Research Report

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Evaluation of PE Film

Final Report

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EXECUTIVE SUMMARY

Laboratory tests were conducted to assess the ability of a 3-mil thick adhesive-backed polyethylene film (**Polymask**) to protect vehicle paint finishes from acid-rain damage. The laboratory tests employed conditions known to be relevant to actual service conditions including: 1) automotive paints of various colors, 2) simulated acid-rain solutions (of pH values from 2.2 to 5.5), and 3) service temperatures (120 to 160 ^{0}F). Laboratory tests included cyclic evaporation and soak tests similar to those employed in a previous series of tests for Toyota (1). Cyclic evaporation tests were performed for 12 cycles and the soak tests were performed for 5 days. Two types of tests were performed: 1) permeability tests to determine the ability of acid rain to damage automotive paints through the protective coating and 2) edge tests to determine the effect of acid rain along the edge (seam) between the unprotected paint and the polyethylene film.

The permeability tests revealed that the film provided excellent resistance to permeability damage. The level of protection was superior to the acrylic polymer transit coating previously tested. However, the edges were sites of elevated damage which was more severe than for the exposed paint. Some undercutting was detected under the film. The undercutting was not prevalent at lower test temperatures and higher acid rain pH values. The edge damage might be prevented by careful placement of the seams or by caulking along the edges.

EVALUATION OF PE FILM

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prepared for Toyota Motor Sales, U.S.A., Inc.
by
University of Kentucky

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INTRODUCTION

Background

This is the second report concerning University of Kentucky (UK) evaluation of acid rain protection provided by transit coatings for Toyota Motor Sales Inc. U.S.A. The first report (1) primarily covered laboratory tests simulating acid rain exposure. Those tests were performed on steel coupons coated with automotive paints. The paint finishes were protected by an acrylic polymer material employed by Toyota Motor Manufacturing as a transit coating. That investigation revealed that the acrylic polymer coating provided a modest level of paint protection. That level of protection was almost constant through the range of pH test values to which the paint coupons were exposed. The susceptibility of a paint (either coated with the acrylic polymer or uncoated) to acid rain damage decreased rapidly when exposed to acid rains having pH values less than 4.0. The level of protection afforded by the acrylic polymer was of concern since the pH of rain in the area of the Georgetown, Kentucky Toyota plant was sometimes less than 4.0.

That research did not involve significant field testing. During the period of the test program (September 1989 to August 1991), environmental conditions in the Georgetown area were not conducive to low pH rainfall (acid rain). Acid-rain conditions are typified by long dry periods followed by light rainfall of short duration. UK laboratory tests indicated that the potential for acid-rain damage was exacerbated by higher temperatures. On a moderate, sunny day, the surface temperatures of dark vehicles stored at the Toyota marshalling yard exceeded 150 ^{0}F. Mild weather was experienced during the summer and fall of 1990 when the UK field tests were initiated. Paint coupons coated with the acrylic polymer experienced increasing levels of acid-rain damage during extended periods of field exposure.

The initial UK report concluded that pH was the controlling factor related to acid-rain damage of automotive finishes. The evaporation process was also determined to be almost a prerequisite for acid-rain damage. UK researchers suspected that evaporation allowed the pH value of a raindrop to decrease. That decrease would be due to the increased concentration of hydrogen ions in the diminishing volume of a gradually evaporating raindrop. It was suspected that evaporation would allow the pH in the raindrop to decrease to a level where it would penetrate the acrylic polymer coating and damage the underlying paint. The evaporation of acid rain may also entail other damage mechanisms.

UK researchers acquired a microelectrode and pH meter to conduct field measurements on raindrops deposited on vehicles at the Toyota marshalling yard. That work was not begun prior to the completion of the study, and the microelectrode and pH meter were turned over to Vehicle Processors Inc. (VPI) personnel at the marshalling yard.

Recent Related Events

In the summer of 1991, VPI personnel used the microelectrode and pH meter to measure the pH of raindrops on vehicle finishes as the drops evaporated. Measurements by VPI personnel confirmed the suspicions of UK researchers regarding the effect of evaporation on raindrop acidity. With continued evaporation, the raindrops decreased in size and their pH values decreased markedly. Those findings were significant since the initial pH readings of the raindrops were not extraordinarily low, yet the pH values of the partially evaporated raindrops were sufficiently low to cause paint damage regardless of the presence of the acrylic polymer coating.

Since the publication of the initial report, UK researchers also measured the pH values of soils at typical locations around the Toyota plant and marshalling yard at Georgetown, Kentucky and found them to be relatively basic in most instances (2). When those soils were deposited upon automobile surfaces, they had a neutralizing effect on acid rain.

New Transit Coatings

Automobile manufacturers are continuing to seek better means of protecting vehicles to be shipped from the factory to dealerships. A recent article in an automotive trade journal, **Automotive News**, reviewed this effort in detail (3). That article provided many useful insights into problems related to transit coating performance and indicated a number of different approaches to resolving the problem. Among the more promising methods mentioned was the use of a polyethylene sheet having an adhesive backing. The material, termed **Polymask**, offered several advantages over sprayed-on acrylic polymers. Among the most important of those were: 1) high impermeability offered by a pre-manufactured resin, 2) better control of protective coverage, and 3) ease of removal once a vehicle has reached its destination.

Toyota Motor Sales Inc., U.S.A., desired to conduct acid-rain tests on the **Polymask** film to determine whether it offered protection against acid-rain damage. The University of Kentucky Transportation Center contracted with Toyota Motor Sales Inc., U.S.A., to conduct a brief study to test and assess the acid-rain damage of the **Polymask** protective film.

LABORATORY TESTING

Test Factors

UK researchers elected to conduct acid-rain damage tests similar to those performed during the preceding study (1). Cyclic evaporation and soaking tests were selected due to: 1) their proven ability to damage vehicle finishes when used with both simulated and actual acid rain, 2) UK researchers experience in performing those tests, and 3) the ability to relate the laboratory tests to actual field events (4,5).

Toyota Motor Manufacturing furnished some steel specimens coated with standard automotive paint for use in the new test program. For convenience, some painted specimens remaining from the previous study were also utilized.

The effect of paint color was not investigated as thoroughly in the latter experiments. The painted specimens furnished for the tests varied in color and prevented UK researchers from using similar paint colors for each type of test. The only tests that involved different colors were the cyclic evaporation edge tests conducted at 140 ^{0}F. Those tests did not reveal significant differences in damage for three different colors (white, light blue, and dark blue).

Results from the preceding test program revealed that simulated and actual acid rain caused similar damage to the paints and coatings. Therefore, either type of acid-rain solution could be used for the new test program. Simulated acid-rain solutions remaining from the preceding study were employed since they closely approximated the pH values desired for the tests. The **Polymask** tests were to be conducted using three pH values: 2.5, 3.2, and 3.7. The two higher pH levels were typical of aggressive acid rains that might be encountered at the Toyota marshalling yard. The lowest pH value was improbable for a rain event, but its level of acidity had been measured on evaporating raindrops on vehicles at the marshalling yard. UK researchers also believed that acid rain having a pH of 2.5 would be sufficiently aggressive to attack older paints that had more completely polymerized. A slightly wider range of pH values was employed in the cyclic evaporation edge tests conducted at 140 ^{0}F. The pH values used for those tests were 2.2, 3.7, 4.6, and 5.5. Those were the initial edge tests performed and a wider range of pH values was selected to allow UK researchers to become acquainted with the effect of acid rain evaporating at the edge of the film.

During the previous test program, temperature was determined to affect acid-rain damage, with higher test temperatures being more aggressive at pH values below 4.0 (6). Three test temperatures 120, 140, and 160 ^{0}F were selected as being representative of possible vehicle surface temperatures that might be encountered. Those temperatures had been previously measured on vehicles at the Toyota marshalling yard (7). The color of the **Polymask** film would probably affect vehicle surface temperature. However, Toyota Motor Sales personnel informed UK researchers that they intended to employ the coating on horizontal surfaces. Therefore, the vertical sides of a vehicle might be exposed to direct sunlight and thereby increase the surface temperature.

The **Polymask** film was 3-mil nominal thickness polyethylene sheet manufactured by the Polymask Corporation of Conover, NC. The top face of the film was white. That color reflected sunlight which would help reduce vehicle surface temperature. Since acid-rain damage to vehicle finishes appears to be affected by vehicle surface temperature, this light color would be beneficial in suppressing acid-rain damage. The back face of the film had a sticky adhesive that securely attached the film to a smooth surface.

Test Procedures

Two specific specimen configurations were employed for both the cyclic evaporation and soak tests. The first configuration was intended to be a permeability test. The second test configuration was an edge test.

The first test was performed by overlaying paint specimens with the **Polymask** film, completely covering the specimen. The film was hand pressed firmly on the painted surface of a specimen. The specimen was placed with the film exterior surface laying face up in a flat tray. A drop (0.02 ml) of acid-rain solution was placed on the film centered on the specimen. The specimen was then placed in a test oven and the drop was evaporated at the specific test temperature. For the cyclic evaporation permeability tests, this procedure was repeated 12 times (cycles). For the soaking permeability tests, the same specimens and films were reused (see below). A drop of acid-rain solution was placed on the film and the specimen was placed in the oven for a 5-day period.

The edge test was intended to determine the effect of acid rain along the seam of the film. A strip of the film was firmly pressed on a specimen covering one half of the painted surface. The specimen was placed with the partially exposed paint surface laying face up in a flat tray. A drop of acid-rain solution was placed at the line between the exposed paint and the edge of the film. The specimen was then placed in a test oven and evaporated at the specific test temperature. For the cyclic evaporation edge tests, this procedure was repeated 12 times (cycles). For the soaking edge tests, a drop of acid-rain solution was placed at the line between the painted surface and the film. The specimen was placed in the oven for a 5-day period.

One set of cyclic evaporation edge tests was conducted using white painted specimens which were mounted in a vertical position with the seam running vertically. To test those specimens, 4 drops of acid-rain solution with a pH of 3.2 were deposited at the top of the specimen at the seam. The drops ran down the seam when they were deposited. Thereafter, the specimens were placed in the oven in a vertical position for testing at 140 ^{0}F. After the specimens had been in the oven for a sufficient time to ensure evaporation, they were removed and additional applications of acid rain and subsequent evaporation tests were repeated in the oven until 12 evaporation cycles were achieved.

Visual Inspections

Inspection of test specimens for acid-rain damage was to be performed using visual examination similar to that employed during the previous tests (8). After the tests were completed, the specimens were removed from the oven and visually inspected. For the permeability tests, the inspectors looked for obvious indications of acid-rain damage (etching). For the edge tests, the inspectors looked for damage to: 1) the exposed painted surfaces (an indication that acid-rain damage would be present), 2) the seam between the film and paint, and 3) damage of paint covered by the plastic film. Nomenclature used for previous inspections was employed (i.e. "D" for visible damage confirmed by both inspectors, "PD" for visible damage where the two inspectors disagreed, and "ND" where both inspectors did not observe damage).

TEST RESULTS

Cyclic Evaporation and Soak Permeability Tests

Inspections of the surface of the **Polymask** film after the cyclic evaporation permeability tests were completed revealed crustaceous deposits on the surface of the film indicating the acid rain had evaporated. Close inspections on both faces of the film did not reveal acid-rain damage. None of the painted surfaces under the film had acid-rain damage (Table 1). Therefore, UK researchers elected to re-use the **Polymask** film and specimens for the permeability soak tests. Inspections of those specimens after the soak tests revealed the film and specimens were not damaged by the acid-rain solutions (Table 2).

Cyclic Evaporation Edge Tests

The cyclic evaporation edge tests had a dramatic effect on specimen damage. Damage was detected at temperatures as low as 120 ^{0}F and for pH values as high as 5.5. The presence of seams (edges) had an escalating effect on the occurrence of visible damage. For acid rains solutions tested at 120 °F, damage was detected on the exposed surface of all specimens (Table 3). Nearly all of those specimens had visible damage along the edge. That damage typically appeared as a straight scribed groove. Some specimens tested at a pH of 2.5 had paint damage that occurred under the adhesive surface of the film. That indicated that either the adhesive was not bonded well to the paint in some instances or that corrosive attack penetrated under the film. That damage was termed undercutting.

Inspection of cyclic evaporation edge tests conducted at 140 ^{0}F revealed that low pH (2.2) acid rain caused extensive damage at the exposed painted surface, along the edge of the film/paint seam, and under the film coated surface (Table 4). With increasing pH values, the extent of damage decreased at all locations (Tables 5 to 7). The greatest decrease was in undercutting damage. At an acid-rain pH of 4.6, only two dark blue specimens had undercutting damage. At an acid-rain pH of 5.5, none of the specimens had undercutting damage. However, for both pH values, the edge damage was more prevalent than the damage detected in the completely exposed paint.

The cyclic evaporation edge tests conducted at 120 and 160 ^{0}F had similar levels of damage at equivalent pH test values (Table 8).

The edge tests conducted with the seam running vertically did not result in a reduction in edge-related damage (Table 9). For those tests, the exposed paint on only one specimen revealed any damage. However, edge damage was noted on every specimen and undercutting damage was detected on 4 of 5 specimens.

Soak Edge Tests

The soak edge tests did not demonstrate a relationship between temperature and acid-rain damage (Tables 10 to 12). At 120 ^{0}F, acid-rain solutions having pH values of 2.5 and 3.2 did not cause any damage to the exposed paint surfaces. However, the acid rain having a pH of 3.7 damaged every exposed painted surface. All of the specimens had edge damage, but no undercutting damage was detected. For soak edge tests conducted at 140 ^{0}F, damage was noted on exposed paint at each acid-rain pH value. The exposed areas of all specimens tested having pH values of 2.5 were damaged. All specimens except one tested at a pH value of 3.7 had edge damage. None of those specimens had undercutting damage. For soak edge tests conducted at 160 ^{0}F, all of the exposed paint and all of the edges showed damage for the three pH test exposure levels. None of the specimens showed definite signs of undercutting damage.

CONCLUSIONS

The **Polymask** demonstrated excellent impermeability to acid rain and appeared to prevent acid-rain damage in the range of pH values studied. At the pH levels of acid-rain solutions employed, cyclic evaporation and soak permeability tests were known to be capable of penetrating conventional acrylic polymer transit coatings and damaging the underlying paint. The performance of the **Polymask** coating represents a significant increase in protection over the conventional transit coatings.

A major problem may occur along edges of the film if acid rain contacts that area. Apparently, capillary action occurs along an edge and retains the moisture. Also, the level of damage along film edges appears to be magnified over the level of damage that is experienced by exposed painted surfaces. Since the edges of the film were straight, the edge damage was easy to detect. Both vertical and horizontal film edges appear to be problem areas. Also, attention should be given to properly contacting the adhesive backing of the film to the paint along the seam to prevent undercutting damage. The edge damage might be prevented by careful location of the seams or by caulking.

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Table 1. Cyclic Permeability Test Results (5 tests for each data point).

D = damage PD = possible damage ND = no damage

120°F	pH = 2.5	pH = 3.2	pH = 3.7
#1	ND	ND	ND
#2	ND	ND	ND
#3	ND	ND	ND
#4	ND	ND	ND
#5	ND	ND	ND

140°F	pH = 2.5	pH = 3.2	pH = 3.7
#1	ND	ND	ND
#2	ND	ND	ND
#3	ND	ND	ND
#4	ND	ND	ND
#5	ND	ND	ND

160°F	pH = 2.5	pH = 3.2	pH = 3.7
#1	ND	ND	ND
#2	ND	ND	ND
#3	ND	ND	ND
#4	ND	ND	ND
#5	ND	ND	ND

Table 2. Soak Permeability Test Results for 120, 140, & 160^{0}F at 5 Days (5 tests for each data point).

D = damage PD = possible damage ND = no damage

120^{0}F	**pH = 2.5**	**pH = 3.2**	**pH = 3.7**
#1	ND	ND	ND
#2	ND	ND	ND
#3	ND	ND	ND
#4	ND	ND	ND
#5	ND	ND	ND

140^{0}F	**pH = 2.5**	**pH = 3.2**	**pH = 3.7**
#1	ND	ND	ND
#2	ND	ND	ND
#3	ND	ND	ND
#4	ND	ND	ND
#5	ND	ND	ND

160^{0}F	**pH = 2.5**	**pH = 3.2**	**pH = 3.7**
#1	ND	ND	ND
#2	ND	ND	ND
#3	ND	ND	ND
#4	ND	ND	ND
#5	ND	ND	ND

Table 3. Cyclic Evaporation Edge Test Results for 120^{0}F (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

pH = 2.5	**A**	**B**	**C**
#1	D	D	D
#2	D	D	D
#3	D	D	PD
#4	D	D	D
#5	D	D	D

pH = 3.2	**A**	**B**	**C**
#1	D	D	ND
#2	D	D	ND
#3	D	D	ND
#4	D	D	ND
#5	D	D	ND

pH = 3.7	**A**	**B**	**C**
#1	D	D	PD
#2	D	PD	ND
#3	D	D	ND
#4	D	D	ND
#5	D	D	ND

Table 4. Cyclic Evaporation Edge Test Results for 140 ^{0}F & pH = 2.2 (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

Lt Blue	A	B	C
#1	D	D	D
#2	D	D	D
#3	D	D	D
#3	D	D	PD
#5	D	D	D

Dk Blue	A	B	C
#1	D	D	D
#2	D	D	D
#3	D	D	D
#4	D	D	D
#5	D	D	D

White	A	B	C
#1	D	D	PD
#2	D	D	ND
#3	D	D	PD
#4	D	D	D
#5	D	D	ND

Table 5. Cyclic Evaporation Edge Test Results for 140 ^{0}F & pH=3.7 (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

Lt Blue	**A**	**B**	**C**
#1	D	D	D
#2	ND	PD	PD
#3	ND	D	PD
#3	PD	D	ND
#5	D	D	ND

Dk Blue	**A**	**B**	**C**
#1	PD	PD	PD
#2	PD	D	ND
#3	ND	D	D
#4	ND	ND	ND
#5	PD	PD	ND

White	**A**	**B**	**C**
#1	D	D	ND
#2	PD	D	ND
#3	ND	PD	ND
#4	D	D	ND
#5	D	D	PD

Table 6. Cyclic Evaporation Edge Test Results for 140 ^{0}F & pH = 4.6 (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

Lt Blue	A	B	C
#1	ND	PD	ND
#2	ND	PD	ND
#3	PD	PD	ND
#4	ND	ND	ND
#5	ND	D	ND

Dk Blue	A	B	C
#1	ND	PD	ND
#2	PD	PD	ND
#3	PD	PD	ND
#4	D	D	D
#5	D	D	D

White	A	B	C
#1	ND	PD	ND
#2	ND	ND	ND
#3	ND	ND	ND
#4	ND	PD	ND
#5	ND	PD	ND

Table 7. Cyclic Evaporation Edge Test Results for 140 ^{0}F & pH = 5.5 (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

Lt Blue	A	B	C
#1	ND	PD	ND
#2	ND	D	ND
#3	ND	PD	ND
#3	ND	PD	ND
#5	ND	D	ND

Dk Blue	A	B	C
#1	ND	D	ND
#2	ND	ND	ND
#3	ND	ND	ND
#4	ND	ND	ND
#5	ND	ND	ND

White	A	B	C
#1	ND	D	ND
#2	ND	D	ND
#3	ND	D	ND
#4	ND	ND	ND
#5	ND	D	ND

Table 8. Cyclic Evaporation Edge Test Results for 160°F & pH values = 2.5, 3.2, & 3.7 (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

pH = 2.5	**A**	**B**	**C**
#1	D	D	D
#2	D	D	D
#3	D	D	PD
#4	D	D	ND
#5	D	D	ND

pH = 3.2	**A**	**B**	**C**
#1	D	D	ND
#2	D	D	ND
#3	D	D	ND
#4	D	D	ND
#5	D	D	D

pH = 3.7	**A**	B	**C**
#1	D	D	ND
#2	D	D	PD
#3	D	D	ND
#4	D	D	ND
#5	D	D	ND

Table 9. Cyclic Evaporation Vertical Edge Test Results for 140 ^{0}F & pH=3.2 (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

Sample #	**A**	**B**	**C**
1.	D	D	D
2.	ND	D	D
3.	ND	D	ND
4.	ND	D	D
5.	ND	D	D

Table 10. Soak Edge Test Results for 120°F and 5 days (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

pH = 2.5	A	B	C
#1	ND	D	ND
#2	ND	D	ND
#3	ND	D	ND
#4	ND	D	ND
#5	ND	D	ND

pH = 3.2	A	B	C
#1	ND	D	ND
#2	ND	D	ND
#3	ND	D	ND
#4	ND	D	ND
#5	ND	D	ND

pH = 3.7	A	B	C
#1	D	D	ND
#2	D	D	ND
#3	D	D	ND
#4	D	D	ND
#5	D	D	ND

Table 11. Soak Edge Test Results for 140⁰F and 5 days (5 tests for each data point).

~~A = damage to exposed paint section~~
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

pH = 2.5	**A**	**B**	**C**
#1	D	D	ND
#2	D	D	ND
#3	D	D	ND
#4	D	D	ND
#5	D	D	ND

pH = 3.2	**A**	**B**	**C**
#1	D	D	ND
#2	ND	D	ND
#3	D	D	ND
#4	ND	D	ND
#5	ND	D	ND

pH = 3.7	**A**	**B**	**C**
#1	ND	D	ND
#2	ND	D	ND
#3	D	D	ND
#4	D	D	ND
#5	ND	ND	ND

Table 12. Soak Edge Test Results for 160^{0}F and 5 days (5 tests for each data point).

A = damage to exposed paint section
B = damage along edge of film
C = undercutting damage

D = damage PD = possible damage ND = no damage

pH = 2.5	A	B	C
#1	D	D	PD
#2	D	D	ND
#3	D	D	ND
#4	D	D	ND
#5	D	D	ND

pH = 3.2	A	B	C
#1	D	D	ND
#2	D	D	ND
#3	D	D	ND
#4	D	D	ND
#5	D	D	PD

pH = 3.7	A	B	C
#1	D	D	ND
#2	D	D	ND
#3	D	D	ND
#4	D	D	ND
#5	D	D	ND