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Technical Memorandum

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INVESTIGATION INTO ACRYLIC PAINT CRACKING (APC) ON ASPHALTIC PAVEMENTS

by

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EXECUTIVE SUMMARY

Airfield paint applied to flexible pavements located in warm climates appears to be contributing to severe cracking within and surrounding painted asphalt. This effort is in response to requests, by the Naval Airfield Criteria Manager and the Naval Pavement Center of Expertise, to investigate Acrylic Paint Cracking (APC) on asphaltic pavements and to identify an APC coating solution. The investigation consisted of the following: 1) Site visits to asphaltic airfields, roads, and parking lots, 2) Field testing of Asphaltic Concrete (AC) and AC wearing surfaces, 3) Field and laboratory testing of six acrylic paints (3 marking paints, 1 elastomeric, 2 experimental blends), and 4) Analysis of paint stresses.

Findings for acrylic marking paints and experimental acrylic blends are as follows.

Coating Property	Acrylic Marking Paints	Experimental Acrylic Blends
Asphaltic Substrate Adhesion	High	High
Overcoat Adhesion	High	N/T*
Flexibility	Poor	Excellent
Abrasion Resistance	High	Moderate
Thermal Expansion	High Rates	Low Rates
Paint Cracking Thickness	Moderate Film Build	Moderate Film Build
Water Absorption	High	Moderate
Asphaltic Bleed Resistance	Moderate	Excellent
Contributions to APC	High	Low

*N/T = Not Tested.

Findings for experimental acrylic blends, when compared to acrylic marking paints suggest increased weatherability and decreased APC.

Total marking paint stress consists of the following synergistic stresses: A) Residual Cure Stress, B) Thermal Stress, C) Aircraft Tire and Load Stress, and D) Moisture Induced Stress. It appears that under the right conditions, each of the above stresses, whether alone or in various combinations, is sufficient to produce APC within acrylic marking paints.

Marking paint recommendations for flexible pavements are as follows: 1) Mark asphaltic pavements (asphaltic airfields) with Federal Specification TT-P-1952D formulated with a second generation acrylic resin, 2) Initiate work with resin suppliers and coating formulators to develop flexible, abrasion resistant, 100 % acrylic waterborne marking paints displaying low water absorption, 3) Demonstrate a 100 % acrylic waterborne blend as an overcoat on a previously coated AC pavement located in a warm climate, 4) Demonstrate a 100 % acrylic waterborne blend on an AC pavement with either a new AC overlay or a new slurry seal located in a warm climate, and 5) Demonstrate glass bead and grit retention in recommendations #3, #4 above.

TABLE OF CONTENTS

INTRODUCTION 1

BACKGROUND 1

SITE VISITS 1
- NAS NORTH ISLAND 2
- NAS POINT MUGU 3
- NS ROOSEVELT ROADS 3
- SHREVEPORT REGIONAL AIRPORT 3
- ROADS AND PARKING LOTS 3

EXPERIMENTAL 4
- COHESIVE STRENGTH OF ASPHALTIC WEARING SURFACES 5
- COHESIVE STRENGTH OF PAINTS 6
- PAINT ADHESION TO AC AND OVERCOAT ADHESION 7
- FLEXIBILITY 7
- ABRASION RESISTANCE 8
- COEFFICIENT OF THERMAL EXPANSION 8
- MODULUS OF ELASTICITY AND GLASS TRANSITION TEMPERATURE 9
- PAINT CRACKING THICKNESS 10
- RESIDUAL CURE STRESS 10
- WATER ABSORPTION 11
- ASPHALTIC BLEED RESISTANCE 12
- ELASTOMERIC ACRYLIC PATCH TEST DEMONSTRATIONS 12

DISCUSSION 13
- RESIDUAL CURE STRESS 13
- THERMAL STRESS 14
- AIRCRAFT TIRE AND LOAD STRESS 15
- MOISTURE INDUCED STRESS 15
- TOTAL STRESS 15
- ASPHALTIC BLEED RESISTANCE 16
- FLEXIBILE COATINGS 16

FINDINGS 16

IDEAL ACRYLIC MARKING PAINT PROPERTIES 17

CONCLUSIONS 17

RECOMMENDATIONS 18

ACKNOWLEDGEMENTS 18

REFERENCES AND ENDNOTES 19

LIST OF TABLES

Table 1: Cohesive Strengths of Asphaltic Wearing Surfaces 5
Table 2: Paint Cohesive Strength @ 70°F 6
Table 3: Cohesive Strengths of Paints I, II at Elevated Temperatures 6
Table 4: Coating Adhesion to AC 7
Table 5: Paint I Overcoat Adhesion @ 60°F 7
Table 6: 1/8" Mandrel Bend Results 7
Table 7: Taber Abrasion Coating Weight Loss 8
Table 8: $T_{(sp)}$ and CTE for Paints I, II at Two Thickness' 8
Table 9: $T_{(sp)}$ and CTE for Paints, SS, and AC 9
Table 10: E and $T_{(g)}$ for Paints and AC 9
Table 11: Additional E Values at 100°F 9
Table 12: Formation of Cracked Paint at Several DFTs 10
Table 13: Residual Cure Stress 11
Table 14: Percent Weight Increase @ 24, 48, 163 hrs Immersion in Water, 73°F 11
Table 15: Asphaltic Bleed Resistance 12
Table 16: Resulting Thermal Paint Stress from a 40°F Temperature Increase 14
Table 17: Findings for Acrylic Marking Paints and Experimental Acrylic Blends 17
Table 18: Ideal Acrylic Marking Paint Properties 17

INTRODUCTION

Airfield paint applied to flexible pavements located in warm climates appears to be contributing to severe cracking within and surrounding painted asphalt. This effort is in response to requests, by the Naval Airfield Criteria Manager and the Naval Pavement Center of Expertise, to investigate Acrylic Paint Cracking (APC) on asphaltic pavements and to identify an APC coating solution. The investigation consisted of the following: 1) Site visits to asphaltic airfields, roads, and parking lots, 2) Field testing of Asphaltic Concrete (AC) and AC wearing surfaces, 3) Field and laboratory testing of six acrylic paints (3 marking paints, 1 elastomeric, 2 experimental blends), and 4) Analysis of paint stresses.

BACKGROUND

As early as 1959, research into Slurry Seal (SS) cracking adjacent marking paints was conducted[1]. Early research focused on color differences (white paint, black asphalt) and on increasing paint flexibility[2]. In one study, edge cracking was eliminated when a marking paint, heavily pigmented with carbon black, was applied to a SS[3]. In 1965, the Navy completed a field evaluation of five marking paints applied to an airfield SS; marking paints with 8 % elongation outperformed those with less than 5 % elongation[4]. In 1967, the Navy completed an additional field evaluation of eighteen marking paint formulations[5]. A total of 160 twenty-foot marking stripes were applied to a split length of Asphaltic Concrete (AC) and SS (20' stripe: 10' AC, 10' SS). Within several months, paints applied to the SS displayed extensive edge cracking and contained various degrees of both lifting and transverse paint cracking. In 1970, Dr. R. Drisko sited three additional mechanisms which may explain marking paint/asphaltic pavement cracking: 1) Marking paints contract when curing and transfer a stress to pavement substrates, 2) Paint cracking occurs when the paint's curing stress exceeds its' cohesive strength. However, marking paints are generally stronger than SSs and either crack or lift the SS before the paint cracks, and 3) When several coats of paint are allowed to buildup, stress increases at the coating/substrate interface[6]. Three additional studies were performed by the Navy and, in general, water-based marking paints (TT-P-1952: Paint, Traffic and Airfield Marking, Waterborne) were preferred[7,8,9]. Presently, three generations of acrylic marking paints are commercially available: A) First Generation (released 1990), B) Second Generation (released 1997), and C) Third Generation or Acrylic Hi-Build (released 1998)[10].

SITE VISITS

Site visits to four asphaltic airfields, two parking lots, and several roads were performed to document Acrylic Paint Cracking (APC) on asphaltic pavements: 1) Naval Air Station (NAS) North Island, CA, 2) NAS Point Mugu, CA, 3) Naval Station (NS) Roosevelt Roads, Puerto Rico, 4) Shreveport Regional Airport, LA, 5) Naval Construction Battalion Center, CA, and 6) Los Angeles County Municipal Roads, CA.

APC, NAS North Island.

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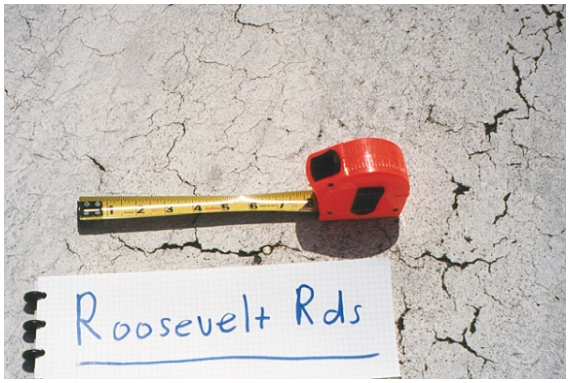
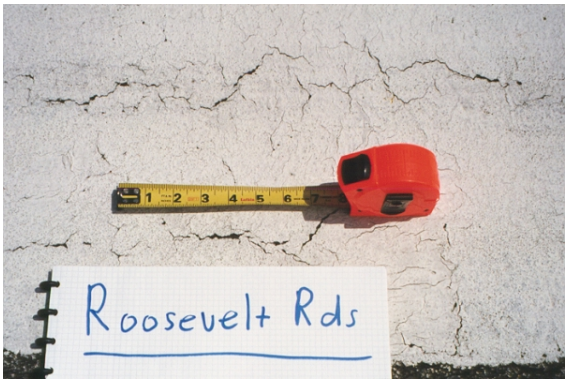


APC, NS Roosevelt Rds.



APC, NS Roosevelt Rds.

Grooved, friction course
Shreveport Regional.

Threshold marking, Shreveport Regional.

NAS North Island

Runway 29 – 11 contains a Slurry Seal (SS) applied to 4” of Asphaltic Concrete (AC) over 8” of Portland Cement Concrete (PCC)[11]. In FY 97, the runway received 129,000 combined take-offs and landings[12]. Extreme annual temperatures range from 30°F to 108°F with daily averages between 56°F to 71°F[13]. In 1987, the runway received a new SS and was subsequently coated[14]. Since 1987, the runway has received two or more overcoats for a total Dry Film Thickness (DFT) ranging from 55 mils to 120 mils (1 mils = 0.001”). White markings displayed 3” to 6” diameter sections of paint outlined by cracks whereas yellow taxi lines displayed smaller 2” to 3” diameter sections of paint

outlined by cracks. In general, APC penetrated the full 3/8" SS depth and, in some cases, cracking was observed to a depth greater than 1".

NAS Point Mugu

Runway 3 – 21 contains a rejuvenating agent applied to 5" of AC over 9" to 12" of crusher run base[15]. In FY 96, the runway received approximately 36,000 combined take-offs and landings[16]. Mean annual temperatures range from 54°F to 66°F with summer highs reaching the low 90s[17]. In 1983, the runway received a new SS and was subsequently coated[18]. In FY 97, existing paint markings were overcoated with TT-P-1952B in lieu of the current TT-P-1952D[19]. The overcoat displayed low hiding, poor asphaltic bleed blocking, and contained various degrees of APC. In addition to the above, previously applied markings appeared to have contributed to severe cracking and lifting of the SS. As a result of the combined paint and SS failures, a 2" depth of centerline AC was removed and overlaid with new AC.

NS Roosevelt Roads

Forty-five percent of Runway 7 – 25 contains 3.5" of AC applied to a paving fabric over 11" of PCC[20]. In FY 95, the runway received approximately 10,300 combined take-offs and landings[21]. Rainfall averages 58 inches per year and mean annual temperatures range from 74°F to 82°F with summer highs reaching the middle 90s[22]. In 1993, the runway received its' AC overlay and was subsequently coated[23]. The overlaid AC contains two coats of marking paint[24]. Overall, painted surfaces displayed moderate APC with paint crack depths ≤ 1/2" and paint crack widths ≤ 3/8". However, dime to quarter sized sections of paint have begun to spot fail and may contribute to an increase in FOD (Foreign Object Damage).

Shreveport Regional Airport

Shreveport Regional's AC runway contains a grooved, friction course. Grooves are 1/4" wide by 3/8" deep and have been placed transverse at 1.75" intervals. Airfield markings contain a 3.5 year-old coating base and, built-up by overcoating, display an approximate thickness of 50 mils[25]. The centerline marking was free of APC whereas threshold markings contained microchecked paint (small, hairline mudcracks). Although combinations of waterborne and water-based acrylics are used, APC, as identified on the above three runways, was absent. It appears that the grooved, friction course may have relieved the stresses which generally produce APC.

Roads and Parking Lots

In addition to flexible airfield pavements, APC is present on both asphaltic roads and asphaltic parking lots. The below photographs were taken at several locations throughout Southern California and show marking paint at various stages of edge cracking and APC.

Early stage of edge cracking.

Early stage of APC.

Advanced stage of edge cracking.

Advanced stage of APC.

Severe edge cracking.

Severe APC.

EXPERIMENTAL

The following white, acrylic waterborne paints were tested: A) First generation marking paint (I), B) Second generation marking paint (II), C) Hi – build or third generation marking paint (HB), D) Elastomeric acrylic (EA), E) 50 % blend of elastomeric acrylic/first generation marking paint (EA/I), and F) 50 % blend of elastomeric acrylic/second generation marking paint (EA/II). *In the below sections, each paint shall be referred to by the letters and numbers contained in the above parentheses.* Paints I, II, HB meet the requirements of TT – P - 1952 whereas Paint EA is a flexible (≥ 230 % elongation), waterborne acrylic commonly used in the roofing industry. Paints EA/I,

EA/II are experimental acrylic blends made by mixing one part (by volume) of either Paint I or Paint II to one part (by volume) Paint EA. Testing consisted of the following: 1) Cohesive strength of asphaltic wearing surfaces, 2) Cohesive strength of paints, 3) Paint adhesion to AC and overcoat adhesion, 4) Flexibility, 5) Abrasion resistance[26], 6) Coefficient of Thermal Expansion[27], 7) Modulus of Elasticity and Glass Transition temperature[28], 8) Paint cracking thickness, 9) Residual cure stress, 10) Water absorption, 11) Asphaltic bleed resistance, and 12) Elastomeric acrylic patch test demonstrations. Paints were applied to test samples by either brush, roller, or squeegee and at temperatures ranging from 60°F to 75°F. Prior to testing, paints were allowed to cure for a minimum period of 48 hours at the above temperatures.

Cohesive Strength of Asphaltic Wearing Surfaces

Poceq Dyna Tester and 2” pull-off puck.

AC cohesive failure: 1/4" of AC attached to pull-off puck.

The cohesive strength of four Southern California asphaltic wearing surfaces was quantified using a Proceq Dyna Tester and 2” diameter pull-off pucks. Cohesive strength testing was conducted in the field and performed on the following wearing surfaces: A) 4 year-old, 3” thick AC pavement with up to 1/2” coarse aggregate, B) 5^{+} year-old road SS, C) 1 year-old parking lot SS, and D) 1 year-old parking lot Seal Coat (SC). Asphaltic wearing surfaces are thermoplastic whereby cohesive strength decreases with increasing temperature. Table 1 lists cohesive strengths for the above wearing surfaces tested at various surface temperatures.

Table 1: Cohesive Strengths of Asphaltic Wearing Surfaces*

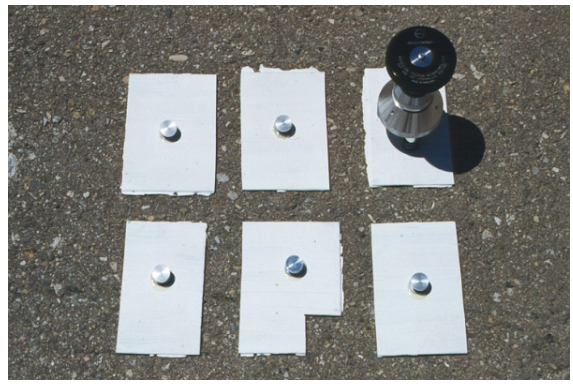
AC @ 63°F	AC @ 108°F	AC @ 116°F	Road SS @ 113°F	P-lot SS @ 103°F	P-lot SC @ 105°F
248 psi	106 psi	69 psi	32 psi	18.5 psi	39 psi

*Results represent the average of two tests per wearing surface.

Cohesive strength values represent the wearing surfaces’ maximum tensile strength and, in general, limits marking paint adhesion to asphaltic surfaces. For example, if a marking paint was applied to the above AC surface and tested for adhesion at 108°F: maximum paint adhesion is displayed when the marking paint produces an AC cohesive failure at 106 psi.

Cohesive Strength of Paints

Pull-off pucks and samples with resulting paint cohesive failures.



Elcometer adhesion tester and 3/4" pull-off pucks attached to paint samples.

An Elcometer adhesion tester with 3/4" diameter pull-off pucks was used to quantify the cohesive strength of paints. Paints were applied to either grit blasted aluminum or grit blasted steel. Table 2 lists the cohesive strength of paints at room temperature whereas Table 3 lists the cohesive strength of Paints I, II at elevated temperatures.

Table 2: Paint Cohesive Strength @ 70°F*

I	II	HB	EA	EA/I	EA/II
410 psi	310 psi	160 psi	270 psi	335 psi	210 psi

*Results represent the average of three tests per paint.

Table 3: Cohesive Strengths of Paints I, II at Elevated Temperatures*

Temperature	I	II
70°F	410 psi	310 psi
125°F	180 psi	100 psi
165°F	100 psi	30 psi

*Results represent the average of three tests per paint.

When comparing Table 2 to Table 1, only Paint HB displays a cohesive strength below that of AC at 63°F. On asphaltic surfaces subjected to heavy aircraft, a marking paint's adhesive strength should slightly exceed the asphaltic substrate's cohesive strength. However, Paint HB does not contain a cohesive strength sufficient to develop maximum adhesion to cold AC and, in areas with heavy traffic, may prematurely lift. When comparing Table 3 to Table 1, the cohesive strengths of Paint II over increasing temperatures is a closer match to the cohesive strengths of AC and, when compared to Paint I, may produce less thermal stress.

Paint Adhesion to AC and Overcoat Adhesion

Paint with attached chunks of AC indicate paint adhesion > AC cohesive strength.

Paints were applied to clean AC in one coat at an approximate Dry Film Thickness (DFT) of 10 mils. Paint adhesion was quantified using a Proceq Dyna Tester and 2" diameter pull-off pucks. Table 4 lists adhesion values at a specific AC surface temperature and represents the average of two tests per paint. Each pull-off test produced an AC cohesive failure and results signify maximum paint adhesion to AC. Table 5 lists overcoat adhesion values of Paint I applied over each of the six paints. Results from overcoat adhesion suggest waterborne acrylics develop excellent bonds to previously applied acrylics.

Table 4: Coating Adhesion to AC

I	II	HB	EA	HB/EA	EA/II
103 psi, 97°F	98 psi, 97°F	153 psi, 80°F	127 psi, 90°F	214 psi, 64°F	188 psi, 70°F

Table 5: Paint I Overcoat Adhesion @ 60°F*

I	II	HB	EA	EA/I	EA/II
270 psi	277 psi	212 psi	183 psi	235 psi	213 psi

*Results represent one adhesion test per paint using the Dyna Tester.

Flexibility

Paints were applied at several DFTs to aluminum panels (30 mils thick) and bent 180° over a 1/8" diameter mandrel at room temperature. Bent regions were visually examined for the presence of lifting, cracks, and other obvious failures. Coatings received a passing rating if failures were not visually detected. Table 6 lists mandrel bend results for paints.

Table 6: 1/8" Mandrel Bend Results

Thickness	I	II	HB	EA	EA/II
4 mils	Fail	Fail	Pass	Pass	Pass
5 mils	Fail	Fail	Pass	Pass	Pass
8 mils	Fail	Fail	N/T*	N/T*	Pass
10 mils	N/T*	N/T*	N/T*	N/T*	Pass

*N/T = Not tested.

Paints I, II displayed poor flexibility whereas Paints HB, EA, EA/II display excellent flexibility. The addition of Paint EA to Paint II at a 1:1 ratio by volume, produced flexibility sufficient to pass the above test at a DFT of 10 mils.

Abrasion Resistance

A Taber Abraser was used to determine coating abrasion resistance. Coatings received 1000 cycles of a 1 kg weighted CS -17 wheel. Three tests per coating were performed and results represent the average weight loss per coating. Table 7 lists the average Taber Abrasion weight loss per coating.

Table 7: Taber Abrasion Coating Weight Loss

I	II	HB	EA	EA/I	EA/II
17.3 mg	19.0 mg	16.2 mg	39.1 mg	30.3 mg	35.9 mg

Overall, coating weight loss from Taber Abrasion was extremely low and the above values should only be used for a relative comparison. As predicted, the unmodified acrylic marking paints (I, II, HB) outperformed both the elastomeric acrylic (EA) and the acrylic blends (EA/I, EA/II). Although significantly lower than the unmodified acrylics, abrasion resistance for the acrylic blends may still be sufficient for airfield pavements. If increased acrylic blend abrasion resistance is desired, blend formulations require higher concentrations of Paints I, II. However, increasing blend abrasion resistance may produce an undesirable decrease in paint flexibility.

Coefficient of Thermal Expansion

A Thermomechanical Analyzer (TMA) was used to test paints, a SS, and one AC pavement sample for the Coefficient of Thermal Expansion (CTE; α). Paint samples and the SS ranged in thickness from 34 mils to 120 mils and were tested at a rate of 10°C/min using the shaft of the expansion probe. The AC pavement sample was approximately 3" in length and was tested at a rate of 3°C/min using a glass dilatometer. Table 8 lists CTEs for Paints I, II tested at two thickness'. Table 9 lists CTEs for the remaining paints as well as the AC sample, a weathered SS from the pavement at NAS North Island (NI), and a marking paint sample from NAS NI. Softening point temperatures ($T_{(sp)}$) are also presented in Tables 8, 9 and represent the temperature at which the material's expansion rate shifts to a negative rate (expansion probe sinks into the soft material).

Table 8: $T_{(sp)}$ and CTE for Paints I, II at Two Thickness'

	I	I	II	II
Thickness	38 mils	107 mils	35 mils	120 mils
CTE (α)	38.2 µin/in°F	65 µin/in°F	45 µin/in°F	38 µin/in°F
$T_{(sp)}$	75°F	158°F	59°F	86°F

Table 9: $T_{(sp)}$ and CTE for Paints, SS, and AC

	NAS NI Paint	NAS NI SS	AC Pavement	HB, EA/I, EA/II	EA**
Thickness	57 mils	90 mils	≥ 3000 mils	35 – 60 mils	40 mils
CTE (α)	30 µin/in°F	3.8 µin/in°F	49 µin/in°F	N/E*	161 µin/in°F
$T_{(sp)}$	158°F	66°F	166°F	N/A	140°F

*N/E = No detectable expansion. **A rate of 2°C/min produced a lower CTE: 102 µin/in°F.

If $\alpha_{paint} = \alpha_{AC}$, thermal stress (from daily heating and cooling) at the marking paint/AC interface is not produced. However, the CTE for Paints I, II, NAS NI, EA each exceed the CTE for NAS NI SS; the CTE for thick Paint I and Paint EA exceed the CTE of standard AC pavement. When subjected to daily thermal cycling, each of the aforementioned paints will contribute to increasing the effects of thermal stress. Conversely, the CTE for Paints HB, EA/I, EA/II were below the detection limits of the TMA and contributions to increasing thermal stress should be minimal.

Modulus of Elasticity and Glass Transition Temperature

The Modulus of Elasticity (E) and Glass Transition Temperature ($T_{(g)}$) for paints were determined using a Dynamic Mechanical Analyzer (DMA). The DMA was set at a frequency of 1 Hertz and at a heating rate of 5°C/min. Table 10 lists E values and the $T_{(g)}$ and, in addition, shows E values for standard Kentucky AC[29]. E values represent data taken from the Flexural Storage Modulus whereas the $T_{(g)}$ represents the peak of the Flexural Loss Modulus. Table 11 lists additional E values at 100°F for both paints and AC.

Table 10: E and $T_{(g)}$ for Paints and AC

Temp.	Ken AC[30] (psi)	I (psi)	II (psi)	HB (psi)	EA (psi)	EA/I (psi)	EA/II (psi)
40°F	1,800,000	841,000	703,250	928,000	181,250	464,000	452,400
80°F	270,000	609,000	566,950	449,500	72,500	118,900	123,250
120°F	100,000	130,500	101,500	53,600	21,750	29,000	29,000
$T_{(g)}$	- 7°F[31]	100°F	103°F	75°F	- 18°F	47°F	50°F

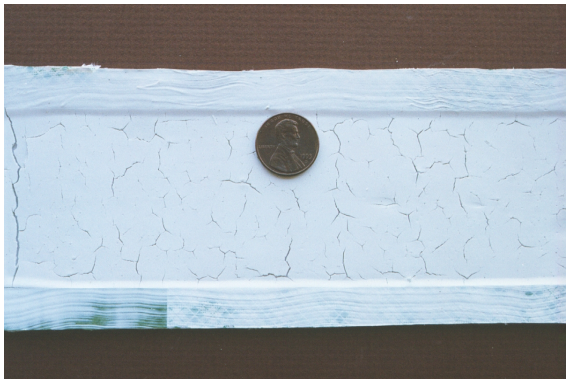
Table 11: Additional E Values at 100°F

Temp.	AC* (psi)	I (psi)	II (psi)	HB (psi)	EA (psi)	EA/I (psi)	EA/II (psi)
100°F	320,000	333,500	304,500	174,000	43,500	49,300	56,200

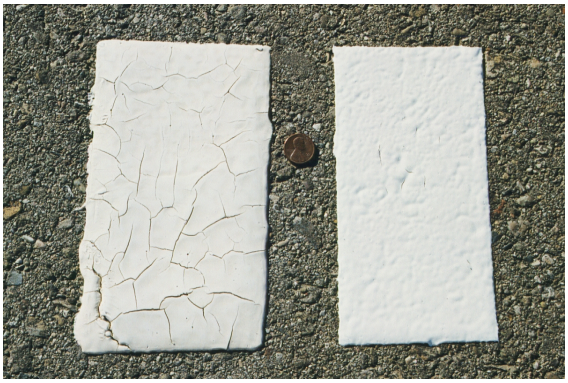
*Value represents the maximum E range at 16 Hertz[32].

If $E_{paint} \leq E_{AC}$, compressive stress (aircraft loads) is either reduced or eliminated at the marking paint/AC interface. When compared to AC at 100°F, only Paint I has an E value negligibly higher than AC. Paint and AC "E" values in combination with "α" values are required to calculate thermal stress over a given temperature range. A discussion of thermal stress, including stress calculations, is presented in the below section titled "Thermal Stress." The $T_{(g)}$ may be used to classify paints and was included in Table 10 as general information.

Paint Cracking Thickness



Paint I cracking at > 30 mils DFT.



Paint I (left), Paint HB (right).

Paints were applied in one coat at several DFTs to either a Teflon sheet or a metal substrate (aluminum, steel) and observed for the presence of cracks. Paint cracking occurs when the paint's internal stress exceeds the paint's cohesive strength. Table 12 identifies the presence of cracked paint at several DFTs.

Table 12: Formation of Cracked Paint at Several DFTs

DFT (mils)	I	II	HB*	HB**	EA	EA/I	EA/II
≤ 22 mils	None***	None	None	None	None	None	None
22 ≤ X mils ≤ 28	Yes****	None	None	Yes	None	None	None
29 ≤ X mils ≤ 40	Yes	Yes	None	Yes	None	Yes	Yes
41 ≤ X mils ≤ 50	Yes	Yes	None	Yes	None	Yes	Yes

*Batch 1. **Batch 2. ***None = no visible cracking. ****Yes = visible cracking.

Paint I and batch two of Paint HB displayed slight cracking at DFTs as low as 22 mils whereas batch one of Paint HB and Paint EA were crack free at DFTs up to 50 mils. As anticipated, the elastomeric modified acrylics (EA/I, EA/II) displayed less cracking at higher DFTs when compared to the unmodified formulations. It was disappointing to observe the high degree of variation between the two commercial batches of Paint HB. The first batch of Paint HB displayed excellent crack resistance whereas the second batch displayed cracking at approximately 1/3 the DFT of batch one.

Residual Cure Stress

Shim bending technique.

Residual Cure Stress (RCS) was quantified using the freely supported beam method (shim bending technique)[33,34,35,36]. Paints were applied to stainless steel shims (0.012" x 10" x 2": SS 302) at DFTs ≥ 38 mils. The initial shim deflection, prior to coating, was used as the zero point. Equations (1) and (2) are presented in Reference 35 and were used to calculate RCS. Table 13 lists RCS per mil of cured paint.

$$S_1 = E_s t^3/[6c_1(t + c_1)(1 - v_s)R] + E_1(t + c_1)/[2R(1 - v_1)] \quad (1)$$

$$R = L^2/8d \quad (2)$$

where

S_1 = Residual Cure Stress (RCS)
E_s = modulus of elasticity for substrate (28,000,000 psi[37])
E_1 = modulus of elasticity for single coating layer (E values @ 73°F were used)
v_s = Poisson's ratio for substrate (0.283[38])
v_1 = Poisson's ratio for coating layer[39]
t = substrate thickness (0.012")
c_1 = average thickness of coating layer (DFT)
R = curvature radius of the coated, bent substrate
L = length between knife-edge shim supports (8.5")
d = vertical deflection following cure

Table 13: Residual Cure Stress

	I	II	HB	EA	EA/II
Stress per mil of dry paint*	4.36 psi/mil	5.31 psi/mil	5.19 psi/mil	1.5 psi/mil	2.84 psi/mil
Film** Cracking	Slight	Moderate to Severe	Moderate to Severe	None	Severe

*Value represents the average of three tests. **Resulting degree of visual cracking in cured paint film.

Maximum internal stress was achieved during the cure of paints whereby several painted shims displayed cracked paint. However, excessive paint cracking relieves RCS and may have contributed to lowering RCS values for Paints II, HB, and EA/II. When the above RCS values are multiplied by 10 mils, the resulting RCS represents a typical paint stress initially transferred to a substrate. At 10 mils DFT, values for RCS range from 15 psi (Paint EA) to 53.1 psi (Paint II) and, if transferred to either a SS or a SC, become significant.

Water Absorption

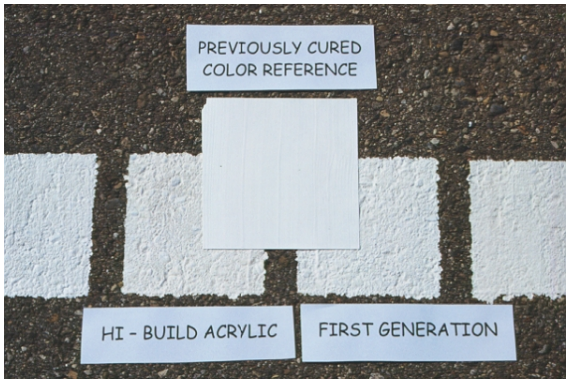
Cured paint samples were immersed in tap water at room temperature and evaluated for water absorption. Table 14 shows percent weight increase per coating at 24, 48, and 163 hours immersion.

Table 14: Percent Weight Increase @ 24, 48, 163 hrs Immersion in Water, 73°F

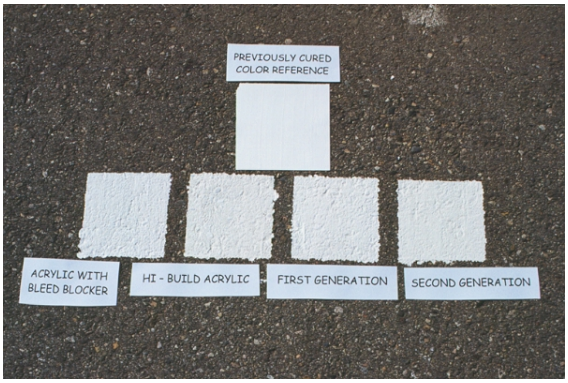
	I	II	HB	EA	EA/I	EA/II
24 hrs	10.22 %	9.55 %	3.23 %	11.24 %	6.33 %	7.58 %
48 hrs	10.25 %	9.59 %	4.39 %	12.65 %	6.03 %	6.61 %
163 hrs	9.95 %	9.58 %	7.74 %	12.4 %	5.5 %	6.46 %

Paints I, II, EA displayed high water absorption whereas Paints EA/I, EA/II, HB displayed considerably lower water absorption. In general, water-absorbing coatings swell and cycling, between periods of wet and dry, increases coating stress. Consequently, marking paints displaying low water absorption are preferred to those with high water absorption.

Asphaltic Bleed Resistance



Paints HB, I displayed poor asphaltic bleed resistance.



Testing for asphaltic bleed resistance.

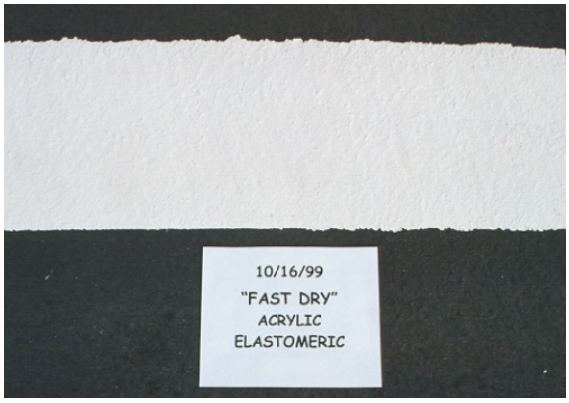
Paints were applied to a clean, four-year old AC surface at approximately 10 mils DFT by brush. Table 15 lists qualitative visual results for asphaltic bleed resistance whereby paint EA, doped with an asphaltic bleed-blocking agent, outperformed the acrylic marking paints.

Table 15: Asphaltic Bleed Resistance*

I	II	HB	EA**
Poor	Good	Poor	Excellent

*Visual subjective rating: Poor, Good, Excellent. **EA contained an asphaltic bleed-blocking agent.

Elastomeric Acrylic Patch Test Demonstrations



Patch applied to parking lot SS.

Crack free at 2 months: Parking lot SS patch.

Patch applied as stripe for stop sign.

Poor abrasion resistance at 2 months service: Stop sign stripe.

Two Paint EA patch tests were applied to the following areas located in Southern California at approximately 10 mils DFT: A) Stop sign stripe over AC, and B) One-year old parking lot SS. Patch A was used to evaluate abrasion resistance whereas Patch B was used to evaluate the effects of both RCS and short-term thermal cycling. Adjacent Patch B, the parking lot SS displayed a cohesive strength of 18.5 psi at 103°F and previously applied marking paints contained significant edge cracking. At two months service, patches were evaluated for performance. After approximately 20,000 car passes, Patch A displayed poor abrasion resistance whereby previously coated high spots had failed. Patch B, however, was not subjected to automotive traffic and remained crack free (0 % edge and internal cracking). Results validate the following Paint EA properties: 1) Poor abrasion resistance, 2) Low transfer of RCS to substrates, and 3) Flexibility sufficient to combat thermally induced SS movement.

DISCUSSION

Residual Cure Stress (RCS)

When acrylic marking paints are applied either excessively thick or allowed to build-up in multiple coats, RCS in excess of both the asphaltic wearing surface's cohesive strength and the paint's cohesive strength may be generated to produce APC. As previously noted, if applied in a single coat at DFTs ≥ 30 mils, Paints I, II, HB generate a level of internal stress which exceeds their cohesive strength and crack when curing. At 9 mils DFT, the RCS for Paints I, II, HB is ≥ 39 psi and is approximately equal to the cohesive strength of SSs and SCs at temperatures ≥ 100°F. However, at 30 mils DFT, the RCS for Paints I, II, HB is ≥ 130 psi and, at temperatures ≥ 100°F, exceeds the cohesive strength of SSs and SCs by greater than a factor of three. A tensile contraction (paint curing) three times greater than the cohesive strength of either a SS or a SC should be more than sufficient to produce pavement surface cracks. At NAS North Island, marking paints were allowed to build-up to an average thickness of 87 mils which equates to an approximate RCS of 378 psi. However, the initial RCS of 378 psi may eventually relax by 50 % to produce a fully relaxed RCS of 189 psi[40]. Still, a relaxed RCS of 189 psi exceeds, at elevated temperatures, the cohesive strength of SSs by greater than a factor of five and significantly contributed to the combined SS/APC at NAS North Island.

Thermal Stress

When exposed to direct sunlight and with an ambient temperature of 94°F, white and black colored surfaces reach temperatures of 102°F and 146°F, respectively[41]. However, on an average summer day, temperature differences between black and white colored surfaces generally remain at 17°F[42]. This difference becomes significant at white marking paint edges and within paint cracks showing exposed black asphalt. Although the CTEs for Paints I, II and AC are almost identical, 17°F of additional thermal loading generates 60 psi of stress at the above interfaces (AC: Eq. 4). When subjected to daily thermal cycling, this additional stress contributes to APC. On a relatively warm summer day, a white coating can experience up to a 40°F temperature fluctuation between the evening low and the daytime high[43]. Equations (3)[44], (4)[45] were used to calculate the resulting thermal paint stress from a 40°F temperature increase. Table 16 lists calculation results.

$$\sigma_{restrained} = E\alpha\Delta T \qquad (3)$$

$$\sigma_{ACrestrained} = E\Delta\alpha\Delta T \qquad (4)$$

where

$\sigma_{restrained}$ = restrained thermal paint stress
$\sigma_{ACrestrained}$ = AC restrained thermal paint stress
E = paint Modulus of Elasticity at 80°F (Table 10)
α = paint Coefficient of Thermal Expansion (CTE: Tables 8, 9)
$\Delta\alpha$ = difference between paint and AC CTE (Tables 8, 9)
ΔT = 40°F

Table 16: Resulting Thermal Paint Stress from a 40°F Temperature Increase

Thermal Stress	I	II	EA*	HB, EA/I, EA/II**
Restrained	925 psi	1020 psi	296 psi	0 psi
AC Restrained	268 psi	91 psi	154 psi	0 psi
Average, Restrained plus AC Restrained	596 psi	555 psi	225 psi	0 psi

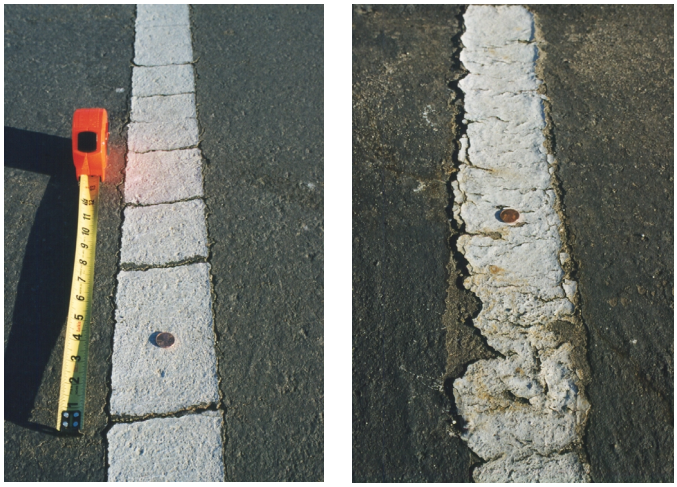
*The lower Coefficient of Thermal Expansion (CTE) was used in calculations. **The CTEs are 0 and produce a thermal stress of 0.

When the AC restrained thermal stress of Paint I is compared to the cohesive strengths of asphaltic wearing surfaces, the thermal stress generated by Paint I exceeds each of the cohesive strengths listed in Table I. Furthermore, AC restrained thermal stress for Paints II, EA exceed the cohesive strengths of AC (≥ 116°F), each of the SSs, and the SC as listed in Table 1. Although AC restrained thermal stress values are high, values do not exceed paint cohesive strengths as listed in Table 2. Consequently, thermal paint stress will be relieved by cracking the surface of the weaker material which, for Paints I, II, EA, is the asphaltic wearing surface. Alternatively, thermal paint stress reality, for marking paints applied to asphaltic pavements, may reflect the average of restrained and AC restrained thermal stress. When restrained and AC restrained stresses for Paints I, II are averaged, cohesive strengths for paints and wearing surfaces are greatly exceeded and should produce APC.

Aircraft Tire and Load Stress

Compressive loading from high-pressure aircraft tires supporting aircraft weights may contribute to APC (centerlines, touchdown areas, etc.). Navy aircraft tire pressures range from 56 psi (C – 117) to 350 psi (RA – 5C) and support aircraft weights ranging from 2,200 lbs (T-34C) to 800,000 lbs (C-5A)[46]. Aircraft tires under load produce various degrees of AC surface deflection. For example, 57 mils of surface deflection was measured at NAS Point Mugu (Runway 3 – 21) using a Heavy Weight Deflectometer (HWD)[47]. The above deflection was produced using a load equivalent to the average F-14 and P-3C aircraft weight[48]. A 57 mil surface deflection is substantial particularly when Runway 3 – 21 receives approximately 25,000 annual take-offs/landings from F-14s and P-3Cs[49]. Therefore, in order to combat aircraft induced pavement deflections and high-pressure aircraft tires, marking paints should display either sufficient flexibility or exhibit a Modulus of Elasticity (E) less than or equal to the AC surface (or both).

Moisture Induced Stress



Stripes were applied at the same time: right stripe receives sprinkler runoff.

Moisture induced stress occurs when coatings absorb moisture from rainfall, high humidity, dew, and pavement moisture vapor emission. Cycling between water absorption (volume increase) and drying (volume contraction) increases cohesive and adhesive paint stress. As previously noted, the tested paints displayed water absorption weight increases ranging from 5.5 % to 12.6 %. In general, a 10 % increase in weight represents approximately a 13 % increase in volume[50]. Paints I, II displayed approximately a 10 % weight increase from water absorption and, since they also displayed poor flexibility, should weather poorly when subjected to high levels of moisture. As evident in the above photographs, high levels of moisture accelerate acrylic marking paint failures.

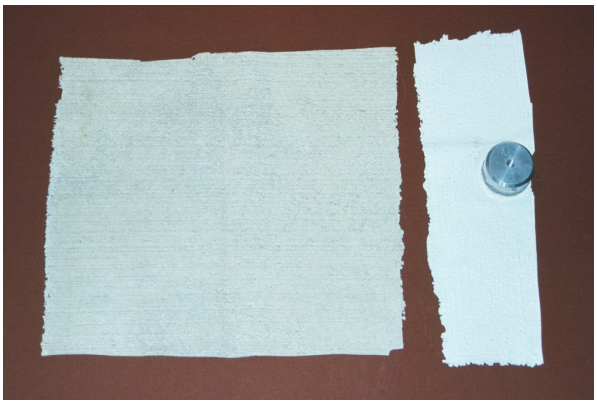
Total Stress

Total marking paint stress consists of the following synergistic stresses: A) Residual Cure Stress, B) Thermal Stress, C) Aircraft Tire and Load Stress, and D) Moisture Induced Stress. It appears that under the right conditions, each of the above stresses, whether alone or in various combinations, is sufficient to produce APC within acrylic marking paints.

Asphaltic Bleed Resistance

Contrary to popular opinion, water-based acrylic paints may discolor when applied to either new or aged asphaltic surfaces. The roofing industry is well aware of this fact and adds a bleed-blocking agent to water-based acrylics for use over bituminous substrates. Bleed resistance is also exacerbated when water-based acrylics are applied to substrates containing iron. If AC surfaces contain iron sulfide aggregate, water-based acrylics, in general, react with the iron to produce dark, flash rusting spots. This effect was present during the site visit to NAS Point Mugu and is easily demonstrated through the application of a thin, white acrylic to blasted steel. If water-based acrylic marking paints are to be applied in one coat to AC surfaces, coatings should contain an asphaltic bleed-blocking agent.

Flexible Coatings



The above flexible acrylic was lifted in sheets, using hand pressure, from a concrete substrate.

Flexible acrylic marking paints designed for asphaltic pavements must contain the appropriate level of tensile strength, adhesive strength, and percent elongation. If coating/substrate adhesion is well below the coating's tensile strength and the paint contains a high percent elongation, the marking paint may fail in sheets when subjected to various stresses. The above photograph shows a flexible coating which developed an adhesive strength of 70 psi to concrete and, as a result of a high percent elongation (≥ 300 %) and a high tensile strength (≥ 300 psi), was pulled off the concrete in sheets. Ideal properties for semi-flexible marking paints are presented in Table 18 below.

FINDINGS

Findings for acrylic marking paints and experimental acrylic blends are presented as a comparison in Table 17. Findings for experimental acrylic blends, when compared to acrylic marking paints suggest increased weatherability and decreased APC.

Table 17: Findings for Acrylic Marking Paints and Experimental Acrylic Blends

Coating Property	Acrylic Marking Paints	Experimental Acrylic Blends
Asphaltic Substrate Adhesion	High	High
Overcoat Adhesion	High	N/T*
Flexibility	Poor	Excellent
Abrasion Resistance	High	Moderate
Thermal Expansion	High Rates	Low Rates
Paint Cracking Thickness	Moderate Film Build	Moderate Film Build
Water Absorption	High	Moderate
Asphaltic Bleed Resistance	Moderate	Excellent
Contributions to APC	High	Low

*N/T = Not Tested.

IDEAL ACRYLIC MARKING PAINT PROPERTIES

Table 18 lists ideal material and performance properties for acrylic marking paints.

Table 18: Ideal Acrylic Marking Paint Properties*

Resin System	100 % acrylic waterborne
Percent Volume Solids	≥ 60 %
Zinc Oxide Biocide	≥ 0.5 lbs/gallon
Volatile Organic Compounds (VOC)	≤ 150 g/l
Cohesive Strength @ 70°F	200 psi – 300 psi
Adhesion to AC @ 65°F	≥ 200 psi
Overcoat adhesion to acrylic paints @ 70°F	≥ 200 psi
Drop-on glass bead adhesion	≥ 200 psi
Flexibility: 180° bend over 1/8" mandrel @ 8 mils DFT, 70°F, Aluminum Panel (30 mils)	Pass: 0 % visual failures at bend
Percent Elongation @ 70°F	70 % – 200 %
Abrasion Resistance: 1000 cycles, CS – 17 wheel, 1 kg weight	≤ 40 mg weight loss
Mean Coefficient of Thermal Expansion: 25 mils DFT, 0°F to 140°F	0 – 40 x 10^{-6}in/in°F
Modulus of Elasticity @ 80°F	90,000 psi – 400,000 psi
Paint Cracking Thickness: 1 coat	0 % visual cracking @ 25 mils DFT
Residual Cure Stress: 1 week cure	≤ 3.5 psi/mil
Water Absorption @ 48 hours immersion	≤ 7 % weight gain
Asphaltic Bleed Resistance: Visual Comparison	Reference color = color of paint applied to asphaltic substrate
No Pick-up @ 70°F, 80 % R/H, 10 mils DFT	≤ 25 minutes

*At present, acrylic marking paints displaying the above properties are not commercially available.

CONCLUSIONS

To decrease APC on slurry seals in warm climates, no more than 20 mils DFT of acrylic marking paint should be allowed to build-up in multiple coats. The initial paint application should be 8 mils DFT and, when overcoating is required, either two separate overcoats at 6 mils DFT or three separate thin overcoats at 4 mils DFT should follow. If

the slurry seal is new, the initial 8 mils of paint should be applied in two coats at 4 mils DFT and with a waiting period of several weeks between coats. To decrease APC on asphaltic concrete in warm climates, no more than 30 mils of acrylic marking paint should be allowed to build-up in multiple coats. For marking asphaltic concrete, the above slurry seal application rates should be followed with the exception of one additional overcoat. When commercially available and succeeding field demonstrations, marking paints conforming to Table 18 should be used on the following asphaltic pavements: A) Airfields, B) Parking lots, and C) Road centerlines. Faster drying times and potentially higher abrasion resistance may be required if the paint detailed in Table 18 is to be used on highways, cross walk stripes, and stop sign stripes.

RECOMMENDATIONS

1) Mark asphaltic pavements (asphaltic airfields) with Federal Specification TT-P-1952D formulated with a second generation acrylic resin.
2) Initiate work with resin suppliers and coating formulators to develop flexible, abrasion resistant, 100 % acrylic waterborne marking paints displaying low water absorption.
3) Demonstrate a 100 % acrylic waterborne blend as an overcoat on a previously coated AC pavement located in a warm climate.
4) Demonstrate a 100 % acrylic waterborne blend on an AC pavement with either a new AC overlay or a new SS located in a warm climate.
5) Demonstrate glass bead and grit retention in recommendations #3, #4 above.

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