ERDC/GSL TR-07-20

Geotechnical and Structures Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

A Comparative Field Study of Permastripe™ Polymer Concrete and Waterborne Airfield Pavement Markings

J. Kent Newman, Donna Speidel, Ron Boeger, and Betsy Hudson

June 2007

ERDC/GSL TR-07-20
June 2007

A Comparative Field Study of Permastripe™ Polymer Concrete and Waterborne Airfield Pavement Markings

J. Kent Newman

U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Donna Speidel

Speidel Construction Company
58 Le-Way Drive
Fredericksburg, VA 22406

Ron Boeger and Betsy Hudson

Flexolite Corporation
125 Cassens Court
Fenton, MO 63026

Final report

Approved for public release; distribution is unlimited.

Prepared for U.S. Air Force Civil Engineering Support Agency
139 Barnes Drive, Suite 1
Tyndall Air Force Base, FL 32403-5319

Abstract: The study reported herein compared polymer concrete pavement markings (Permastripe™) to Federal specification waterborne airfield marking paint for field durability and retroreflectivity. The markings were placed at Tyndall Air Force Base (AFB) (hot, wet climate) and Mountain Home AFB (cold, snowy climate). American Association of State Highway and Transportation Officials Type I, Type III, and a Type I/Type III retroreflectivity bead combinations were included at Tyndall AFB. Additionally, Adsil™, a novel clear coating, was used at Tyndall AFB to evaluate the effects on retroreflectivity and durability of Permastripe™ and paint.

This study suggests that Permastripe™ is more durable than standard airfield paint, may exhibit better bead retention, and holds promise as a durable pavement marking if certain technical problems can be overcome. The Permastripe™ studied in this work is not readily removable from asphalt pavement using water-blasting. The data clearly show that high-refractive index Type III beads result in higher retroreflectivity than Type I beads initially and over time.

The Adsil™ clear coating applied to the markings resulted in significant reductions in retroreflectivity. The retroreflectivity data from one test clearly indicate that the retroreflectivity increases with time as the coating wears.

Contents

Figures and Tables

Figures

Tables

Preface

The research reported herein was sponsored by the U.S. Air Force Civil Engineering Support Agency, headquartered at Tyndall Air Force Base (AFB), Florida. Project officer was Mike Ates. The research was conducted by personnel at the U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL), Engineering Systems and Materials Division (ESMD), Airfields and Pavements Branch (APB).

This study was conducted under the direct supervision of Don R. Alexander, Chief, APB, while under the general supervision of Dr. Albert J. Bush III, Chief, ESMD; Dr. William P. Grogan, Deputy Director, GSL; and Dr. David W. Pittman, Director, GSL. Project principal investigator was Dr. J. Kent Newman, APB. Dr. Newman prepared this report, along with Donna Speidel, Speidel Construction Company, Fredericksburg, VA, and Ron Boeger and Betsy Hudson, Flexolite Corporation, Fenton, MO.

This work could not have been accomplished without the generous in-kind support provided by Speidel Construction Company (placement of paint markings, numerous retroreflectivity measurements, and preliminary editing of this document); Flexolite Corporation (LTL-2000 retroreflectometer and donation of retroreflective beads for all Tyndall AFB projects and for the Mountain Home AFB project); and Polycon, Inc., Madison, MS, a subsidiary of IHC Corporation (John Edwards provided placement of Permastripe™ markings at Tyndall AFB and Mountain Home AFB).

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms

Executive Summary

This study compared polymer concrete pavement markings (Permastripe™) to Federal specification waterborne airfield marking paint for field durability and retroreflectivity. The markings were placed at Tyndall AFB (hot, wet climate) and Mountain Home AFB (cold, snowy climate). Tyndall AFB traffic consisted of high repetitions of high tire pressure F-15C aircraft. Mountain Home AFB consisted of lower numbers of fighter aircraft, occasional tanker aircraft, and the severe damaging effects of snowplow traffic during the winter months. AASHTO Type I, Type III, and a Type I/Type III retroreflectivity bead combinations were included at Tyndall AFB to gauge the effectiveness of different bead types in both Permastripe™ and paint. Additionally, a novel clear coating was included in the test matrix at Tyndall AFB to evaluate the effects on retroreflectivity and durability of Permastripe™ and paint.

The results of this study indicate that the Permastripe™ product requires continued development for implementation in the military airfield market. This study suggests that Permastripe™ is more durable than standard airfield paint, may exhibit better bead retention, and holds promise as a durable pavement marking if certain technical problems can be overcome. The main problem is inconsistent material properties that result from variable viscosity. The variation in viscosity arises from a lack of control over base materials and mixing conditions. This results in variable thickness and inconsistent retroreflective bead embedment. Additionally, the Permastripe™ studied in this work is not readily removable from asphalt pavement using water-blasting, and some test lines suffered from soiling by algal/mildew growth.

The data clearly show that high-refractive index Type III beads result in higher retroreflectivity than Type I beads initially and over time in paint and Permastripe™. Because of a higher index of refraction, Type III beads return a higher intensity of light back to the light source compared with Type I. However, this may be of variable benefit to pilots as the light reflected from the beads is dependent on the intensity and location of the light source on the aircraft in relation to the pilot and the distance of the aircraft from the markings.

The Adsil™ clear coating applied to the markings resulted in significant reductions in initial retroreflectivity on one set of test lines and smaller effects on another set. This was particularly evident with Type III beads and the amount of light reflected from 30 meters (LTL-2000 reflectometer). The differences are surmised to arise primarily from the flattening agent that was present in one formulation and absent in the other. The retroreflectivity data from one test clearly indicate that the retroreflectivity increases with time as the Adsil™ coating wears. These results suggest that the coating may increase the durability of the line as the abrasion and environmental effects are borne by the coating, not the substrate.

1 Introduction

Polymer concrete pavement markings (PCPM) represent a potential new application of polymer concretes. At the start of this work, two PCPM products were available, Lumimark™ and Permastripe™. Lumimark™ is a PCPM placed into a prepared recess that is milled into the pavement surface such that it will not be abraded by snowplow traffic. Lumimark™ contained both topically applied and embedded glass beads such that, as the coating wore, more beads would become exposed. Permastripe™ pavement marking is a PCPM placed either by a screed or spray. The mixture is pigmented to provide proper color. Retroreflectivity is achieved by application of reflective glass beads on the surface. Unfortunately, Lumimark™ declined to participate in this study and the company has since ceased operations.

Permastripe™ pavement marking is a polymer-modified concrete containing latex or dry polymer, portland cement (or other types of hydraulic cements), proprietary additives (pozzolans, plasticizers, air-entraining agents, etc.), and aggregate (filler). Initial demonstrations of Permastripe™ manufactured by Polycon, Inc., Madison, MS, and placed in 1998, showed that the materials were promising based on success of Polycon's E-Krete™ product. Visual assessments of E-Krete™ and Permastripe™ for durability, abrasion resistance, and retroreflectivity were performed at the U.S. Army Engineer Research and Development Center (ERDC) and the Air Force Civil Engineering Support Agency (AFCESA) test sites on a limited scale. As a result of these initial assessments, a detailed study of the potential for Permastripe™ to be employed as a durable alternative to conventional airfield marking paint was initiated by AFCESA.

2 Objective and Scope

The objective of this study was to evaluate the durability, retroreflectivity, placement qualities, and removal of Permastripe™ at two different climactic zones. Tyndall AFB was chosen as the hot, wet climate, and Mountain Home AFB was chosen as the cold, wet location for snowplow operations. The American Association of State Highway and Transportation Officials (AASHTO) designations Type I, Type III, and Type I/III blend retroreflective beads were included in the test. During the course of the investigation, a clear coat (Adsil™) was included to evaluate the ability of the coating to extend durability of pavement markings.

3 Background

Airfield pavement markings provide pilots and ground personnel with indicators of traffic flow, boundaries, and access points. Airfield markings should be bright, easily seen in day and night, and durable. Historically, pavement markings have been outdoor-quality paints dissolved in organic solvents. However, in recent years, waterborne paints have become the norm to minimize the impact of volatile organic compounds that evaporate into the biosphere.

Typically, a waterborne paint consists of a polymer resin (usually an acrylic), pigment, filler, additives, water, and surfactants. The additives are generally employed to alter rheological properties, promote film formation and curing, and increase durability. Durable alternatives to waterborne systems have come in the form of epoxy, methacrylate, and urethane-based polymers (Bagot 1995). Recently, polyurea-urethane formulations have been introduced by 3M Corporation. These durable markings are typically two-component, 100 percent solids, containing no solvent or water. Retroreflective beads and aggregate are added to provide marking clarity at night and skid resistance, respectively (Bagot 1994).

Waterborne systems harden or “cure” via water loss from the emulsion. An emulsion contains solid particles that are “suspended” within a water matrix by an emulsifier. These solid particles are called micelles. Emulsifiers are surfactants that are chemically similar in function and structure to soaps and detergents. The surfactants coat the surface of the solid to form a micelle. As water evaporates, the particles must coalesce to create a continuous solid. This requires the initial formation of a film on the surface of the coating. For the film to form properly, the temperature must be high enough to allow enough molecular mobility of the surfactant and solid particles to coalesce. This is typically referred to as the “minimum film-forming temperature” or MFT. When placing an emulsion coating on a surface, the surface temperature must be above the MFT for proper film formation to occur. Below MFT, the particles within the emulsion will not properly interact, and the coating will not adhere well to the substrate or form a cohesive solid, which may result in peeling and high abrasion. Most marking paint formulations (FS TT-B-1952D;

AFCESA 1997) also contain approximately 10 percent methanol to aid in rapid curing to prevent pickup under traffic.

The PCPM employed in this study contains a proprietary latex polymer, portland cement, and fine aggregate. It is manufactured by Polycon, Inc., of Madison, MS. The temperature application guidelines are similar to those of concrete. The latex within the Permastripe™ system also requires that the pavement temperature be above the MFT of the latex, approximately 55 °F. Special curing considerations are generally not necessary, as the polymer acts as its own curing agent by trapping water within the matrix, slowing evaporation, and allowing the water to be available for reaction with the cement. A Permastripe™ based on portland cement will require a full 28 days to reach its limiting strength; however, the material can typically withstand limited traffic in as little as 4 hr after placement.

The study of Permastripe™ was prompted, in part, by the success of the E-Krete™ polymer concrete micro-overlay for fuel-resistance parking areas. E-Krete™ and Permastripe™ have similar components, with the Permastripe™ being pigmented. Field demonstrations were based upon the outcome of the initial laboratory testing and, given the satisfactory performance of the E-Krete™ in the laboratory, field trials were initiated. The first test section was placed at ERDC in August 1998 with subsequent sections placed at seven more locations around the country in October and November 1998. Those locations were Norfolk Naval Station (Norfolk, VA), MacDill AFB (Tampa, FL), Tyndall AFB (Panama City, FL), Forbes Field (Topeka, KS), McConnell AFB (Wichita, KS), North Island NAS (San Diego, CA), and Edwards AFB (Barstow, CA). Permastripe™ was placed at several of these locations as part of the demonstrations (Newman and Shoenberger 2003).

The field demonstrations were successful with performance at or above expectations at all sites; however, this is based on only 3 years of experience with E-Krete™ and Permastripe™. At McConnell AFB, softening of the E-Krete™ product occurred due to contact with synthetic jet turbine fluid (MIL SPEC 7808K AM1 Grade 3 Synthetic Turbine Engine Fluid) at elevated temperatures. A similar phenomenon was observed at MacDill AFB, but the exact source of the fluid is not known. The fluid was discharged from a KC-135 tanker and is suspected to be synthetic jet turbine lubricating fluid. The Permastripe™ lines at all of these locations were placed by hand using a squeegee system to coat the line onto the pavement surface. Beads were then placed by hand sprinkling using a gravity feed (Newman and Shoenberger 2003).

The specification governing application of waterborne pavement paints to Air Force pavements is Air Force ETL 97-18 (AFCESA 1997). Overall, for federal projects, the specification for waterborne marking material is Federal Specification TT-P-1952D and, for reflective beads, is TT-B-1325C (AFCESA 1994). These specifications are designed to ensure that the pavement marking material meets the strict demands, such as abrasion resistance and durability to weathering, that are required in actual service. However, many of the test methods and procedures employed in TT-P-1952D are not applicable to Permastripe™ as these materials are very different from a typical pavement marking paint.

Permastripe™ has potential for application as an airfield pavement marking material. The advantage over paints should be durability to weathering, traffic, and bead retention. The disadvantages are application, cost, and removal. A Permastripe™ contains added components compared with paints, which results in difficulty in spraying. However, for certain airfield areas that require frequent repainting, Permastripe™ may offer added benefit.

Retroreflectivity

*Retroreflectivity is the reflection of light back to the source. Thus, a retroreflective surface appears the brightest when the observer is closest to the light source. Retroreflective media perform well for night drivers as the angle between the driver, the pavement markings, and the headlights is small. However, for aircraft, the visibility of markings at night can vary significantly depending on the location of the lights on the aircraft in relation to the pilot and the distance from the pavement markings. The angle between the pilot, pavement markings, and light source may be much larger (e.g., wing lights) compared to a typical automobile. Thus, the amount of light directed back to the pilot will differ widely depending on the location of the lights on the aircraft.

For pavement markings, retroreflectivity is typically obtained using spherical beads. There are numerous types and sizes of beads. For the purpose of this work, only AASHTO Type I and Type III beads were considered. The Type designation refers to the size, gradation, and index of refraction of commercial beads that are available (AASHTO M-247 and FS TT-B-1325C). Type I beads have an index of refraction (IOR) of 1.5 and Type III have an IOR of 1.9. The higher the IOR, the higher the intensity of light directed back to the source. Thus, Type III beads will appear much brighter than Type I beads when the observer is closer to the light source, such as in a car. Studies on military airfield markings (Walrond and Ates 1995) suggested that the use of Type I beads resulted in higher durability and that the increased cost of the Type III beads was not warranted for military airfield applications. For military applications, the minimum acceptable retroreflectivity for white lines is 200 millicandelas/square meter/lux and for yellow lines, 175 millicandelas/square meter/lux (Air Force ETL 97-18; AFCESA 1997).

Traffic

At Tyndall AFB, the majority of traffic is F-15C aircraft. These aircraft are typically operating at a gross weight of approximately 50,000 lbs with wheel loads on the main gear tires of approximately 24,000 lbs. Tire pressures are 350 psi. Traffic volume is high at Tyndall AFB, as it is a training facility. Yearly aircraft operations on Taxiway P average approximately 5,000. Sweeping operations occur daily, with the sweepers using nylon bristles.

At Mountain Home AFB, traffic type varies with F-15, F-16, and occasional KC-10 traffic. Yearly traffic operations on Taxiway B average approximately 1000. Sweeping operations occur daily, with the sweepers using nylon bristles. During the winter, snowplow operations occur as needed with snowfall. During the winter of 2003-2004, snowfall amounts were normal. It is estimated that the number of snowplow operations on Taxiway Bravo was approximately 50.

4 Results and Discussion

Note that all values of retroreflectivity are measured in millicandelas/square meter/lux. The units will not be placed on each individual retroreflectivity number discussed in the following text.

All Permastripe™ markings at Tyndall AFB and Mountain Home AFB were provided and placed by Polycon, Inc. of Madison, MS. All retroreflective beads were provided by Flexolite Corporation of Fenton, MO. All paint lines at Tyndall AFB were placed by Speidel Construction, Inc., of Fredericksburg, VA, using Ennis, Inc., paint. Waterblasting for markings removal at Tyndall AFB was also performed by Speidel Construction, Inc. Paint markings at Mountain Home AFB were placed by AA Striping of Boise, ID. Markings removal at Mountain Home AFB was performed by waterblasting during September 2005 as part of an airfield repainting project.

Tyndall AFB

Summary of results

The results described below indicate that although Permastripe™ has promise as a durable marking material, it suffered from insufficient quality control. This deficiency arises from an inability to control the base material properties that affect the viscosity of the uncured product prior to placement. Permastripe™ requires blending a dry mix of fast-setting white cement, aggregate, and filler with a proprietary pigmented emulsion. This must be accomplished in small batches as the cement set time is rapid. Mixing is typically done with small paddles (like a Jiffy™ mixer) and results in incomplete mixing. This necessitates the screening of unmixed lumps of cement. Under these conditions, consistent viscosity cannot be achieved. Viscosity control is absolutely essential to controlling spray properties which affects line thickness and retroreflective bead float. It is impossible to control retroreflectivity without proper viscosity control. However, given the ability to achieve viscosity control, it is expected that a highly durable, cost-effective pavement marking could result.

For all bead types, the retroreflectivity observed by the pilot will be highly dependent on the intensity and location of the source light in relation to the pilot and the distance to the retroreflective marking. The retroreflectivity data clearly show that the higher IOR (1.9) Type III beads are far superior to Type I (IOR, 1.5) beads in initial and long-term retroreflectivity. Thus, the Type III beads will be much more visible from farther distances as the angle between the source light and the retroreflective bead is small. The problems with using Type III beads for airfield applications are twofold: they are more expensive and the ultimate visibility of the retroreflective marking to the pilot may be highly dependent on aircraft type. Previous studies (Walrond and Ates 1995) indicated a preference for Type I beads for military airfield markings.

The use of the Adsil™ coating to improve long-term durability of the lines was inconclusive. In Test 2, the Adsil™ did not affect the retroreflectivity of the markings to the level observed in Test 3. For Test 3, the Adsil™ coating significantly adversely affected the initial retroreflectivity (for the Type III beads in particular). However, over time, the retroreflectivity values rose significantly, but not to the level observed prior to the coating application. This effect was more noticeable with the LTL-2000 device, which measures retroreflectivity at a 30-meter distance. It is important to note that the Adsil™ applied in Test 2 did not contain a flattening agent and was sprayed on the markings. A flattening agent was included in the Test 3 formulations to minimize gloss. The Adsil™ in Test 3 was also applied by roller which may have increased the film thickness and incorporated soil picked up on the rollers into the coating. It is surmised that the flattening agent caused the severe loss of retroreflectivity observed on coated lines in Test 3.

Field demonstrations of waterborne airfield markings paint and Permastripe™ were placed on Taxiway P between Taxiways C and D at Tyndall AFB in October 2001 (Test 1) including some markings placed on the asphalt runway in April 2002 (Test 2) and August 2003 (Test 3) in a side-by-side field comparison. The markings placed on Taxiway P in October 2001 were removed due to technical problems and replaced in April 2002. Additional markings were placed in August 2003. All markings were removed in June 2005. The Permastripe™ runway markings placed in October 2001 were painted over in June 2005 as they could not be removed without damaging the asphalt surface. This study included Type I, Type III, and a Type I/Type III combination of retroreflective beads in both paint and Permastripe™. Also, Adsil™ was applied to some Test 2 lines in a preliminary test. A more controlled study of Adsil™ was conducted in Test 3.

Test 1 – October 2001

Summary – Test 1

A total of 18 initial test lines (nine paint and nine Permastripe™) were placed on both Taxiway P and the south runway in October 2002 in three colors: red, yellow, and white. All lines used Type I retroreflectivity beads. The Test 1 lines were removed in April 2002 due to inconsistent and overly thick Permastripe™ line thickness and poor retroreflectivity of the Permastripe™. The Permastripe™ was placed using a screed application, and thicknesses could not be well controlled using this application technique (Figure 1). Additionally, the Permastripe™ was mixed without any viscosity control (other than a subjective visual indication). It was a windy day which resulted in significant overspray of the paint. Because the removal aspects of the Permastripe™ were unknown, the above results and conditions indicated that it was prudent to remove the Test 1 lines, gauge the removal process, and replace these lines with sprayed Permastripe™. It was noted that after only a few months, significant discoloration of the Permastripe™ lines were occurring. Subsequent investigations revealed that mildew or algae were the likely source. Apparently, the porous nature of Permastripe™ allows for moisture to be trapped within the matrix and provides a substrate for organism growth (similar to concrete). The retroreflective beads on the Permastripe™ were placed by hand, resulting in inconsistent application of reflective media; consequently, retroreflectivity readings on those markings will not be discussed.

Weather conditions

Markings were placed October 6, 2001. The day was bright, sunny, and cloudless. Daytime temperatures were 70 to 85 °F with winds steady at 10 to 15 mph and gusting to 20 mph. High and gusting winds created problems with overspray and rapid curing for both the Permastripe™ and paint markings.

Placement of markings

The markings layout was achieved by using a tape measure and chalk line. Lines are spaced 10 ft apart, are 15 ft in length, beginning at 1 ft away from the outside of the runway or taxiway centerline markings, and were placed in groups of three stripes of three colors. A total of 18 lines at two different locations were placed.

The paint was applied using a standard walk-behind gas-powered spray device equipped with a Potters Industries retroreflective bead dispenser. No masking was used other than a roofing shingle being placed at the start and end of each line to provide a convenient cut-on and cut-off. In general, the paint application was simple with the only serious problem being significant overspray due to the high winds present during much of the day.

Application of the Permastripe™ required significantly more setup time than paint and required hand mixing prior to application. On the grooved runway, Permastripe™ was applied by a spray technique that required masking of the line using tape. No controls over the mixing viscosity were exercised resulting in inconsistencies in the spray and screed application from batch-to-batch. In addition, due to the mixing technique, lumps were present in the Permastripe™ that required sieving of the material prior to spraying/screening. The thickness of the Permastripe™ lines was hard to control because the lines were placed with a hopper-type spray device commonly used in residential construction to apply textures to ceilings and walls. Bead placement was accomplished by hand-throwing the beads into the wet surface of the Permastripe™ immediately after placement.

For the screed application of Permastripe™, the line thickness is dependent on the die opening on the screed device, speed of operation, and the rheology (flow properties) of the Permastripe™. Both the beginning and end of each Permastripe™ line was significantly thicker because of the placement of roofing shingles to provide a convenient cut-on and cut-off. The screed pull started on the shingles and ended on the shingles. The middle portion of the lines is also significantly thicker than the 32-mil die opening. It is speculated that the material viscosity was high, resulting in lifting of the screed device such that the final line thickness was slightly higher than the die opening. For the first two red Permastripe™ lines, beads could not be placed on the line because of an approximate 2-min delay after the line placement. The surface had cured to the point that the beads would not embed or stick to the surface of the marking. In addition, surface cracks developed on these lines as a result of shrinkage due to water loss. The two Permastripe™ lines were then over-coated with a red solvent-based topcoat and the beads manually dispersed into the surface.

Adhesion measurements of coatings to pavement surfaces

The adhesion measurements were taken according to ASTM D 4541 using an Elcometer and glue-on plugs. The measurements were attempted approximately 4 hr after placement of the final lines. However, most of the plugs failed in adhesion at low values. Additional measurements taken after 3 months indicated both paint and Permastripe™ failed in adhesion on the concrete taxiway with Elcometer values of approximately 100 psi.

Coating thickness measurements

Thickness measurements were obtained using a wet thickness gauge and a dry measurement technique. As with the pull-off strength measurements, a lack of complete cure immediately after placement prevented proper dry thickness measurements, especially with the paint. The thickness measurement technique uses a cutting device that cuts the coating at an angle such that the width of the cut at the coating surface is proportional to the depth. By measuring the width of the cut at the coating surface, the coating thickness can be determined. Because of incomplete curing of the paint, a well-defined cut was not possible. However, some measurements of the Permastripe™ material were possible and these measurements yielded values of 80 to 100 mils, with 100 mils being the maximum range of the measuring device. From visual observation, it was estimated that Permastripe™ thickness was 1/16 to 1/8 in. in thickness.

Wet film thickness measurements of the paint yielded values between 15 and 25 mils. Dry film measurements on the paint after 3 months of cure resulted in values between 7- and 15-mil thickness. These values are low and could be attributed to the gusting wind. Typically, the paint contains approximately 50 percent liquids such that after cure, a film thickness approximately half of the wet film thickness is obtained. Thus, the dry film thicknesses and wet film thicknesses agree well.

Retroreflectivity measurements

Retroreflectivity measurements were taken with a Mirolux 12 retroreflectometer. Values are expressed in millicandelas/square meter/lux. The device is not capable of measurements on grooved runway surfaces. Measurements were taken on the taxiway lines only. Six measurements were taken on each line at approximately 2.5-foot intervals beginning at approximately 1.5 feet from the line end. Three measurements were taken in one direction and the remaining three in the other.

For the white and yellow lines, the paint had much higher retroreflectivity than the Permastripe™. Typical values for white paint were approximately 300 and for Permastripe™, less than 200. For the yellow lines, paint exhibited values of approximately 250 and for the Permastripe™ lines, less than 150. For the red lines, the Permastripe™ lines had overall higher retroreflectivity; however, two of three Permastripe™ lines are over-coated with a red topcoat and those exhibit the highest retroreflectivity. It was observed using a magnifying lens that the beads were buried well into the surface of the Permastripe™ line that was not top-coated.

Removal of Test 1 lines

Removal of the Test 1 lines on concrete pavement was accomplished in April 2002 using waterblasting at 32,000 psi. It was obvious that the Permastripe™ lines required significantly more effort for removal than the paint. Removal of the test Permastripe™ lines on asphalt resulted in significant damage to the surrounding asphalt to the point that the removal was halted.

Test 2 – April 2002

Summary - Test 2

A total of 18 lines were placed in April 2002 consisting of nine paint and nine Permastripe™ markings in three colors: red, yellow, and white. Three beads type were applied to both Permastripe™ and paint for Test 2. Type I, Type III, and a Type I/Type III blend (Brite Blend™) of beads were used. Visual observations of the markings, as well as durability and retroreflectivity measurements were measured at selected intervals from April 2002 to June 2005 with a Mirolux 12 and LTL 2000 retroreflectometer. Traffic almost consisted entirely of F-15C aircraft with approximately 5,000 passes per year, leading to a total of nearly 15,000 passes over the life of the Test 2 lines.

The Permastripe™ material displayed a tendency to harbor algae, resulting in a splotchy appearance (Figure 2). The retroreflectivity of the Permastripe™ compared to paint was significantly lower. The low retroreflectivities were due in part to a more rapid curing of the Permastripe™ during placement compared to what had been observed in test trials in preparation for Test 2. This rapid curing led to low bead density and shallow embedment. Strict control over Permastripe™ base materials, viscosity, and proper application equipment will allow for better control of line thickness, bead embedment, and curing rates. The differences in retroreflectivity of the different bead types in Permastripe™ and paint were evident. As expected, the Type III beads resulted in higher initial and final retroreflectivities, but lost a higher percentage of the initial retroreflectivity than either Type I or the Brite Blend™ Type I/Type III blend.

Due to a miscommunication, the Adsil™ coating was applied more in a random fashion rather than to half of each line as was sought. As a result, definitive conclusions about the performance of the material could not be reached. However, the Adsil™ was applied by spray and did not contain any flattening agent. The lines that were coated exhibit significant reductions in retroreflectivity on the order of approximately 30 percent which was lower than those observed in Test 3.

Weather conditions

Markings placement was on April 15, 2002. The day was bright, sunny, and cloudless. Daytime temperatures were 75 to 85 °F with winds steady at 5 to 10 mph. Conditions were ideal for pavement marking placement.

Placement of markings

The marking layout was achieved by using a tape measure and chalk line. Lines were spaced 10 ft apart, were 15 ft in length beginning at 1 ft away from the outside of the runway or taxiway centerline markings, and were placed in groups of three stripes of three colors: red, yellow, and white. A total of 18 lines at two different locations were placed. The final layout of the lines is provided in Figure 3. The runway lines placed in October 2001 were left undisturbed after an attempt to remove a Permastripe™ line using waterblasting resulted in excess pitting of the asphalt surface. A white Permastripe™ line was placed over the pitted asphalt to reduce the possibility of Foreign Object Damage (FOD).

Permastripe™ placement was much improved over that in Test 1, but still suffered from a lack of control over viscosity and application conditions. The Permastripe™ prototype applicator employed a modified drywall texture application device mounted to a self-propelled lawn mower (Figure 4). This resulted in acceptable Permastripe™ line thickness (25 to 30 mils). However, bead embedment was inconsistent due to rapid curing of the Permastripe™ that was not observed in test trials run in preparation for Test 2. This required changing the bead applicator during the test. The original bead applicator used a gravity drop and was switched to a Potter Industries dispenser. The paint was applied using a standard walk-behind gas-powered spray device equipped with a Potters Industries retroreflective bead dispenser (Figure 5). No masking was used.

Application of the Permastripe™ required more setup time than that needed for paint and required hand mixing prior to application. As in Test 1, the lumps of unmixed materials were strained prior to loading the applicator. Viscosity control was attempted by using a makeshift funnel with an attached tube and measuring the flow time. However, flow times of only a few seconds were measured with the possibility of gross errors in the viscosity of the Permastripe™. It was strongly recommended that a flow time apparatus be constructed that would result in flow times of between 45 and 60 seconds. This would allow for proper control of viscosity and provide enough fidelity that flow time boundaries could be established.

Coating thickness measurements

The thickness measurement techniques have been previously described. Values for the paint averaged from 7 to 15 mils, and values for the Permastripe™ averaged from 25 to 30 mils.

Retroreflectivity measurements

Retroreflectivity measurements were taken as previously described in Test 1. The average values for each line are reported in Figures 6-11. The initial and ending values are given in Table 1 for the Mirolux 12 and Table 2 for the LTL-2000. It should be noted that the lines coated with Adsil™ resulted in approximately 30 percent lower retroreflectivity values after application.

Table 1. Mirolux 12 retroreflectivity measurements immediately after placement and at the end of Test 2.

Marking Type	Bead Type Retroreflectivity - Mirolux 12 (millicandelas/square miles/lux)					
	Type I		Brite Blend		Type III	
	0 Days	1100 Days	0 Days	1100 Days	0 Days	1100 Days
White Paint	299	208	573	391	1059	382[1]
White Permastripe	183	153	295	143	645	235[1]
Yellow Paint	219	79[1]	350	223	583	351
Yellow Permastripe	117	78	180	83	343	47[1]
Red Paint	136	88[1]	253	148	364	233
Red Permastripe	137	92	128	60	445	221[1]

[1] Coated with Adsil approximately 200 days after placement.

Table 2. LTL-2000 retroreflectivity measurements immediately after placement and at the end of Test 2.

Marking Type	Bead Type Retroreflectivity - LTL 2000 (millicandelas/square miles/lux)					
	Type I		Brite Blend		Type III	
	0 Days	1100 Days	0 Days	1100 Days	0 Days	1100 Days
White Paint	195	189	497	356	1339	357[1]
White Permastripe	117	135	338	111	995	258[1]
Yellow Paint	142	65[1]	291	186	689	375
Yellow Permastripe	73	66	178	74	343	26[1]
Red Paint	45	55[1]	158	105	400	178
Red Permastripe	57	52	94	27	387	122[1]

[1] Coated with Adsil approximately 200 days after placement.

Adsil™ coating

The Adsil™ coating was applied to selected paint and Permastripe™ lines August 9, 2002, to gauge the effectiveness of this material at providing durability to the markings. The Adsil™ was sprayed on the lines using a common garden sprayer. The Adsil™ resulted in a glossy appearance on the surface of lines. It did not contain flattening agent. The durability of the Adsil™ application on the Test 2 lines could not be ascertained due to a miscommunication that led to random lines being coated; thus, no control was available for direct comparison. This result, combined with the poor retroreflectivity of the Permastripe™ lines, eventually led to Test 3. Although definitive conclusions about the durability could not be drawn, it is evident that this formulation of Adsil™ without flattening agent reduced retroreflectivity by approximately 30 percent, but less than the Adsil™ formulation with flattening agent (Test 3).

Removal of Test 2 lines

Removal of the Test 2 lines on concrete pavement was accomplished in June 2005 using waterblasting at 32,000 psi. As with Test 1, it was obvious that the Permastripe™ lines required significantly more time for removal than the paint.

Test 3 – August 2003

Summary - Test 3

On August 2, 2003, 36 additional test lines were added to the existing 18 lines that were placed in October 2002. Of the 36 additional lines added to the test area, 18 were standard airfield marking paint and 18 were Permastripe™. Type I and Type III reflective beads were used and selected lines were coated with either one or two coats of Adsil™. Traffic consisted almost entirely of F-15C aircraft with approximately 10,000 passes over the life of the Test 3 lines.

Placement of the paint and Permastripe™ lines was conducted with the same equipment as in Test 2. Slightly higher line thicknesses for the paint were noted (15 to 20 mils), and similar line thickness to those in Test 2 for Permastripe™ (25 to 30 mils) were obtained. Poor bead embedment was noted for the Permastripe™ material and was surmised to have resulted from poor material consistency. Weak embedment was noted for some lines and over-embedment was observed for others. On several lines, inspection with a magnifying glass showed that the beads had sunk well into the surface with only approximately 20-30 percent exposure. The Permastripe™ did not exhibit signs of soiling as in Test 2; this was surmised to result from differences in surface porosity. This suggests significant differences from Test 2 for quality control of the Permastripe™. This is consistent with the slight rise in retroreflectivity for the uncoated Permastripe™ lines, as the traffic wore the surface, the beads became more exposed.

The Adsil™ coating resulted in a sharp decrease in retroreflectivity immediately after placement. The coating was applied using a roller, and likely resulted in much greater thickness than when applied by spray. There may also have been soil deposited on the lines from the rollers that were picked up from the pavement. Also, the formulation of Adsil™ for

Test 3 contained a flattening agent to reduce the glossy appearance. Over time, the retroreflectivity readings increased as the coating wore off.

As in Test 2, the retroreflectivity data indicate that the Type III beads display much higher retroreflectivity than the Type I beads. However, in Test 3, the degree of retroreflectivity loss of the Type III beads over a similar time frame is significantly lower than in Test 2. A potential cause may be the higher paint thickness in Test 3 (15 to 20 mils) than that measured in Test 2 (10 to 15 mils).

Weather conditions

Markings placement was on August 2, 2003. The day was bright and sunny with few clouds. Daytime temperatures were 75-92°F (24-34°C) with winds steady at 5-10 mph and gusting to 15 mph. Conditions were good for striping and resulted in rapid curing of both paint and Permastripe™.

Placement of markings

The marking layout was achieved by using a tape measure and chalk line. Lines were spaced 3 feet (1 m) apart, were 15 feet (4.57 m) in length beginning at one foot (.305 m) away from the outside of the runway or taxiway centerline markings, and were placed in groups of three stripes of three colors. A total of 18 lines at two different locations were placed. The final layout of the Tyndall AFB test lines (Test 2 and Test 3) lines are provided in Figure 12.

The paint was applied using a standard walk-behind gas-powered spray device equipped with a Potters Industries retroreflective bead dispenser. No masking was used other than a roofing shingle being placed at the start and end of each line to provide a convenient cut-on and cut-off.

Application of the Permastripe™ required significantly more setup time than paint and required hand mixing prior to application. As in Test 2, the lumps of unmixed materials were strained prior to loading the applicator and viscosity control was attempted by using a makeshift funnel with an attached tube and measuring the flow time. This process had not been improved over that in Test 2 despite the obvious shortcomings. The prototype Permastripe™ spray application device was also the same as in Test 2 (Figure 4).

Coating thickness measurements

The dry thickness measurement technique has been previously described. Values for the paint averaged 15 to 20 mils, and values for the Permastripe™ averaged 25 to 30 mils.

Retroreflectivity measurements

Retroreflectivity measurements were taken as previously described in Test 1. The average values for each line are reported in Figures 13-24. The initial and ending values for retroreflectivity are presented in Tables 3-8.

These data clearly show that the Adsil™ coating adversely affects initial retroreflectivity values. However, the data also show that as the Adsil™ coating wears off, the retroreflectivity values increase. This suggests that Adsil™ may have value to improve the durability of pavement markings if the issue with retroreflectivity can be solved.

The data also clearly indicate that the use of Type III beads provide higher retroreflectivity initially and over time.

Table 3. Mirolux 12 retroreflectivity measurements immediately after placement and at the end of Test 3 for lines with no Adsil™ coating.

Marking Type	Bead Type Retroreflectivity - Mirolux 12 (millicandelas/square miles/lux)			
	Type I		Type III	
	0 Days	672 Days	0 Days	672 Days
White Paint	267	232	687	564
White Permastripe	228	259	378	263
Yellow Paint	199	184	330	272
Yellow Permastripe	173	131	181	129

Table 4. LTL-2000 retroreflectivity measurements immediately after placement and at the end of Test 3 for lines with no Adsil™ coating.

Marking Type	Bead Type Retroreflectivity - LTL 2000 (millicandelas/square miles/lux)			
	Type I		Type III	
	0 Days	672 Days	0 Days	672 Days
White Paint	199	221	1216	834
White Permastripe	177	243	544	321
Yellow Paint	154	180	426	320
Yellow Permastripe	200	124	191	133

Table 5. Mirolux 12 retroreflectivity measurements immediately after placement and at the end of Test 3 for lines with one coat of Adsil™.

Marking Type	Bead Type Retroreflectivity - Mirolux 12 (millicandelas/square miles/lux)			
	Type I		Type III	
	0 Days	672 Days	0 Days	672 Days
White Paint	252	141	369	337
White Permastripe	106	175	257	170
Yellow Paint	90	117	245	198
Yellow Permastripe	97	96	96	66

Table 6. LTL-2000 retroreflectivity measurements immediately after placement and at the end of Test 3 for lines with one coat of Adsil™.

Marking Type	Bead Type Retroreflectivity - LTL 2000 (millicandelas/square miles/lux)			
	Type I		Type III	
	0 Days	672 Days	0 Days	672 Days
White Paint	79	120	236	302
White Permastripe	45	139	97	101
Yellow Paint	52	88	171	161
Yellow Permastripe	56	73	41	52

Table 7. Mirolux 12 retroreflectivity measurements immediately after placement and at the end of Test 3 for lines with two coats of Adsil™.

Marking Type	Bead Type Retroreflectivity - Mirolux 12 (millicandelas/square miles/lux)			
	Type I		Type III	
	0 Days	672 Days	0 Days	672 Days
White Paint	137	182	236	282
White Permastripe	137	108	157	135
Yellow Paint	97	105	158	151
Yellow Permastripe	75	89	87	65

Table 8. LTL-2000 retroreflectivity measurements immediately after placement and at the end of Test 3 for lines with two coats of Adsil™.

Marking Type	Bead Type Retroreflectivity - LTL 2000 (millicandelas/square miles/lux)			
	Type I		Type III	
	0 Days	672 Days	0 Days	672 Days
White Paint	65	169	128	365
White Permastripe	66	109	61	104
Yellow Paint	39	91	82	124
Yellow Permastripe	30	87	39	48

Removal of Test 3 lines

Removal of the Test 3 lines on concrete pavement was accomplished in June 2005 using waterblasting at 32,000 psi. As with Test 1, it was obvious that the Permastripe™ lines required significantly more time for removal than the paint.

Mountain Home AFB

Summary of results – May 2003

On Saturday, June 14, 2003, standard airfield marking paint and polymer concrete pavement markings were placed on Taxiway B at Mountain Home Air Force Base (MHAFB). The primary objective was to gauge the effects of snowplow operations. Type I beads were used to provide retroreflectivity. The location of the markings on Taxiway B was approximately halfway between Taxiway E and F and at the intersection of the old East/West runway. The markings were removed after 1 year of service in September 2004. Originally, the intention was to leave the markings through two winters of snowplow operations. However, after reviewing the retroreflectivity data and the condition of the lines, it was determined that additional time in service was not warranted.

The retroreflectivity measurements indicated that the Permastripe™ lines had maintained the retroreflectivity levels better than paint. However, the initial retroreflectivity levels of the Permastripe™ lines were lower than those of paint. The Permastripe™ markings were also significantly more stained than the standard paint lines and showed a moderate amount of scuffing from the pavement sweepers and snowplows, presumably from the greater thickness of the Permastripe™ markings. Both paint and Permastripe™ exhibited delamination from the concrete surface although the severity of the Permastripe™ adhesion loss was greater.

Condition surveys and retroreflectivity measurements were conducted on September 30, 2003, January 27, 2004, May 11, 2004, and August 24, 2004, to track performance after approximately 3, 7, 11, and 14 months of service. Retroreflectivity measurements indicated both the paint and polymer concrete markings exhibited significant loss of retroreflectivity (Figure 25). Compared to initial values, the markings lost between 50 and 70 percent retroreflectivity after approximately 14 months of service. The general condition of the markings after 14 months was fair to poor. The Permastripe™ showed signs of delamination at the edges of several lines (Figure 26) and was stained in several areas (Figure 27). Although not as severe, staining and delamination was also noted in several areas for paint lines (Figure 28). The staining of the Permastripe™ appeared to be the result of joint sealant that was picked up on the sweepers and subsequently deposited onto the Permastripe™ during warm weather. This deposition of joint sealant was not as prevalent on the paint markings although it was present on some paint lines. This is surmised to result from the greater thickness and a more rough surface texture of the Permastripe™ than the paint.

Weather conditions

June 14, 2003, was bright, sunny, and cloudless. Daytime temperatures were 70-85°F (21-30°C) with winds steady at 10-15 mph and gusting to 20 mph. High and gusting winds created problems with overspray and rapid drying for both the Permastripe™ and paint markings.

Placement of markings

The Permastripe™ markings were sprayed using a modified drywall texture application device mounted on a modified self-propelled lawn mower (Figure 4). This resulted in acceptable Permastripe™ line thickness

(25 to 30 mils). A hand-operated pressure wand was used to apply the bead on the Permastripe™ lines. This resulted in flooding of the lines (bead density appeared too high).

The marking layout was achieved by using a tape measure and chalk line. Lines were spaced 10 ft apart and were 15 ft in length beginning 1 ft away from the outside of the runway or taxiway centerline markings, and were placed in groups of three stripes of three colors; red, yellow, and white. A total of 18 lines were placed. The final layout of the lines is shown in Figure 29.

The paint was applied using a standard walk-behind gas-powered spray device equipped with a Potters Industries retroreflective bead dispenser. No masking was used. Application of the Permastripe™ required more setup time than paint and required hand mixing prior to application. As in the Tyndall AFB tests, the lumps of unmixed materials were strained prior to loading the applicator. Viscosity control was attempted by using a makeshift funnel with an attached tube and measuring the flow time. However, flow times of only a few seconds were measured with the possibility of gross errors in the viscosity of the Permastripe™. As in Test 3, it was strongly recommended that a flow time apparatus be constructed that would result in flow times of between 45 and 60 seconds. The prototype Permastripe™ spray application device (Figure 4) was employed to place the lines.

Adhesion measurements of coatings to pavement surface

The pull-off measurements were taken according to ASTM D 4541 using an Elcometer and glue-on plugs. The measurements were taken approximately 3 months after placement of the final lines. However, most of the plugs failed in adhesion at values less than 100 psi.

Coating thickness measurements

The dry thickness measurement technique has been previously described. Values for the paint averaged from 10 to 20 mils and values for the Permastripe™ averaged 20 to 30 mils.

Retroreflectivity measurements

Retroreflectivity measurements were taken with a Mirolux 12 retroreflectometer. At least three measurements in each direction were taken on each line at intervals of approximately two feet, beginning at the line end. The data from January 27, 2004, will not be shown, as it is known to be in error, apparently due to a thin layer of ice on the lines that was not visible to the eye. Average values for each set of similar lines are given in Figure 25, plotted as a function of days in service.

At the conclusion of the test, the visible conditions of the paint lines were better than the Permastripe™ lines. However, the loss of retroreflectivity, on a percentage basis, is higher for the paint. Significantly less adhesion loss was noted for the paint lines compared to the Permastripe™. According to MHAFB civil engineering personnel, poor paint adhesion to the concrete is a recurring problem. The degree of staining of the paint lines from joint sealant picked up by the sweepers was also considerably less than the Permastripe™.

There was some minor adhesion loss on the leading edges of the paint lines where the sweepers and snowplows first encounter the lines. The sweepers and snowplows generally follow the same traffic patterns day after day, traversing the taxiway on the west side of the taxiway going south and the east side going north. The Permastripe™ lines exhibited significant adhesion loss in several areas. Adhesion loss was particularly significant on the leading edges of the lines where the sweepers and snowplows first encounter the lines based on their traffic patterns. Numerous areas of scuffing on the surface of the Permastripe™ lines were noted, probably caused by the snowplow blades. This scuffing was not as serious on the paint lines due to the lower paint line thickness compared to the Permastripe™.

5 Conclusions and Recommendations

Conclusions

The Permastripe™ shows promise as a durable marking; however, it requires significant improvements for commercial airfield applications. Until the problems with material consistency are solved, line thicknesses and bead embedment cannot be controlled.

Placement of Permastripe™ on asphalt requires that the marking be permanent. If the marking has any chance of being moved or altered, it should be marked with paint. Once Permastripe™ is placed on asphalt, it cannot be removed using standard waterblasting techniques without significantly damaging the surrounding asphalt.

Type III beads and the Type I/III bead blend are clearly superior to Type I in initial and long-term retroreflectivity. Although the higher retroreflective beads return a higher intensity of light back to the light source, this may be of variable benefit to pilots depending on the intensity and location of the light source on the aircraft in relation to the pilot and the distance the aircraft is from the markings. Clearly, the smaller the angle between the retroreflected light and the source results in a brighter appearance of the pavement markings to the pilot.

The Adsil™ coatings significantly degraded initial retroreflectivity. However, the data from Test 3 clearly shows that, as the coating wears, the retroreflectivity values increase. Thus, the use of the Adsil™ coating to extend pavement marking durability show promise.

Recommendations

Until the technical problems associated with Permastripe™ are solved, it is not recommended for use on military airfield facilities. A draft ETL (Engineering Technical Letter) is included in Appendix A of this document and should serve only as a starting point for Permastripe™ implementation.

Pavement markings require accurate and precise control of viscosity. For Permastripe™, using filler and a consistent sand source, high-shear mixing to minimize lumps, and a continuous mixing device should significantly improve consistency. Once consistency of material is obtained, spraying and bead placement variables will be able to be determined. The results from Mountain Home AFB suggest that Permastripe™ may exhibit stronger adhesion to retroreflective beads compared to paint. This result was not clear based on the tests at Tyndall AFB.

The use of durable markings such as PCPM, methacrylate, epoxy, etc., should be used only when it is certain that the marking will not be moved; edge lines are an example. Durable lines should not be used on asphalt unless an appropriate removal method is available.

The use of higher retroreflective media than Type I beads should be allowed on military airfield facilities on a case-by-case basis. The cost/benefit ratio, safety factor, aircraft type, and pilot input should be weighed on an individual basis by the airfield manager, safety personnel, and base engineer.

The use of Adsil™ coatings for increasing the durability of pavement markings requires further study. The main detriment for use is the large decreases in retroreflectivity after coating.

A definitive study to measure the effects (both in quantitative fashion and subjective observations) of various bead types on nighttime visibility needs to be undertaken. This study should include quantitative measurement of reflectivity at various angles from a fixed light source as well as measurements of scattered light from ambient lighting. This data would be highly useful in ground traffic simulators such that accurate models (and subsequent simulations) of nightline markings visibility could be constructed based on the source lighting location (to accommodate different aircraft types). These data should be buttressed with subjective recordings of pilot observations from different aircraft and photography at various angles from source lighting.

References

AASHTO. 2002. *Glass beads used in traffic paint*. AASHTO M-247. Washington, DC: American Association of State Highway Transportation Officials.

Air Force Civil Engineering Support Agency. 1997. *Guide specification for airfield and roadway marking*. Air Force ETL 97-18 (Federal Specification TT-P-1952D, 1994; Paint, Traffic, and Airfield Marking, Waterborne). Tyndall AFB, FL.

_____. 1994. *Beads (glass spheres) retroreflective*. Federal Specification TT-B-1325C, 1993; Paint, Traffic, and Airfield Marking, Waterborne. Tyndall AFB, FL.

Bagot, K. 1995. *Evaluation of alternative pavement marking materials*. DOT/FAA/CT-94/119. Atlantic City, NJ: FAA Technical Center.

_____. 1994. *Evaluation of retro-reflective beads in airport markings*. DOT/FAA/CT-94/120. Atlantic City, NJ: FAA Technical Center.

Newman, J. K., and J. E. Shoenberger. 2003. *E-Krete™ polymer composite micro-overlay for airfields: Laboratory results and field demonstrations*. ERDC/GSL TR-03-24. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Walrond, G. E., and M. D. Ates. 1995. *Evaluation of retroreflective airfield pavement markings, Ellsworth AFB, South Dakota, and Tyndall AFB, Florida*. Tyndall AFB, FL: U.S. Air Force Civil Engineering Support Agency.

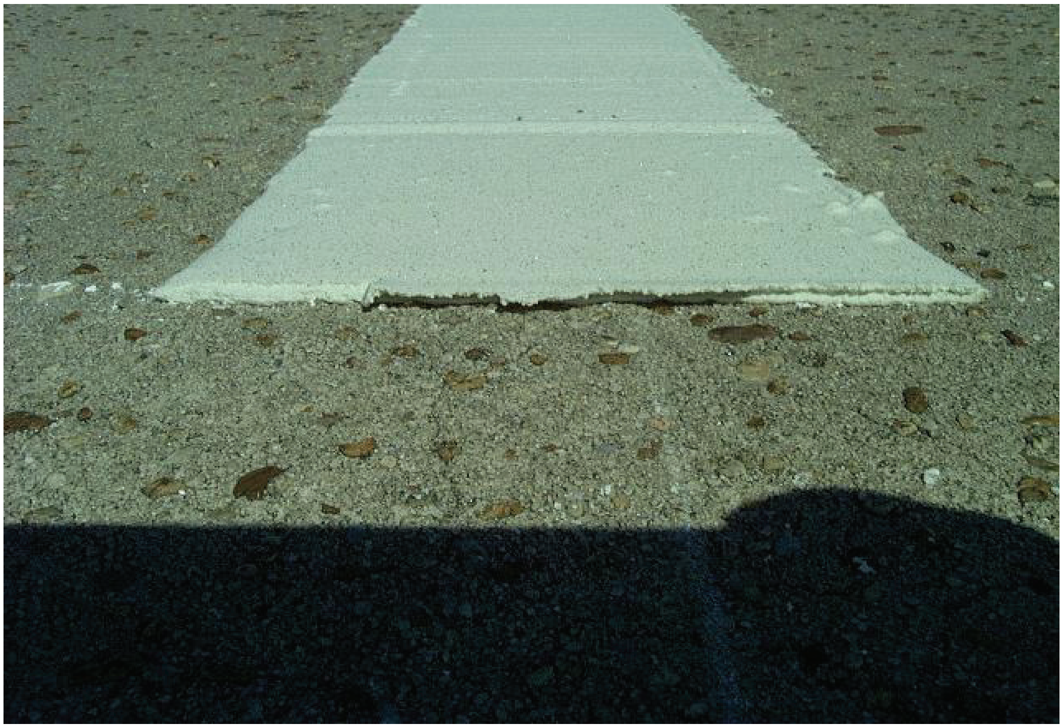

Figure 1. End-on view of Permastripe™ line from Test 1 at Tyndall AFB showing thickness.

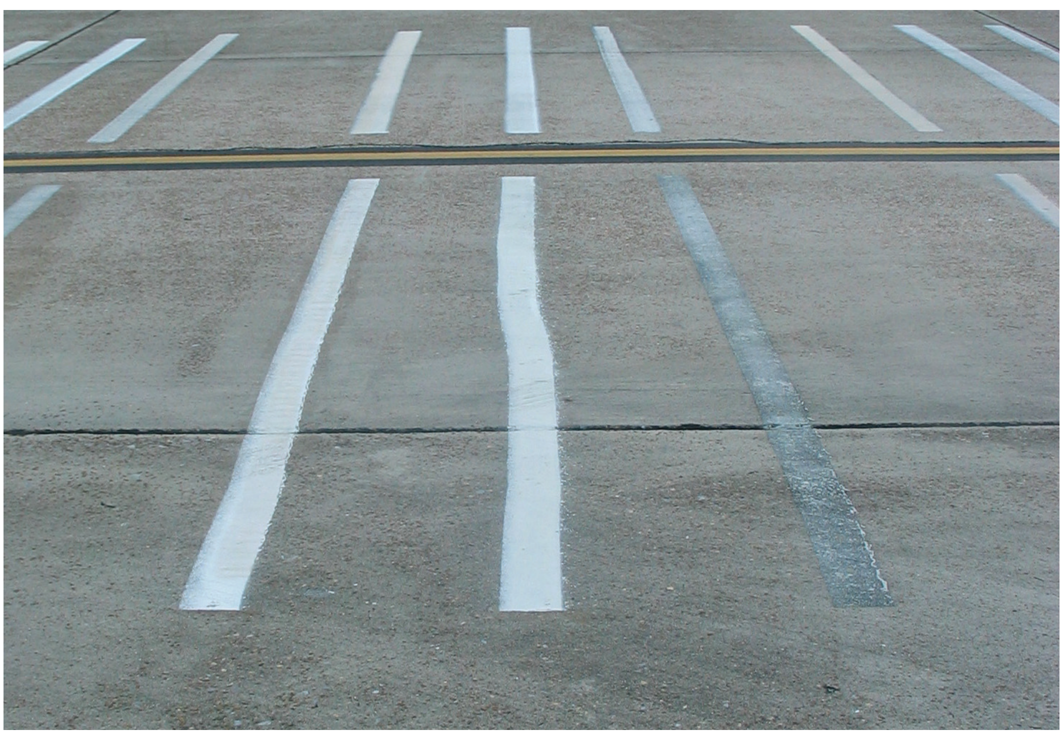

Figure 2. Soiling of Permastripe™ line from test 2 at Tyndall AFB.

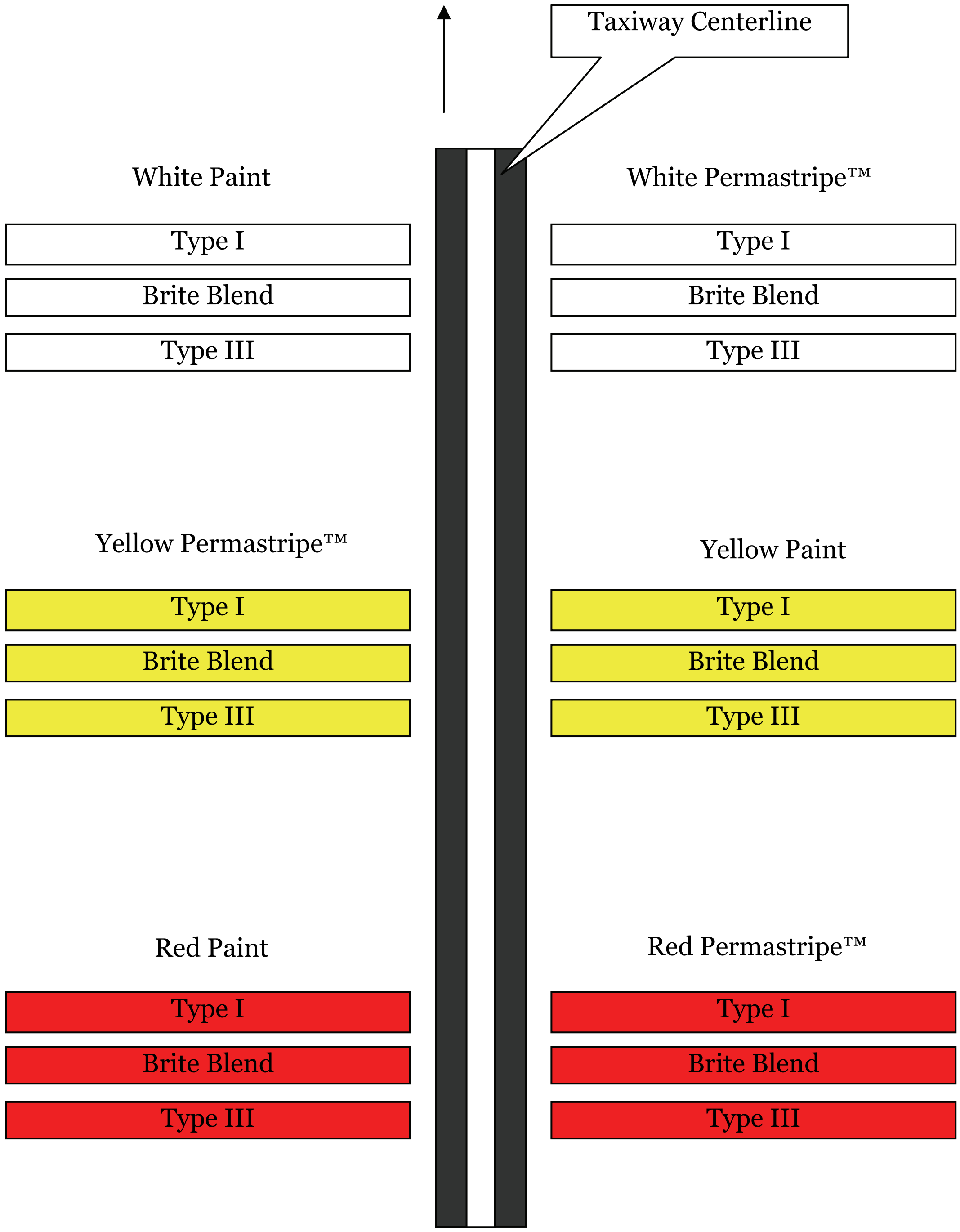

Figure 3. Layout of Test 2 lines at Tyndall AFB.

Figure 4. Prototype of the Hardliner™; application device for Permastripe™.

Figure 5. Paint striping machine used in Test 2 and Test 3 at Tyndall AFB.

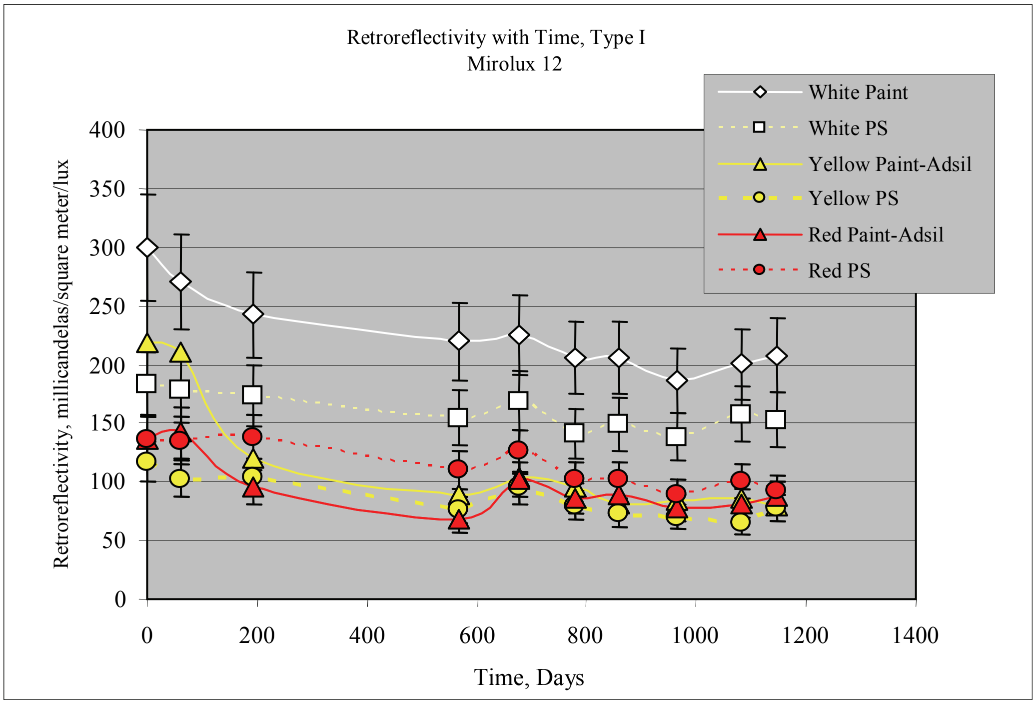

Figure 6. Retroreflectivity of Type I beads measured by the Mirolux 12 retroreflectometer for Test 2 at Tyndall AFB. *Note that the Adsil™ coating was applied prior to the data point near 200 days of service.*

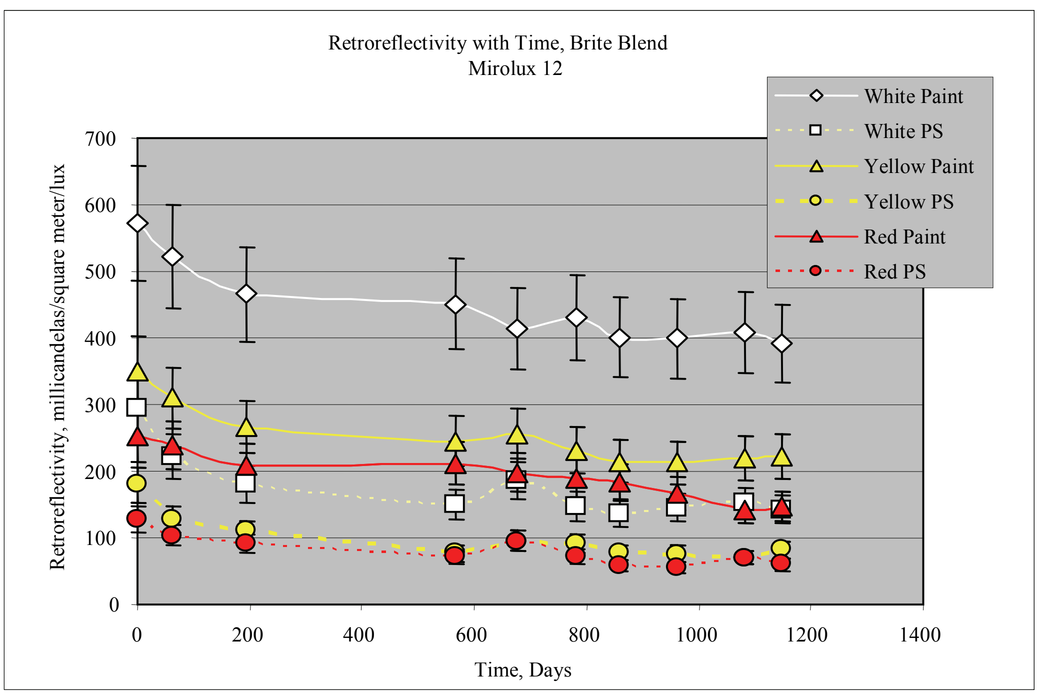

Figure 7. Retroreflectivity of Type I/Type III bead combination (Brite Blend™) measured by the Mirolux 12 retroreflectometer for Test 2 at Tyndall AFB. No Adsil™ was applied to Brite Blend™ lines.

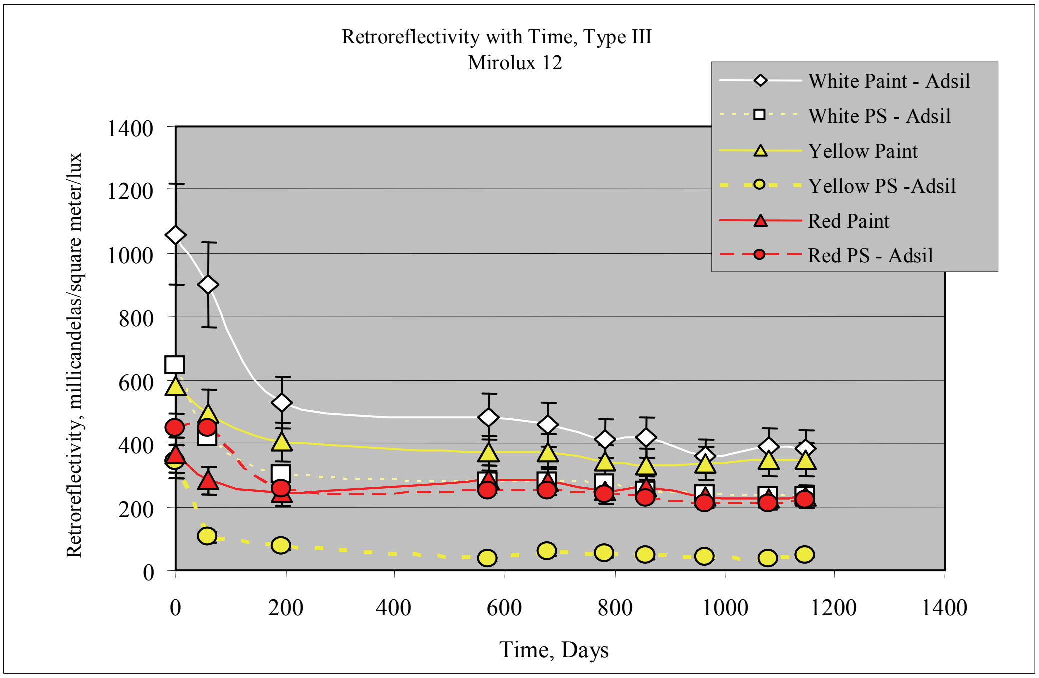

Figure 8. Retroreflectivity Type III beads measured by the Mirolux 12 retroreflectometer for Test 2 at Tyndall AFB. *Note that the Adsil™ coating was applied prior to the data point near 200 days of service.*

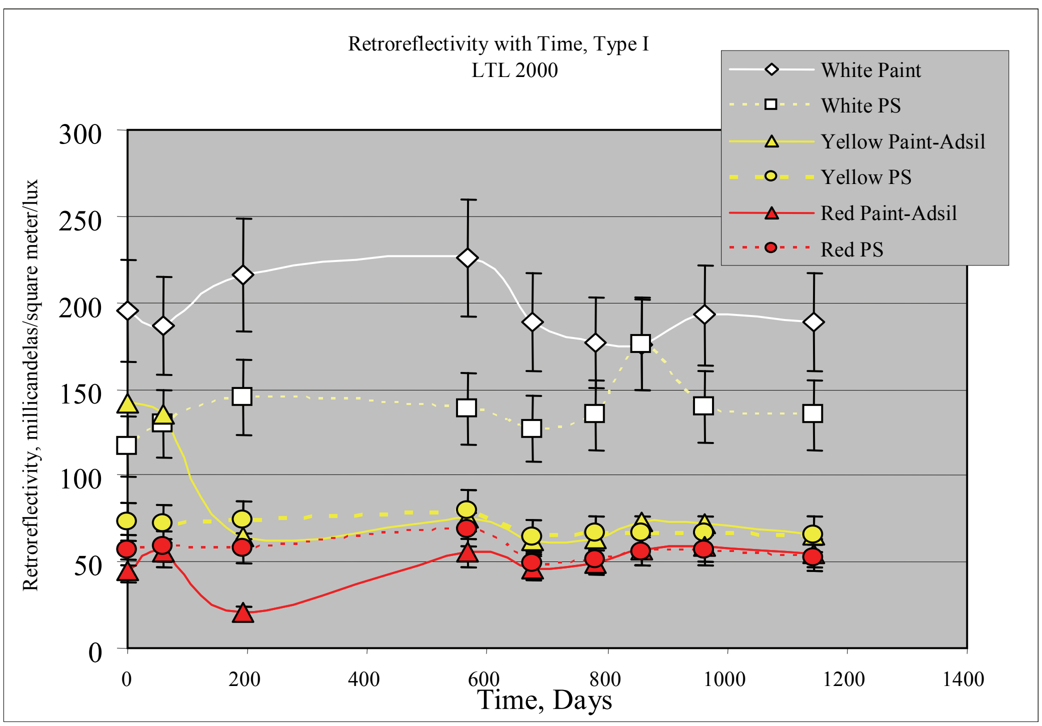

Figure 9. Retroreflectivity Type I beads measured by the LTL-2000 retroreflectometer for Test 2 at Tyndall AFB. Note that the Adsil™ coating was applied prior to the data point near 200 days of service.

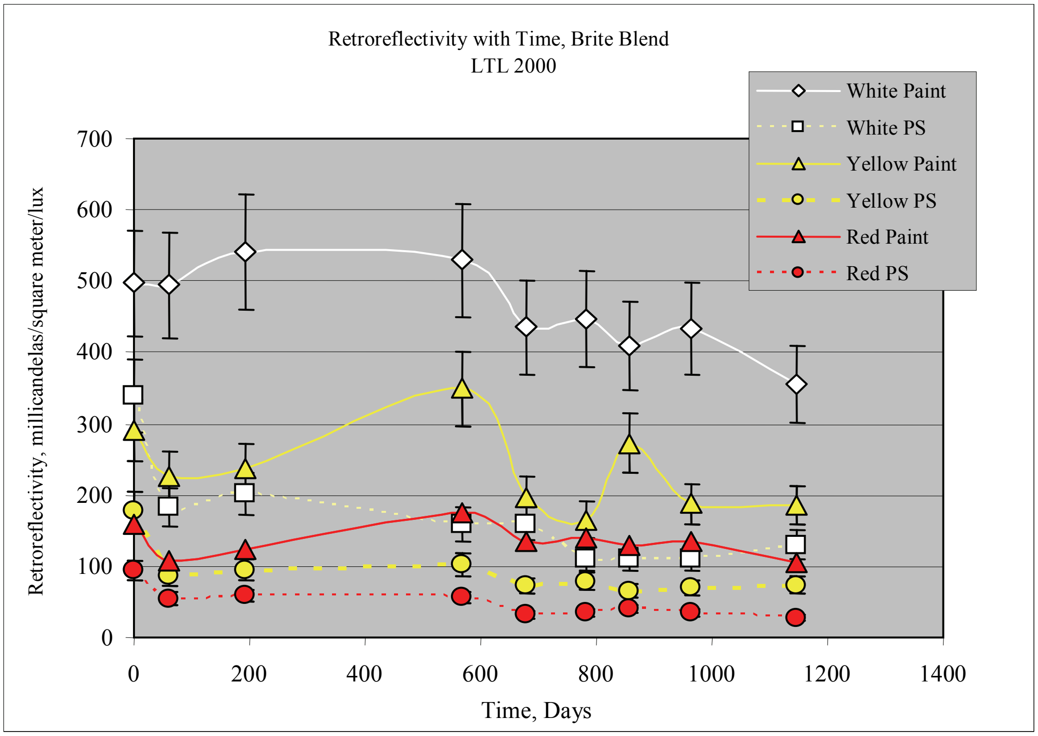

Figure 10. Retroreflectivity of Type I/III bead combination (Brite Blend™) measured by the LTL-2000 retroreflectometer for Test 2 at Tyndall AFB. No Adsil™ was applied to Brite Blend™ lines.

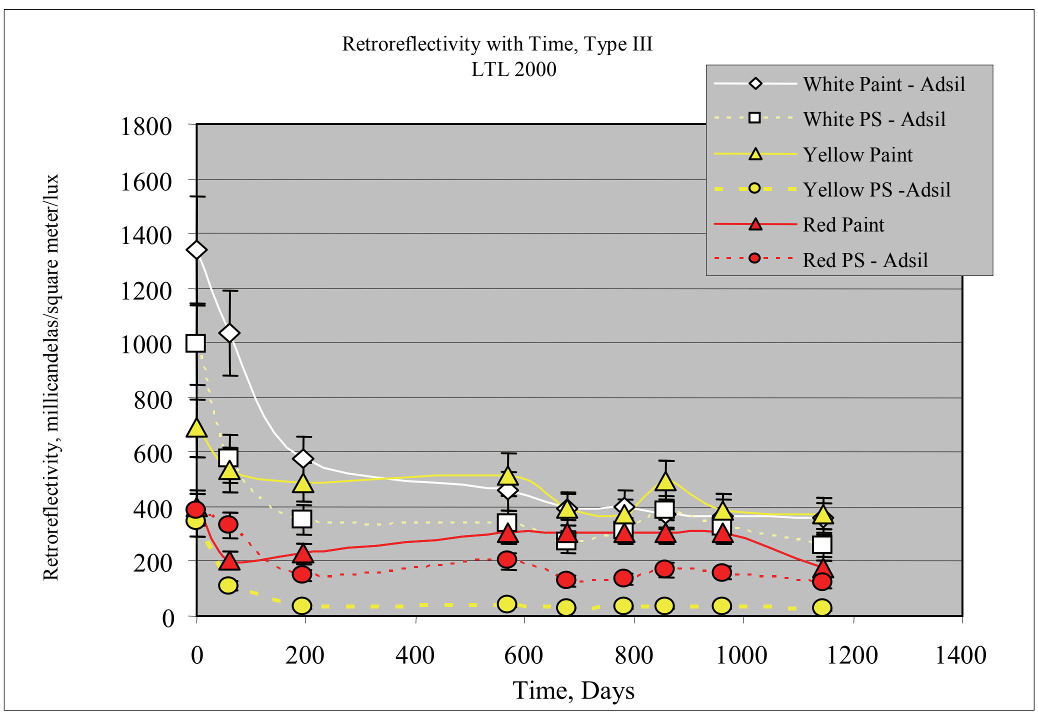

Figure 11. Retroreflectivity of Type III beads measured by the LTL-2000 retroreflectometer for Test 2 at Tyndall AFB. Note that the Adsil™ coating was applied prior to the data point near 200 days of service.

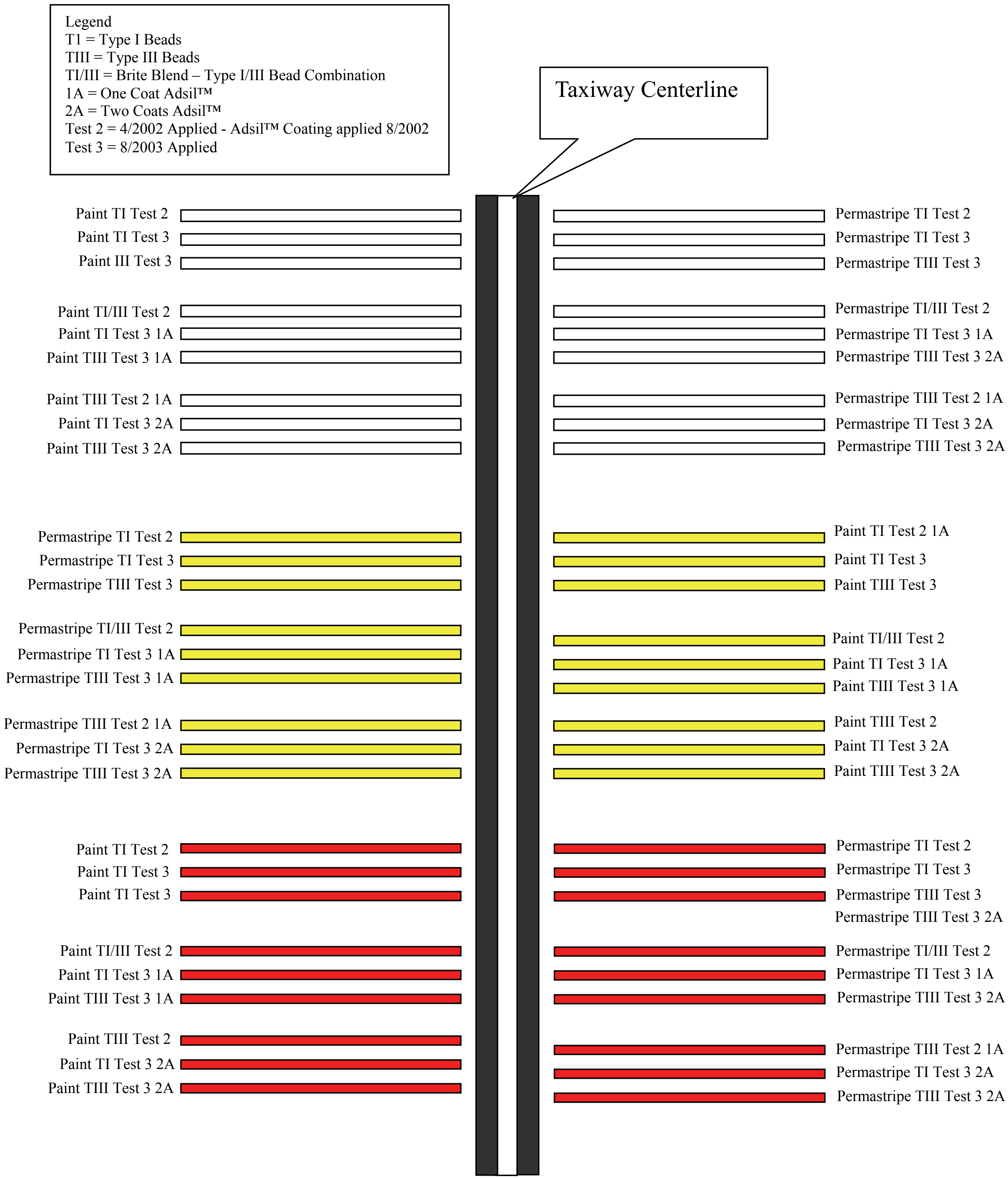

Figure 12. Layout of Test 2 and Test 3 lines at Tyndall AFB.

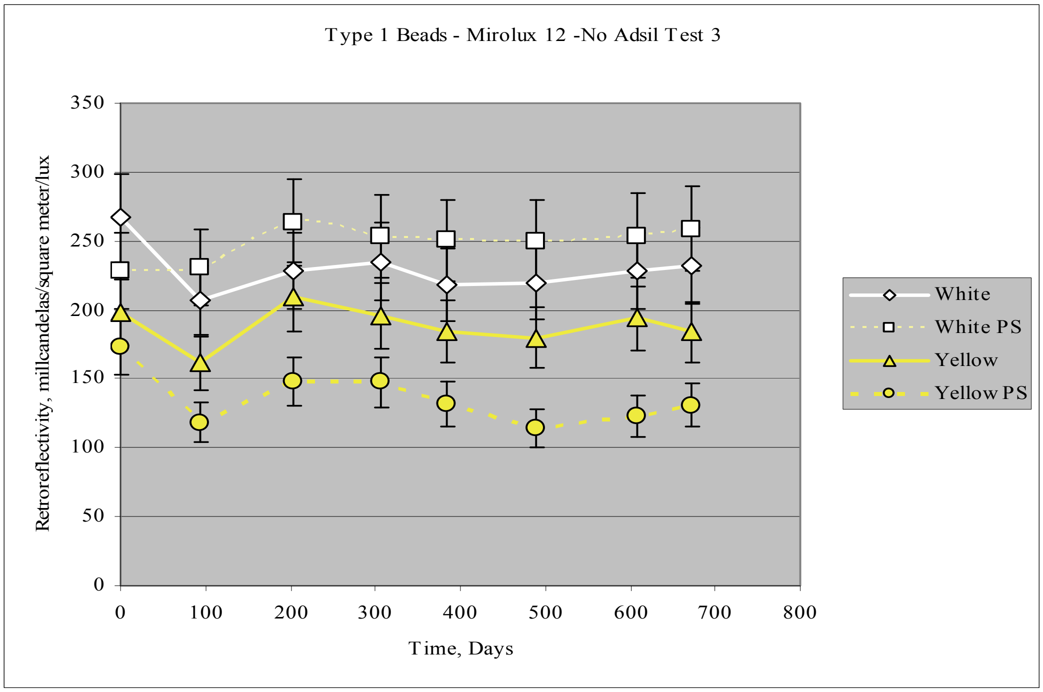

Figure 13. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type I beads measured by the Mirolux-12 retroreflectometer.

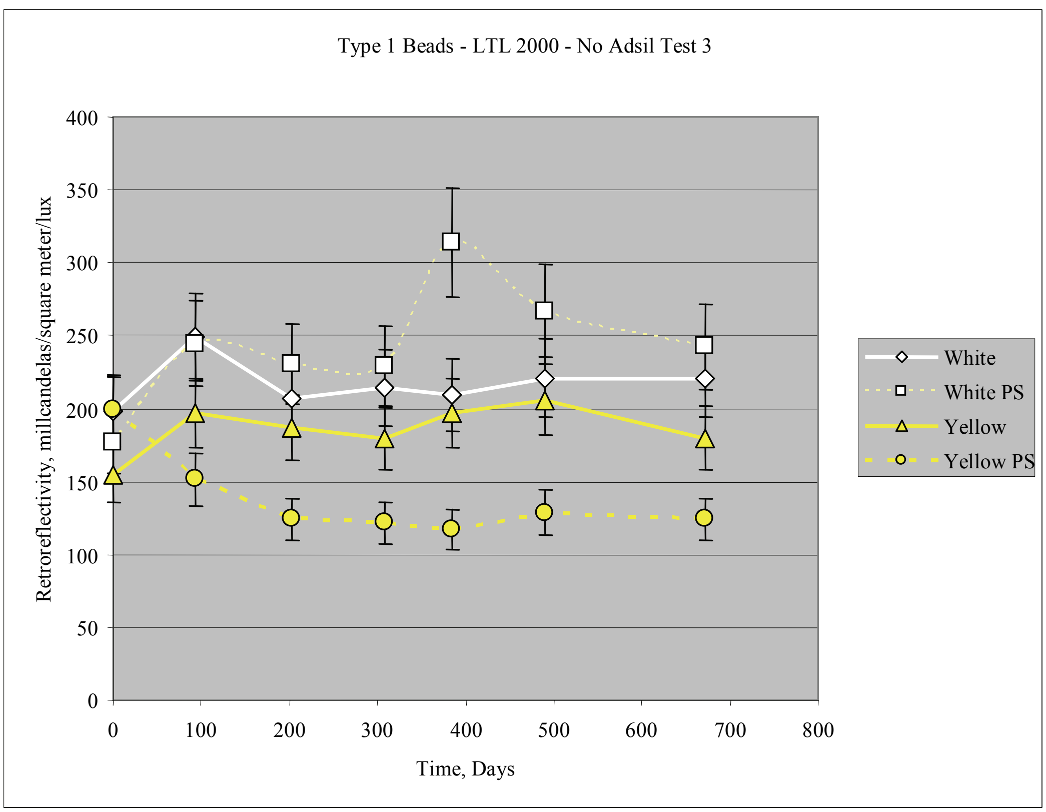

Figure 14. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type I beads measured by the LTL-2000 retroreflectometer.

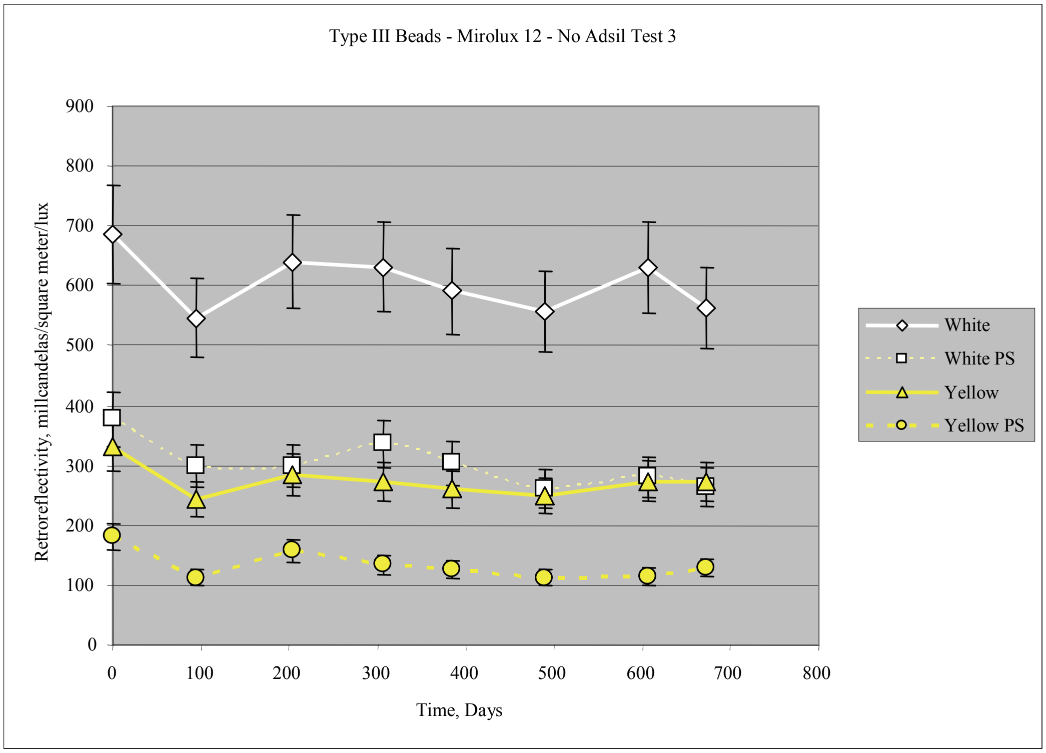

Figure 15. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type III beads measured by the Mirolux-12 retroreflectometer.

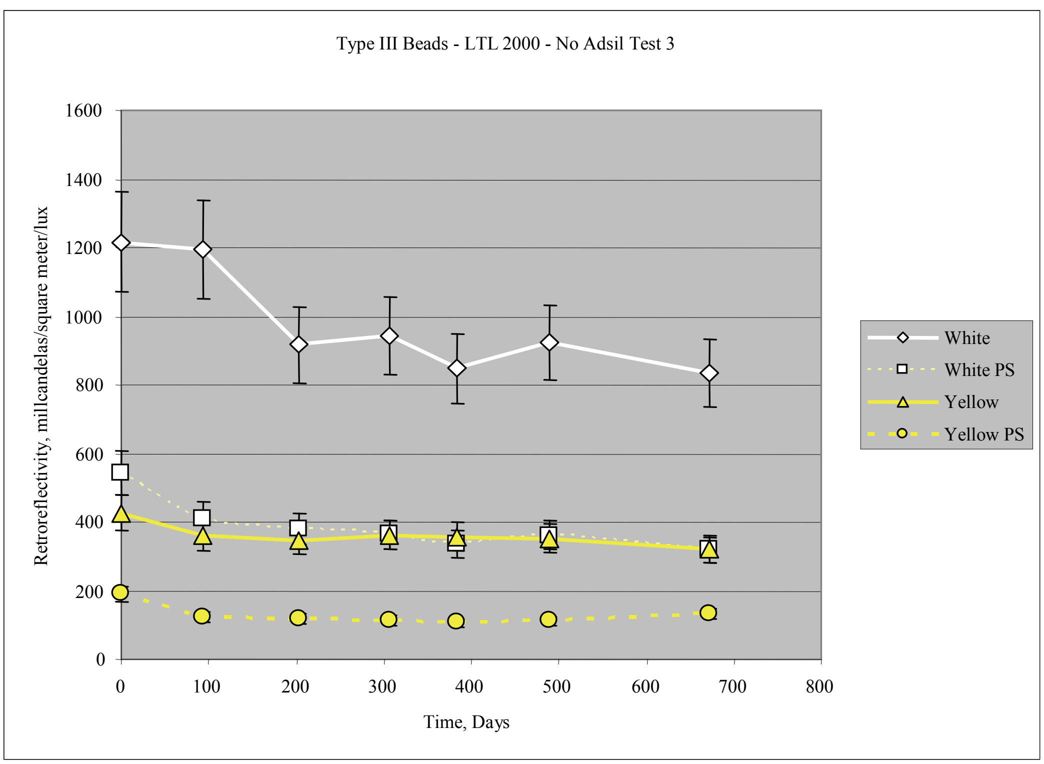

Figure 16. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type III beads measured by the LTL-2000 retroreflectometer.

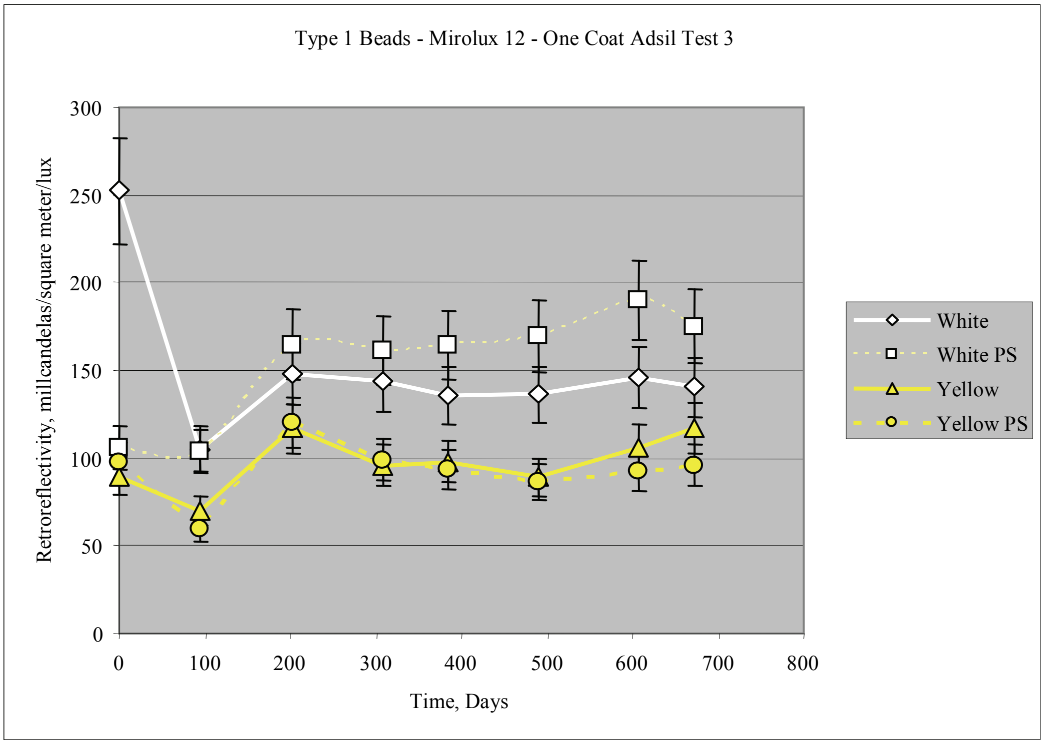

Figure 17. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type I beads with one coat of Adsil™ measured by the Mirolux-12 retroreflectometer.

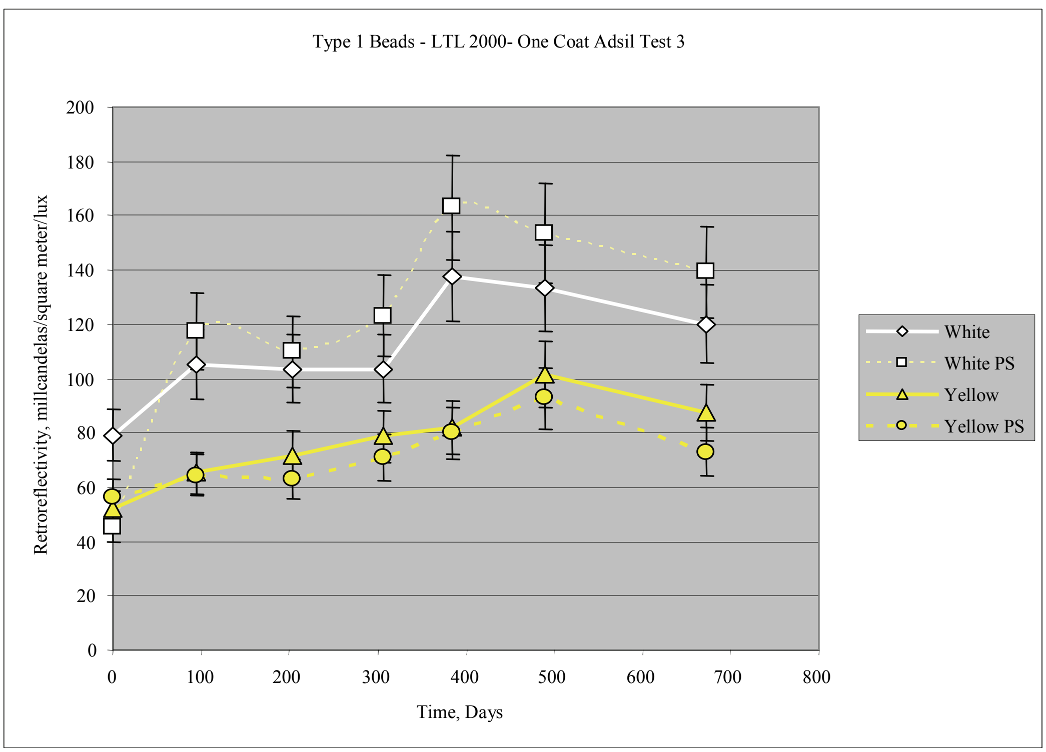

Figure 18. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type III beads with one coat of Adsil™ measured by the LTL-2000 retroreflectometer.

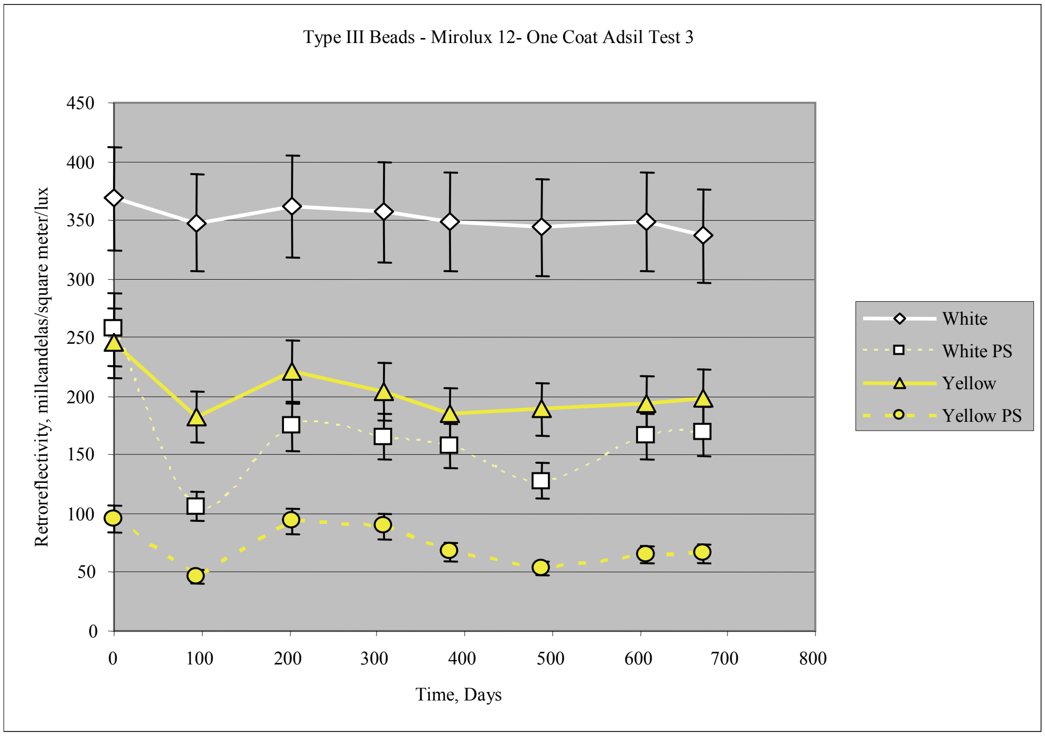

Figure 19. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type III beads with one coat of Adsil™ measured by the Mirolux-12 retroreflectometer.

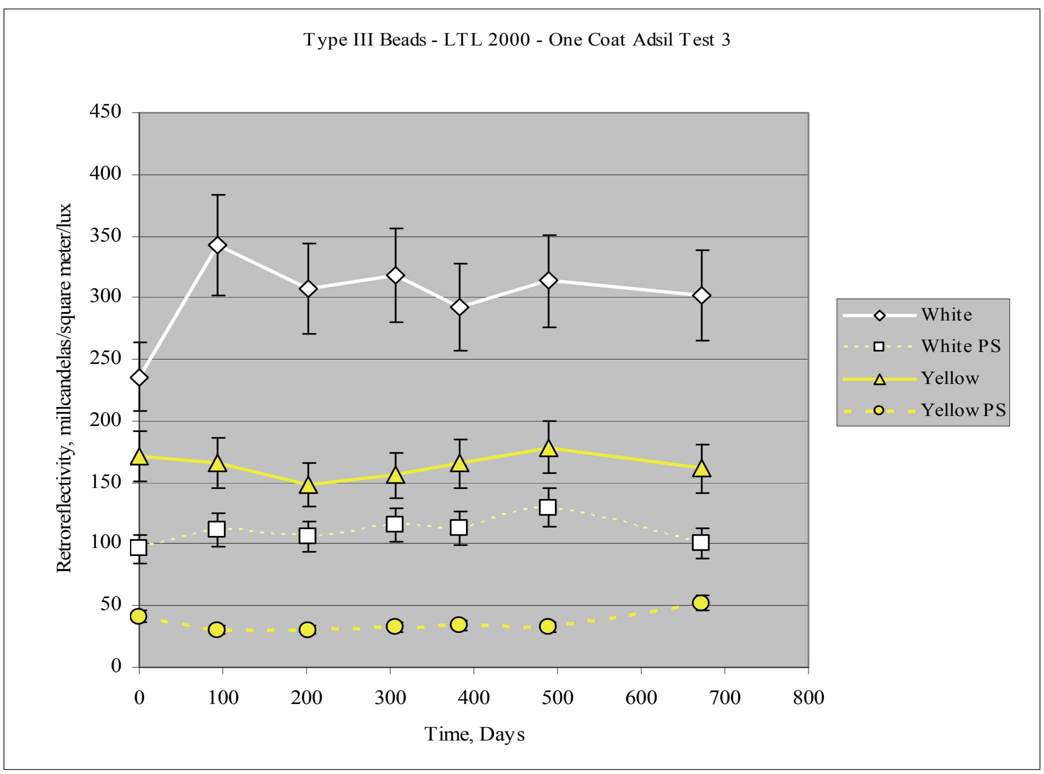

Figure 20. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type III beads with one coat of Adsil™ measured by the LTL-2000 retroreflectometer.

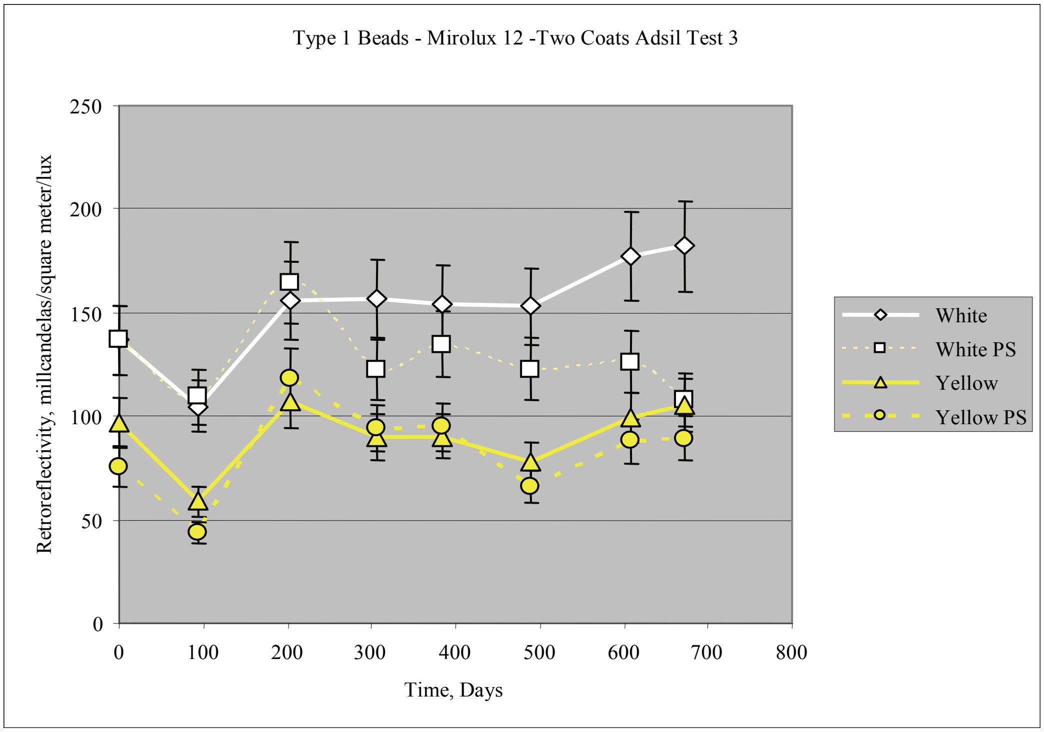

Figure 21. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type I beads with two coats of Adsil™ measured by the Mirolux-12 retroreflectometer.

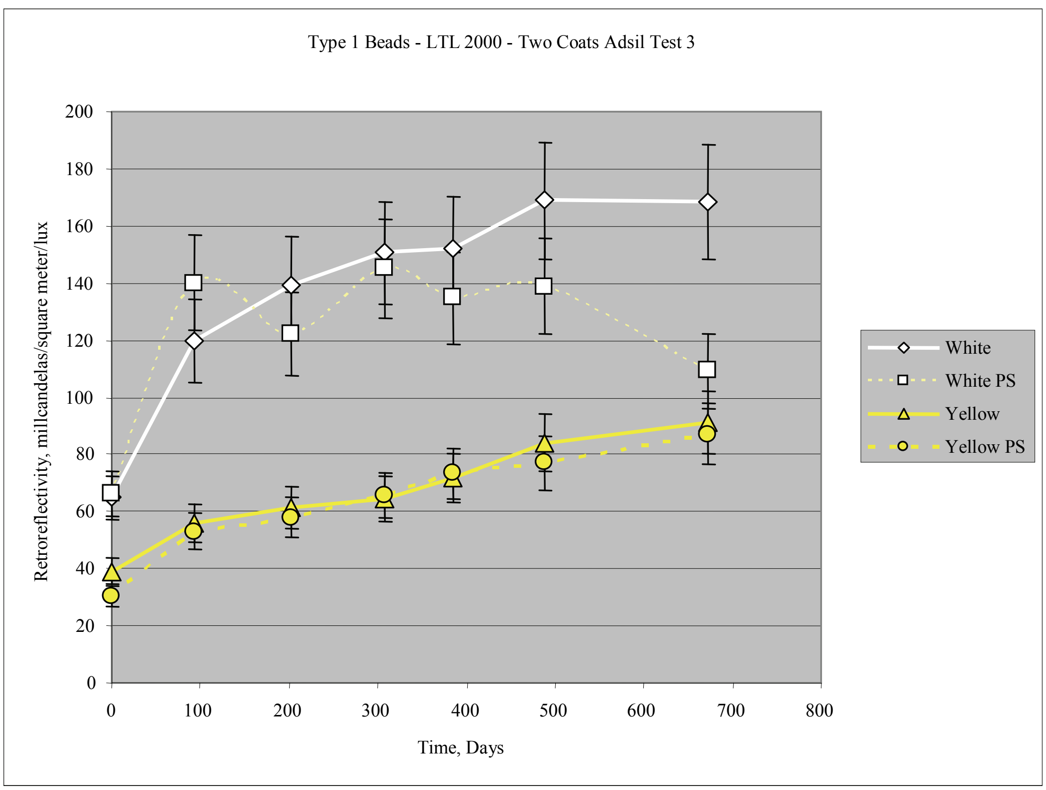

Figure 22. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type I beads with two coats of Adsil™ measured by the LTL-2000 retroreflectometer.

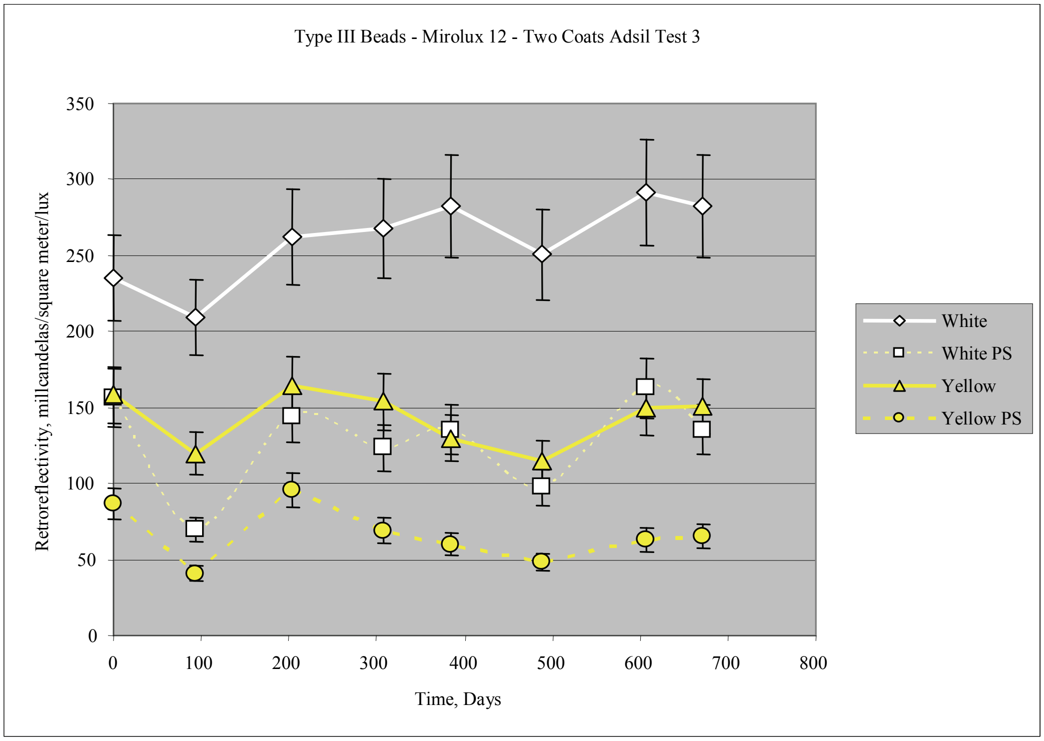

Figure 23. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type III beads with two coats of Adsil™ measured by the LTL-2000 retroreflectometer.

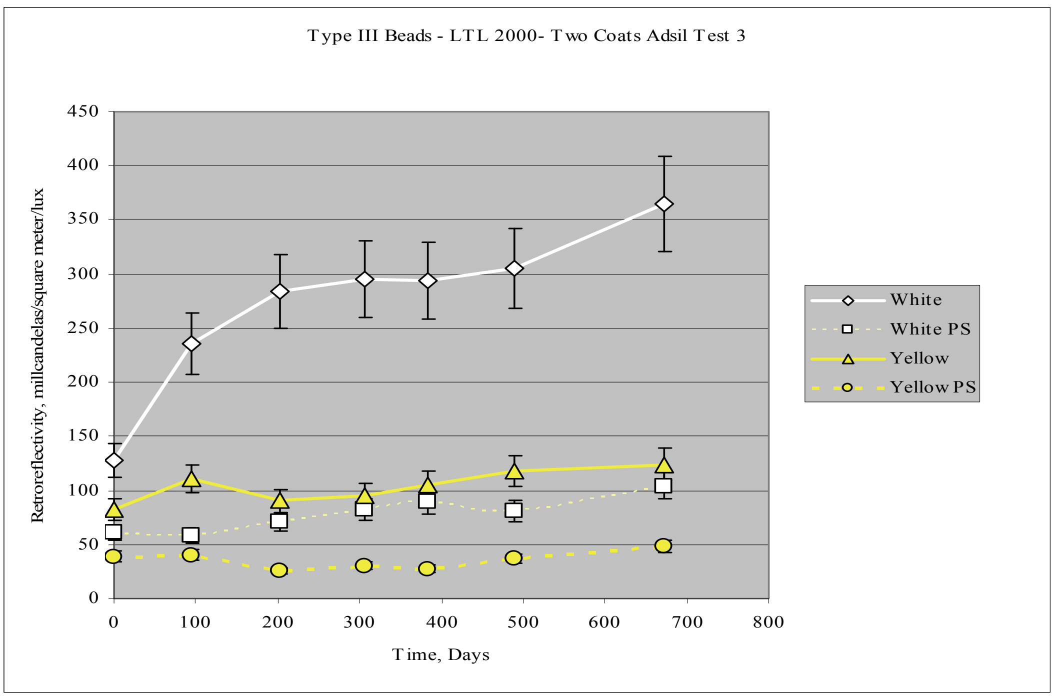

Figure 24. Retroreflectivity of Test 3 lines at Tyndall AFB lines with Type III beads with two coats of Adsil™ measured by the LTL-2000 retroreflectometer.

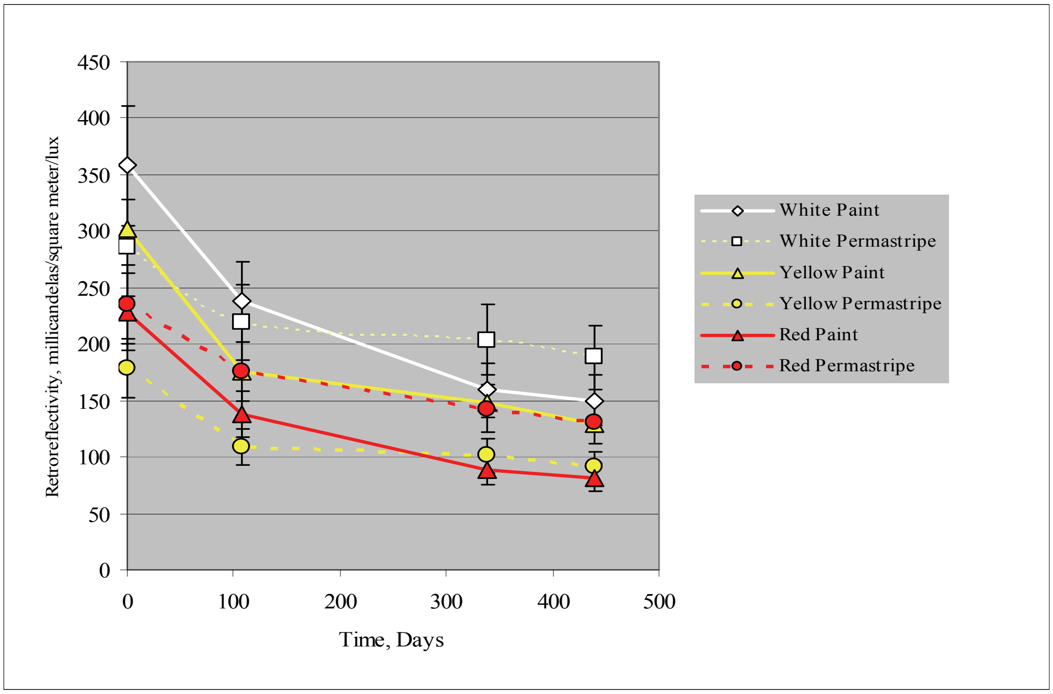

Figure 25. Retroreflectivity of test lines at Mountain Home AFB lines with Type I beads measured by the Mirolux-12 retroreflectometer.

Figure 26. Severe delamination of the Permastripe™ markings at Mountain Home AFB.

Figure 27. Staining of Permastripe™ markings at Mountain Home AFB.

Figure 28. Severe delamination of paint markings at Mountain Home AFB.

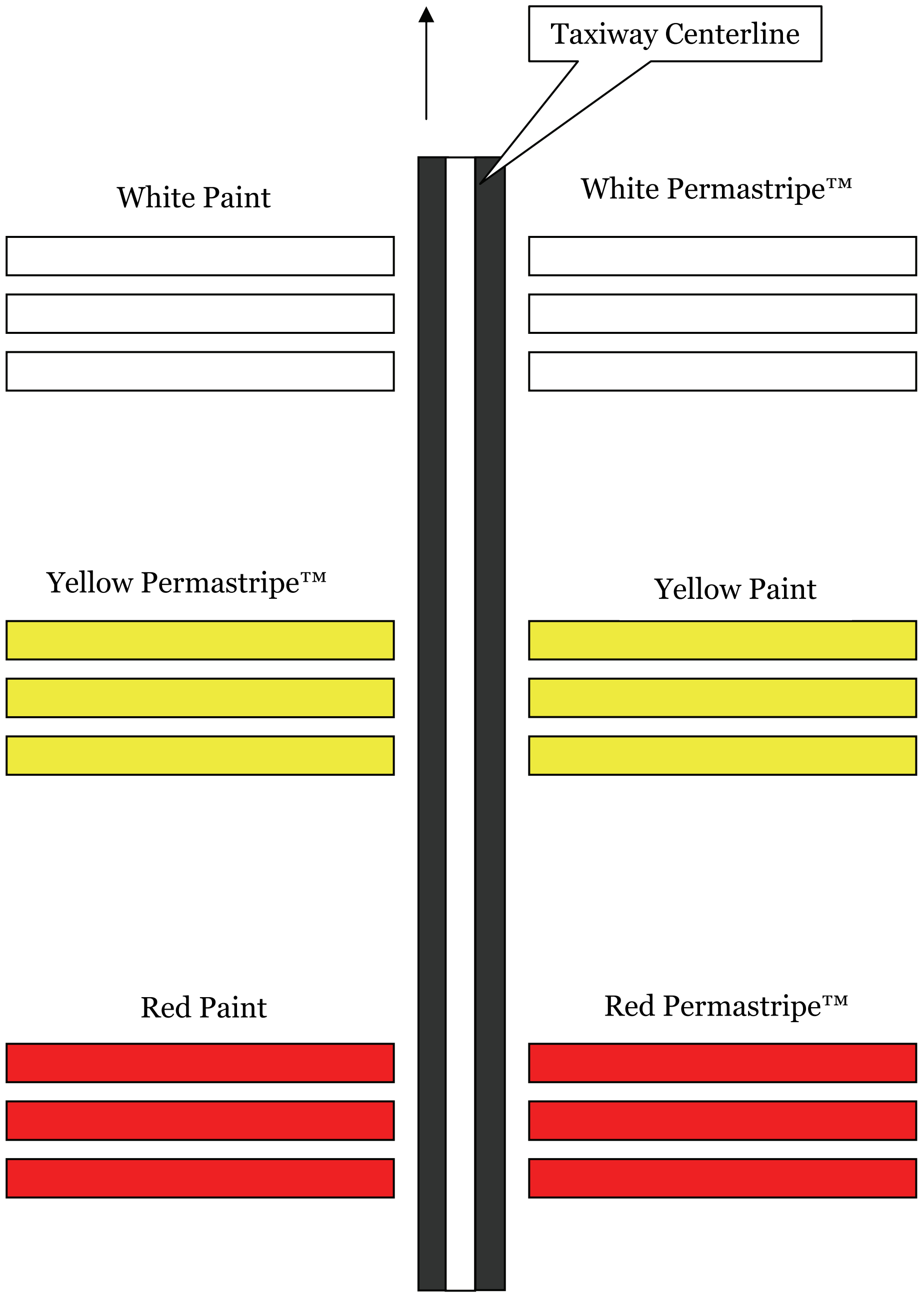

Figure 29. Layout of test markings at Mountain Home AFB.

Appendix A: Draft Engineering Technical Letter for Permastripe™ Polymer Concrete Pavement Markings

FROM: HQ AFCESA/CES
139 Barnes Drive, Suite 1
Tyndall AFB, FL 32403-5319

SUBJECT: **Engineering Technical Letter (ETL) 06-X: Polymer Concrete Pavement Markings**

1. **Purpose.** This ETL provides a specification for polymer concrete pavement markings (PCPM) for durable pavement markings on Air Force facilities.

2. **Summary of Revisions.** Not applicable.

3. **Application.** Polymer concrete pavement markings are a new application of pigmented polymer-modified concrete. PCPM is applied using specialized spray devices at thicknesses ranging from 20-30 mils. Retroreflective media are applied to the surface of the PCPM to provide nighttime visibility. PCPM are intended for use primarily on portland cement concrete (PCC) pavements. PCPM should not be used on asphalt cement (AC) pavements unless the marking patterns will remain without change for an indefinite period of time. This is due to the difficulty of removing the material from asphalt without damaging the substrate. PCPM should not be used on any grooved pavement as the PCPM may fill the grooves.

3.1 Authority:

- AFPD 32-10, Installations and Facilities, available at http://www.e-publishing.af.mil/
- AFI 32-1042, Standards for Marking Airfields, available at http://www.e-publishing.af.mil/

3.2 Effective Date: Immediately.

3.3 Intended Users: Base Civil Engineers.

3.4 Coordination: USAF Major Commands.

4. References.

4.1. American Society for Testing Materials (ASTM)

- ASTM C 117 (2004) Materials Finer Than 75 micrometer (No. 200) Sieve in Mineral Aggregates by Washing
- ASTM C 136 (2004) Sieve Analysis of Fine and Coarse Aggregates
- ASTM C 144 (2003) Aggregate for Masonry Mortar
- ASTM C 150 (2004a) Portland Cement
- ASTM C 33 (2003) Concrete Aggregates
- ASTM C 387 (2004) Packaged, Dry, Combined Materials for Mortar and Concrete

4.2. American Association of State Highway & Transportation Officials.

- AASHTO M-247 (2002) Glass Beads Used in Traffic Paint, American Association of State Highway Transportation Officials

4.3. Air Force.

- Air Force ETL 97-18 (1997) Guide Specification for Airfield and Roadway Marking, Air Force Civil Engineering Support Agency Engineering Technical Letter

4.4. Federal Specifications.

- TT-B-1325C, (1994) Beads (Glass Spheres) Retroreflective.
- FED-STD-595, *Colors Used in Government Procurement*

5. Acronyms and Definitions:

5.1 PCPM – Polymer Concrete Pavement Markings

5.2 Retroreflectivity – The light reflected from a surface directed back to the light source. For nighttime visibility of markings, retroreflective media (typically specialized glass beads) are embedded in the surface of pavement markings. For car headlights, the driver is close to the angle made between the headlights and the pavement markings. The light reflected from the pavement markings from the headlights make the pavement marking highly visible to the driver. For aircraft, the lights are often located away from the cockpit so a pavement marking with retroreflective media may not appear as bright they appear in a car.

6. Specific Requirements

6.1 General. This work consists of furnishing and applying Polymer Concrete Pavement Marking (PCPM) on a prepared substrate in accordance with these specifications and in conformity with the dimensions, patterns, locations, color, and other details shown on the plans or established by the Contracting Officer (CO), or Contracting Officer's Representative (COR). The pavement marking may be applied with or without reflective beads, as required for the intended application. The markings may be applied with or without contrast enhancing borders as required for the specific project.

6.2 Materials. Pre-blended PCPM materials will be stored in their original containers with manufacturer's label markings clearly visible. Materials shall be stored in a manner so they are protected from freezing and exposure to moisture. Containers shall be properly sealed at all times when not in use.

6.2.1. Portland Cement. Portland cement shall conform to the requirements of ASTM C150 for portland cement.

6.2.2. Aggregates. Materials shall be either a natural or manufactured aggregate of uniform quality composed of clean, hard, uncoated particles, and shall meet the requirements for deleterious substances contained in ASTM C-33. Aggregates used in the manufacture of the cement/aggregate dry blend shall meet the gradations shown in Table 1.

Table 1. Aggregate Gradations For Dry Blend Aggregate.

Sieve Size, US (Metric)	Percentage by Weight Passing Sieves	Allowable Tolerance Percent
No. 40	13.3	+/- 2
No. 60	38.4	+/- 2
No. 70	26.9	+/- 2
No. 100	15.6	+/- 2
No. 140	5.8	+/- 1

6.2.3. Polymer Emulsion. The polymer emulsion shall be as specified by the manufacturer. See Section 6.2.9. for more information.

6.2.4. Water. No water shall be added to the PCPM.

6.2.5. Cement/Aggregate Dry Blend. The cement/aggregate dry blend shall conform to the requirements of ASTM C 387 for a Type M mortar. Composition shall meet the requirements in Table 2.
6.2.6. Chemical Admixtures. Chemical admixtures used in PCPM shall be approved by the manufacturer.

Table 2. Cement/Aggregate Dry Blend

Material	Percent by Weight of Total Dry Mix	Allowable Tolerance Percent
Cement	30	+/- 1
Aggregate	70	+/- 1

6.2.7. Reflective Media. Glass beads, if required, shall be of Type I variety (TT-B-1325C or AASHTO M247, as applicable). Glass beads shall conform to the quality requirements for roundness, crushing resistance, moisture resistance, and refractive index. Glass bead coatings for adhesion promotion and/or floatation requirements shall be as required by the bead specification selected.

6.2.8. Pigments. Pigments used in the manufacture of PCPM shall be selected and blended to conform to FED-STD-595, *Colors Used in Government Procurement*. The pigments shall be manufactured without lead containing chemicals, and be free of mercury, lead, hexavalent chromium, halogenated solvents, and carcinogens, as defined in 29 CFR 1910.1200.

6.2.9. Material Acceptance. Prior to the use of materials, the Contractor shall provide a Certificate of Analysis (COA) for the polymer emulsion, and cement/aggregate dry blend verifying that the materials meet the requirements outlined in Section 6.1 and 6.2. The Certificate of Analysis shall be traceable to the batch/lot of material received from the supplier. The COA shall include all information for the specific material requirements, including allowable tolerances.

6.2.10. Material Data. A minimum of 30 days prior to bid opening, the Contractor shall supply material data, general product data, and other appropriate information detailing the 'or equal' product with respect to the project specifications. Adequate technical data shall be included to clearly demonstrate equivalency. Incomplete or inadequate submittals will not be reviewed. The Contractor and manufacturer of the materials and equipment shall submit a statement signed by an officer of the company and notarized that clearly states the product substitution fulfills the specification requirements, and meets all physical and performance attributes of the specified material. The statement shall include certification that the substitution will be utilized at no additional cost and with no claim for delays with respect to the required work. Requests containing incomplete or inadequate information will not be considered.

5.2.11. Characteristics. When mixed, applied, and cured in accordance with the manufacturer's directions, the materials shall demonstrate the properties in Table 3.

Table 3. Material Properties

Physical Property	Test Method	Minimum Test Value
Accelerated Weathering	ASTM G-23, 4000 hr	Unaffected
Bond Adhesion	ASTM C-882	>550 PSI
Slip resistance	ASTM D-2047	0.74 (wet)
Slip resistance	ASTM D-2047	0.78 (dry)
Chemical Resistance	ASTM D2299	Unaffected
Freeze-Thaw Scaling Resistance	ASTM C-672-98	0 (No Scaling)
Compressive Strength– 28 days	ASTM C 109	3950 PSI
Splitting Tensile Strength	ASTM C-496-96	435 PSI
Abrasion Resistance (60 minutes)	ASTM C-779-00	.016 inch
Unit Weight	N/A	117 lb/Ft^3
Flow Rate	N/A	42 Sec.
Elastic Modulus	ASTM C469-02	280,000 PSI
Tensile Bond Strength	ASTM C-190	615 PSI

6.3. Construction Methods.

6.3.1. General. The contractor shall furnish all labor, materials, tools, and equipment necessary for performance of the work. The polymer composite pavement marking shall provide a fuel and abrasion resistant surface.

6.3.2. Proportioning. The contractor shall be responsible for the mix proportions and all subsequent adjustments necessary to produce the specified mix. Any change in material source during construction will be subject to prior approval by the CO or COR.

6.3.3. Mixing. The measuring and mixing operation shall be capable of producing a consistent homogenous mix sufficient to maintain the production levels required for the work. The polymer emulsion and cement/aggregate dry blend shall be blended to the desired consistency without the addition of any water.

6.3.4. Equipment. Equipment and tools shall be capable of handling materials, performing the work, and producing a product of the specified quality; and be maintained in good mechanical condition. The equipment shall be designed and manufactured specifically for the placement of PCPM.

6.3.4.1. Material Handling Equipment. The equipment shall be capable of handling and transferring the materials for PCPM to the mixer free of spillage, segregation, or contamination.

6.3.4.2. PCPM Transfer Equipment. The equipment shall transfer the mix to the placing equipment without spillage, segregation, or contamination.

6.3.4.3. Placement Equipment. PCPM may be applied by spraying or squeegee as practical for the type of marking, as recommended by the manufacturer (see Section 6.3.7.1).

6.3.4.3.1. Spray Placement. The spray equipment shall be capable of fully atomizing the PCPM. It shall produce an even and uniform film thickness at the required coverage without running or spattering, with a clean cut-off at the edges.

6.3.4.3.2. Hand Placement. Areas of such dimensions or at locations that are not practical for machine placement may be applied by hand with a squeegee or pull blade. A stencil may be used or the area to be marked shall be masked to provide the proper dimensions.

6.3.4.3.3. Broadcast Bead Equipment. Process for application of reflective beads shall be properly designed to uniformly distribute the beads at the required rate (see Section 6.3.8).

6.3.5. Substrate Preparation. The contractor must ensure that the concrete to receive pavement markings must be structurally sufficient for its intended purpose and free of oils, curing agent, etc.

6.3.5.1. Cleaning of Substrate. The substrate that is to receive the PCPM system shall be cleaned of old markings, sand, dirt, dust, rock, or any other debris that could prevent proper adhesion. Cleaning shall be accomplished by power broom, scraping, blowing, washing, or other approved methods necessary to assure bonding between the PCPM friction course and the substrate.

6.3.5.1.1. An approved degreaser, if needed, will be used to thoroughly remove oils, fuels, or other contaminants that could prevent proper adhesion.

6.3.5.1.2. When PCPM is to be used on a concrete substrate, all curing compound or other surface contaminates that may adversely affect bonding will be removed by a method recommended by the manufacturer and acceptable to the CO or COR.

6.3.5.1.3. PCPM operations shall not be started until the surface is in a condition as recommended by the manufacturer and acceptable to the CO or COR.

6.3.6. Limitations on Placement of PCPM. PCPM shall not be applied when the surface is wet or impending weather conditions will not allow proper curing. The time elapsed from the addition of polymer emulsion to the mix until final finishing shall not exceed the workability time limits of the mixture. When rain appears imminent, all placement operations shall cease and the work shall not be resumed until the threat of rain has passed. PCPM shall not be applied over old pavement markings that will inhibit the bonding performance of the new markings. Placement during high winds should be avoided. This will result in overspray and rapid curing of PCPM.

6.3.6.1. Testing for Moisture. Pavement markings shall be applied to dry pavement only. The Contractor shall test the pavement surface for moisture before beginning work after each period of rainfall, fog, high humidity, or cleaning, or when the ambient temperature has fallen below the dew point. Do not commence marking until the pavement is sufficiently dry and the pavement condition has been approved by the CO or authorized representative. Employ the "plastic wrap method" to test the pavement for moisture as follows: Cover the pavement with a 300 mm by 300 mm (12 inch by 12 inch) section of clear plastic wrap and seal the edges with tape. After 15 minutes, examine the plastic wrap for any visible moisture accumulation inside the plastic. Do not begin marking operations until the test can be performed with no visible moisture accumulation inside the plastic wrap.

6.3.6.2. Cold Weather Limitations. The PCPM shall not be placed until ambient and substrate temperatures are 50° F and rising and expected to remain above 50° F for 8 hours, unless otherwise directed by the Engineer.

6.3.6.3. Hot Weather Limitations. Care should be taken when placing the PCPM when the substrate temperature exceeds 130° F. Application temperatures of the substrate above 130° F should be closely monitored for performance during the course of application. Any observable defects occurring as a result of extreme temperature should be cause for immediate halting of placement operations.

6.3.7. Application. PCPM shall be constructed so that the finished lines have reasonably well defined edges and be free of waviness. The edges of the markings shall not vary from a straight line more than 1 inch in 50 feet, and the dimensions shall be within a tolerance of plus or minus 5 percent.

6.3.7.1. Application Rate. Application thicknesses shall range from 20-30 mils wet film thickness. This corresponds to application rates of approximately 50-80 ft^2/gallon. However, application rates can vary significantly from these values for pavements with different surface textures. Application rates can be determined by placing a known volume of PCPM and measuring the surface area covered by the PCPM to determine actual application rates. The actual application rate should be verified on the test section (Section 6.3.12). The minimum threshold for application is 15 mils.

6.3.8. Glass Beads. Glass beads, where required, shall be applied immediately after application of the PCPM. Glass beads shall be applied at the rate of 0.2 pounds per square foot of pavement marking.

6.3.8.1. Minimum Retroreflectivity Values. Minimum retroreflectivity for fully cured, new pavement markings shall be 200 millicandelas/square mater/lux for white markings and 175 millicandelas/square mater/lux for yellow markings using a Mirolux 12 retroreflectometer or equal. Markings applied that do not meet these values shall be removed and replaced at the contractor's expense.

6.3.9. **Project Reports.** The Contractor shall furnish project reports as required to assure conformity with these specifications. The contractor shall produce and maintain written records that document PCPM placement conditions on the project. Documentation of PCPM produced shall include the proportioning expressed in the number of pounds of dry blend and the number of gallons of polymer emulsion in the mix. In addition, a record shall be produced that documents the air temperature, substrate temperature, wind velocity (speed and direction), and humidity. Documentation shall also be required that records the amount of coverage expressed in square feet per gallon of PCPM.

6.3.10. **Curing and Opening to Traffic.** Care shall be taken by the Contractor to protect the PCPM from traffic until the area is sufficiently cured. Curing time will vary depending on ambient and surface temperatures. The PCPM shall not be opened to traffic until it has reached sufficient strength that the surface will not be damaged by vehicular or aircraft traffic and the area has been approved for opening by the CO or COR.

6.3.11. Defective PCPM. Defective PCPM shall be repaired or replaced at the Contractor's expense. The Contractor's corrective work plan shall be approved prior to performing the work.

6.3.11.1. Field Inspection of PCPM. Field inspection of PCPM involves measurement of application thickness (wet film gauge) and or rate (measurement of amount placed in a known area). Additionally, PCPM should be inspected for excessive pinholes and bubbling.

6.3.11.2. Delamination. If at the time of substantial completion the PCPM has not bonded to the substrate, the affected marking shall be removed to such point where the remaining PCPM is solidly bonded to the pavement. The area to be remarked will be prepared in accordance with Section 6.3.5 prior to the replacement. PCPM shall be used to repair the removed area.

6.3.11.3. Low Application Rate. Areas of PCPM that are determined deficient due to inadequate thickness or low application rate shall be removed and replaced at the expense of the contractor.

6.3.11.4. Poor Retroreflectivity. PCPM markings that do not meet minimum retroreflectivity standards (see Section 6.3.8.1) shall be removed and replaced at the contractor's expense.

6.3.12. Test Section. Before beginning work, the Contractor shall mark test stripes within the work area to demonstrate the proposed materials and equipment to be used for the contract. Apply separate test stripes in each of the line widths and configurations required in the contract, using the equipment proposed for the contract. Mark the test stripes long enough to determine the proper speed and operating parameters for the application equipment, but not less than 50 feet long.

6.3.12.1. Demonstration of Application Rates. In applying the test stripes, the Contractor shall demonstrate the ability to comply with the application rates specified in Section 6.3.7.1. Document the equipment speed and operating pressures required to meet the specified rates in each configuration of the equipment, and provide a copy of the documentation to the CO or COR before proceeding with the work.

6.3.12.2. Demonstration of Retroreflective Values. After the test stripes have cured to a "no-track" condition, the Contractor shall demonstrate compliance with the average retroreflective values specified in Section 6.3.8.1. Take a minimum of ten readings on each test stripe with a Mirolux 12 Retroreflectometer, or similar instrument with the same measuring geometry, and direct readout in millicandelas per square meter per lux ($mcd/m^2/lx$).

6.3.12.3. Demonstration of Level of Performance. The CO or COR will be present at the test area to observe the result obtained on the test stripe and validate the operating parameters of the equipment. The application of test stripes shall be used to determine if the proposed methods and equipment can achieve the level of performance required for the contract. If accepted by the CO or COR, the test stripes shall be the measure of performance required of the Contractor for the marking project. The Contractor shall not proceed with the work until the results of the test stripes are satisfactory to the CO or COR.

6.4. Measurement.

6.4.1. Measurement for payment shall be for the quantities completed and accepted for each of the pay items as shown on the plans. If the actual placement differs from the plan dimensions, actual field measurements shall be used.

6.5. Payment. (To be used for unit prices.)

6.5.1. Measurement. The unit of measurement for pavement markings shall be the number of square feet of retroreflective and nonreflective markings applied by the Contractor and accepted by the CO or COR.

6.5.2. Payment. The number of square meters marked by the Contractor and accepted by the CO or COR will be paid for at the contract unit prices for retroreflective and non-reflective markings. Payment will constitute full compensation for all tests, labor, materials, tools, equipment, appliances, surface preparation, waste disposal, material certifications, documentation, and performance of all activities required to mark the areas designated in the plans.

6.5.3. Aircraft Traffic Interruptions. The Contractor shall specify on the bid schedule an hourly rate for aircraft traffic interruption. Time measurement for traffic interruptions shall begin with the notification to the Contractor to clear the runway and shall end ten minutes after the Contractor is notified that he can re-occupy the runway. The Contractor shall be paid for a minimum of one hour for each interruption. Interruptions longer than one hour shall be calculated on the half-hour: i.e., a delay of over one hour but less than one and one-half hours would be paid as one and one-half hours; a delay over one and one-half hours but less than two hours would be paid as two hours.

6.6. Operations On The Airfield.

6.6.1. Access to Controlled Zones. The Contractor shall perform all contracted work within the controlled zones of the base or the airfield. Coordinate access to or through the base with the CO or COR. Coordinate access to or through the radio controlled zone of the airfield with the Chief of Airfield Management. When within the radio controlled zone of the airfield, the Contractor shall maintain continuous verbal and visual contact with the control tower. The Contractor shall verbally inform the control tower and the Chief of Airfield Management when the work has been completed and all equipment, personnel, and materials have been removed from the airfield.

6.6.2. Runway Operations. It is the intention of the Government to close the runway to all aircraft traffic while marking operations are ongoing. However, work may be interrupted to provide a runway for aircraft in an emergency or when a special or unscheduled mission is assigned. If the runway is needed for aircraft operations, the Contractor shall remove all equipment from the operational surfaces of the airfield and beyond the hold line within 15 minutes of notification to clear the runway. A scheduled landing or departure that has been identified to the Contractor prior to the start of the Contractor's work shift shall not be considered an interruption.

6.6.3. Work Schedule. The Contractor must adhere to the preapproved schedule for execution of the work, weather permitting, as (runway (and) roadway) closures must be coordinated in advance. If Contractor's schedule is delayed by weather conditions or mechanical equipment breakdown, the Contractor shall notify the Engineer or authorized representative, and a new work schedule will be established. The Engineer or authorized representative will coordinate the (runway (and) roadway) closure schedule with the using agencies.

6.7. The Contractor shall clean debris from the (runway (and) roadway) surface as the work proceeds, and maintain the lay down area in a neat and orderly way. Materials and debris shall not be allowed to remain unsecured where they may be blown about.

6.8. Method of Operation and Execution.

6.8.1. The Contractor shall conduct all marking operations in strict compliance with all local, state, and Federal environmental statutes and regulations, including, but not limited to, regulations promulgated under 29 C.F.R. 1910, et seq., 42 U.S.C. 6901, et seq.; and 42 U.S.C. 9601, et seq.

6.8.2. The Contractor shall provide all cones, barriers (barricades), lights, signs, placards, flags, and flagging personnel necessary to establish an adequate and safe work zone and control traffic in and around the work area until newly applied markings are dry and the area reopened to traffic. The Contractor shall establish and maintain work zones as necessary throughout the period of the contract, prominently identifying potential hazards and dangers to personnel and traffic in or near the work area.

6.8.2.1. As a minimum, the Contractor shall comply with the provisions of AFI 32-1042, ETL 04-2, UFC 3-535-01, and UFC 3-260-01, Attachment 15 (Operational Safety on Airfields During Construction) for temporary pavement closures on airfields.

6.8.2.2. When marking roads and streets, the Contractor shall comply with all state and local requirements and the provisions of Part VI, "Traffic Controls for Street and Highway Construction, Maintenance, Utility and Emergency Operations," of The Manual on Uniform Traffic Control Devices.

6.8.3. The Contractor shall remove all debris, waste, spillage, and by-products generated by the marking operations from the base and shall strictly comply with all applicable state, local, and Federal environmental statutes and regulations regarding disposal, including, but not limited to, regulations promulgated under 42 U.S.C. 6901, et seq.; 42 U.S.C. 9601, et seq.; and 49 U.S.C. 1801, et seq.

7. Point of Contact:

Dr. J. Kent Newman
U.S. Army Engineer Research and Development Center
CEERD-GM-A
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Telephone: 601-634-3858 fax: 601-634-3020
john.k.newman@erdc.usace.army.mil

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* June 2007	**2. REPORT TYPE** Final report	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE

A Comparative Field Study of Permastripe™ Polymer Concrete and Waterborne Airfield Pavement Markings

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

J. Kent Newman, Donna Speidel, Ron Boeger, and Betsy Hudson

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199;
Speidel Construction Company, 58 Le-Way Drive, Fredericksburg, VA 22406;
Flexolite Corporation, 125 Cassens Court, Fenton, MO 63026

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/GSL TR-07-20

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Air Force Civil Engineering Support Agency
139 Barnes Drive, Suite 1
Tyndall Air Force Base, FL 32403-5319

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The study reported herein compared polymer concrete pavement markings (Permastripe™) to Federal specification waterborne airfield marking paint for field durability and retroreflectivity. The markings were placed at Tyndall Air Force Base (AFB) (hot, wet climate) and Mountain Home AFB (cold, snowy climate). American Association State Highway and Transportation Officials Type I, Type III, and a Type I/Type III retroreflectivity bead combinations were included at Tyndall AFB. Additionally, Adsil™, a novel clear coating, was used at Tyndall AFB to evaluate the effects on retroreflectivity and durability of Permastripe™ and paint.

This study suggests that Permastripe™ is more durable than standard airfield paint, may exhibit better bead retention, and holds promise as a durable pavement marking if certain technical problems can be overcome. The Permastripe™ studied in this work is not readily removable from asphalt pavement using water-blasting. The data clearly show that high-refractive index Type III beads result in higher retroreflectivity than Type I beads initially and over time.

The Adsil™ clear coating applied to the markings resulted in significant reductions in retroreflectivity. The retroreflectivity data from one test clearly indicate that the retroreflectivity increases with time as the coating wears.

15. SUBJECT TERMS

Durable pavement markings	Pavement striping	Retroreflectivity
Pavement markings	Polymer concrete	

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON Andrew Morang**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		68	