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Research Report

AN ACCELERATED TEST FOR THE CRACKING OF HOUSE PAINT ON WOOD

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AN ACCELERATED TEST FOR THE CRACKING OF HOUSE PAINT ON WOOD

INTRODUCTION:

One of the most serious shortcomings of emulsion house paint is the fact that it fails rapidly by cracking and flaking when applied to old paint in poor condition. Linseed oil house paint may give relatively good performance over the same surface. For instance in the 1956 house tests, on two houses where the old paint showed extensive flaking, #50 Acrylic White has fallen to ratings of 6 and 5 for film integrity, while the linseed oil control, #42 Outside White, is still rated 9. This is the difference between a paint that has failed badly and one that is still in good condition. As a result of such observations, #50 Acrylic White is recommended only for application to bare wood with a coat of the solution-type #38 Primer as a first coat.

Project P-2191 has been established to develop an emulsion house paint which will be at least equal in durability to linseed oil for repaint work, regardless of the condition of the previous paint. As part of this Project, it has been desirable to develop an accelerated test for the failure of emulsion house paint by cracking. The work has led to a better understanding of the mechanism of failure of house paint in general.

OBJECTIVE:

Develop an accelerated test for the typical failure of emulsion house paint over old paint.

SUMMARY AND CONCLUSIONS:

Mechanism of cracking

In general, house paint either of the linseed oil type or of the emulsion type cracks when the wood substrate swells by absorption of moisture. Since fresh films of most house paint compositions have sufficient elongation to stretch without breaking when the wood swells, cracking occurs only after the film has been embrittled by a period of weathering.

The problem of cracking is particularly acute with emulsion paint for two reasons:

(1) Emulsion films of the type of #50 Acrylic White are highly permeable to liquid water, so that the wood absorbs more water than it would under a solution-type film.

(2) At low temperature (30°F), #50 Acrylic White has less elongation than linseed oil house paint before weathering and falls to a very low value after weathering.

Accelerated Test for Cracking

The tendency for emulsion paint to crack over old house paint in poor condition can be determined by exposing suitable panels in the AWC-2 accelerated weathering cycle. The panels consist of wooden house siding on which the old paint has begun to flake. The siding is cut into small pieces, and only pieces on which the old paint is flaking are selected for use. Several different lots of weathered siding have been used, some taken from a demolished house and some consisting of test fence exposure panels. As is to be expected, there may be large variation from specimen tospecimen, so that it is necessary to expose several replicates and to treat the results statistically. This test consistently shows linseed oil house paint to be superior to #50 Acrylic White when they are compared over old flaking paint, in agreement with the tests on houses.

We expect that the reproducibility of the test will be improved by greater care to seal the back and edges of the wooden panels against the entry of water. It is also possible in the future that specifications can be set up for elongation and permeability of the weathered film, so that it will be unnecessary to expose the paint on wooden panels for accelerated evaluation.

Leads Toward Improvement of Emulsion House Paint

A number of polymers with better elongation have been prepared by Dr. Cummings in another phase of this project. A paint based on the best of them, HA polymer, is much better than #50 Acrylic White in the cracking test over old paint. It has better elongation than linseed oil before and after weathering, but its permeability is still high. The permeability of emulsion films can be greatly reduced by the use of a portion of drying oil in the binder as recommended by Elchem Department, the Dow Chemical Company, and others. The use of volatile coalescing agents, compatible plasticizers and pigments that would give a tightly packed film are other possibilities.

ACTION TAKEN:

The mechanism of cracking of house paint is under further investigation to determine the desirable levels of permeability and elongation of the paint film.

The HA polymer, which shows a definite improvement in the cracking test, is being prepared on a semiplant scale for field testing.

The test will be used to evaluate other systems, particularly to follow the leads toward lower water permeability.

PATENT SITUATION:

No patents are involved in the method of evaluating emulsion house paint. The possibility of patents on composition will be considered in other parts of this project.

PUBLICATIONS PROPOSED:

Since this work is primiarily of commercial interest, no publication is proposed.

DISCUSSION:

General Mechanism of Cracking of House Paint on Wood

In Exposure Series #17663 experiments have been carried out to confirm the view that cracking is caused by swelling of the wood substrate when it absorbs water. A number of solution type linseed oil and alkyd house paints were made up with variations in composition that were expected to lead to failure by cracking or checking on wood. Films were applied to flat grain white pine and exposed in the accelerated weathering cycle. Although a number of compositions in this study were known to have poor durability, none of them showed appreciable failure up to 1000 hours exposure on white pine panels in the AWC-II accelerated cycle. All the films lasted 2000 hours on aluminum panels with the exception that erosion of two of the alkyd paints occurred toward the end of the exposure. None of the paints showed cracking or checking. This demonstrates that mere exposure to the accelerated weathering cycle will not produce cracking.

One set of panels was removed after 300 hours accelerated weathering. The strippable coating that protected the back and edges from the entry of water was removed and the panels were then soaked in water at 40°F. Severe cracking occurred with the less distensible films, and definite cracking occurred in all but one of the linseed oil paints. The data are shown in Table I. They demonstrate that cracking of the film results from swelling of the wood.

Cracking of the film takes place the first time the wood swells. The cracks sometimes close and become less visible when the wood dries out. Repeated soaking and drying has little further effect.

In the experiments described here, the panels were always soaked at 40°F, since the films are less distensible at low temperature than at room temperature. It is possible that cracking would occur to almost the same extent if the panels were soaked at room temperature, but no experiments have been carried out to decide whether the temperature of soaking is important.

Embrittlement of the film by the process of weathering is a necessary part of the mechanism for typical house paint compositions. When fresh films on flat grain white pine were soaked in the same manner, no cracking occurred.

Additional experiments show that neither absorption of water by the film itself nor low temperature are sufficient to cause cracking. There was no film failure when weathered films on aluminum were repeatedly soaked and dried, nor when films on wood were repeatedly cooled to 0°F.

Grain Raising of Emulsion Paint on Bare Wood

Two emulsion paints, 389-095 #50 Acrylic House Paint, and an experimental paint with Lytron-680 latex, were included in Series 17663. Data are included in Table I. These paints showed microscopic cracking after 300 hours exposure in the accelerated weathering cycle and had reached a stage of visual failure after 1000 hours exposure. Microscopic examination shows that the wood fibers below the paint film swell and produce a very rough surface with sharp angles; the paint cracks at the swollen fibers, and the cracks grow progressively larger. This is the same failure that occurs outdoors when emulsion paints are applied direct to wood. Deliberate soaking of the panel does not increase failure, apparently because the surface of the wood has reached maximum swelling by the water that has been absorbed during weathering through the film of emulsion paint.

Performance Over Old Paint That Has Begun to Flake

Data from Exposure Series #17789 and 17867 are presented in Tables II and III to illustrate the accelerated test for the cracking of emulsion house paint over old paint that has begun to flake. The test paints included (1) 301-918 #40 Outside White as a typical linseed oil house paint, (2) an alkyd solution-type house paint similar to the alkyd house paint tested extensively 25 years ago, (3) #50 Acrylic White, (4) the Lytron-680 paint, and (5) 389-016 an emulsion house paint in which the binder consists of polyvinyl acetate, alkyd resin and plasticizer.

The data in Table II are for films that were painted over white pine siding that had been taken from a demolished house. The siding had a thick coating of old house paint which had begun to flake. The siding was planed to 1/2" thickness and was cut in pieces 2-7/8 x 3-1/2" to fit the accelerated weathering apparatus. Specimens were selected on which part of the surface was bare because of the flaking of the old paint. These specimens were then recoated with the test paint and exposed in the AWC-II accelerated weathering cycle.

Failure was rapid on this substrate. The data at 300 hours exposure are presented because they show the greatest spread between the solution type controls and the emulsion paints. The exposure was actually continued to 1000 hours with progressive. failure between 300 and 1000 hours. At 300 hours, linseed oil house paint and the alkyd paint showed little or no failure on most of the specimens. The alkyd modified polyvinyl acetate, 389-016, was intermediate. #50 Acrylic White and the Lytron-680 paint had cracked badly on all speciments.

The wide panel-to-panel variation in the cracking of linseed oil or alkyd house paint may be explained by the fact that the system of sealing the back and edges of the panel was not completely effective. As discussed below, the linseed oil and alkyd paints owe their superiority to their low permeability toward water. Later evidence from Series 17867 indicates that some panels become saturated by water entering from the back; when this happens, the effect of the permeability of the test paint is lost.

Table III presents data for a second type of substrate. In this case, the wood siding was bevelled yellow pine which had been coated with linseed oil house paint of the type of #40 Outside White and exposed 45°S on the test fence in Texas until the film had failed by flaking. Specimens were cut from these exposure panels and recoated with the same set of test paints. Since failure was somewhat slower on this substrate, the results shown in Table III are for 1000 hours exposure in the accelerated weathering cycle. The order of the paints is the same as in Table II. On this type of panel, none of the specimens coated with linseed oil paint or the alkyd house paint had failed at 1000 hours, while all panels with #50 Acrylic White or with the Lytron-680 paint showed some degree of failure. The alkyd modified polyvinyl acetate paint was again intermediate.

The elongation and permeability of the test paints are shown in Table IV in comparison with the order of performance over old paint in the exposure test. The permeability shown here is permeability to liquid water; see the section on "Details" for a discussion of the measurement of permeability. There is an obvious correlation between the permeability to liquid water and the resistance to cracking when exposed over old flaking paint. The AWC-II cycle keeps the panel almost continuously wet, so that there is opportunity for liquid water to penetrate the film and to saturate the wood underneath if the film has high permeability. This explains why mere exposure to the accelerated cycle is sufficient to produce cracking of some of the films, and no additional soaking procedure is found necessary.

There is no direct correlation between elongation and the resistance to cracking in this set of paints. However, it is noteworthy that the paint with the lowest elongation, 389-016, forms wider cracks than the other emulsion paints, although they are fewer in number.

The Performance of Experimental Emulsion Systems

Table V lists a number of experimental emulsion systems and solution type controls tested in Series #17867. The substrate is the same as in Table III - yellow pine coated with a linseed oil house paint of the type of #40 and exposed in Texas until flaking had occurred. The table includes the permeability of the test paints to liquid water and the elongation of weathered and unweathered films.

The specimens were weighed at intervals to determine the amount of water absorbed. There were a number of cases where panels which were presumably replicates differed greatly in the amount of water absorbed. Leaks through the back or edges are suspected in these cases.

The relations between the paints are best shown by plotting the degree of cracking versus the amount of water absorbed. This is done in Figure I for cracking at 1000 hours in the AWC-II accelerated weathering cycle.

The test paints fall into four general groups:

(1) Linseed oil and alkyd solution paints prevent the entrance of water, so that the distensibility of the paint film is not a controlling factor. For the one panel in this group that shows bad cracking, the specimen had absorbed more water than is needed to produce maximum swelling; in this case there was presumably a leak in the backing material. It is also noteworthy that one specimen coated with linseed oil paint (System #9) absorbed 15% of water but showed no cracking although the wood was close to saturation and must have approached the maximum degree of swelling.

(2) Solution type primers under #50 Acrylic White or systems in which drying oil is added to the first coat of #50 Acrylic White are very much less permeable to liquid water than is #50 Acrylic White self primed. In general, the special primer prevents the wood from becoming saturated. In the cases where the wood absorbs enough water to become saturated, the film shows about as much cracking as would be expected from #50 Acrylic White self primed.

The alkyd-modified polyvinyl acetate emulsion paint 389-016 (System #6) belongs to the same group. It shows much less permeability to liquid water than does #50 Acrylic White.

(3) The experimental methacrylate copolymers made for this project have higher elongation than Rhoplex AC-33, the vehicle in #50 Acrylic White, but they have equally high permeability to liquid water. HA polymer is outstanding in this group; it shows little cracking even on a specimen where the wood is saturated. The group in general shows slightly less cracking than #50 Acrylic White at an equal degree of water absorption.

(4) #50 Acrylic White falls in a class with paints at higher pigment volume either with Rhoplex AC-33 as vehicle or with HA polymer. These paints show cracking even for specimens where the water absorption is low enough not to cause maximum swelling, and they show relatively worse cracking on the speciments that have become saturated with water. The observation that #50 Acrylic White falls in a class with paints at higher pigment volume suggests that the paint is formulated above the critical volume concentration for this particular blend of pigments. It is to be expected that some improvement in resistance to cracking can be made merely by a change in pigmentation. Later measurements not reported here in detail show that a reduction in the pigment volume of #50 Acrylic White from 30% to 20% brings the permeability to liquid water to a much lower value.

The high permeability to liquid water that characterizes #50 Acrylic White and the paints made with the experimental emulsion polymers suggests that the films are not completely coalesced. The films become porous in some manner when they are saturated with water, and water passes through them by a process of percolation rather than by molecular diffusion. Data for the emulsion films containing drying oil and for the alkyd modified paint 389-016 show that emulsion paints can be made in which the permeability to liquid water is not greater than the permeability to water vapor. Low permeability to liquid water will be one of the properties sought in an improved emulsion house paint.

EXPERIMENTAL DETAILS:

Composition:

The experimental emulsion paints discussed in this report have the same pigmentation as 389-095 #50 Acrylic White:

W-16	"Ti-Pure"* FF titanium dioxide	3% pigment volume
W-50	"Ti-Pure" R-610 " "	13% " "
W-4	Asbestine 3X talc	7% " "
W-88	Water ground mica	7% " "
	Total	30% " "

*Registered Du Pont Trademark

Tensile Measurements:

All tensile measurements have been made on 1 inch strips at 30°F with a rate of elongation of 2% per minute.

Permeability Measurements:

It is known that measurements of water permeability on emulsion paint films give values that differ according to the conditions under which the test is run. A study has been made of the permeability of #50 Acrylic White in comparison with 301-918 #40 Outside White Linseed Oil House Paint to determine the effect of film thickness, of the humidity level, and of the transmission of liquid water as compared with water vapor.

Since emulsion paint films frequently have air bubbles which may form pinholes through the film, the emulsion films for determination of permeability were cast in two coats to eliminate pinholes. It is believed that the values for permeability shown are characteristic of the composition of the paint, and that the effect of pinholes and leaks has been eliminated.

In order to make sure that the determining factor was the permeability of the film and not a layer of stagnant air next to the film, all measurements were carried out with an air velocity of several hundred feet per minute across the exposed face of the film. It is found that the air velocity does make some difference in the numerical value for emulsion films of relatively high vapor permeability. It has no effect on films at the level of permeability of linseed oil house paint.

The permeability of 301-918 is in inverse proportion to the film thickness for a given set of humidity conditions according to Fick's law. This relation does not hold for #50 Acrylic White; films twice as thick transmit more than half as much water.

The effect of the humidity level at which the measurement is carried out and the difference between permeability to water and water vapor are shown in Table VI. To measure permeability at a high level of humidity, the film was tested in a Payne cup with water on the inside of the cup and the back of the film exposed to the atmosphere of the constant temperature room (50% relative humidity, 25°C). To test at a low level of humidity, the Payne cup was filled with calcium chloride, with the face of the film exposed to the atmosphere of the constant temperature room. At both humidity levels, the gradient of water vapor pressure is 12 mm. of mercury.

Films of linseed oil house paint transmit twice as much water at the high level of humidity as at the low level of humidity. This may be explained by the fact that the linseed oil paint absorbs a considerable amount of water (20% by weight); the water acts as plasticizer and permits more rapid molecular diffusion through the film.

Films of #50 Acrylic White transmit almost 20 times as much water at the high level of humidity as at the low level. However, these films absorb less water than linseed oil paint - 5% as compared with 20%.

Measurements of the transmission rate with liquid water in contact with the film were made by turning the Payne cup upside down so that the water rested on the film. If transmission of water is by molecular diffusion, it should make no difference in permeability whether liquid water is in contact with the film or whether the interface is between the film and saturated water vapor. This is found to be true for 301-918 Linseed Oil House Paint; the rate of permeability is the same whether the cup is measured upside down or right side up. The rate remains steady over a long period of time.

For #50 Acrylic White, the permeability to liquid water is very much greater than the permeability to saturated water vapor. Moreover, the transmission of liquid water does not reach a steady rate; it begins at a relatively high level and then increases progressively for the three days during which it can be measured. At the end of three days the 10 grams of water originally placed in the permeability cup have passed through the film and the cup is dry. The numerical value shown in Table VI is for the second 24 hour period; at this stage the transmission of liquid water is 100 times as great for the emulsion film as for the linseed oil house paint film.

Since it is liquid water in the form of rain or melting ice which would lead to maximum swelling of the wood on the side of a house, the permeability for liquid water has been used throughout this report.

REFERENCES:

Exposure Series:

17763 Accelerated Checking and Cracking of House Paint

17725 Accelerated Test of New Emulsion Polymers for House Paints

17784 Tensile Properties of Representative House Paint after Accelerated Weathering

17789 Accelerated Testing of Emulsion House Paint over Old Paint

17821 Accelerated Tests of Polymers HC, HC-1 and HD in Emulsion House Paint

17856 Tensile Properties of HB Polymer

17867 Accelerated Test of House Paint Latices over Old Paint

Report R-59-21, L. H. Cummings, "Preparation of Emulsion Methacrylate Copolymers for House Paints".

TABLE I

EFFECT OF WOOD SWELLING ON THE CRACKING OF HOUSE PAINT

Accelerated Weathering Substrate		300 Hr. White Pine		1000 Hr White Pi
Soaking and Drying at 40°F		Before Soaking	After Soaking	No Soaki
301-D-54741	White lead/zinc oxide/asbestine in linseed oil	10	7.5 cr.	10
301-D-54742	Lithopone/zinc oxide in linseed oil	10	5 cr.	10
301-D-54744	Linseed oil control similar to #40 White	10	7 cr.	10
301-D-54745	90/10 Linseed oil/ester gum house paint	10	9.5	10
87-D-54747	RC-141 alkyd house paint	10	9.5	10
87-D-54748	85/15 alkyd/ester gum house paint	10	10	10
87-D-54749	Zinc oxide in alkyd house paint	10	6 cr.	9.8 m
389-095	#50 Acrylic house paint	9 gr.	9 gr.	6 gr.
389-D-22699	Lytron 680 house paint	9 gr.	9.5 gr.	8 gr.

cr - cracking
e - erosion
gr - grain raising
mc - microcracking

TABLE II

FILM INTEGRITY AT 300 HOURS IN AWC-II CYCLE OVER THICK OI
ON WHITE PINE THAT HAS BEGUN TO FLAKE

Exposure Series	Panel Set	301-918 Linseed Oil	87-D-54747 Solution alkyd	389-095 Acrylic latex	389-D-22699 Lytron 680
17789	A	10	7	5	5
	B	8	10	7	7
	C	10	10	6	8
	D	10	10	7	5
	E	5	5	6	5
	F	6	10	5	6
	G	10	10	5	5
	H	10	10	6	5
17867	1A	8	-	5, 7	-
	1B	6	-	6, 6	-
Average		8.3	9.0	5.9	5.8
95% confidence Limits		± 1.2	1.0,-1.3	± 0.6	± 0.8

TABLE III

FILM INTEGRITY AT 1000 HOURS IN AWC-II CYCLE OVER WEATHERE
#40 WHITE FLAKING ON YELLOW PINE

Exposure Series	Panel Set	301-918 Linseed Oil	87-D-54747 Solution alkyd	389-095 Acrylic Latex	389-D-2269 Lytron 680
17789	I	10	10	9	7
	J	10	10	6.5	6.5
	K	10	10	6	6
	L	10	10	7.5	7
	M	10	10	7	6
	N	10	10	8	6
17867	51-A	10	10	7,8	-
	51-B	10	10	8,9	-
Average		10	10	7.6	6.4
95% confidence limits		-	-	± 0.6	± 0.9

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TABLE IV

FILM PROPERTIES COMPARED WITH PERFORMANCE OVER FLAKING PAINT ON

PAINT	Rank over flaking paint on wood	Permeability to water gm/10 sq. cm per 24 hr.	Elongation % at 30°F unweathered	AWC-II 300 hr
87-D-54747 Solution Alkyd	1	0.03	3	3
301-918 Linseed Oil	2	0.02	8	5
389-016 PVAc/alkyd emulsion	3	0.3	1.3	1.2
389-095 acrylic latex	4	2.0	3	1.4
389-D-22699 Lytron 680 latex	5	1.4	4	0.9

TABLE V

SYSTEMS EXPOSED IN SERIES #17867

SYSTEM	COMPOSITION	PERMEABILITY TO LIQUID WATER	% ELONGATION UNWEATHERED
GROUP 1			
7	301-918 #40 White (linseed oil)	0.02	8
8	301-948 #42 White (linseed oil)	0.02	8
9	87-D-54747 Solution alkyd	0.03	3
20	87-894 Trim and Shutter(alkyd)	0.02	-
GROUP 2			
10	67-027 #38 Primer (alkyd) under 389-095	0.04	-
21	347-907 #39 Primer (linseed oil) under 389-095	0.04	-
12	389-095 with linseed oil added to first coat	0.14	-
11	389-095 with tung oil added to first coat	0.11	-
6	389-016 polyvinyl acetate/alkyd emulsion	0.3	1.3
GROUP 3			
2	HA polymer: HMA/BMA/MAA 80/19.5/0.5	1.1	36
3	HD polymer: HMA/BMA/MAA 70/29/1	1.4	19
18,19	HC polymer: HMA/MMa/MAA 90/9/1	1.5	12
17	HB polymer BMA/EA/MAA 80/19.5/0.5	1.3	15

TABLE V (continued)

GROUP 4	COMPOSITION	PERMEABILITY TO LIQUID WATER	% ELONGATION AT 30°	
			UNWEATHERED	300 h
4, 5	389-095 #50 Acrylic White (Rhoplex AC-33 at 30% PV)	2.0	3	1.4
15	Rhoplex AC-33 at 40% PV	8.0	1.4	1.1
16	Rhoplex AC-33 at 50% PV	-	1.3	0.7
13	HA polymer at 40% PV	7.0	7	2
14	HA polymer at 50% PV	-	4	1.7

TABLE VI

EFFECT OF HUMIDITY LEVEL ON PERMEABILITY TO WATER VAPOR AND LIQUID WATER AT 25°C

Humidity Conditions	Grams water transmitted through 10 sq. cm. of 4 mil film in 24 hours	
	389-095	301-918
50 to 0% relative humidity	0.02	0.010
100% to 50% relative humidity	0.34	0.019
Liquid water to 50% relative humidity	2.0	0.020

FIGURE I - CRACKING AND WATER ABSORPTION IN SERIES 17867 AT 1000 HOURS IN THE AWC II WEATHERING CYCLE

(See Table V for key to system numbers)