekend.

TABLE 6 Conversion of ASTM D 714 Data to Numerical Scale

FREQUENCY-> SIZE \	VERY FEW	FEW	MEDIUM	MEDIUM DENSE	DENSE
8	9	9	8	7	6
6	8	7	6	5	4
4	6	5	4	3	2
2	4	3	2	1	0
1	3	2	1	0	0

TABLE 7 Converted Smooth Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	RUST RATINGS #					
FVY	PP-1	TSC-1	AA	NO Spheres	9.7	9.7	9	9	9	9
FVZ	PP-1	TSC-1	AA	NO Spheres	10.0	9.7	9.7	9.7	9.7	9.7
FWA	PP-1	TSC-1	AA	NO Spheres	9.7	9.7	9.7	9.7	9.0	9.0
A1	PP-1	TSC-1	SP 5	NO Spheres	9.7	9.7	9.7	9.7	9.0	9.0
A2	PP-1	TSC-1	SP 5	NO Spheres	10.0	9.7	9.7	9.7	9.7	9.7
A3	PP-1	TSC-1	SP 5	NO Spheres	9.7	9.7	9.7	9.7	9.0	9.0
FVY1	PP-1	TC	AA	NO Spheres	9.7	9.7	9.7	9.7	9.7	9.7
FWF1	PP-1	TC	AA	NO Spheres	10.0	9.7	9.7	9.7	9.7	9.7
FVZ1	PP-1	TC	AA	NO Spheres	9.7	9.7	9.7	9.7	9.7	9.7
B1	PP-1	TC	SP 5	NO Spheres	9.7	9.7	9.7	9.7	9.7	8.7
B2	PP-1	TC	SP 5	NO Spheres	10.0	9.7	9.7	9.7	9.7	9.7
B3	PP-1	TC	SP 5	NO Spheres	9.0	9.0	9.0	9.0	9.0	9.0
FVW1	PP-1	TSC-1	AA	Spheres	10.0	9.7	9.7	9.7	9.7	9.7
FWB	PP-1	TSC-1	AA(sb)	Spheres	9.7	9.0	9.0	9.0	9.0	9.0
FWB1	PP-1	TSC-1	AA	Spheres	9.7	9.7	9.7	9.7	9.0	8.7
C1	PP-1	TSC-1	SP 5	Spheres	10.0	9.7	9.7	9.7	9.7	9.0
C2	PP-1	TSC-1	SP 5(sb)	Spheres	9.7	9.7	9.7	9.7	9.7	9.7
C3	PP-1	TSC-1	SP 5	Spheres	9.0	9.0	9.0	9.0	9.0	9.0
FWD1	PP-1	TSC-2	AA	Spheres	10.0	9.7	9.7	9.7	9.7	9.7
FWC1	PP-1	TSC-2	AA(sb)	Spheres	9.7	9.7	9.7	9.7	9.7	9.0
FWD	PP-1	TSC-2	AA	Spheres	9.7	9.0	9.0	9.0	9.0	8.7
D1	PP-1	TSC-2	SP 5	Spheres	10.0	9.0	8.3	8.0	8.0	8.0
D2	PP-1	TSC-2	SP 5(sb)	Spheres	9.0	9.0	9.0	9.0	9.0	9.0
D3	PP-1	TSC-2	SP 5	Spheres	9.0	9.0	9.0	9.0	8.0	8.0
FVP	PP-1	TC	AA	Spheres	10.0	9.0	9.0	9.0	9.0	9.0
FVP1	PP-1	TC	AA(sb)	Spheres	10.0	9.7	9.7	9.7	9.7	9.7
FVR	PP-1	TC	AA	Spheres	10.0	10.0	9.7	9.7	9.7	9.7
E1	PP-1	TC	SP 5	Spheres	10.0	9.7	9.7	9.7	9.7	9.7
E2	PP-1	TC	SP 5(sb)	Spheres	10.0	9.0	9.0	9.0	9.0	9.0
E3	PP-1	TC	SP 5	Spheres	8.0	8.0	8.0	9.0	9.0	9.0
FVR1	PP-2	TSC-1	AA	NO Spheres	9.7	9.7	9.0	9.0	9.0	9.0
FVS1	PP-2	TSC-1	AA	NO Spheres	10.0	9.7	9.7	9.7	9.7	9.7
FVS	PP-2	TSC-1	AA	NO Spheres	9.7	9.0	9.0	9.0	9.0	9.0
F1	PP-2	TSC-1	SP 5	NO Spheres	9.7	9.0	9.0	9.0	9.0	9.0
F2	PP-2	TSC-1	SP 5	NO Spheres	10.0	9.7	10.0	10.0	10.0	9.7
F3	PP-2	TSC-1	SP 5	NO Spheres	9.7	9.7	9.7	9.7	9.0	9.0
FWF	PP-2	TC	AA	NO Spheres	9.0	9.0	9.0	9.0	8.7	8.7
FVT1	PP-2	TC	AA	NO Spheres	10.0	10.0	9.7	9.7	9.7	9.7
FVT	PP-2	TC	AA	NO Spheres	9.0	9.0	9.0	9.0	9.0	9.0
G1	PP-2	TC	SP 5	NO Spheres	9.0	9.0	9.0	8.7	8.7	8.7
G2	PP-2	TC	SP 5	NO Spheres	10.0	9.7	9.7	9.7	9.7	9.7
G3	PP-2	TC	SP 5	NO Spheres	9.7	9.7	9.7	9.7	9.7	9.7
FVW	PP-2	TSC-1	AA	Spheres	10.0	10.0	10.0	10.0	10.0	9.7
FVU1	PP-2	TSC-1	AA(sb)	Spheres	10.0	10.0	9.7	9.7	9.7	9.7
FVV	PP-2	TSC-1	AA	Spheres	9.0	9.0	9.0	9.0	9.0	9.0

TABLE 7 Converted Smooth Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw (continued)

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	RUST RATINGS #					
H1	PP-2	TSC-1	SP 5	Spheres	10.0	9.7	9.7	9.7	9.7	9.0
H2	PP-2	TSC-1	SP 5(sb)	Spheres	10.0	10.0	10.0	10.0	9.7	9.7
H3	PP-2	TSC-1	SP 5	Spheres	9.0	9.0	9.0	9.0	8.7	8.7
FVX	PP-2	TSC-2	AA	Spheres	10.0	10.0	9.7	9.7	9.7	9.7
FVX1	PP-2	TSC-2	AA(sb)	Spheres	10.0	9.7	9.7	9.7	9.7	9.7
FWC	PP-2	TSC-2	AA	Spheres	9.7	9.7	9.7	9.7	9.7	9.7
I1	PP-2	TSC-2	SP 5	Spheres	10.0	9.7	9.7	9.7	9.7	9.7
I2	PP-2	TSC-2	SP 5(sb)	Spheres	10.0	10.0	10.0	10.0	9.7	9.7
I3	PP-2	TSC-2	SP 5	Spheres	8.0	8.0	8.0	7.0	7.0	7.0
FWE	Paint 25	Paint 104	AA	control	9.7	9.7	9.7	9.7	9.7	9.7
FWE1	Paint 25	Paint 104	AA	control	10.0	9.7	9.7	9.7	9.7	9.7
FVU	Paint 25	Paint 104	AA	control	9.7	9.0	9.0	9.0	9.0	9.0
J1	Paint 25	Paint 104	SP 5	control	9.7	9.7	9.7	9.7	9.7	9.7
J2	Paint 25	Paint 104	SP 5	control	10.0	9.7	9.7	9.7	9.0	8.0
J3	Paint 25	Paint 104	SP 5	control	9.7	9.0	9.0	9.0	9.0	9.0
FWG	latex	latex	AA	control	9.0	9.0	9.0	9.0	9.0	8.0
FWG1	latex	latex	AA	control	10.0	9.7	9.7	9.7	9.0	9.0
FWA1	latex	latex	AA	control	9.0	9.0	8.0	8.0	8.0	8.0
K1	latex	latex	SP 5	control	10.0	9.7	9.7	9.7	9.7	9.7
K2	latex	latex	SP 5	control	10.0	10.0	10.0	10.0	9.7	9.7
K3	latex	latex	SP 5	control	10.0	10.0	9.7	9.7	9.7	9.7
FWI	epoxy	epoxy	AA	control	10.0	10.0	10.0	10.0	9.7	9.7
FWH1	epoxy	epoxy	AA	control	10.0	10.0	10.0	10.0	10.0	10.0
FVQ	epoxy	epoxy	AA	control	10.0	9.7	9.7	9.7	9.7	9.7
L1	epoxy	epoxy	SP 5	control	10.0	10.0	10.0	10.0	10.0	10.0
L2	epoxy	epoxy	SP 5	control	10.0	10.0	10.0	10.0	10.0	10.0
L3	epoxy	epoxy	SP 5	control	10.0	10.0	10.0	10.0	10.0	10.0

TABLE 7 Converted Smooth Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw (continued)

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	BLISTER RATINGS*					
FVY	PP-1	TSC-1	AA	NO Spheres	10	10	10	10	10	10
FVZ	PP-1	TSC-1	AA	NO Spheres	10	10	10	10	10	10
FWA	PP-1	TSC-1	AA	NO Spheres	10	10	10	10	10	10
A1	PP-1	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
A2	PP-1	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
A3	PP-1	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
FVY1	PP-1	TC	AA	NO Spheres	10	10	10	10	10	10
FWF1	PP-1	TC	AA	NO Spheres	10	10	10	10	10	10
FVZ1	PP-1	TC	AA	NO Spheres	10	10	10	10	10	10
B1	PP-1	TC	SP 5	NO Spheres	10	10	10	10	10	10
B2	PP-1	TC	SP 5	NO Spheres	10	10	10	10	10	10
B3	PP-1	TC	SP 5	NO Spheres	10	10	10	10	10	10

TABLE 7 Converted Smooth Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw (continued)

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	BLISTER RATINGS*					
FVW1	PP-1	TSC-1	AA	Spheres	10	10	10	10	10	10
FWB	PP-1	TSC-1	AA(sb)	Spheres	10	10	10	10	10	10
FWB1	PP-1	TSC-1	AA	Spheres	10	10	10	10	10	10
C1	PP-1	TSC-1	SP 5	Spheres	10	10	10	10	10	10
C2	PP-1	TSC-1	SP 5(sb)	Spheres	10	10	10	10	10	10
C3	PP-1	TSC-1	SP 5	Spheres	10	10	10	10	10	10
FWD1	PP-1	TSC-2	AA	Spheres	10	10	10	10	10	10
FWC1	PP-1	TSC-2	AA(sb)	Spheres	10	10	10	10	10	10
FWD	PP-1	TSC-2	AA	Spheres	10	10	10	10	10	10
D1	PP-1	TSC-2	SP 5	Spheres	10	10	10	10	10	10
D2	PP-1	TSC-2	SP 5(sb)	Spheres	10	10	10	10	10	10
D3	PP-1	TSC-2	SP 5	Spheres	10	10	10	10	10	10
FVP	PP-1	TC	AA	Spheres	10	10	10	10	10	10
FVP1	PP-1	TC	AA(sb)	Spheres	10	10	10	10	10	10
FVR	PP-1	TC	AA	Spheres	10	6	6	6	6	6
E1	PP-1	TC	SP 5	Spheres	10	10	10	10	10	7
E2	PP-1	TC	SP 5(sb)	Spheres	10	6	6	6	6	6
E3	PP-1	TC	SP 5	Spheres	10	6	6	6	6	6
FVR1	PP-2	TSC-1	AA	NO Spheres	10	10	10	10	10	10
FVS1	PP-2	TSC-1	AA	NO Spheres	10	10	10	10	10	10
FVS	PP-2	TSC-1	AA	NO Spheres	10	10	10	10	10	10
F1	PP-2	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
F2	PP-2	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
F3	PP-2	TSC-1	SP 5	NO Spheres	10	10	10	10	10	10
FWF	PP-2	TC	AA	NO Spheres	10	10	10	10	10	10
FVT1	PP-2	TC	AA	NO Spheres	10	10	10	10	10	10
FVT	PP-2	TC	AA	NO Spheres	10	10	10	10	10	10
G1	PP-2	TC	SP 5	NO Spheres	10	10	10	10	10	10
G2	PP-2	TC	SP 5	NO Spheres	10	10	10	10	10	10
G3	PP-2	TC	SP 5	NO Spheres	10	10	10	10	10	10
FVW	PP-2	TSC-1	AA	Spheres	10	10	10	10	10	10
FVU1	PP-2	TSC-1	AA(sb)	Spheres	10	10	10	10	10	10
FVV	PP-2	TSC-1	AA	Spheres	10	10	10	10	10	10
H1	PP-2	TSC-1	SP 5	Spheres	10	10	10	10	10	10
H2	PP-2	TSC-1	SP 5(sb)	Spheres	10	10	10	10	10	10
H3	PP-2	TSC-1	SP 5	Spheres	10	10	10	10	10	10
FVX	PP-2	TSC-2	AA	Spheres	10	10	10	10	10	10
FVX1	PP-2	TSC-2	AA(sb)	Spheres	10	10	10	10	10	10
FWC	PP-2	TSC-2	AA	Spheres	10	10	10	10	10	10
I1	PP-2	TSC-2	SP 5	Spheres	10	10	10	10	10	10
I2	PP-2	TSC-2	SP 5(sb)	Spheres	10	10	10	10	10	10
I3	PP-2	TSC-2	SP 5	Spheres	10	10	10	10	10	10
FWE	Paint 25	Paint 104	AA	control	10	8	8	8	8	8
FWE1	Paint 25	Paint 104	AA	control	10	6	6	6	6	5
FVU	Paint 25	Paint 104	AA	control	10	7	7	7	7	7

TABLE 7 Converted Smooth Exposure Data, Prohesion/UV-Condensation/Freeze-Thaw (continued)

				EXPOSURE TIME (hours) ->	168	336	672	1008	1344	1704
Panel ID	Primer	Topcoat	Panel Type	Loading	BLISTER RATINGS*					
J1	Paint 25	Paint 104	SP 5	control	10	10	10	10	10	10
J2	Paint 25	Paint 104	SP 5	control	10	10	10	10	10	10
J3	Paint 25	Paint 104	SP 5	control	10	10	10	10	10	10
FWG	latex	latex	AA	control	10	6	4	4	4	4
FWG1	latex	latex	AA	control	10	8	7	7	6	6
FWA1	latex	latex	AA	control	10	6	4	4	4	4
K1	latex	latex	SP 5	control	10	10	10	10	6	6
K2	latex	latex	SP 5	control	10	5	5	5	4	4
K3	latex	latex	SP 5	control	10	5	5	5	5	5
FWI	epoxy	epoxy	AA	control	10	10	10	10	10	10
FWH1	epoxy	epoxy	AA	control	10	10	10	10	10	10
FVQ	epoxy	epoxy	AA	control	10	10	10	10	10	10
L1	epoxy	epoxy	SP 5	control	10	10	10	9	9	9
L2	epoxy	epoxy	SP 5	control	10	10	10	10	10	10
L3	epoxy	epoxy	SP 5	control	10	10	10	10	10	10

All data converted to 0 to 10 scale (see text for conversions).

AA = Aged alkyd
AA(sb) = Aged alkyd (spheres broken with sweep blast)
SP 5 (sb) = Spheres broken by sweep blast
SSPC-Vis 2 (ASTM D 610)
* ASTM D 714

PP-1 = Penetrating primer 1 (oxyrane)
PP-2 = Penetrating primer 2 (epoxy emidoamine)
TSC-1 = Thermal spray coating 1
TSC-2 = Thermal spray coating 2
TC = Zero VOC Topcoat (liquid applied)

CYCLE 1 week in prohesion (1 hour spray at 30° C; 1 hour dry at 40° C) alternating with 1 week in UV-Condensation (4 h UV at 60° C; 4 h condensation at 40° C). Use UV-A-340 lamps. All panels are in a freezer each weekend.

TABLE 8 Exposure Data - 1704 Hours, Prohesion/UV-Condensation/Freeze-Thaw

Panel ID	Primer	Topcoat	Panel Type	Loading	Rust	Blister	Rust/Blister AVERAGE	Replicate Average		Rust/Blister REP. AVE.
								Rust	Blister	
FVY	PP-1	TSC-1	AA	No Spheres	9.0	10	9.5	9.2	10.0	9.6
FVZ	PP-1	TSC-1	AA	No Spheres	9.7	10	9.9			
FWA	PP-1	TSC-1	AA	No Spheres	9.0	10	9.5			
A1	PP-1	TSC-1	SP 5	No Spheres	9.0	10	9.5	9.2	10.0	9.6
A2	PP-1	TSC-1	SP 5	No Spheres	9.7	10	9.9			
A3	PP-1	TSC-1	SP 5	No Spheres	9.0	10	9.5			
FVY1	PP-1	TC	AA	No Spheres	9.7	10	9.9	9.7	10.0	9.9
FWF1	PP-1	TC	AA	No Spheres	9.7	10	9.9			
FVZ1	PP-1	TC	AA	No Spheres	9.7	10	9.9			
B1	PP-1	TC	SP 5	No Spheres	8.7	10	9.4	9.1	10.0	9.6
B2	PP-1	TC	SP 5	No Spheres	9.7	10	9.9			
B3	PP-1	TC	SP 5	No Spheres	9.0	10	9.5			
FVW1	PP-1	TSC-1	AA	Spheres	9.7	10	9.9	9.1	10.0	9.6
FWB	PP-1	TSC-1	AA(sb)	Spheres	9.0	10	9.5			
FWB1	PP-1	TSC-1	AA	Spheres	8.7	10	9.4			
C1	PP-1	TSC-1	SP 5	Spheres	9.0	10	9.5	9.2	10.0	9.6
C2	PP-1	TSC-1	SP 5(sb)	Spheres	9.7	10	9.9			
C3	PP-1	TSC-1	SP 5	Spheres	9.0	10	9.5			
FWD1	PP-1	TSC-2	AA	Spheres	9.7	10	9.9	9.1	10.0	9.6
FWC1	PP-1	TSC-2	AA(sb)	Spheres	9.0	10	9.5			
FWD	PP-1	TSC-2	AA	Spheres	8.7	10	9.4			
D1	PP-1	TSC-2	SP 5	Spheres	8.0	10	9.0	8.3	10.0	9.2
D2	PP-1	TSC-2	SP 5(sb)	Spheres	9.0	10	9.5			
D3	PP-1	TSC-2	SP 5	Spheres	8.0	10	9.0			
FVP	PP-1	TC	AA	Spheres	9.0	10	9.5	9.5	8.7	9.1
FVP1	PP-1	TC	AA(sb)	Spheres	9.7	10	9.9			
FVR	PP-1	TC	AA	Spheres	9.7	6	7.9			
E1	PP-1	TC	SP 5	Spheres	9.7	7	8.4	9.2	6.3	7.8
E2	PP-1	TC	SP 5(sb)	Spheres	9.0	6	7.5			
E3	PP-1	TC	SP 5	Spheres	9.0	6	7.5			
FVR1	PP-2	TSC-1	AA	No Spheres	9.0	10	9.5	9.2	10.0	9.6
FVS1	PP-2	TSC-1	AA	No Spheres	9.7	10	9.9			
FVS	PP-2	TSC-1	AA	No Spheres	9.0	10	9.5			

TABLE 8 Exposure Data - 1704 Hours, Prohesion/UV-Condensation/Freeze-Thaw (continued)

Panel ID	Primer	Topcoat	Panel Type	Loading	Rust	Blister	Rust/Blister AVERAGE	Replicate Average		Rust/Blister REP. AVE.
								Rust	Blister	
F1	PP-2	TSC-1	SP 5	No Spheres	9.0	10	9.5	9.2	10.0	9.6
F2	PP-2	TSC-1	SP 5	No Spheres	9.7	10	9.9			
F3	PP-2	TSC-1	SP 5	No Spheres	9.0	10	9.5			
FWF	PP-2	TC	AA	No Spheres	8.7	10	9.4	9.1	10.0	9.6
FVT1	PP-2	TC	AA	No Spheres	9.7	10	9.9			
FVT	PP-2	TC	AA	No Spheres	9.0	10	9.5			
G1	PP-2	TC	SP 5	No Spheres	8.7	10	9.4	9.4	10.0	9.7
G2	PP-2	TC	SP 5	No Spheres	9.7	10	9.9			
G3	PP-2	TC	SP 5	No Spheres	9.7	10	9.9			
FVW	PP-2	TSC-1	AA	Spheres	9.7	10	9.9	9.5	10.0	9.7
FVU1	PP-2	TSC-1	AA(sb)	Spheres	9.7	10	9.9			
FVV	PP-2	TSC-1	AA	Spheres	9.0	10	9.5			
H1	PP-2	TSC-1	SP 5	Spheres	9.0	10	9.5	9.1	10.0	9.6
H2	PP-2	TSC-1	SP 5(sb)	Spheres	9.7	10	9.9			
H3	PP-2	TSC-1	SP 5	Spheres	8.7	10	9.4			
FVX	PP-2	TSC-2	AA	Spheres	9.7	10	9.9	9.7	10.0	9.9
FVX1	PP-2	TSC-2	AA(sb)	Spheres	9.7	10	9.9			
FWC	PP-2	TSC-2	AA	Spheres	9.7	10	9.9			
I1	PP-2	TSC-2	SP 5	Spheres	9.7	10	9.9	8.8	10.0	9.4
I2	PP-2	TSC-2	SP 5(sb)	Spheres	9.7	10	9.9			
I3	PP-2	TSC-2	SP 5	Spheres	7.0	10	8.5			
FWE	Paint 25	Paint 104	AA	control	9.7	8	8.9	9.5	6.7	8.1
FWE1	Paint 25	Paint 104	AA	control	9.7	5	7.4			
FVU	Paint 25	Paint 104	AA	control	9.0	7	8.0			
J1	Paint 25	Paint 104	SP 5	control	9.7	10	9.9	8.9	10.0	9.5
J2	Paint 25	Paint 104	SP 5	control	8.0	10	9.0			
J3	Paint 25	Paint 104	SP 5	control	9.0	10	9.5			
FWG	latex	latex	AA	control	8.0	4	6.0	8.3	4.7	6.5
FWG1	latex	latex	AA	control	9.0	6	7.5			
FWA1	latex	latex	AA	control	8.0	4	6.0			
K1	latex	latex	SP 5	control	9.7	6	7.9	9.7	5.0	7.4
K2	latex	latex	SP 5	control	9.7	4	6.9			
K3	latex	latex	SP 5	control	9.7	5	7.4			

TABLE 8 Exposure Data - 1704 Hours, Prohesion/UV-Condensation/Freeze-Thaw (continued)

Panel ID	Primer	Topcoat	Panel Type	Loading	Rust	Blister	Rust/Blister AVERAGE	Replicate Average		Rust/Blister REP. AVE.
								Rust	Blister	
FWI	epoxy mastic	epoxy mastic	AA	control	9.7	10	9.9	9.8	10.0	9.9
FWH1	epoxy mastic	epoxy mastic	AA	control	10.0	10	10.0			
FVQ	epoxy mastic	epoxy mastic	AA	control	9.7	10	9.9			
L1	epoxy mastic	epoxy mastic	SP 5	control	10.0	9	9.5	10.0	9.7	9.8
L2	epoxy mastic	epoxy mastic	SP 5	control	10.0	10	10.0			
L3	epoxy mastic	epoxy mastic	SP 5	control	10.0	10	10.0			

All data converted to 0 to 10 scale (see text for conversions).

AA = Aged alkyd
AA(sb) = Aged alkyd (spheres broken with sweep blast)
SP 5 (sb) = Spheres broken by sweep blast
Rust ratings follow SSPC-Vis 2 (ASTM D 610).
Blister ratings follow ASTM D 714.

PP-1 = Penetrating primer 1 (oxyrane)
PP-2 = Penetrating primer 2 (epoxy emidoamine)
TSC-1 = Thermal spray coating 1
TSC-2 = Thermal spray coating 2
TC = Zero VOC Topcoat (liquid applied)

CYCLE: 1 week in prohesion (1 hour spray at 30° C; 1 hour dry at 40° C) alternating with 1 week in UV-Condensation (4 h UV at 60° C; 4 h condensation at 40° C). Use UV-A-340 lamps. All panels are in a freezer each weekend.

TABLE 9 Exposure Data - 1704 Hours, Aged Alkyd Substrate, Prohesion/UV-Condensation/Freeze-Thaw

Panel ID	Primer	Topcoat	Panel Type	Loading	Rust	Blister	Rust/Blister AVERAGE	Replicate Average Rust	Replicate Average Blister	Rust/Blister REP. AVE.
FVY	PP-1	TSC-1	AA	No Spheres	9.0	10	9.5	9.2	10.0	9.6
FVZ	PP-1	TSC-1	AA	No Spheres	9.7	10	9.9			
FWA	PP-1	TSC-1	AA	No Spheres	9.0	10	9.5			
FVY1	PP-1	TC	AA	No Spheres	9.7	10	9.9	9.7	10.0	9.9
FWF1	PP-1	TC	AA	No Spheres	9.7	10	9.9			
FVZ1	PP-1	TC	AA	No Spheres	9.7	10	9.9			
FVW1	PP-1	TSC-1	AA	Spheres	9.7	10	9.9	9.1	10.0	9.6
FWB	PP-1	TSC-1	AA(sb)	Spheres	9.0	10	9.5			
FWB1	PP-1	TSC-1	AA	Spheres	8.7	10	9.4			
FWD1	PP-1	TSC-2	AA	Spheres	9.7	10	9.9	9.1	10.0	9.6
FWC1	PP-1	TSC-2	AA(sb)	Spheres	9.0	10	9.5			
FWD	PP-1	TSC-2	AA	Spheres	8.7	10	9.4			
FVP	PP-1	TC	AA	Spheres	9.0	10	9.5	9.5	8.7	9.1
FVP1	PP-1	TC	AA(sb)	Spheres	9.7	10	9.9			
FVR	PP-1	TC	AA	Spheres	9.7	6	7.9			
FVR1	PP-2	TSC-1	AA	No Spheres	9.0	10	9.5	9.2	10.0	9.6
FVS1	PP-2	TSC-1	AA	No Spheres	9.7	10	9.9			
FVS	PP-2	TSC-1	AA	No Spheres	9.0	10	9.5			
FWF	PP-2	TC	AA	No Spheres	8.7	10	9.4	9.1	10.0	9.6
FVT1	PP-2	TC	AA	No Spheres	9.7	10	9.9			
FVT	PP-2	TC	AA	No Spheres	9.0	10	9.5			
FVW	PP-2	TSC-1	AA	Spheres	9.7	10	9.9	9.5	10.0	9.7
FVU1	PP-2	TSC-1	AA(sb)	Spheres	9.7	10	9.9			
FVV	PP-2	TSC-1	AA	Spheres	9.0	10	9.5			
FVX	PP-2	TSC-2	AA	Spheres	9.7	10	9.9	9.7	10.0	9.9
FVX1	PP-2	TSC-2	AA(sb)	Spheres	9.7	10	9.9			
FWC	PP-2	TSC-2	AA	Spheres	9.7	10	9.9			

TABLE 9 Exposure Data - 1704 Hours, Aged Alkyd Substrate, Prohesion/UV-Condensation/Freeze-Thaw (continued)

Panel ID	Primer	Topcoat	Panel Type	Loading	Rust	Blister	Rust/Blister AVERAGE	Replicate Average		Rust/Blister REP. AVE.
								Rust	Blister	
FWE	Paint 25	Paint 104	AA	control	9.7	8	8.9	9.5	6.7	8.1
FWE1	Paint 25	Paint 104	AA	control	9.7	5	7.4			
FVU	Paint 25	Paint 104	AA	control	9.0	7	8.0			
FWG	latex	latex	AA	control	8.0	4	6.0	8.3	4.7	6.5
FWG1	latex	latex	AA	control	9.0	6	7.5			
FWA1	latex	latex	AA	control	8.0	4	6.0			
FWI	epoxy mastic	epoxy mastic	AA	control	9.7	10	9.9	9.8	10.0	9.9
FWH1	epoxy mastic	epoxy mastic	AA	control	10.0	10	10.0			
FVQ	epoxy mastic	epoxy mastic	AA	control	9.7	10	9.9			

All data converted to 0 to 10 scale (see text for conversions).

AA = Aged alkyd
AA(sb) = Aged alkyd (spheres broken with sweep blast)
Rust ratings follow SSPC-Vis 2 (ASTM D 610).
Blister ratings follow ASTM D 714.

PP-1 = Penetrating primer 1 (oxyrane)
PP-2 = Penetrating primer 2 (epoxy emidoamine)
TSC-1 = Thermal spray coating 1
TSC-2 = Thermal spray coating 2
TC = Zero VOC Topcoat (liquid applied)

CYCLE: 1 week in prohesion (1 hour spray at 30° C; 1 hour dry at 40° C) alternating with 1 week in UV-Condensation (4 h UV at 60° C; 4 h condensation at 40° C). Use UV-A-340 lamps. All panels are in a freezer each weekend.

TABLE 10 Analysis of Variance, Comparison of Penetrating Primer With and Without Spheres, Topcoat TSC-1, Aged Alkyd Substrate

	Degrees of Freedom	Sum of Squares	Mean Square	F-Test
Between Groups	1	0.013	0.013	0.08
Within Groups	10	1.673	0.167	p = .7835
Total	11	1.687		

	Count	Mean	Standard Deviation	Standard Error
With Spheres	6	9.300	0.452	0.184
Without Spheres	6	9.233	0.361	0.148

Model II estimate of between group variance = -0.154

Data are Rust Ratings after 1704 Hours in Cyclic Laboratory Exposure Test

TABLE 11 Three Week Pull-Off Adhesion Data*, Prohesion/UV-Condensation/Freeze-Thaw for 504 Hours

		PULL-OFF RATINGS (top)						PULL-OFF RATINGS (bottom)					
Panel	Panel	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
ID	Type	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode
FVY	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FVZ	AA	1.4	G	NT	NT	NT	NT	1.4	G	1.4	G	NT	NT
FWA	AA	1.0	G	NT	NT	NT	NT	1.0	G	2.1	G	NT	NT
A1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
A2	SP 5	NT	NT	NT	NT	NT	NT	1.7	G	0.7	G	1.0	G
A3	SP 5	NT	NT	NT	NT	NT	NT	2.1	G	2.4	G	2.4	G
FVY1	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FWF1	AA	2.8	IF	NT	NT	NT	NT	2.1	IF	2.8	G	NT	NT
FVZ1	AA	3.1	IF/S	NT	NT	NT	NT	2.8	S	2.8	S	NT	NT
B1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
B2	SP 5	NT	NT	NT	NT	NT	NT	2.1	G	2.1	G	2.1	G
B3	SP 5	NT	NT	NT	NT	NT	NT	3.1	G	4.1	G/T	3.4	G
FVW1	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FWB	AA(sb)	2.2	G	NT	NT	NT	NT	1.0	G	3.1	G	NT	NT
FWB1	AA	2.8	G	NT	NT	NT	NT	1.7	G	3.4	G	NT	NT
C1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
C2	SP 5(sb)	NT	NT	NT	NT	NT	NT	1.4	G	1.4	G	1.4	G
C3	SP 5	NT	NT	NT	NT	NT	NT	1.7	G	3.4	G	1.0	G
FWD1	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FWC1	AA(sb)	3.1	G	NT	NT	NT	NT	2.1	G	1.7	G	NT	NT
FWD	AA	2.4	G	NT	NT	NT	NT	4.1	G	2.1	G	NT	NT
D1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
D2	SP 5(sb)	NT	NT	NT	NT	NT	NT	2.9	G	3.4	G	2.1	G
D3	SP 5	NT	NT	NT	NT	NT	NT	1.4	G	1.4	G	3.4	G
FVP	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FVP1	AA(sb)	1.4	IF	NT	NT	NT	NT	2.1	IF	3.4	IF	NT	NT
FVR	AA	2.8	IF	NT	NT	NT	NT	1.4	IF	1.4	IF	NT	NT
E1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
E2	SP 5(sb)	NT	NT	NT	NT	NT	NT	0.7	G	1.4	G	1.4	G
E3	SP 5	NT	NT	NT	NT	NT	NT	2.8	G	2.4	G/S	2.8	G
FVR1	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FVS1	AA	0.7	G	NT	NT	NT	NT	1.0	G	1.0	G	NT	NT
FVS	AA	1.0	G	NT	NT	NT	NT	1.4	G	1.4	G	NT	NT
F1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
F2	SP 5	NT	NT	NT	NT	NT	NT	1.4	G	1.7	G	1.4	G
F3	SP 5	NT	NT	NT	NT	NT	NT	1.7	G	2.8	G	1.4	G
FWF	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FVT1	AA	0.7	T	NT	NT	NT	NT	0.7	IF	1.4	IF	NT	NT
FVT	AA	2.1	IF	NT	NT	NT	NT	1.7	IF	0.7	IF	NT	NT
G1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
G2	SP 5	NT	NT	NT	NT	NT	NT	1.0	T	0.7	T	1.4	T
G3	SP 5	NT	NT	NT	NT	NT	NT	1.0	G	0.7	G	2.1	G
FVW	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FVU1	AA(sb)	0.7	G	NT	NT	NT	NT	2.1	G	1.7	G	NT	NT
FVV	AA	2.1	G	NT	NT	NT	NT	2.8	G	2.1	G	NT	NT

TABLE 11 Three Week Pull-Off Adhesion Data*, Prohesion/UV-Condensation/Freeze-Thaw for 504 Hours (continued)

		PULL-OFF RATINGS (top)						PULL-OFF RATINGS (bottom)					
Panel	Panel	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
ID	Type	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode
H1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
H2	SP 5(sb)	NT	NT	NT	NT	NT	NT	2.1	G	1.0	G	1.0	G
H3	SP 5	NT	NT	NT	NT	NT	NT	2.4	G	1.4	G	2.1	G
FVX	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FVX1	AA(sb)	1.4	G	NT	NT	NT	NT	3.4	G	2.8	G	NT	NT
FWC	AA	0.7	G	NT	NT	NT	NT	2.4	G	2.1	G	NT	NT
I1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
I2	SP 5(sb)	NT	NT	NT	NT	NT	NT	2.8	T	4.5	T	2.1	T
I3	SP 5	NT	NT	NT	NT	NT	NT	1.4	G	1.4	G	1.4	G
FWE	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FWE1	AA	2.1	AP	NT	NT	NT	NT	0.7	IF	0.7	AP	NT	NT
FVU	AA	0.7	P	NT	NT	NT	NT	1.4	P	3.1	P	NT	NT
J1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
J2	SP 5	NT	NT	NT	NT	NT	NT	1.4	P	1.4	P	2.1	P
J3	SP 5	NT	NT	NT	NT	NT	NT	0.2	S	0.2	S	0.2	S
FWG	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FWG1	AA	1.4	IF	NT	NT	NT	NT	2.1	AP	2.1	AP	NT	NT
FWA1	AA	1.4	P	NT	NT	NT	NT	1.4	P	2.8	P	NT	NT
K1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
K2	SP 5	NT	NT	NT	NT	NT	NT	1.4	P	0.7	P	0.7	P
K3	SP 5	NT	NT	NT	NT	NT	NT	1.0	P	0.3	P	0.3	P
FWI	AA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
FWH1	AA	1.4	T	NT	NT	NT	NT	2.1	IF	0.7	IF	NT	NT
FVQ	AA	2.1	IF	NT	NT	NT	NT	1.4	IF	2.1	IF	NT	NT
L1	SP 5	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
L2	SP 5	NT	NT	NT	NT	NT	NT	3.4	T	2.8	T	1.7	T
L3	SP 5	NT	NT	NT	NT	NT	NT	5.5	S	4.1	S	6.2	S

1000 lb/sq in = 6.895 MPa

NT = Not Tested

* Pull-off adhesion test - ASTM D 4541
Only aged alkyd panels need 6 pull-off trials.
AA = Aged alkyd
AA(sb) = Aged alkyd sweep blasted
SP 5 (sb) = Spheres broken by sweep blast

FAILURE MODE:
G = Glue failure
AP = Failed within aged primer
AT = Failed within aged topcoat
T = Failed within topcoat
S = Failed at steel/paint interface
IF = Failed at interface between coats of paint

TABLE 12 Final Pull-Off Adhesion Data*, Prohesion/UV-Condensation/Freeze-Thaw for 1704 Hours

		Top of Aged Alkyd Panels						Bottom of Aged Alkyd Panels						
Panel	Panel	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6		
ID	Type	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode	Average
FVY	AA	1.7	G	2.1	G	0.7	G	2.8	G	2.8	G	3.4	G	2.2
FVZ	AA	2.1	G	2.1	G	1.4	G	1.4	G	1.7	G	1.4	G	1.7
FWA	AA	0.7	G	1.0	G	1.0	G	1.4	G	1.7	G	1.0	G	1.6
A1	SP 5	1.0	G	1.0	G	1.0	G							1.0
A2	SP 5	1.4	G	1.0	G	1.0	G							1.1
A3	SP 5	1.0	G	1.0	G	1.4	G							2.8
FVY1	AA	2.4	G/T	1.4	G/T	1.0	G/T	1.4	G/T	0.7	G/T	1.4	G/T	1.4
FWF1	AA	3.1	IF	4.1	IF	6.2	IF	2.4	IF	2.8	IF	2.1	IF	3.4
FVZ1	AA	0.7	G	1.4	G	1.4	G	0.7	G	1.4	G	1.4	G	1.1
B1	SP 5	1.0	G/T	1.4	G/T	1.0	G/T							1.1
B2	SP 5	2.1	G/T	1.7	G/T	1.4	G/T							1.7
B3	SP 5	1.4	G	0.7	G	1.7	G							1.2
FVW1	AA			2.8	G	1.7	G	1.4	G	1.7	G	1.4	G	1.8
FWB	AA(sb)	2.1	G/T	2.1	G	2.8	G	2.1	G	1.7	G	1.0	G	2.0
FWB1	AA	1.0	G	1.4	G	1.0	G	2.4	G	4.1	G	1.4	G	1.7
C1	SP 5	1.4	G	1.4	G	1.0	G							1.3
C2	SP 5(sb)	0.7	G	0.7	G	1.0	G							0.8
C3	SP 5	1.0	G	1.0	G	1.0	G							0.9
FWD1	AA	2.8	G	2.1	G	1.7	G			2.4	G	2.4	G	2.3
FWC1	AA(sb)	1.4	G	2.8	G	1.7	G	1.4	G	1.4	G	1.4	G	1.7
FWD	AA	1.0	G	1.4	G	1.0	G	0.7	G	1.0	G	1.4	G	1.3
D1	SP 5	2.1	G	1.4	G	4.1	G							2.5
D2	SP 5(sb)	1.7	G	0.7	G	1.4	G							1.3
D3	SP 5			1.4	G	0.7	G							1.5
FVP	AA	4.1	IF	3.4	IF	3.1	AP	6.9	AP	2.8	AP	4.8	AP	4.2
FVP1	AA(sb)	2.8	IF	3.4	AP	6.9	AP	4.1	AP	3.1	AP	4.3	AP	4.1
FVR	AA	1.4	G	1.0	G	1.4	G	1.4	G	1.4	G	1.0	G	1.3
E1	SP 5	1.4	G/T	0.7	G/T	1.4	G/T							1.1
E2	SP 5(sb)	0.7	G/T	1.4	G/T	1.0	G/T							1.0
E3	SP 5	1.4	G/T	1.7	G/T	1.7	G/T							1.9
FVR1	AA	0.7	G	0.7	G	0.7	G	0.7	G	0.7	G	0.7	G	0.7
FVS1	AA	2.1	G	1.7	G/T	1.4	G	1.4	G			1.0	G	1.5
FVS	AA	1.4	G	1.0	G	1.4	G	1.0	G	1.4	G	1.4	G	2.2
F1	SP 5	1.0	G/T	1.0	G/T	1.0	G/T							1.0
F2	SP 5	2.1	G	2.4	G	1.4	G							2.0
F3	SP 5	1.4	G	2.1	G	1.4	G							3.0
FWF	AA	2.1	G/T	1.4	G/T	1.4	G/T	1.0	G/T	5.5	G/T	1.7	G/T	2.2
FVT1	AA	4.1	IF	2.8	IF	1.7	IF	2.1	IF	1.4	IF	0.7	IF	2.1
FVT	AA	1.4	G/T	3.4	T	1.0	G/T	1.0	G/T	1.4	G/T	0.7	G/T	1.5
G1	SP 5	1.7	T	2.1	T	0.7	G/T							1.5
G2	SP 5	2.8	IF	1.4	IF	1.4	IF							1.8
G3	SP 5	1.7	G	2.8	G	2.1	G/T							2.2
FVW	AA	1.0	G	2.1	G	2.1	G	2.4	G	1.0	G	1.4	G	1.7
FVU1	AA(sb)	2.8	G	1.0	G	1.0	G	0.7	G	1.4	G	1.4	G	1.4
FVV	AA	0.7	G	1.7	G	1.0	G	1.0	G	1.4	G	1.0	G	1.6
H1	SP 5	2.1	G	0.7	G	1.0	G							1.3
H2	SP 5(sb)	2.1	G	1.4	G	1.7	G							1.7
H3	SP 5	1.0	G	1.4	G	0.7	G							2.0
FVX	AA	2.1	G	1.7	G	2.1	G	2.1	G	2.1	G	1.0	G	1.8
FVX1	AA(sb)	2.1	G	1.7	G	1.7	G	2.4	G	1.7	G	2.8	G	2.1
FWC	AA	1.4	G	1.0	G	3.8	G	1.4	G	2.8	G	1.4	G	2.5

TABLE 12 Final Pull-Off Adhesion Data*, Prohesion/UV-Condensation/Freeze-Thaw for 1704 Hours (continued)

		Top of Aged Alkyd Panels						Bottom of Aged Alkyd Panels						
Panel	Panel	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6		
ID	Type	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode	Average
I1	SP 5	2.8	G	2.8	G	2.4	G							2.6
I2	SP 5(sb)	1.4	G	1.7	G	1.4	G							1.5
I3	SP 5	1.4	G	2.1	G	2.1	G							2.4
FWE	AA	2.8	NP	4.1	NP	1.7	NP	6.2	NP	1.7	NP	3.4	NP	3.3
FWE1	AA	2.1	NP	2.8	NP	2.1	NP	2.1	NP	1.4	NP	1.0	NP	1.9
FVU	AA	1.7	P	1.7	P	1.7	P	1.7	P	2.8	P	1.4	P	1.8
J1	SP 5	2.1	NP	2.1	NP	1.4	NP							1.8
J2	SP 5	2.1	NP	2.1	NP	2.1	NP							2.1
J3	SP 5	0.7	S	1.4	S	1.4	S							1.1
FWG	AA	2.1	IF	2.1	IF	2.4	IFF	0.7	IF	1.4	IF	1.7	IF	1.7
FWG1	AA	1.7	IF	1.7	IF	2.1	IF	1.4	NP	1.4	NP	1.0	NP	1.6
FWA1	AA	2.1	IF	2.1	IF	2.1	IF	0.7	NP	0.7	NP	0.7	NP	1.4
K1	SP 5	1.4	S	2.1	S	0.7	S							1.4
K2	SP 5	1.4	IF	0.7	IF	1.7	IF							1.3
K3	SP 5	1.7	IF	0.7	IF	0.3	IF							0.9
FWI	AA	1.0	T	0.7	T	1.0	T	1.0	T	1.4	T	1.7	T	1.1
FWH1	AA	1.4	S	1.4	S	2.1	S	2.1	S	1.0	S	1.4	S	1.6
FVQ	AA	7.2	T	1.0	T	1.0	T	5.5	T	1.0	T	1.7	T	2.9
L1	SP 5	1.7	G/T	1.4	G/T	1.4	G/T							1.5
L2	SP 5	2.1	S	2.1	S	1.4	S							1.8
L3	SP 5	2.8	T	2.1	T	2.1	T							2.3

The ratings below were made on dollies attached with #910 adhesive.
These additional pull-off values are included in the averages computed above.

		Top of Aged Alkyd Panels						Bottom of Aged Alkyd Panels					
Panel	Panel	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
ID	Type	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode	MPa	mode
FWA	AA	3.8	G					2.1	G/T				
A3	SP 5	4.5	G			2.4	G	4.8	G	6.6	G	1.0	G
B3	SP 5	1.4	G					1.0	G				
FWB1	AA	1.4	G					1.0	G/AP				
C3	SP 5	0.7	G					0.5	G				
FWD	AA	1.7	G					2.1	G/AP				
D3	SP 5	3.4	G					0.3	G				
E3	SP 5	1.4	G					3.4	G/S				
FVS	AA	4.8	G/IF					5.5	G				
F3	SP 5	5.5	G/IF					4.5	IF				
FVV	AA	3.4	AP					2.1	AP				
H3	SP 5	4.5	G/IF					2.4	G				
FWC	AA	6.6	G					1.7	S				
I3	SP 5	3.4	G					3.1	G				

* Pull-off adhesion test, ASTM D 4541

AA = Aged Alkyd
AA(sb) = Sweep blasted
SP 5 (sb) = Spheres broken by sweep blast

1000 lb/sq in = 6.895 MPa

FAILURE MODE:
G = Glue failure
AP = Failed within aged primer
NP = Failed within new primer
IF = Failed at interface between coats of paint
S = Failed at steel/paint interface
T = Failed within topcoat

TABLE 13 Final Pull-Off Adhesion Data*, Aged Alkyd Substrate, Prohesion/UV-Condensation/Freeze-Thaw for 1704 Hours

		Top of Aged Alkyd Panels						Bottom of Aged Alkyd Panels						
Panel	Panel	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6		
ID	Type	lb/sq in	mode	lb/sq in	mode	lb/sq in	mode	lb/sq in	mode	lb/sq in	mode	lb/sq in	mode	AVERAGE
FVY	AA	1.7	G	2.1	G	0.7	G	2.8	G	2.8	G	3.4	G	2.2
FVZ	AA	2.1	G	2.1	G	1.4	G	1.4	G	1.7	G	1.4	G	1.7
FWA	AA	0.7	G	1.0	G	1.0	G	1.4	G	1.7	G	1.0	G	1.6
FVY1	AA	2.4	G/T	1.4	G/T	1.0	G/T	1.4	G/T	0.7	G/T	1.4	G/T	1.4
FWF1	AA	3.1	IF	4.1	IF	6.2	IF	2.4	IF	2.8	IF	2.1	IF	3.4
FVZ1	AA	0.7	G	1.4	G	1.4	G	0.7	G	1.4	G	1.4	G	1.1
FVW1	AA			2.8	G	1.7	G	1.4	G	1.7	G	1.4	G	1.8
FWB	AA(sb)	2.1	G/T	2.1	G	2.8	G	2.1	G	1.7	G	1.0	G	2.0
FWB1	AA	1.0	G	1.4	G	1.0	G	2.4	G	4.1	G	1.4	G	1.7
FWD1	AA	2.8	G	2.1	G	1.7	G	0.0		2.4	G	2.4	G	2.3
FWC1	AA(sb)	1.4	G	2.8	G	1.7	G	1.4	G	1.4	G	1.4	G	1.7
FWD	AA	1.0	G	1.4	G	1.0	G	0.7	G	1.0	G	1.4	G	1.3
FVP	AA	4.1	IF	3.4	IF	3.1	AP	6.9	AP	2.8	AP	4.8	AP	4.2
FVP1	AA(sb)	2.8	IF	3.4	AP	6.9	AP	4.1	AP	3.1	AP	4.3	AP	4.1
FVR	AA	1.4	G	1.0	G	1.4	G	1.4	G	1.4	G	1.0	G	1.3
FVR1	AA	0.7	G	0.7	G	0.7	G	0.7	G	0.7	G	0.7	G	0.7
FVS1	AA	2.1	G	1.7	G/T	1.4	G	1.4	G	0.0		1.0	G	1.5
FVS	AA	1.4	G	1.0	G	1.4	G	1.0	G	1.4	G	1.4	G	2.2
FWF	AA	2.1	G/T	1.4	G/T	1.4	G/T	1.0	G/T	5.5	G/T	1.7	G/T	2.2
FVT1	AA	4.1	IF	2.8	IF	1.7	IF	2.1	IF	1.4	IF	0.7	IF	2.1
FVT	AA	1.4	G/T	3.4	T	1.0	G/T	1.0	G/T	1.4	G/T	0.7	G/T	1.5
FVW	AA	1.0	G	2.1	G	2.1	G	2.4	G	1.0	G	1.4	G	1.7
FVU1	AA(sb)	2.8	G	1.0	G	1.0	G	0.7	G	1.4	G	1.4	G	1.4
FVV	AA	0.7	G	1.7	G	1.0	G	1.0	G	1.4	G	1.0	G	1.6
FVX	AA	2.1	G	1.7	G	2.1	G	2.1	G	2.1	G	1.0	G	1.8
FVX1	AA(sb)	2.1	G	1.7	G	1.7	G	2.4	G	1.7	G	2.8	G	2.1
FWC	AA	1.4	G	1.0	G	3.8	G	1.4	G	2.8	G	1.4	G	2.5
FWE	AA	2.8	NP	4.1	NP	1.7	NP	6.2	NP	1.7	NP	3.4	NP	3.3
FWE1	AA	2.1	NP	2.8	NP	2.1	NP	2.1	NP	1.4	NP	1.0	NP	1.9
FVU	AA	1.7	P	1.7	P	1.7	P	1.7	P	2.8	P	1.4	P	1.8
FWG	AA	2.1	IF	2.1	IF	2.4	IFF	0.7	IF	1.4	IF	1.7	IF	1.7
FWG1	AA	1.7	IF	1.7	IF	2.1	IF	1.4	NP	1.4	NP	1.0	NP	1.6
FWA1	AA	2.1	IF	2.1	IF	2.1	IF	0.7	NP	0.7	NP	0.7	NP	1.4
FWI	AA	1.0	T	0.7	T	1.0	T	1.0	T	1.4	T	1.7	T	1.1
FWH1	AA	1.4	S	1.4	S	2.1	S	2.1	S	1.0	S	1.4	S	1.6
FVQ	AA	7.2	T	1.0	T	1.0	T	5.5	T	1.0	T	1.7	T	2.9

TABLE 13 Final Pull-Off Adhesion Data*, Aged Alkyd Substrate, Prohesion/UV-Condensation/Freeze-Thaw for 1704 Hours (continued)

The ratings below were made on dollies attached with #910 adhesive.
These additional pull-off values are included in the averages computed above.

		Top of Aged Alkyd Panels						Bottom of Aged Alkyd Panels					
Panel	Panel	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
ID	Type	lb/sq in	mode	lb/sq in	mode	lb/sq in	mode	lb/sq in	mode	lb/sq in	mode	lb/sq in	mode
FWA	AA	3.8	G					2.1	G/T				
FWB1	AA	1.4	G					1.0	G/AP				
FWD	AA	1.7	G					2.1	G/AP				
FVS	AA	4.8	G/IF					5.5	G				
FVV	AA	3.4	AP					2.1	AP				
FWC	AA	6.6	G					1.7	S				

* Pull-off adhesion test, ASTM D 4541

AA = Aged Alkyd
AA(sb) = Sweep blasted
SP 5 (sb) = Spheres broken by sweep blast

1000 lb/sq in = 6.895 MPa

FAILURE MODE:
G = Glue failure
AP = Failed within aged primer
NP = Failed within new primer
IF = Failed at interface between coats of paint
S = Failed at steel/paint interface
T = Failed within topcoat

TABLE 14 Impact Threshold Data, Aged Alkyd Substrate

Panel ID	Primer	Topcoat	Panel Type	Loading	Impact Threshold (Joules)	
					Top	Bottom
FVZ	PP-1	TSC-1	AA	No Spheres	7.9	7.9
FWF1	PP-1	TC	AA	No Spheres	3.4	2.3
FWB	PP-1	TSC-1	AA(sb)	Spheres	7.9	7.9
FWB1	PP-1	TSC-1	AA	Spheres	7.9	7.9
FWC1	PP-1	TSC-2	AA(sb)	Spheres	7.9	7.9
FWD	PP-1	TSC-2	AA	Spheres	7.9	7.9
FVR	PP-1	TC	AA	Spheres	2.3	1.7
FVS1	PP-2	TSC-1	AA	No Spheres	7.9	7.9
FVT1	PP-2	TC	AA	No Spheres	1.1	1.7
FVU1	PP-2	TSC-1	AA(sb)	Spheres	7.9	7.9
FVV	PP-2	TSC-1	AA	Spheres	7.9	7.9
FVX1	PP-2	TSC-2	AA(sb)	Spheres	7.9	7.9
FWC	PP-2	TSC-2	AA	Spheres	7.9	7.9
FWE1	Paint 25	Paint 104	AA	control	0.6	1.1
FWG1	latex	latex	AA	control	0.6	0.6
FWH1	epoxy mastic	epoxy mastic	AA	control	2.3	1.7

The following data were taken after the panels were ground to a total film thickness of 380 - 460 μm (15 - 18 mils).

FWB1	PP-1	TSC-1	AA	Spheres	7.9	
FWD	PP-1	TSC-2	AA	Spheres	7.9	
FVZ	PP-1	TSC-1	AA	No Spheres	7.9	
FVX1	PP-2	TSC-2	AA	Spheres	4.0	

Prior to testing, panels were exposed for 1704 h in cyclic salt fog/UV-condensation/freeze-thaw.

The limit of the test is 7.9 Joules (70 in-lb).

AA = Aged Alkyd
AA(sb) = Sweep blasted

1 in-lb = 0.113 Joules
1 Mil = 25.4 μm

PP-1 = Penetrating primer 1 (oxyrane)
PP-2 = Penetrating primer 2 (epoxy emidoamine)
TSC-1 = Thermal spray coating 1
TSC-2 = Thermal spray coating 2
TC = Zero VOC Topcoat