NO TRACK THERMOPLASTIC

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NO TRACK THERMOPLASTIC

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16. Abstract

The objectives of this research are (1) to search and review existing practices for installing and evaluating no track thermoplastic markings; (2) to develop a test method/procedure to determine whether a thermoplastic marking is a no track marking; and (3) to run field tests and experiments to obtain the performance data through real applications of no track thermoplastic markings. To achieve the research objectives, real thermoplastic installation projects were arranged and test equipment/instruments were used onsite to measure the performance of industry proclaimed and marketed no track thermoplastic markings. Retroreflectivity and color were evaluated for the field test of no track thermoplastic marking materials. Four thermoplastic marking materials were selected for the field tests, including three no track thermoplastic markings and one regular thermoplastic marking. The research team found that none of the selected no track thermoplastic traffic marking materials is completely resistant to wheel tracking of asphalt. By visual inspection of traffic marking appearance in the field one cannot distinguish between no track and regular thermoplastic markings. The best parameter that can be used to identify if a particular thermoplastic marking is a no track marking is the color differences between the initial and in-service traffic markings. The difference between initial and in-service color can be quantified by using either the CIELAB ΔE^* value or the CIE94 color tolerance ΔE^*_{94}. It was found that the selected no track thermoplastic traffic marking materials have lower ΔE^* and ΔE^*_{94} values as compared to the regular thermoplastic marking, implying that the selected no track thermoplastic markings are more resistant to the tracking of bitumen as compared to the ordinary thermoplastic striping.

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NO TRACK THERMOPLASTIC

BACKGROUND

Thermoplastic material is a durable traffic marking material which has been widely used in the State of Florida. To install thermoplastic markings on newly constructed pavement, the roadway needs to be closed and traffic has to be stopped. This would cause significant delay to traveling public. Recently, a new type of thermoplastic material called "no track" thermoplastic has been introduced in practical applications. The main benefit of a no track thermoplastic marking is that it can be placed on a fresh asphalt surface. Thus, the roadway can be opened to traffic with a minimum waiting time as compared to traditional thermoplastic markings.

Recent practices have indicated a problem associated with some so called no track thermoplastic markings. The problem is that with new asphalt being placed into service, bitumen tracks onto the thermoplastic markings. Thus, during the final asphalt cure time, the markings become discolored with the asphaltic materials, resulting in discoloration and reduced retroreflectivity performance. In order to be a no track thermoplastic marking, the marking is supposed to provide resistance to tracking of asphaltic materials onto the marking. Similar to other traffic marking materials, a no track thermoplastic marking should also meet the initial requirements, including shape, adhesion, color, and reflectance for a certain time period as specified by the Florida Department of Transportation (FDOT).

OBJECTIVES

The main objectives of this research are (1) to search and review existing practices for installing and evaluating no track thermoplastic markings; (2) to develop a test method/procedure to determine whether a thermoplastic marking is a no track marking; and (3) to run field tests and experiments to obtain the performance data (such as reflectivity and color performance) through real applications of no track thermoplastic markings.

FINDINGS AND CONCLUSIONS

To achieve the research objectives, real thermoplastic installation projects were arranged and test equipment/instruments were used onsite to measure the performance of industry proclaimed and marketed no track thermoplastic markings. Four thermoplastic marking materials were selected for the field tests, including three no track thermoplastic markings and one regular thermoplastic marking. Factors considered in field tests include color of traffic markings and the use of glass beads. It total, sixteen transverse lines were installed at a selected test section for the field tests, including four yellow lines with glass beads applied on the surfaces of traffic markings, four yellow lines without glass beads, four white lines with glass beads applied and four white lines without glass beads. In this study, retroreflectivity and color were evaluated for the field test of no track thermoplastic marking materials. Retroreflectivity was measured using a MX-30 handheld retroreflectometer. Color was measured using a BYK Gardner Handy colorimeter. When measuring retroreflectivity, procedures provided by the ASTM standard E 1710 were followed. The color measurements followed the test methods provided by the ASTM standard E 1347. In total, the research team conducted nine field visits to collect performance data, and took 1463 retroreflectivity measurements and 2230 color measurements at the test section.

The appearance of traffic markings by visual inspection in the field showed that the selected no track thermoplastic markings were not completely resistant to the wheel tracking of asphalt on to the traffic marking surfaces. In fact, with visual inspection one could not distinguish between no track and regular thermoplastic markings. The mean initial retroreflectance for selected thermoplastic markings varies from 189 to 255 $mcd/lx \cdot m^2$ for yellow traffic markings, and from 330 to 440 $mcd/lx \cdot m^2$ for white traffic markings. Based on the collected retroreflectivity data, degradation curves were developed to illustrate the change of retroreflectivity over time. The retroreflectivity degradation curves were used to compare the no track and regular thermoplastic markings. For yellow traffic markings, the selected no track thermoplastic markings were found to be superior to the selected regular thermoplastic marking in terms of the higher in-service retroreflectivity. For white traffic markings, even though the selected no track thermoplastic markings meet initial and in-service requirements for retroreflectance specified by the FDOT, they do not provide better retroreflectivity as compared to the regular thermoplastic marking.

In this study, two parameters were used to quantify the discoloration of traffic markings during the asphalt curing time and to compare the discoloration of no track thermoplastic markings to that of the regular thermoplastic marking. These two parameters include the ΔE^* value which is calculated based on the L^*, a^*, b^* values from the CIELAB color space, and CIE94 color tolerance ΔE^*_{94}. It was found that both parameters increase with the time. The selected no track thermoplastic marking materials are found to be more resistant to the tracking of asphalt as compared to the regular thermoplastic marking material in terms of the lower ΔE^* and ΔE^*_{94} values.

BENEFITS

This study developed a test method and conducted field tests to evaluate the performance no track thermoplastic markings. It was found that the best parameter that can be used to identify if a particular thermoplastic marking is a no track marking is the differences between initial and in-service color. The difference can be quantified by using either the CIELAB ΔE^* value or the CIE94 color tolerance ΔE^*_{94}. It was found that the selected no track thermoplastic marking materials have lower ΔE^* and ΔE^*_{94} values as compared to the regular thermoplastic marking, implying that the selected no track thermoplastic markings are more resistant to the tracking of bitumen as compared to the ordinary thermoplastic striping.

The study provided some quantified results about the change of retroreflectivity and color over time for both no track and regular thermoplastic marking materials. The quantified results can help the FDOT develop technical specifications for the use of no track thermoplastic marking materials.

This research project was conducted by Jian John Lu, Ph.D., P.E., of the University of South Florida. For more information, contact Paul Vinik, P.E., Project Manager, at (850) 414-4615, Paul.Vinik@dot.state.fl.us.

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1 INTRODUCTION

1.1 Background

Pavement markings are important traffic control devices which communicate roadway delineation information to drivers. There are several types of traffic markings, such as paint, thermoplastic, raised marker, etc. In Florida, thermoplastic traffic marking materials are widely used and have been considered one of the most cost effective durable materials. Thermoplastics materials are materials that can be heated to a liquid state, reshaped, and cooled to form a new object. When properly applied, thermoplastics can be the most successful of all marking materials (*1*).

To install thermoplastic markings on newly constructed pavement, the roadway needs to be closed and traffic has to be stopped. This could cause significant delay to traveling public. Recently, a new type of thermoplastic material called "no track" thermoplastic has been introduced in practical applications. The main benefit of a no track thermoplastic marking is that it can be placed on a fresh asphalt surface. Thus, the roadway can be open to public traffic with a relative short time as compared to traditional thermoplastic markings

Recent practices have indicated a problem associated with some so called no track thermoplastic markings. The problem is that with new asphalt roadways placed into service, bituminous components track onto the thermoplastic markings. Thus, during the final asphalt cure time, the markings become discolored with the materials leaching from asphalt materials, resulting in discoloration and reduced reflectivity performance. In order to be a no track thermoplastic marking, the marking is supposed to be resistant to the tracking of the asphalt onto the marking. Similar to other traffic marking materials, a no track thermoplastic marking should also meet the initial requirements, including shape, adhesion, color, and reflectance for a certain time period as specified by the Florida Department of Transportation (FDOT).

Upon cooling to ambient air and pavement surface temperature, the no track thermoplastic materials shall produce an adherent, reflective pavement marking capable of resisting deformation by traffic and specially formulated to resist the tracking and discoloration from materials deposited by motor vehicle tires under normal traffic conditions. The material shall meet the initial requirements of shape, adhesion, color or reflectance for the first 60 days of placement. The applied markings shall meet the initial color requirements specified by Florida Standard Specifications for Road and Bridge Construction, Section 711 (*2*), for a period of 12 months from the Department's acceptance of the original application on the pavement surface.

Until recently, little documentation is available regarding the performance of various no track thermoplastic materials. In order to successfully use no track thermoplastic markings, research is needed to develop a test procedure and to run field tests to evaluate the performance of proclaimed no track thermoplastic markings. The purpose of field measurement is to identify whether a thermoplastic marking is a no track marking or not. Results of the tests and experiments will result in test procedures and, potentially, technical specifications to be used by FDOT in real engineering applications.

1.2 Research Objectives

The main objectives of the research are (1) to search and review existing practices for installing and evaluating no track thermoplastic markings; (2) to develop a test method/procedure to determine whether a thermoplastic marking is a no track marking; and (3) to run field tests and experiments to obtain the performance data (such as reflectivity and color performance) through real applications of no track thermoplastic markings.

To achieve the research objective, actual in-service roadways were used as no track thermoplastic installation projects. Hand-held field instruments were used to evaluate the performance of industry proclaimed no track thermoplastic markings. The research team installed three no track thermoplastic markings and one regular thermoplastic marking on a newly constructed pavement for performance evaluation. The selected testing parameters include retroreflectivity and color. The field tests followed the procedures specified by the American Society of Testing Materials (ASTM) specifications and/or FDOT specifications.

1.3 Literature Review

In this study, extensive work was conducted to search and review existing practices for installing and evaluating no track thermoplastic markings. Literature was reviewed as well as any other past studies or on going projects to determine the current practices related to the usage of no track thermoplastic pavement markings. However, no previous studies were found to be directly related with this topic. Several studies have tested the performance of thermoplastic marking materials and the studies are briefly summarized below.

In a project sponsored by the FDOT, Ahmad et al. studied the bonding strengths of thermoplastic pavement markings on concrete and asphalt roadway surfaces. A test site with asphalt and concrete surfaces was selected to perform the adhesion test. Four different surface preparation techniques were used on both types of surfaces. These techniques include: (1) Waterblasting, (2) Grinding/scarifying, (3) Sandblasting, and (4) Wire brushing. It was found that grinding/scarifying produced the best result on both asphalt and concrete surfaces. Sandblasting and wire brushing were found to be the least effective techniques on asphalt and concrete respectively. The study also demonstrated that thermoplastic markings have poor bonding strengths on concrete pavement surfaces (*3*).

Several studies have evaluated the degradation of retroreflectivity over time for roadway pavement markings, and used the results to determine service life of pavement markings (*4*, *5*, *6*, and *7*). Using retroreflectivity data measured on approximately 80 test sections throughout Washington State, Kopf developed regression curves to predict the degradation of retroreflectivity of pavement markings over time. It was found that the resulting retroreflectivity values from roadways with similar average annual daily traffic (AADT) and environments displayed a significant amount of variability. Based on the data observed, the authors of that study concluded that it is not possible to predict retroreflectivity with a high level of statistical confidence (*4*).

Using data collected from 85 study sites in 19 states and 363 longitudinal pavement marking lines, Migletz et al. evaluated service life of different marking materials including epoxy, flat and profiled polyester, flat and profiled poly, flat and profiled thermoplastic, and profiled preformed tape; glass beads; and standard and snow-plowable raised retroreflective pavement markers. In that study, the service life of marking materials and roadway types was modeled as a function of time and cumulative traffic passages. The authors found that the first and second order linear relationships, along with exponential decay models outperform the other modeling techniques for predicting pavement marking service life (*5*).

In a study conducted in Michigan, Scheuer et al. developed service life models for several types of pavement marking materials. The results of that study show that retroreflectivity levels of paint lines did not vary as a function of material; pavement surface had little effect on lane-marking performance; and snowplowing and sanding appeared to be the main factors affecting the decay of lane line retroreflectivity (*6*).

David et al. investigated factors affecting the relationship between initial and one-year retroreflectivity of waterborne and spray thermoplastic pavement markings. The factors considered include winter maintenance, marking type, marking color, etc. It was found that spray thermoplastic markings have a statistically higher one-year retroreflectivity than waterborne paint, and pavement marking line color was not shown to be a factor in retained retroreflectivity (*7*).

In summary, retroreflectivity of traffic markings degrades over time for a variety of reasons such as the abrasion by traffic, sun and heat exposure, application methods, material type and chemical spilled on the road surface. Traffic markings can reach the end of service life either because bead loss resulting in poor retroreflectivity, loss of the base material because of chipping and abrasion, or color change or the loss of contrast of the base material of the marking (*8*). The factors that influence traffic marking retroreflectivity are summarized in Table 1.1.

Several studies have evaluated the color performance of pavement markings (*9* and *10*). Jacobs and Johnson conducted participant evaluation to assess the apparent nighttime color of a range of pavement marking products. A total of 24 different materials were viewed at night from an automobile using low-beam illumination with vehicle-to-target distances ranging from 12 to 36 m. Participants viewed the samples and rated the color on a scale of 1 to 5 from white to yellow. It was found that pavement marking materials showed significant different colors. At shorter distances, more of the materials appeared yellow than at longer distances. At longer distances observer ratings showed greater separation of color distinction between the materials. Retroreflective color was measured at geometries corresponding to 12 and 36 m. Brightness did not appear to correlate with color. Color measurements for the different distances also showed the dependence of color on test conditions. The authors also found that daytime color and night time color are not the same. Some yellow pavement markings having acceptable daytime color were white in retroreflective color during night time (*10*).

Table 1−1. Factors that Influence Pavement Marking Retroreflectivity (*8*)

Factor	Characteristic of Factor	Factor Effects
Glass Beads	Amount and Dispersion	Amount: bead surface area for retroreflective
		Dispersion: scattering of reflection between beads
	Embedment Depth	Surface area available for retroreflectance, adhesion to binder material
	Refractive Index	Amount of light directed to reflecting binder surface
	Size	Surface area for retroreflection, wet weather performance
	Clarity	Diffusion of light within the bead
	Roundness	Direction of retroreflection
Binding Material	Color	White reflects more than yellow
	Type	Some materials are more durable than others
	Thickness	Marking longevity
Other Factors	Pavement Surface Roughness	Material adhesion
	Dirt or Other "Blinding" Material	Any object obscuring the view of the marking
	Type of Retroreflectometer Used for measurements	Ability to reproduce measurements varies between instruments

Even though numerous studies have studied the performance of thermoplastic marking materials, these studies have not focused on the performance of no track thermoplastic markings. Until now, there is no documented study regarding the performance of no track thermoplastic markings. In addition, no guidelines or standards exit regarding test procedures used for field evaluation of no track thermoplastic traffic markings. As a result, the performance of industry proclaimed no track thermoplastic markings is still not clear. The major objectives of this study are to develop a test method/procedure to determine whether a thermoplastic marking is a no track marking; and to run field tests and experiments to obtain the performance data (such as reflectivity and color performance) through in-situ applications of no track thermoplastic markings. The field tests followed the procedures specified by ASTM specifications and/or FDOT specifications. More specifically, the ASTM specifications and FDOT specifications that will be used in this study include:

- ASTM D 713 (Standard Practice for Conducting Road Service Tests on Fluid Traffic Marking Materials) (*11*)
- ASTM D 1710 (Standard Test Method for Measurement of Retroreflectivity of Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer) (*12*)
- ASTM D 6359 (Standard Specification for Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments) (*13*)
- ASTM E 1347 (Standard Test Method for Color and Color Difference Measurement by Tristimulus (Filter) Colorimetry (*14*)
- ASTM D 2244 (Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates) (*15*)
- ASTM D 6628 (Standard Specification for Color of Pavement Marking Materials) (*16*)
- Florida Method of Test for Traffic Striping Retroreflectivity (Designation: FM 5-579) (*17*)
- Florida Method of Test for Traffic Striping Field Test (Designation: FM 5-541) (*18*)
- Florida Standard Specifications for Road and Bridge Construction, Section 711 (*2*)

- Florida Standard Specifications for Road and Bridge Construction, Section 971 (*19*)

1.4 Outline of the Report

This report consists of five chapters. Chapter 1 provides a brief introduction of the research, including the background of the research, research objectives and past studies conducted in this area. Chapter 2 summarizes the methods developed for field testing no track thermoplastic markings. Data analysis results and findings are presented in chapter 3. Finally, Chapter 4 provides a summary and the conclusions of this research.

2 TEST METHOD

The major objectives of this study are to develop a test method/procedure to determine whether a thermoplastic marking is a no track marking and to run field tests and experiments to obtain the performance data through in-situ applications of no track traffic thermoplastic markings. To achieve the research objectives, field tests were conducted to collect performance data for selected no track thermoplastic materials. For comparison purpose, the research team also selected a regular thermoplastic marking material as a control group and compared the performance of no track thermoplastic markings to that of the regular thermoplastic marking. In total, four different types of thermoplastic marking products, including three no track thermoplastic markings and one regular thermoplastic marking were used for field tests. Factors considered in field tests included color (yellow or white) and the presence of glass beads. The topics covered in this chapter include the selected test parameters, apparatus, layout of the test site and test procedures.

2.1 Test Parameters

No track thermoplastic traffic marking materials should be capable of being installed onto fresh asphalt materials shortly after finishing paving operations. Upon cooling to ambient temperature, the no track thermoplastic materials shall produce an adherent, reflective pavement marking capable of resisting deformation by traffic and specially formulated to resist the tracking and discoloration from materials deposited by motor vehicle tires under normal traffic conditions. In this study, retroreflectivity and color were evaluated for the field test of no track thermoplastic marking materials.

Retroreflectivity:

Retroreflectivity is the parameter that makes traffic markings visible at night. Traffic markings are reflective because glass beads retroreflect light back to drivers' eyes. The most commonly used measure of retroreflectivity is the coefficient of retroreflected luminance $R_{L,}$ which is defined as the ratio of the luminance L, of a projected surface to the normal illuminance $E_{\perp,}$ at the surface on a plane normal to the incident light. The coefficient of retroreflected luminance is expressed in candelas per square meter per lux (mcd/lx·m^2). As required by the FDOT, the white and yellow pavement markings shall attain an initial retroreflectance of not less than 300 mcd/lx·m^2 and 250 mcd/lx·m^2. The retroreflectance of the white and yellow pavement markings at the end of the six month service life shall not be less than 150 mcd/lx·m^2 (*19*)

The retroreflectance of a traffic marking is usually measured by using retroreflectometers. There are two major types of retroreflectometers, including mobile retroreflectometers and handheld retroreflectometers. Handheld retroreflectometer is a retroreflectometer that can be used in the field or laboratory for measuring the coefficient of retroreflected luminance, while mobile retroreflectometer is a retroreflectometer that has been mounted to a vehicle for the purpose of taking measurements while the vehicle is moving.

The advantage of using a handheld retroreflectometer is location precision and improved repeatability. The disadvantage is that it requires maintenance of traffic and can be quite cumbersome for examining large segments of roadway striping. In this study, a handheld MX-30 retroreflectometer, was used to measure retroreflectance of no track striping on in-situ roadways. A picture for the MX-30 retroreflectometer is given in Figure 2.1.

The field tests measured the retroreflectivity for both newly applied thermoplastic markings and the markings that have been opened to traffic for a certain period of time. Based on the measured retroreflectance data, degradation curves were developed to illustrate the decay of retroreflectivity over time and to compare between no track and regular thermoplastic traffic striping.

The field measurements of retroreflectivity followed the procedures specified by the ASTM standards E 1710 (*12*). The retroreflectometer was calibrated at the beginning of each day of use and additional calibrations were performed if the instrument was turned off, recharged, or if testing conditions changed, e.g. substantial change in ambient temperature. According to ASTM standards, retroreflectivity was measured at a 30 Meter CEN Geometry. The 30 Meter CEN Geometry is specified by the European Committee for Standardization (CEN). The 30 Meter CEN Geometry corresponds to a headlamp height of 0.65 meters and an observer height of 1.2 meters at a distance of 30 meters from the center of the reflective stripe. This results in the entrance and observation angles of 88.76° and 1.05°, respectively. A figure depicting the 30 Meter CEN Geometry is given in Figure 2.2.

Figure 2−1. MX-30 Handheld Retroreflectometer

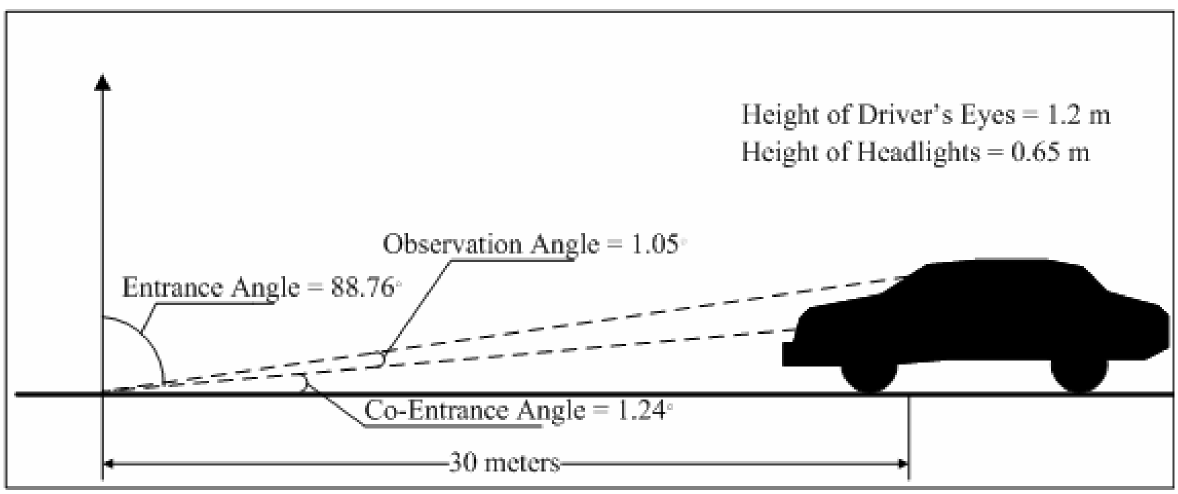

Figure 2−2. 30 Meter CEN Geometry

Color

The major benefit of no track thermoplastic materials is that they can be installed onto fresh asphalt materials shortly after paving operations. The problem is that the markings can be discolored or badly stained by tire tracks during the asphalt curing time. To ensure no track thermoplastic markings are resistant to tracking and bitumen contamination, color was measured to provide quantified results regarding the discoloration of selected no track thermoplastic markings.

The research team only measured the daytime colors for selected thermoplastic markings. Daytime color was measured in accordance with ASTM test method E 1347. The test method provides procedures for measuring CIE color coordinates of object colors by instrumental measurement using colorimeters or spectrophotometers (*14*). The CIE color coordinates were created by the International Commission on Illumination (CIE) in 1931. The CIE system characterizes colors by a luminance parameter Y and two color coordinates x and y which specify the points on the chromaticity diagram. With CIE color coordinates x and y, the daytime colors of markings can be represented by points in the CIE chromaticity diagram. The luminance parameter Y and color coordinates x and y can be easily converted to CIE tristimulus values X, Y, and Z by using the following equations:

$$x = \frac{X}{X + Y + Z} \tag{2-1}$$

$$y = \frac{Y}{X + Y + Z} \tag{2-2}$$

In this study, daytime luminance (Y) and chromaticity (x, y) was measured using a BYK Gardner Handy Color, as shown in Figure 2.3. This data was measured using 45/0 (0/45) geometry, CIE illuminant D65 and the 1931 CIE 2° standard observer. Similar to the use of the retroreflectometer, the colorimeter was also calibrated at the beginning of each day of use and additional calibrations were performed if the instrument is turned off, recharged, or if testing conditions changed.

Figure 2−3. Measure Color using a BYK Gardner Handy Color.

The Florida standard specifications for road and bridge construction 2007 section 971 and ASTM standard E 6628 has specified the performance requirements for the colors of pavement marking materials (*16* and *19*). Based on these standards, the initial and in-service daytime chromaticity for yellow and white materials shall fall within the box created by the coordinates given in Table 2.1. In addition, the initial luminance parameter Y should be at least 35 for white markings and 25 for yellow markings.

Table 2−1. Daytime Chromaticity Coordinates (Corner Points)

Color	Daytime Chromaticity Coordinates (Corner Points)							
	1		2		3		4	
	x	y	x	y	x	y	x	y
White	0.355	0.355	0.305	0.305	0.285	0.325	0.335	0.375
Yellow[a]	0.530	0.456	0.510	0.485	0.455	0.444	0.472	0.400
Yellow[b]	0.530	0.456	0.510	0.485	0.435	0.429	0.449	0.377

a. Initial daytime chromaticity coordinates for yellow markings
b. In-service daytime chromaticity coordinates for yellow markings

This study measured the color differences between new pavement markings and markings which have been installed on pavement for a certain period of time. The color differences measured in the field can be used to quantify the discoloration of pavement markings during asphalt curing time. More importantly, the data can be used to compare the discoloration of no track thermoplastic markings to that of regular thermoplastic markings to determine if the selected no track thermoplastic markings are no track markings.

The color differences between new and in-service pavement markings can be measured by visually inspecting traffic marking appearance in the field. Traffic marking appearance is the general condition of the test lines when observed without any detailed inspection, from a distance of at least 10 ft. The appearance of markings is rated either acceptable or unacceptable (*11*). The problem with the visual inspection method is that the method does not provide quantifiable results and the rate of traffic marking appearance heavily relies on observers' subjective judgment.

Another way of measuring color differences is to plot the CIE color coordinates (x, y) measured at different times during the study period on the CIE 1931 chromaticity diagram. The distance between difference data points in the chromaticity diagram measures the difference in chromaticity. The problem with this method is that it also does not provide for the quantifiable results about color differences. In addition, the CIE 1931 and 1964 color spaces are not perceptually uniform color space. Consequently, color difference are seldom if ever computed directly from differences in x, y, and Y (*15*).

The ASTM standard D 2244 provides methods for calculating color differences from instrumentally measured color coordinates (*15*). To measure color differences, tristimulus values X, Y, Z from the CIE 1931 and 1964 color spaces were converted to L*, a*, b* values in the CIELAB color space, which is an approximately uniform color space based on nonlinear expansion of the tristimulus values and taking differences to produce three opponent aces that approximate the percepts of lightness-darkness, redness-greenness and yellowness-blueness. The values of L*, a*, b* can be calculated as follows:

$$L^* = 116\, f(Q_Y) - 16 \quad (2\text{-}3)$$

$$a^* = 500[\, f(Q_X) - f(Q_Y)] \quad (2\text{-}4)$$

$$b^* = 200[\, f(Q_Y) - f(Q_Z)] \quad (2\text{-}5)$$

where:

$$Q_X = (X/X_n);\ Q_Y = (Y/Y_n);\ Q_Z = (Z/Z_n)$$

and

$$F(Q_i) = Q_j^{1/3} \text{ if } Q_j > (6/29)^3$$

else

$$F(Q_i) = (841/108)Q_i^{1/3} \text{ if } Q_j =< (6/29)^3$$

Here, i varies as X, Y, and Z. X_n, Y_n and Z_n are the chromaticity coordinates of a fully satin white surface for the luminant and the standard observer, which are referred to as the chromaticity coordinates. Since X, Y and Z data were measured using 45/0 (0/45) geometry, CIE illuminant D65 and the 1931 CIE 2° standard observer, X_n equals 95.05, Y_n equals 100 and Z_n equals 108.90.

The total color difference between two colors can be estimated as:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2\text{-}6)$$

where ΔE^* is the total color difference between two colors , ΔL^* measures the lightness difference, Δa^* measures the red/green difference and Δb^* measures the yellow/blue difference of two colors.

Another parameter used in this study for measuring the color difference is the CIE94 color tolerances. The parameter is based on the more intuitive perceptual variables of lightness, chroma and hue instead of the lightness, redness/greenness and yellowness/blueness used in E.q. (2-6). The CIE94 tolerance can be computed as:

$$\Delta E_{94}^{*} = k_v[(\frac{\Delta L^*}{K_L S_L})^2 + (\frac{\Delta C^*}{K_C S_C})^2 + (\frac{\Delta H^*}{K_H S_H})^2]^{\frac{1}{2}} \tag{2-7}$$

where ΔE_{94}^{*} is the CIE94 color tolerance, which measures the difference between two colors. ΔL^*, ΔC^*, and ΔH^* measures the difference in lightness, chroma, and hue angle. The CIE 1976 metric hue angles h^* and chroma C^* can be calculated as follows:

$$h^* = \tan^{-1}(\frac{b^*}{a^*}) \tag{2-8}$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \tag{2-9}$$

In E.q.(2-7), k_L, k_C, k_H are numeric parametric factors that permit the independent weighting of lightness (ΔL*), chroma (ΔC*), and hue (ΔH*) differences, and k_v is used to adjust the size of the tolerance volume for industrial bias. All the k values were set to be 1 for the defined viewing reference conditions for perceived color difference. The reference conditions include: CIE D65, CIE 100 Observer, 1000 lx illuminance, gray background, minimal specimen separation, homogeneous specimen structure, 0 to 5 ΔE*, and normal color vision.

The parameters S_L, S_C, and S_H are CIE94 weighting functions that adjust the CIE differences (ΔL*, ΔC*, ΔH*) depending upon the location of the standard in CIE 1976 color space. The parameters can be calculated using the following equations:

$$S_L = 1 \tag{2-10}$$

$$S_c = 1 + 0.045 \times C^* \tag{2-11}$$

$$S_H = 1 + 0.015 \times C^* \tag{2-12}$$

2.2 Layout of the Test Site

The selected site is located at the intersection of Northeast Waldo Road and Northeast 39th Avenue in Gainesville, Florida. A photo of the test site is given in Figure 2.4. The right-turn lane from the northbound approach of the Northeast Waldo Road was selected as the test section. The Northeast 39th Avenue connects Northeast Waldo Road to an industrial park. The research team counted right-turn volume at the selected test section. Daily right-turn volume at the right-turn lane was found to be 250 vehicles per day. About 20% of these vehicles are heavy vehicles. That is, about 200 passenger cars and 50 heavy vehicles pass over the traffic markings installed at the left-turn lane each day.

On March 26th 2007, pavement at the selected site was reconstructed and markings were installed at the test section on the same day. Selected thermoplastic materials were extruded onto the pavement by using a manually operated device. To ensure that significant numbers of vehicles will pass over the markings installed at the test section, transverse lines were installed for performance evaluation.

As mentioned before, three industry proclaimed no track thermoplastic marking products plus one regular thermoplastic marking product were installed at the test section for performance evaluation. In this report, we do not provide the names of manufactures. For convenience, three no track thermoplastic products were named as product C, product D and product E, and the regular thermoplastic product was named as product R. The following scenarios were considered in field tests:

(1) Marking Products: three no track thermoplastic marking products and one regular thermoplastic marking product;
(2) Color: white markings and yellow markings;
(3) Glass Beads: markings with/without glass beads

In total, sixteen transverse lines were installed in the field for performance evaluation, including four yellow lines with glass beads applied on the surfaces of traffic markings, four yellow lines without glass beads, four white lines with glass beads applied and four white lines without glass beads. A picture illustrating the pavement marking configuration at the test section is given in Figure 2.5.

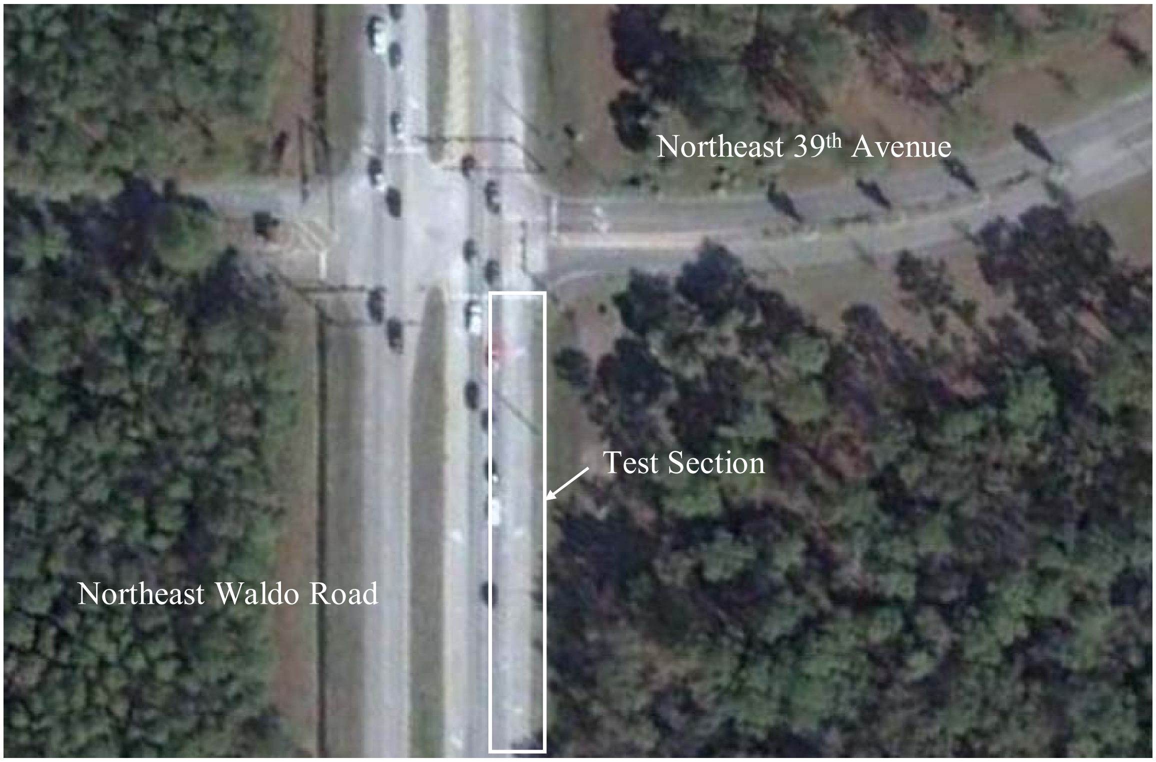

Figure 2−4. Aero Photo of Test Site

Figure 2−5. Test Site and Pavement Marking Configuration

2.3 Field Tests

The field tests started on March 26th, 2007 and lasted five months. The last field visit was made on August 23rd, 2007. Four thermoplastic marking materials were selected for the field test, including three proclaimed no track thermoplastic markings and one regular thermoplastic marking. Sixteen transverse lines were installed at the test section, including eight yellow lines and eight white lines. For each test line, the research team took at least 15 measurements for retroreflectivity and color data. Considering the fact that each test line is about 15 ft long, the measurements were made approximately every 1 ft along the test line.

The research team randomly selected 15 points from each transverse line and measured both initial and in service performance data for the applied thermoplastic markings. Retroreflectivity was measured using a MX-30 handheld retroreflectometer. Color was measured using a BYK Gardner Handy colorimeter. When measuring retroreflectivity, procedures provided by the ASTM standard E 1710 were followed. The color measurements followed the test methods provided by the ASTM standard E 1347. Pictures were also taken in the field to illustrate the change of appearance of traffic markings over time. In total, the research team conducted nine field visits to collect performance data. Data were only collected during clear daylight hours and were not collected when the pavement is wet.

3 DATA ANALYSIS AND RESULTS

From March 26th, 2007 to August 23rd, 2007, the research team made nine field visits to collect performance data for selected thermoplastic traffic marking products installed at the test section. Four thermoplastic marking products were installed at the test section, including three no track thermoplastic markings and one regular thermoplastic marking. For convenience, the three no track thermoplastic marking products were named as product C, D, and E, respectively, and the regular thermoplastic marking was named as product R.

Pictures were taken in the field to illustrate the change of traffic marking appearance over time. Some pictures taken in the field are given in Figure 3-1 through 3-4. As shown in Figure 3-1 through 3-4, when vehicle tires pass over the test lines, they bring tracks on to the surface of both no track and regular thermoplastic markings. Selected no track thermoplastic markings were not found to be completely resistant to wheel tracking of asphalt on to marking surface; and visual inspection cannot distinguish between no track and regular thermoplastic markings. Retroreflectivity and color data must be collected to quantitatively evaluate the change of performance during asphalt curing time for selected thermoplastic traffic marking products.

3.1 Retroreflectivity

Retroreflectivity data were only measured at eight test lines with glass beads applied to the surface of the traffic markings. In total, the research team took 1463 retroreflectivity measurements at the test section. The collected retroreflectivity data were saved into a database for data analysis. Descriptive statistics for retroreflectivity data for different thermoplastic markings at different times during the study period were given in Table 3-1 through 3-8. Based on the collected retroreflectivity data, degradation curves were developed to illustrate the change of retroreflectivity over time for different thermoplastic marking materials. The degradation curves are shown in Figure 3-5 and 3-6.

Figure 3-1. Wheel Tracking of Asphalt on to Surface of Pavement Marking
(Product: R, Color: Yellow, Glass Beads: No)

Figure 3-2. Wheel Tracking of Asphalt on to Surface of Pavement Marking
(Product: D, Color: Yellow, Glass Beads: No)

Figure 3-3. Wheel Tracking of Asphalt on to Surface of Pavement Marking
(Product: C, Color: Yellow, Glass Beads: No)

Figure 3-4. Wheel Tracking of Asphalt on to Surface of Pavement Marking
(Product: E, Color: Yellow, Glass Beads: No)

Table 3-1. Descriptive Statistics for Retroreflectance (Product: R, Color: Yellow)

# of Days	Sample Size	Minimum	Maximum	Mean	Median	Std. Deviation
1	15	87	125	101.8	100.5	12.70
2	40	116	252	181.6	184.5	22.39
3	15	146	196	179.8	189	17.96
10	30	74	329	152.0	146	42.07
31	15	143	192	165.3	168	12.83
38	15	122	202	161.0	162	27.43
52	20	93	183	139.0	136.5	26.44
108	15	176	256	207.9	196	26.57
151	15	95	211	151.5	156	31.64

Table 3-2. Descriptive Statistics for Retroreflectance (Product: C, Color: Yellow)

# of Days	Sample Size	Minimum	Maximum	Mean	Median	Std. Deviation
1	15	73	208	156.6	157.5	39.89
2	40	191	301	241.6	237.0	24.31
3	15	218	330	255.1	255.0	24.30
10	30	21	241	170.2	188.0	61.43
31	15	130	256	205.8	205.0	32.16
38	16	100	254	188.6	204.0	51.32
52	20	81	268	166.5	172.5	45.48
108	15	151	295	241.1	260.0	49.90
151	15	127	253	198.7	203.0	43.02

Table 3-3. Descriptive Statistics for Retroreflectance (Product: E, Color: Yellow)

# of Days	Sample Size	Minimum	Maximum	Mean	Median	Std. Deviation
1	15	60	174	112.9	117.5	39.72
2	40	89	255	187.6	187.0	26.80
3	15	161	227	195.9	197.0	16.21
10	30	41	307	163.0	168.0	53.59
31	15	131	224	193.8	192.0	24.02
38	16	91	258	175.1	167.5	44.71
51	20	67	219	153.3	145.0	35.46
108	15	162	292	235.1	239.0	33.71
151	15	149	307	217.6	219.0	41.54

Table 3-4. Descriptive Statistics for Retroreflectance (Product: D, Color: Yellow)

# of Days	Sample Size	Minimum	Maximum	Mean	Median	Std. Deviation
1	15	116	204	178.7	181.5	21.51
2	40	90	352	233.9	256.5	58.38
3	15	151	298	246.5	254.0	36.84
10	30	124	337	208.1	195.0	48.16
31	15	165	281	228.7	242.0	35.44
38	18	94	273	213.0	215.5	49.80
51	21	129	271	180.1	162.0	42.19
108	15	112	311	248.4	257.0	49.67
151	15	218	359	277.9	293.0	39.03

Table 3-5. Descriptive Statistics for Retroreflectance (Product: R, Color: White)

# of Days	Sample Size	Minimum	Maximum	Mean	Median	Std. Deviation
1	14	201	345	261.6	260.5	35.92
2	39	206	446	379.9	401.0	60.56
3	15	261	439	374.3	376.0	48.56
10	30	125	411	310.4	344.0	77.49
31	15	326	441	387.2	392.0	36.18
38	17	227	398	328.2	327.0	53.02
51	23	167	419	291.0	290.0	67.06
108	15	370	539	452.3	432.0	48.05
151	15	231	471	392.1	394.0	53.97

Table 3-6. Descriptive Statistics for Retroreflectance (Product: C, Color: White)

# of Days	Sample Size	Minimum	Maximum	Mean	Median	Std. Deviation
1	15	222	284	256.2	258.0	16.05
2	40	260	401	334.0	340.5	34.51
3	15	285	365	330.3	330.0	20.71
10	30	167	439	290.1	296.0	63.68
31	15	140	360	312.8	320.0	51.34
38	17	143	359	289.3	300.0	59.87
51	23	145	340	263.2	270.0	45.87
108	15	302	443	374.5	391.0	46.71
151	15	282	403	346.5	343.0	37.29

Table 3-7. Descriptive Statistics for Retroreflectance (Product: E, Color: White)

# of Days	Sample Size	Minimum	Maximum	Mean	Median	Std. Deviation
1	14	234	343	298.0	302.5	33.29
2	40	310	511	432.3	441.0	45.97
3	15	326	481	433.5	440.0	35.46
10	30	81	462	352.4	382.0	98.38
31	15	275	447	402.5	410.0	41.00
38	18	243	452	358.1	367.5	67.77
51	23	200	409	310.7	322.0	51.01
108	15	399	567	495.9	495.0	46.83
151	15	315	497	433.5	447.0	51.40

Table 3-8. Descriptive Statistics for Retroreflectance (Product: D, Color: White)

# of Days	Sample Size	Minimum	Maximum	Mean	Median	Std. Deviation
1	14	89	209	149.9	154.5	30.26
2	40	242	452	373.4	373.0	54.47
3	15	265	455	380.7	385.0	53.92
10	30	72	437	285.1	306.5	104.81
31	15	192	417	350.8	367.0	58.95
38	18	155	385	281.2	274.5	76.54
51	23	170	442	294.9	285.0	75.13
108	16	107	537	375.3	380.0	96.80
151	15	205	431	318.2	316.0	71.42

As required by the FDOT, pavement markings shall attain an initial retroreflectance of not less than 300 mcd/lx·m^2 and 250 mcd/lx·m^2 for white and yellow markings respectively. The retroreflectance of the white and yellow pavement markings at the end of the six month service life shall not be less than 150 mcd/lx·m^2 (*19*). The curves in Figure 3-5 and 3-6 show that the retroreflectances of traffic markings increase with time and reach the maximum values after the markings have been installed on the road for three days. After three days, the retroreflectances of selected thermoplastic traffic markings reach a relatively steady state. In this study, the retroreflectance measured on the third day was defined as the initial retroreflectance.

The mean initial retroreflectance for selected thermoplastic markings varies from 189 to 255 mcd/lx·m^2 for yellow traffic markings, and from 330 to 440 mcd/lx·m^2 for white traffic markings. For yellow traffic markings, only product C and product D meet the FDOT requirements for initial retroreflectance. Products R and E did not meet the initial requirements. For white markings, all selected thermoplastic marking products successfully meet the initial requirements for retroreflectance.

During asphalt curing time, thermoplastic markings can become discolored or badly stained by tire tracks. This could result in reduced retroreflectivity of traffic markings. Theoretically, if the selected no track thermoplastic markings are resistant to the tracking of asphalt, they should have larger retroreflectance than regular thermoplastic markings after they have been installed on the road and opened to traffic for a certain period of time.

As shown in Figure 3-5, the mean retroreflectance for yellow regular thermoplastic marking dropped to 156 mcd/lx·m^2 after the marking has been installed on the road for 151 days. The value is slightly higher than the minimum in-service retroreflectance required by the FDOT. For yellow no track thermoplastic markings, the mean retroreflectance after 151 days varies from 203 to 293 mcd/lx·m^2. These values are much greater than the retroreflectance of the regular thermoplastic marking. The data show that the selected no track thermoplastic markings are superior to the selected regular thermoplastic marking in terms of the higher in-service retroreflectivity.

For white test lines, however, the benefits of using no track thermoplastic markings are not so clear. As shown in Figure 3-6, the mean retroreflectance after 151 days varies from 316 to 447 mcd/lx·m^2. All these values are much higher than the minimum in-service retroreflectance required by the FDOT, which is 156 mcd/lx·m^2. The regular thermoplastic marking has the second highest in-service retroreflectance after 151 days, which is found to be 394 mcd/lx·m^2. The traffic marking with the lowest retroreflectance after 151 days is found to be product D. The results show that even though the selected no track thermoplastic markings meet the FDOT requirements about the initial and in-service retroreflectance of white traffic markings, they do not provide better retroreflectivity as compared to the selected regular thermoplastic marking.

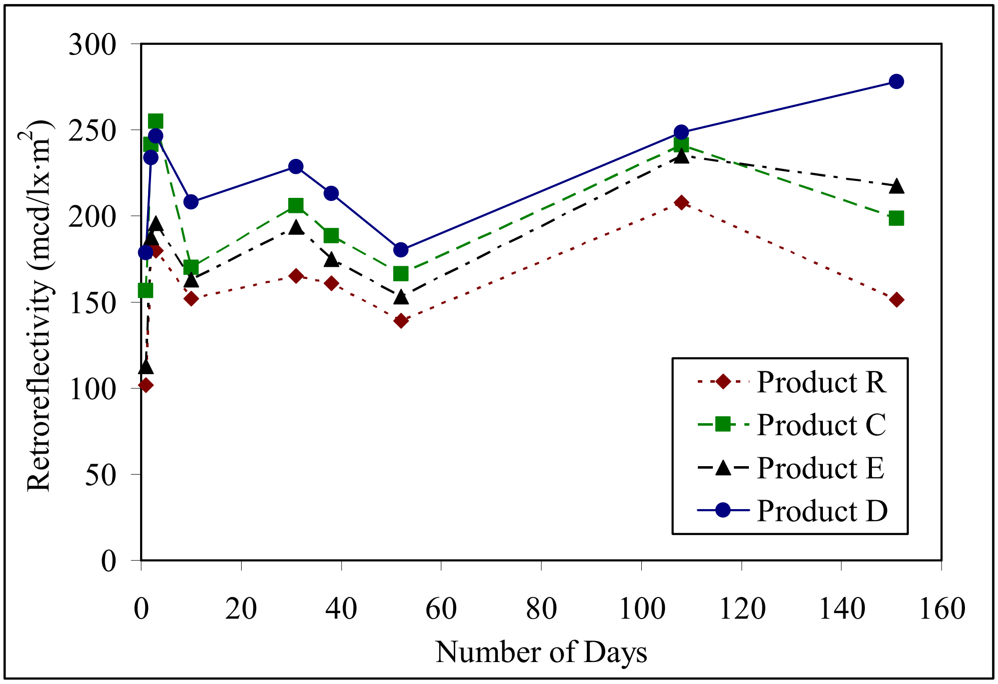

Figure 3-5. Change of Retroreflectivity over Time for Yellow Markings

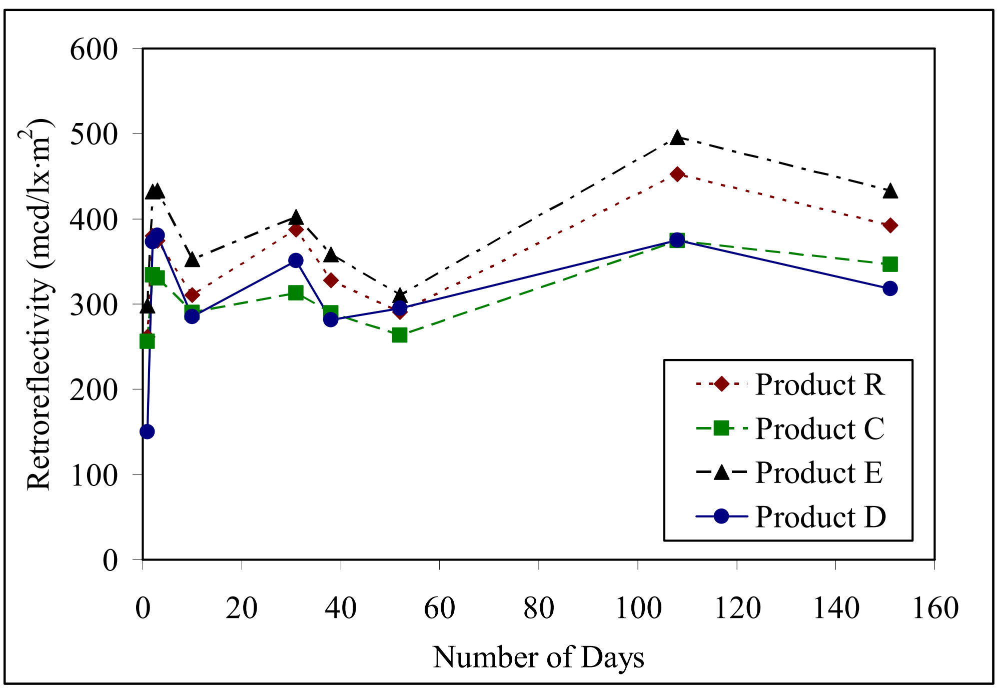

Figure 3-6. Change of Retroreflectivity over Time for White Markings

3.2 Color

Color data were measured for all sixteen test lines, including eight yellow lines and eight white lines. The research team also studied the impacts of glass beads on the discoloration of traffic markings. The assumption is that traffic markings with glass beads dropped on the surface are more resistant to the tracking of asphalt because vehicle tires will pass over the glass beads, not the surface of traffic marking materials. The sixteen test lines include four yellow lines with glass beads applied, four yellow lines without glass beads, four white lines with glass beads applied and four white lines without glass beads.

At least fifteen measurements were taken at each test line for each evaluation. In total, the research team took 2230 color measurements at the test section. The color measurements were represented on the CIE 1931 chromaticity diagram to check if the in-service color is complied with the chromaticity limits established by the FDOT, and to illustrate the discoloration of traffic markings over time. As shown in Figure 3-7 through 3-22, most of the color measurements fall within the box created by the coordinates provided by the FDOT. The data points fall outside of the box represent the points on traffic markings that are badly stained by wheel tracking of asphalts. Average chromaticity for each test line is also given in Figure 3-23 through 3-38. By looking at these figures, however, it is difficult to identify the pattern of discoloration over time and to quantify the color differences between initial and in-service traffic markings.

In this study, two parameters were used to quantify the discoloration of traffic markings during the asphalt curing time and to compare the discoloration of no track thermoplastic markings to that of the regular thermoplastic marking. These two parameters include the ΔE^* value which is calculated based on the L*, a*, b* values from the CIELAB color space, and CIE94 color tolerance ΔE^*_{94}. These two parameters quantify the color differences between newly applied thermoplastic traffic markings and the traffic markings that have been installed in the field for a certain period of time. Theoretically, traffic markings with lower ΔE^* and ΔE^*_{94} values are more resistant to the tracking of asphalt. Procedures for calculating these two parameters were described in chapter 2. The calculated color difference parameters at different times during the study period for different test lines are given in Table 3-9 through 3-12.

Data in Table 3-9 through 3-12 show that both ΔE^* and ΔE^*_{94} values increase with the time, indicating the fact that these two parameters can be used to quantify the discoloration of traffic markings over time. To better illustrate the discoloration of selected thermoplastic traffic marking materials, ΔE^* and ΔE^*_{94} values for different test lines were compared in Figure 3-23 through 3-26. The figures show that the selected no track thermoplastic marking materials are more resistant to the tracking of asphalt as compared to the regular thermoplastic marking material in terms of the lower ΔE^* and ΔE^*_{94} values. The data also show that the assumption about the impact of glass beads is not true. Traffic markings with glass beads dropped on the surface were not found to be more resistant to the tracking of asphalt. In fact, for most of the test lines, traffic markings with glass beads dropped on the surface have larger ΔE^* and ΔE^*_{94} values as compared to those without glass beads.

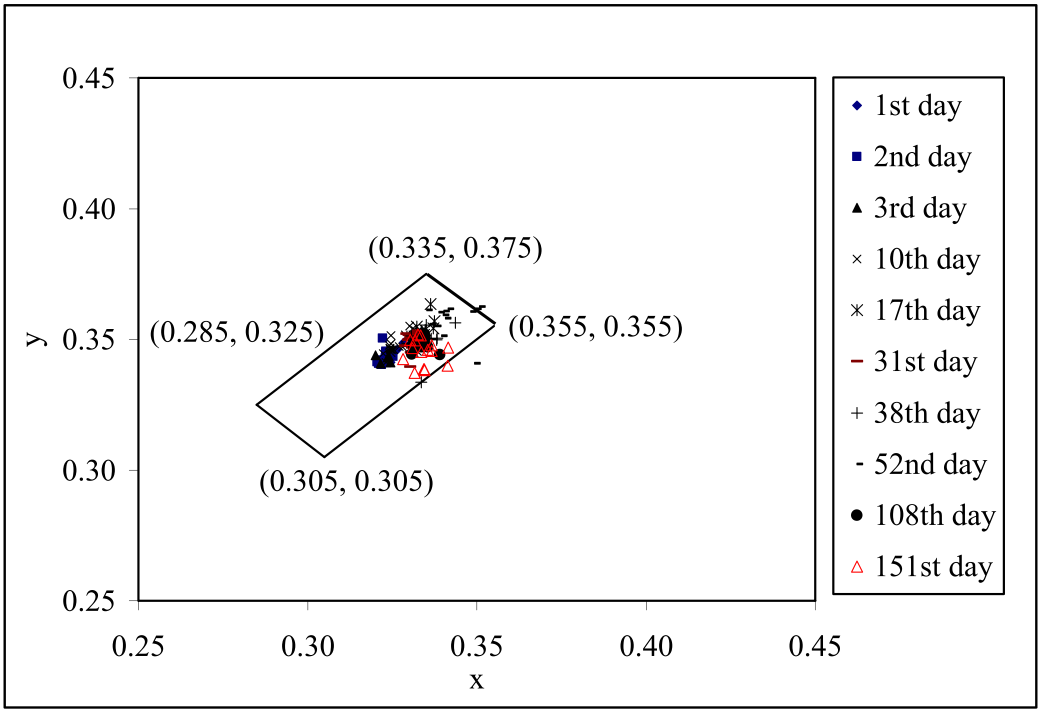

Figure 3-7. Change of Chromaticity over Time (Product: R, Color: White, Glass Beads: No)

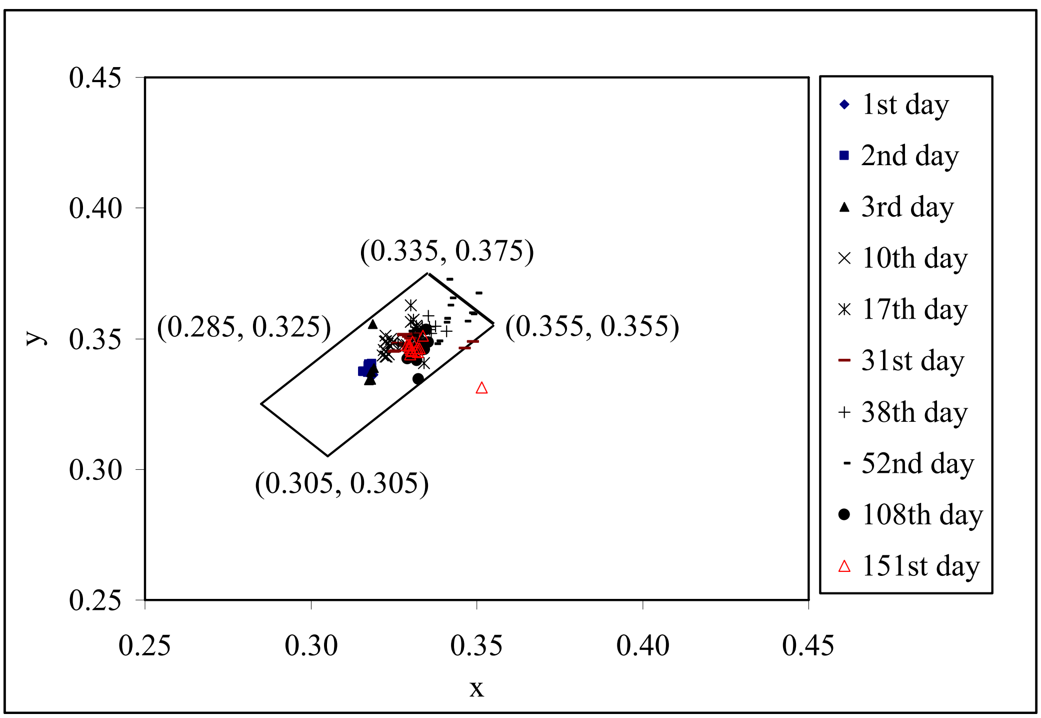

Figure 3-8. Change of Chromaticity over Time (Product: C, Color: White, Glass Beads: No)

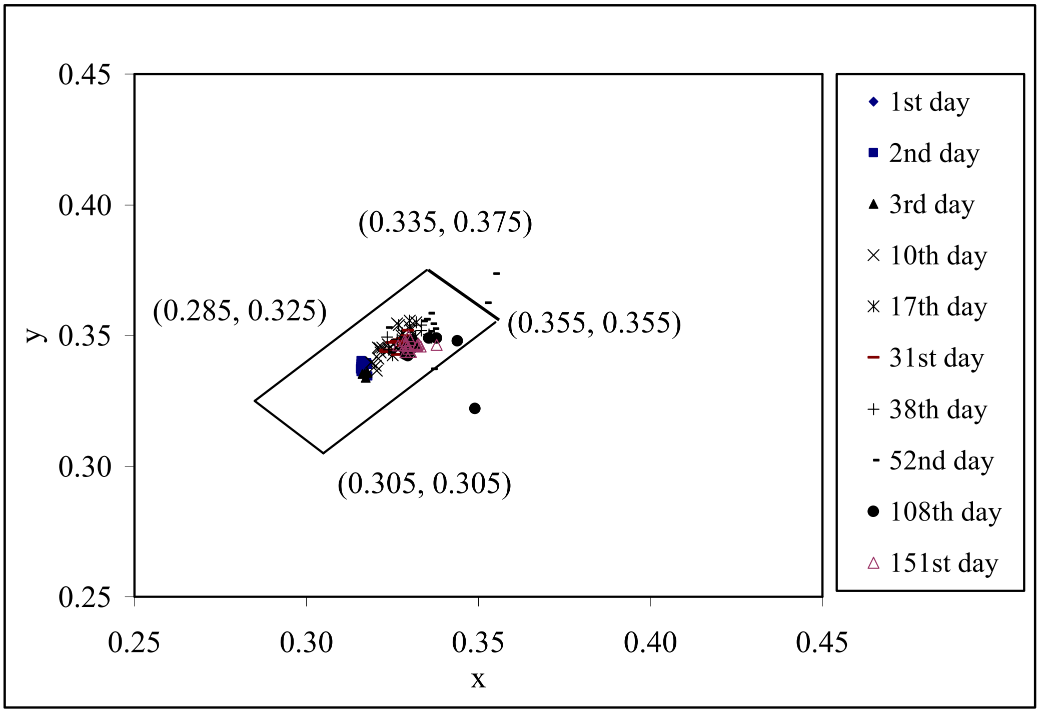

Figure 3-9. Change of Chromaticity over Time (Product: D, Color: White, Glass Beads: No)

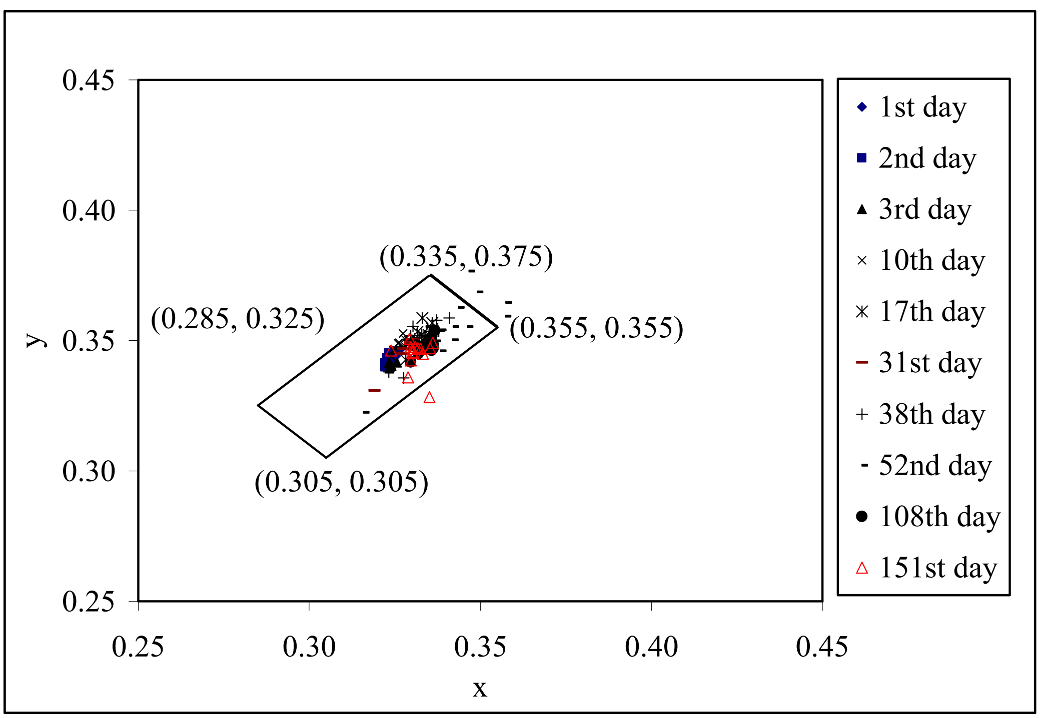

Figure 3-10. Change of Chromaticity over Time (Product: E, Color: White, Glass Beads: No)

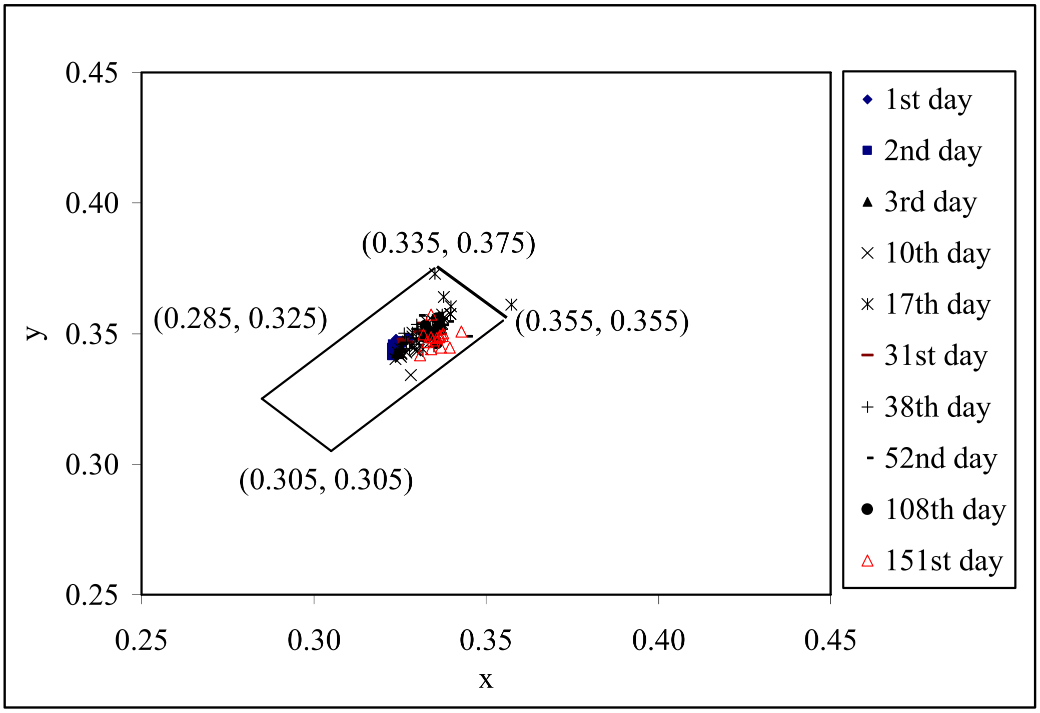

Figure 3-11. Change of Chromaticity over Time (Product: R, Color: White, Glass Beads: Yes)

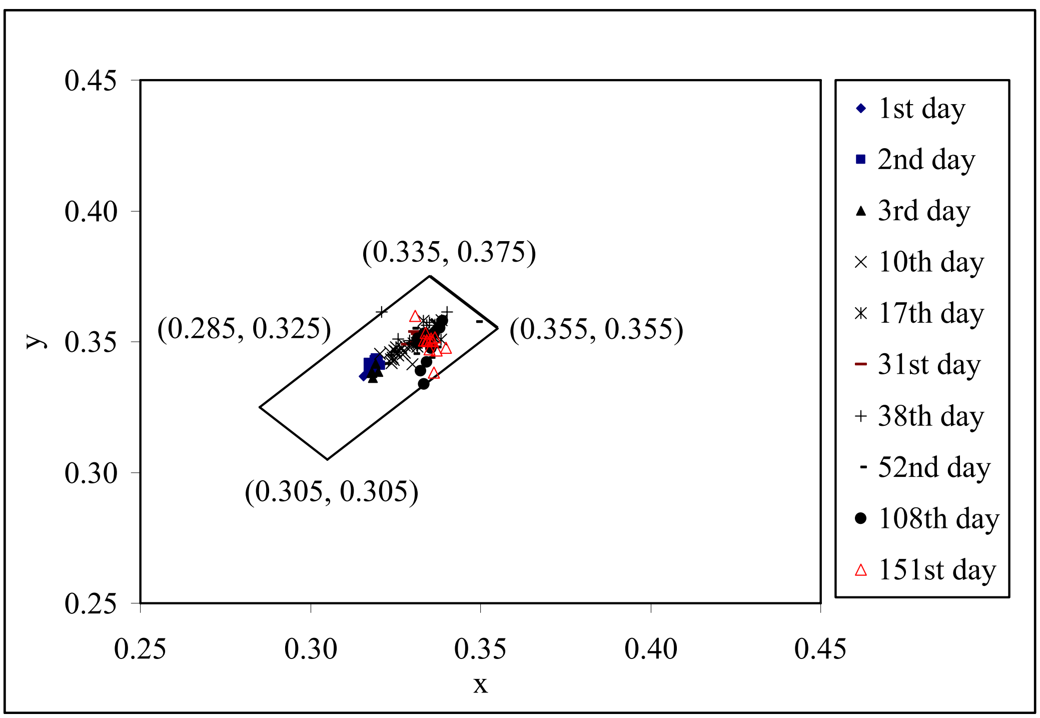

Figure 3-12. Change of Chromaticity over Time (Product: C, Color: White, Glass Beads: Yes)

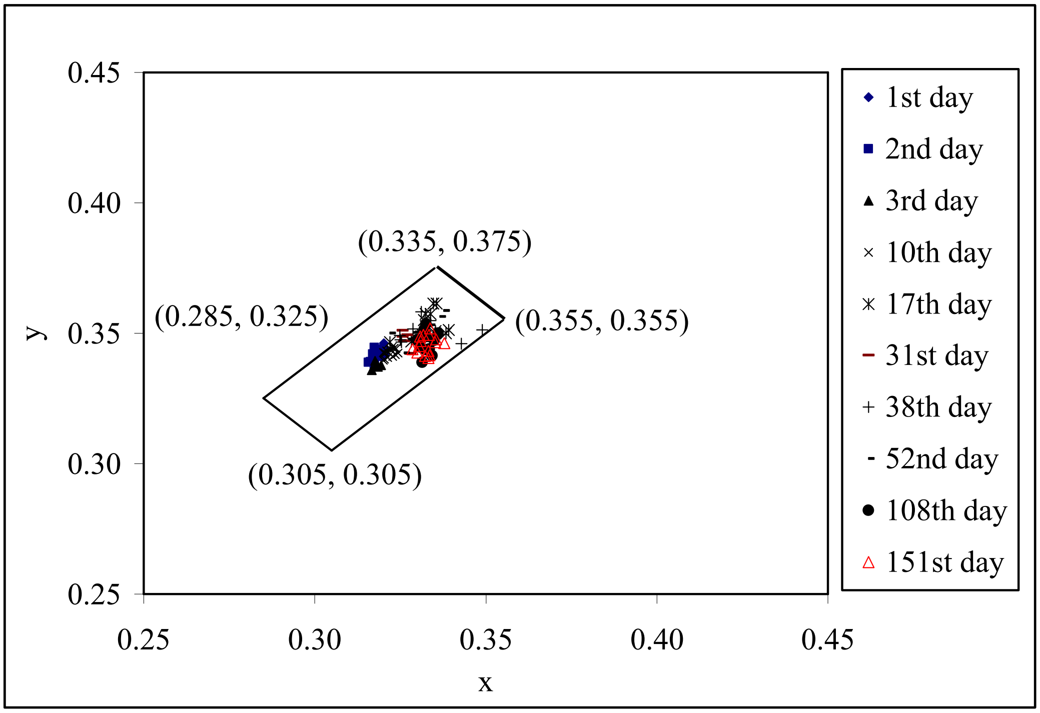

Figure 3-13. Change of Chromaticity over Time (Product: D, Color: White, Glass Beads: Yes)

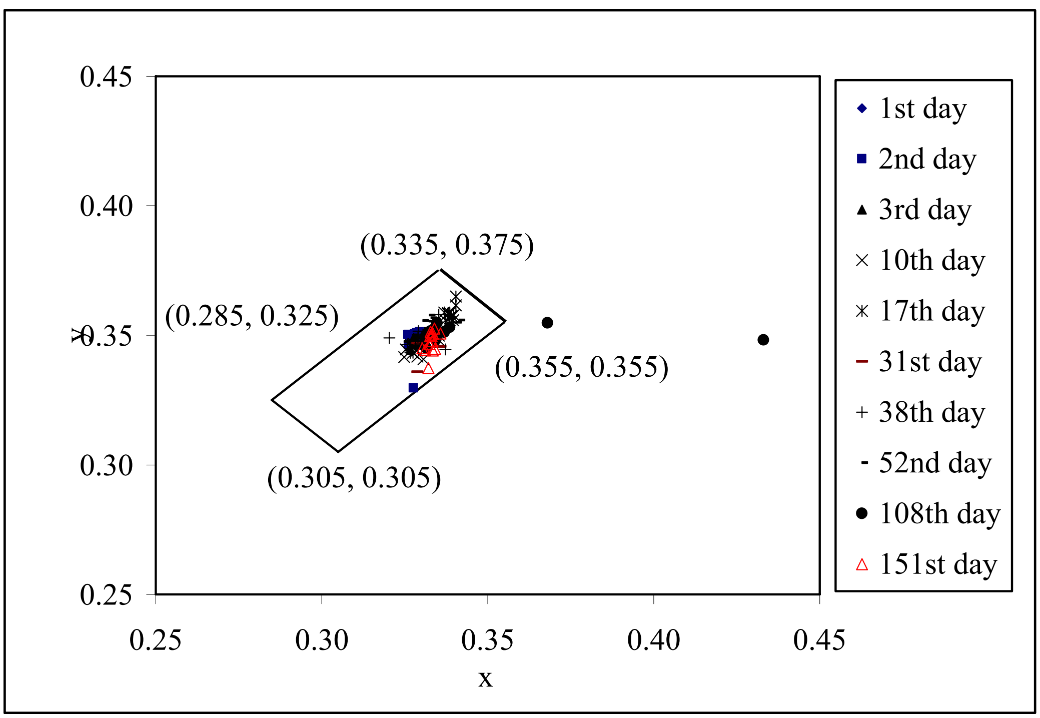

Figure 3-14. Change of Chromaticity over Time (Product: E, Color: White, Glass Beads: Yes)

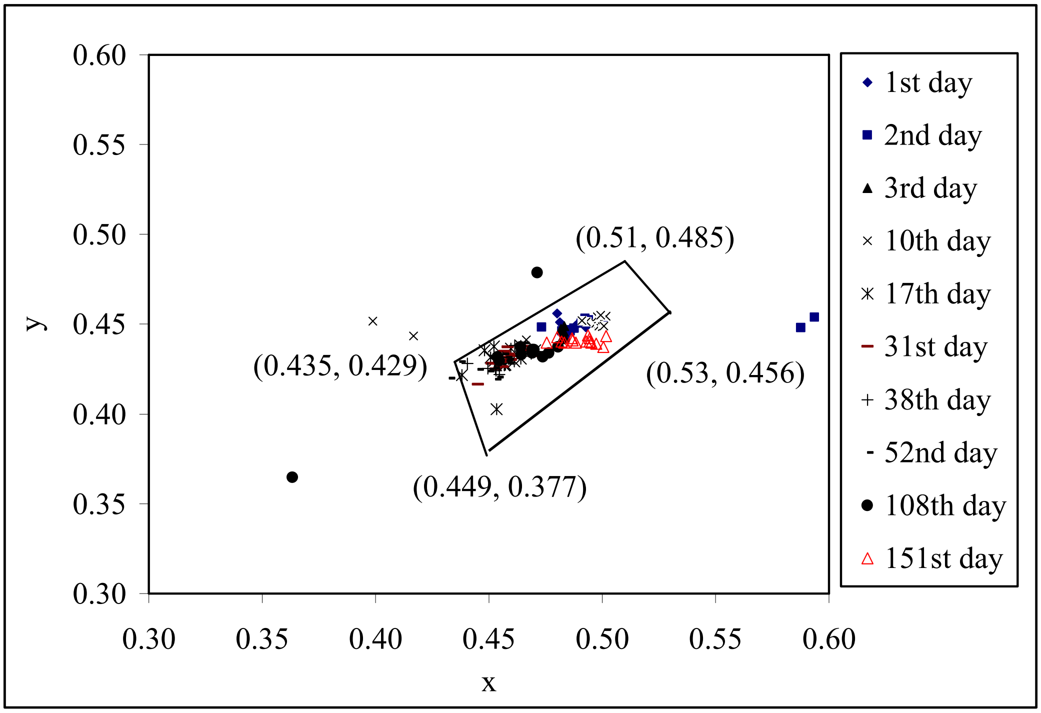

Figure 3-15. Change of Chromaticity over Time (Product: R, Color: Yellow, Glass Beads: No)

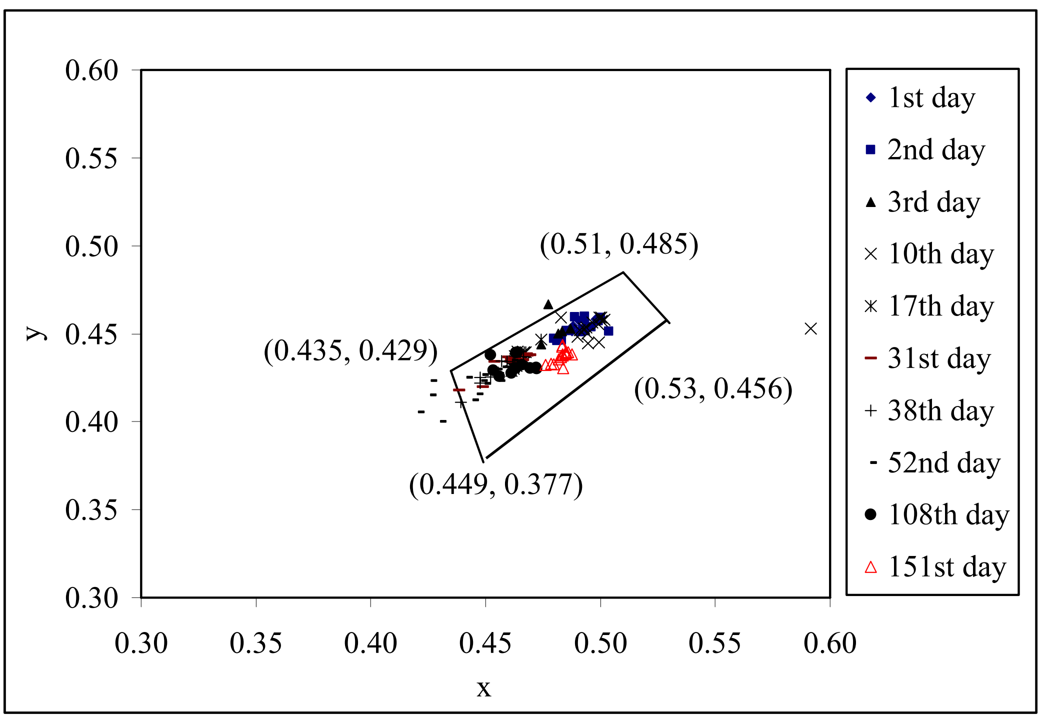

Figure 3-16. Change of Chromaticity over Time (Product: C, Color: Yellow, Glass Beads: No)

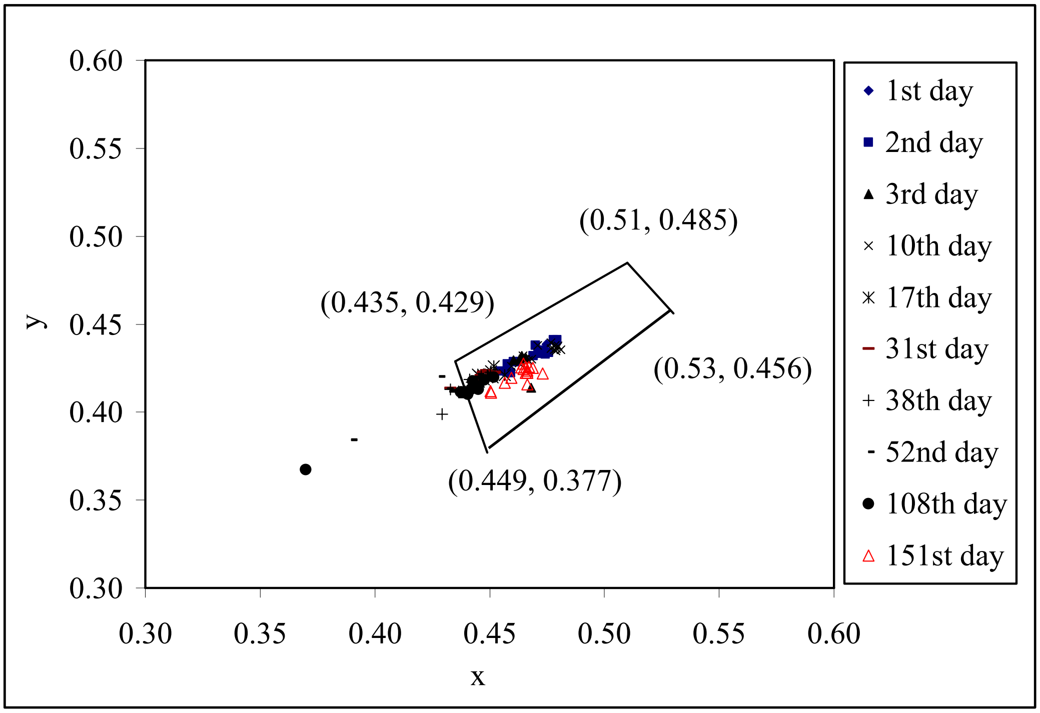

Figure 3-17. Change of Chromaticity over Time (Product: D, Color: Yellow, Glass Beads: No)

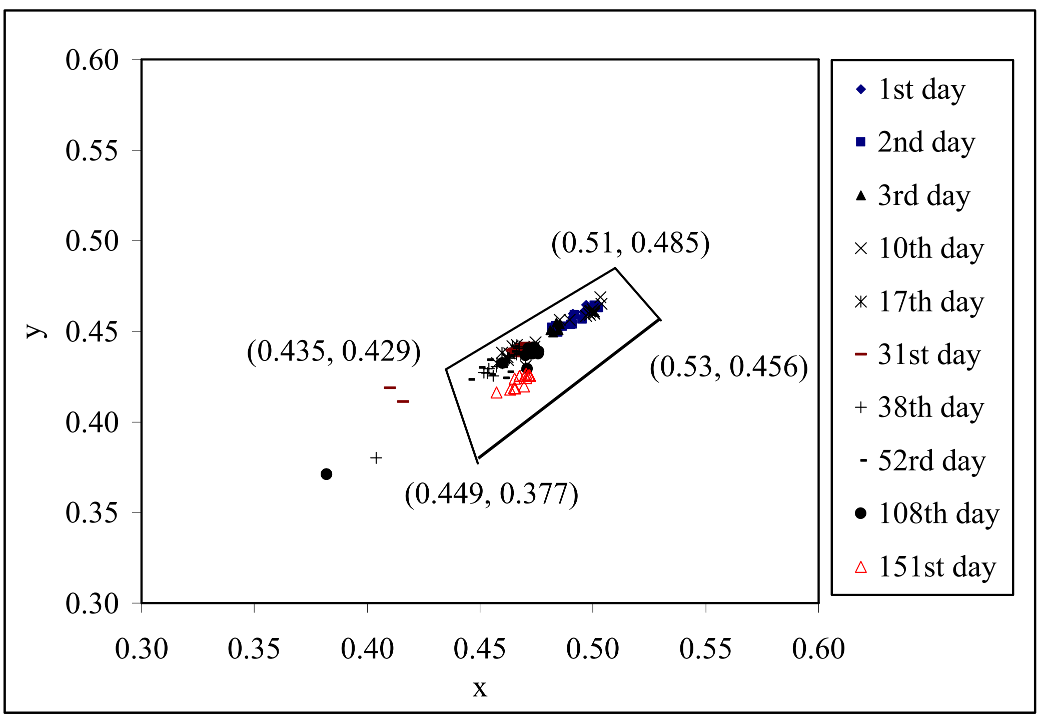

Figure 3-18. Change of Chromaticity over Time (Product: E, Color: Yellow, Glass Beads: No)

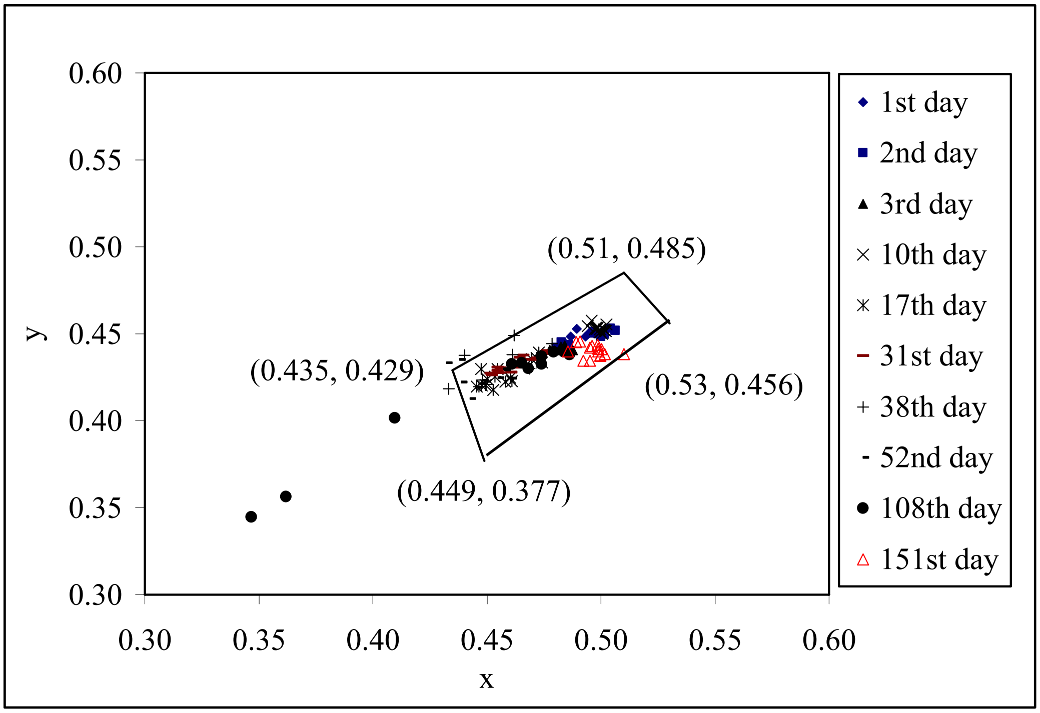

Figure 3-19. Change of Chromaticity over Time (Product: R, Color: Yellow, Glass Beads: Yes)

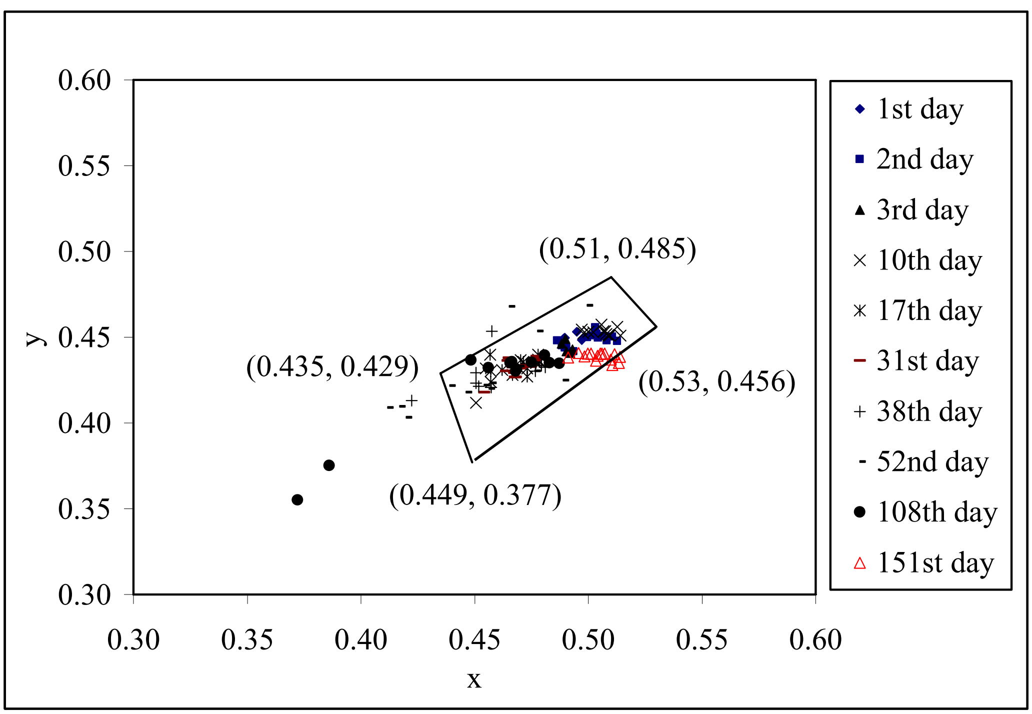

Figure 3-20. Change of Chromaticity over Time (Product: C, Color: Yellow, Glass Beads: Yes)

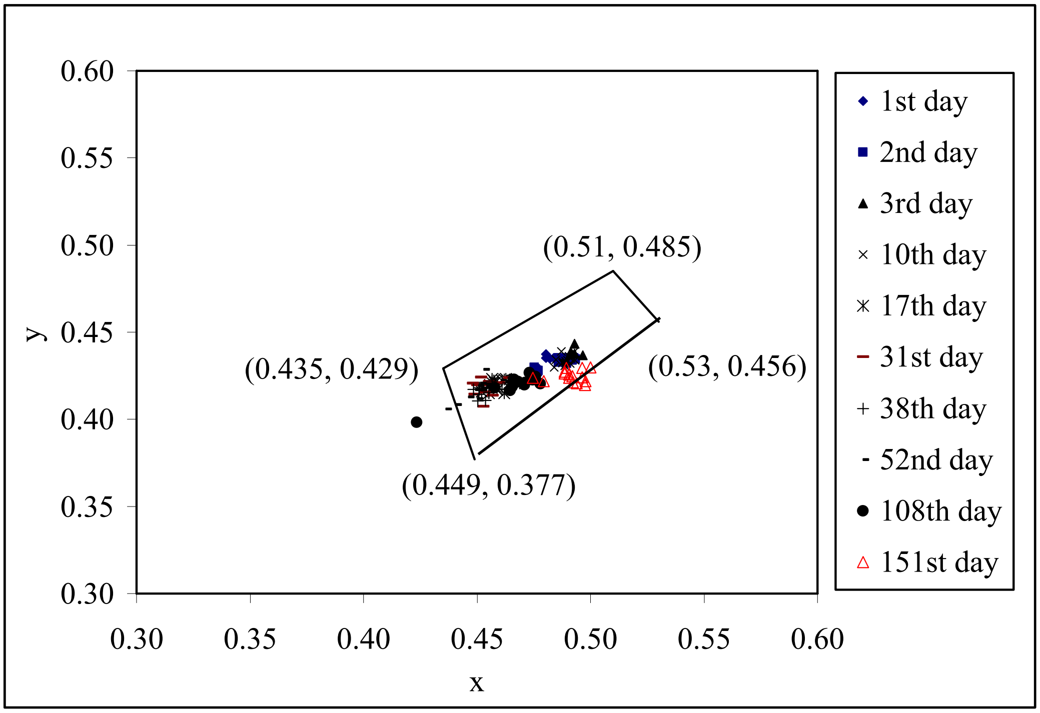

Figure 3-21. Change of Chromaticity over Time (Product: D, Color: Yellow, Glass Beads: Yes)

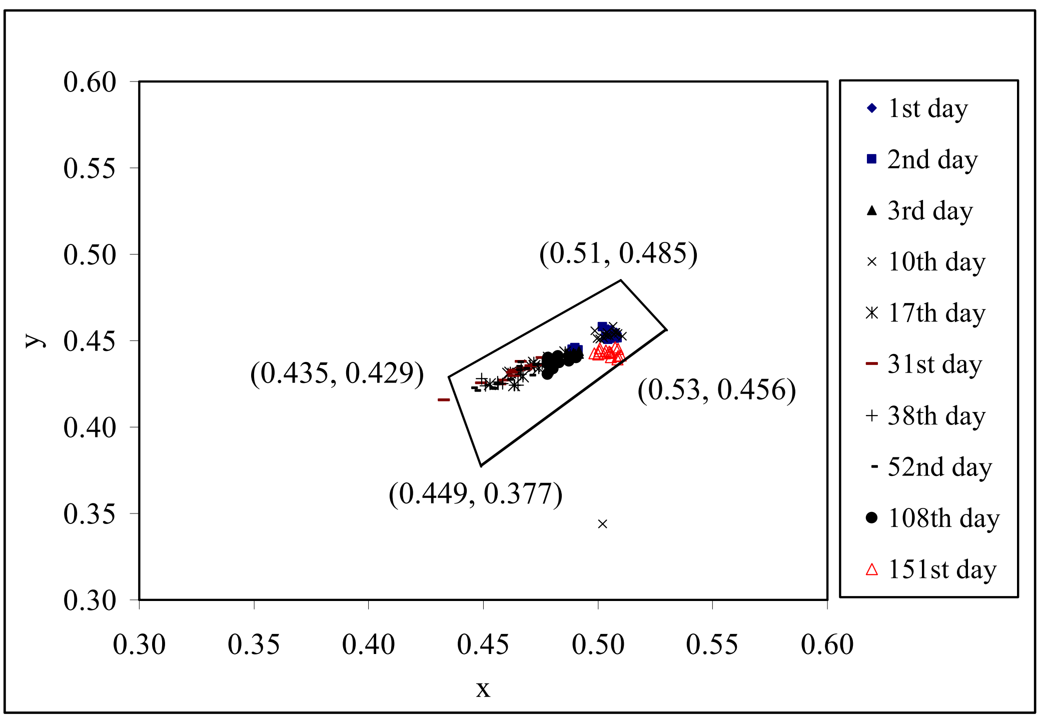

Figure 3-22. Change of Chromaticity over Time (Product: E, Color: Yellow, Glass Beads: Yes)

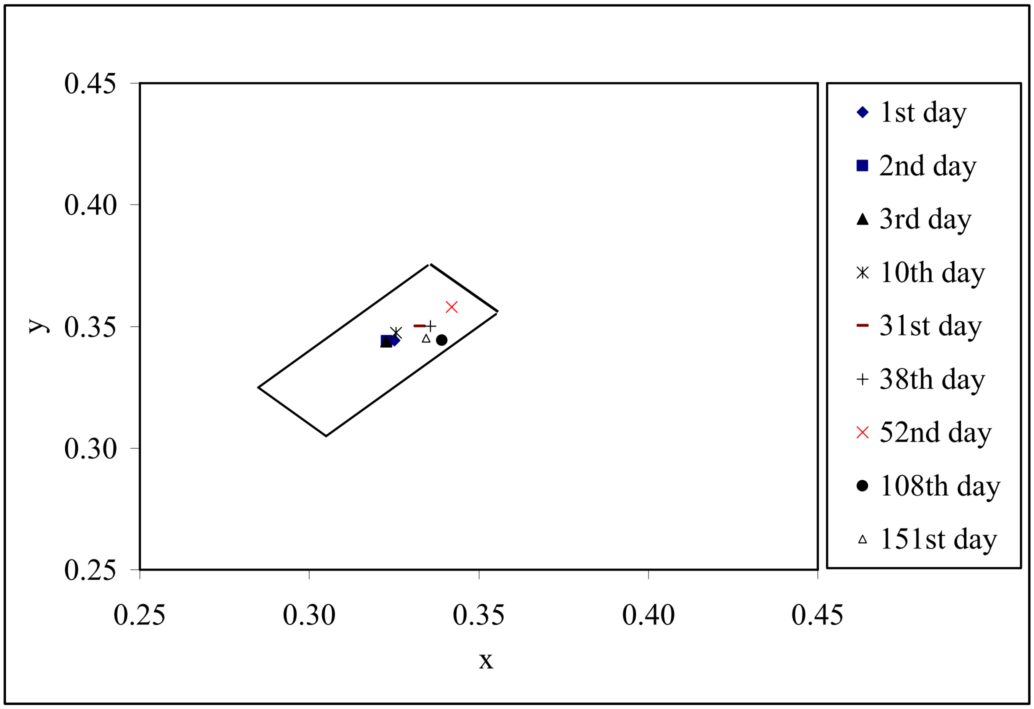

Figure 3-23. Change of Average Chromaticity over Time (Product: R, Color: White, Glass Beads: No)

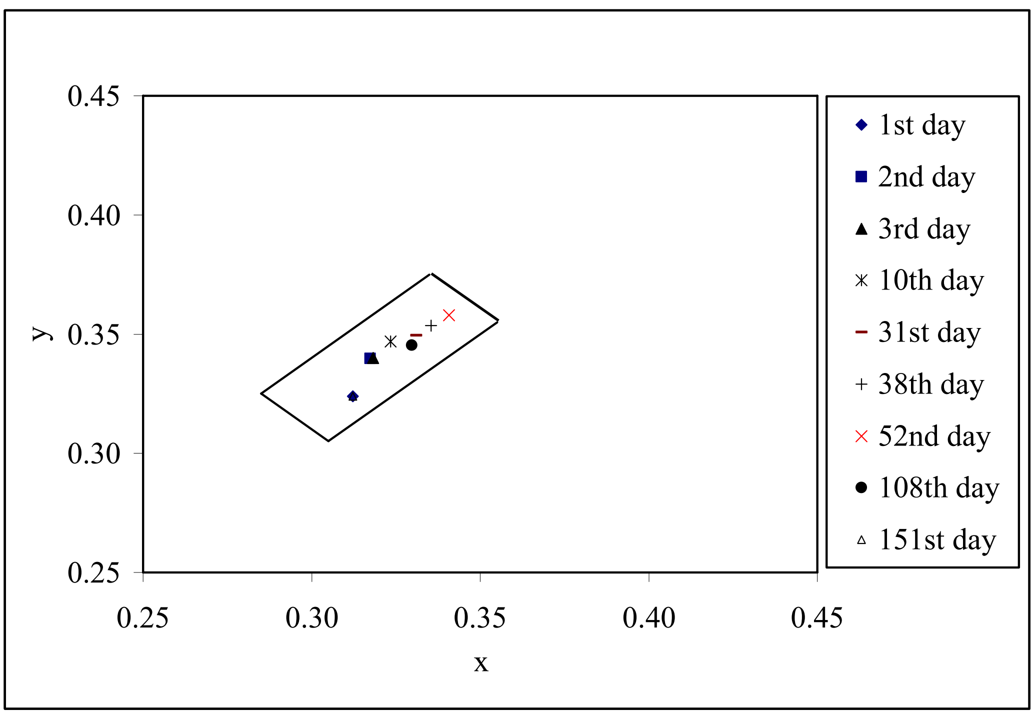

Figure 3-24. Change of Average Chromaticity over Time (Product: C, Color: White, Glass Beads: No)

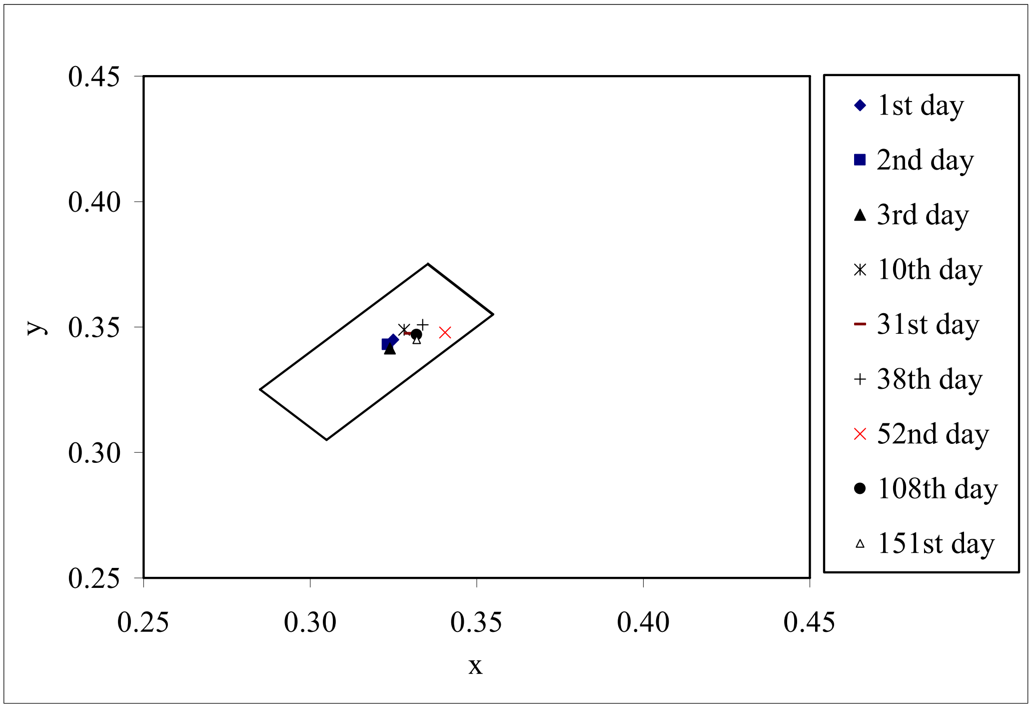

Figure 3-25. Change of Average Chromaticity over Time (Product: E, Color: White, Glass Beads: No)

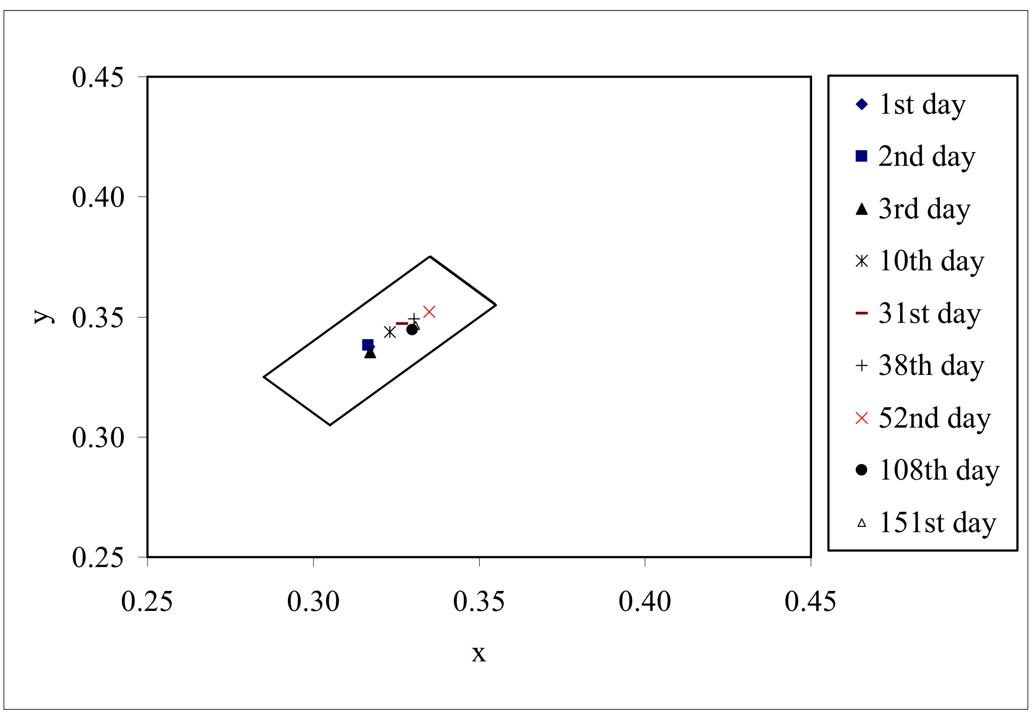

Figure 3-26. Change of Average Chromaticity over Time (Product: D, Color: White, Glass Beads: No)

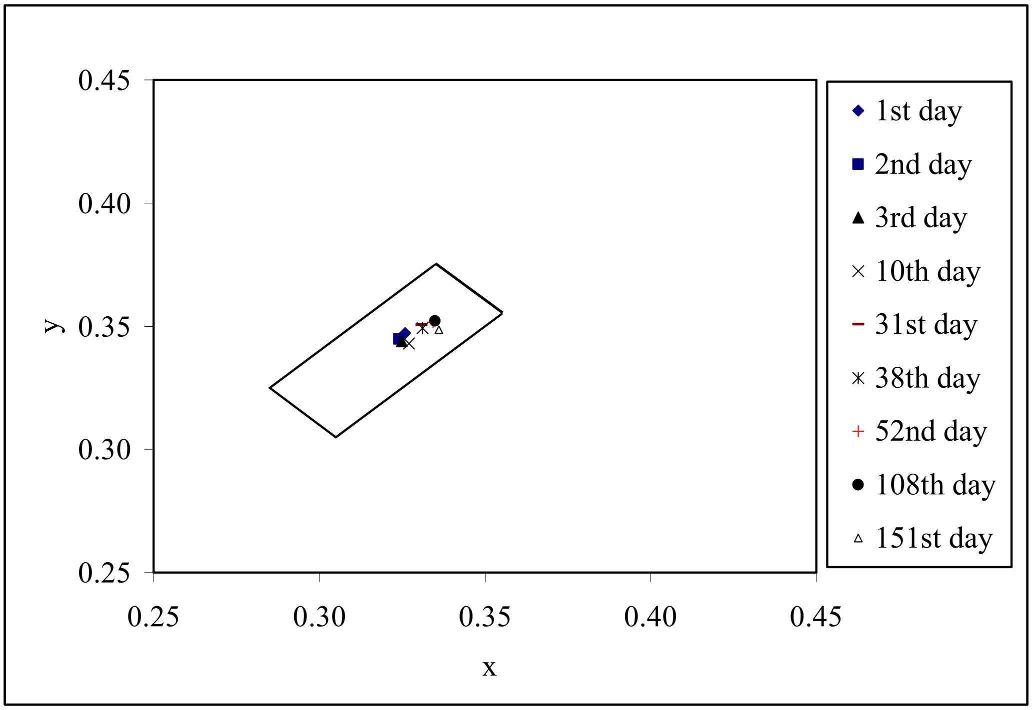

Figure 3-27. Change of Average Chromaticity over Time (Product: R, Color: White, Glass Beads: Yes)

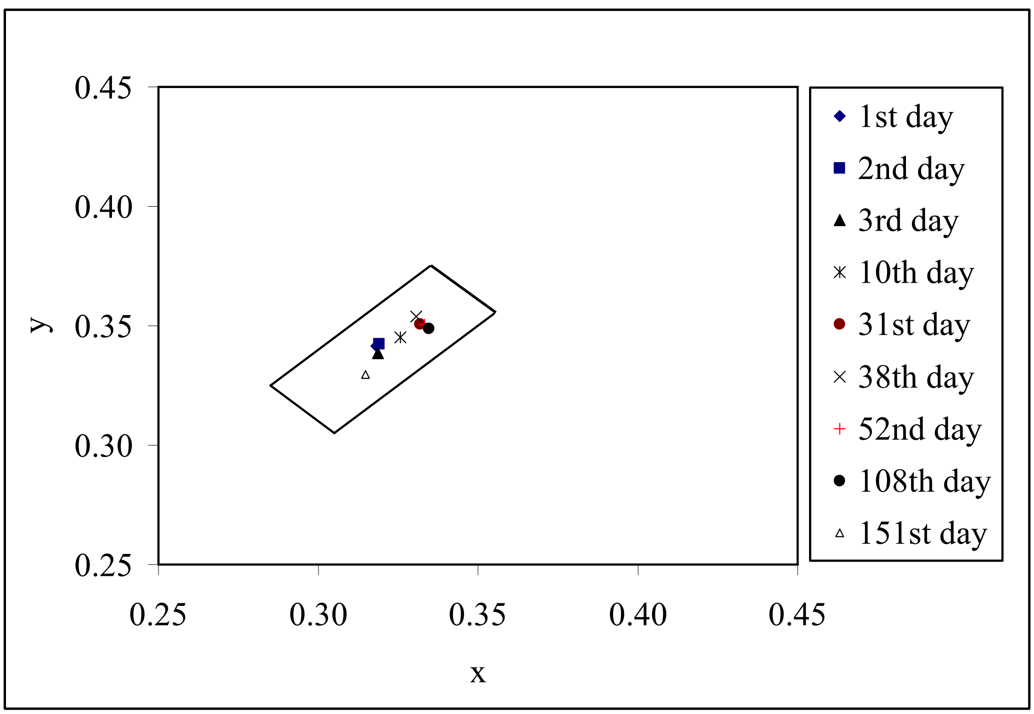

Figure 3-28. Change of Average Chromaticity over Time (Product: C, Color: White, Glass Beads: Yes)

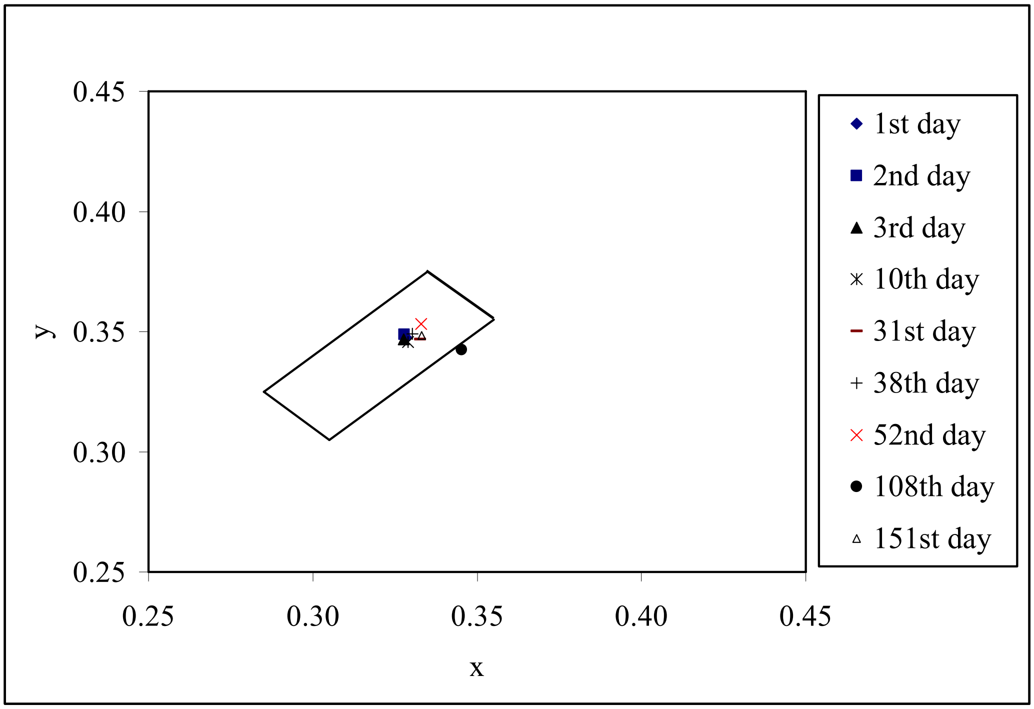

Figure 3-29. Change of Average Chromaticity over Time (Product: E, Color: White, Glass Beads: Yes)

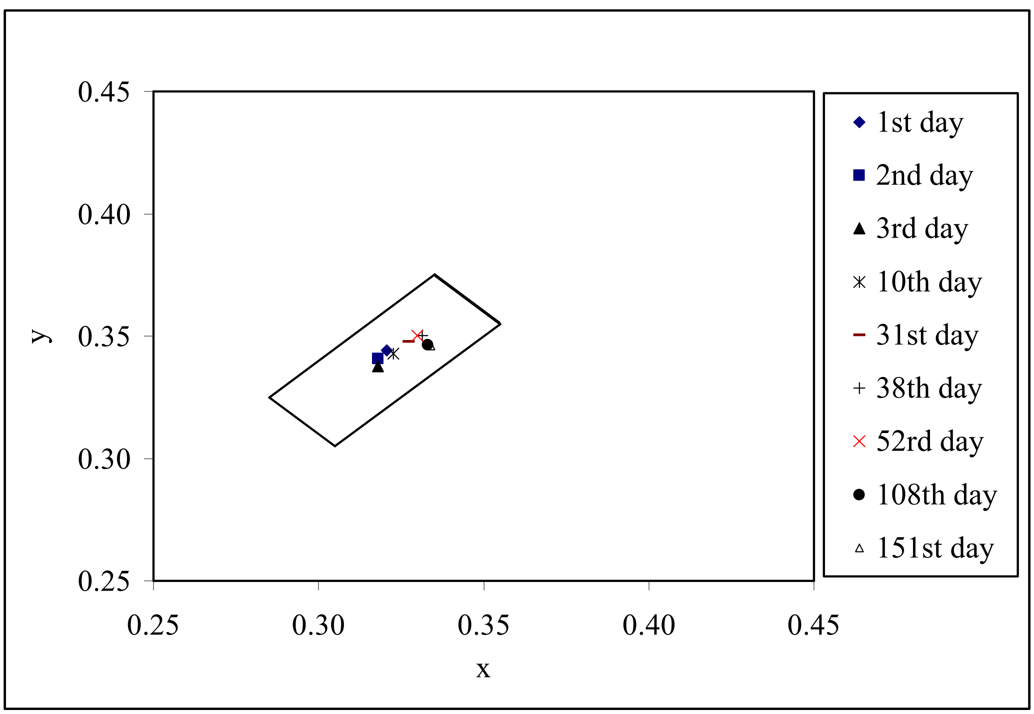

Figure 3-30. Change of Average Chromaticity over Time (Product: D, Color: White, Glass Beads: Yes)

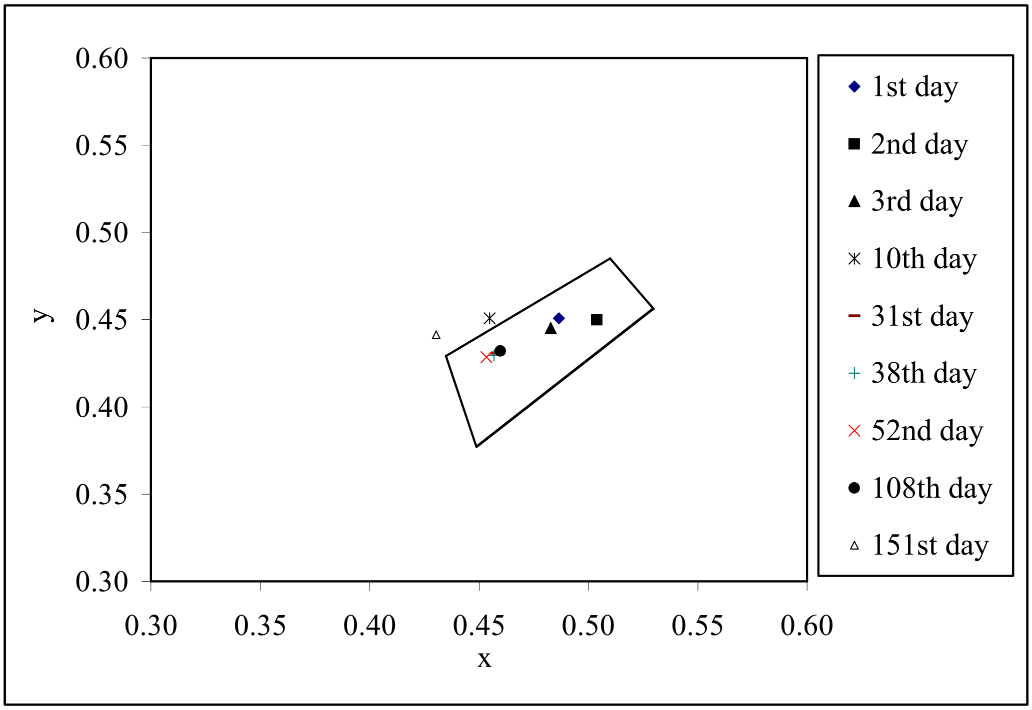

Figure 3-31. Change of Average Chromaticity over Time (Product: R, Color: Yellow, Glass Beads: No)

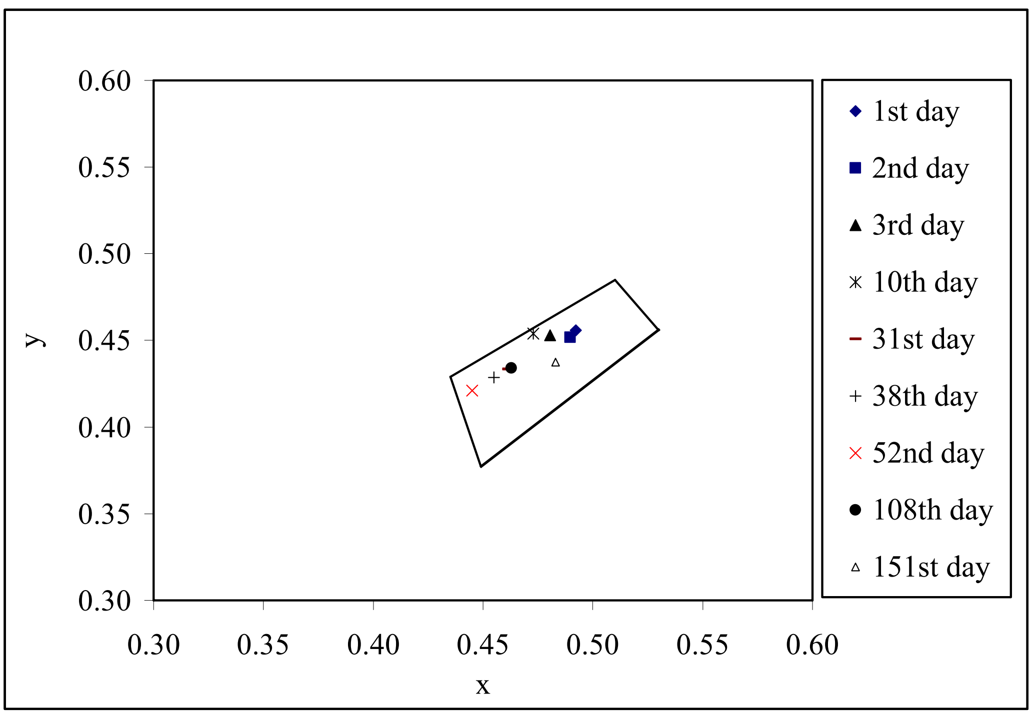

Figure 3-32. Change of Average Chromaticity over Time (Product: C, Color: Yellow, Glass Beads: No)

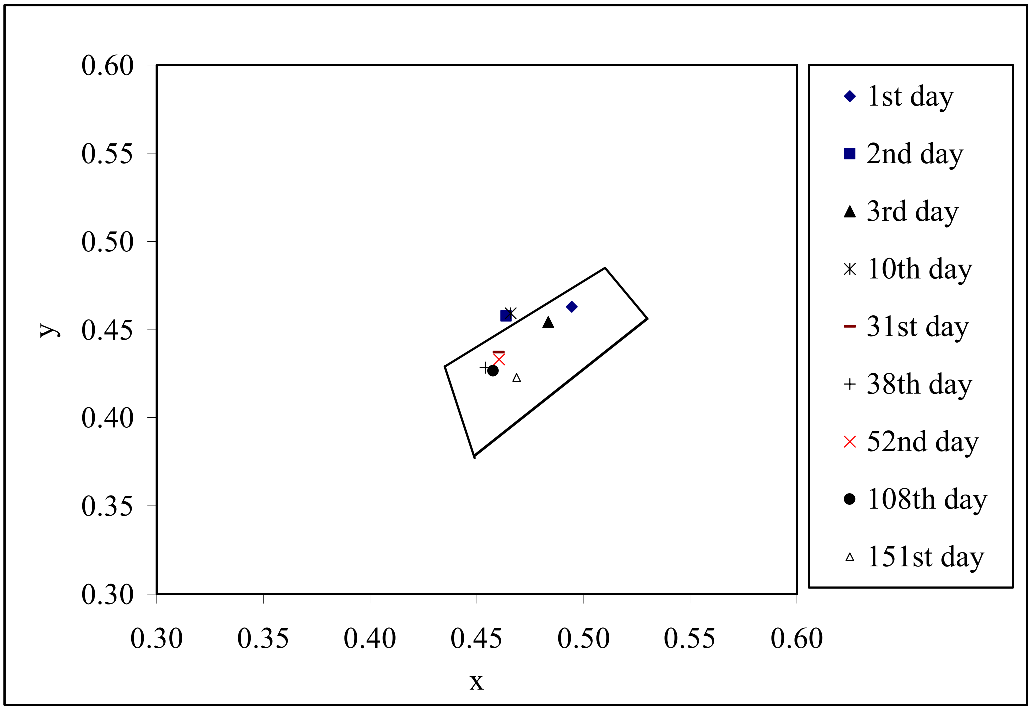

Figure 3-33. Change of Average Chromaticity over Time (Product: E, Color: Yellow, Glass Beads: No)

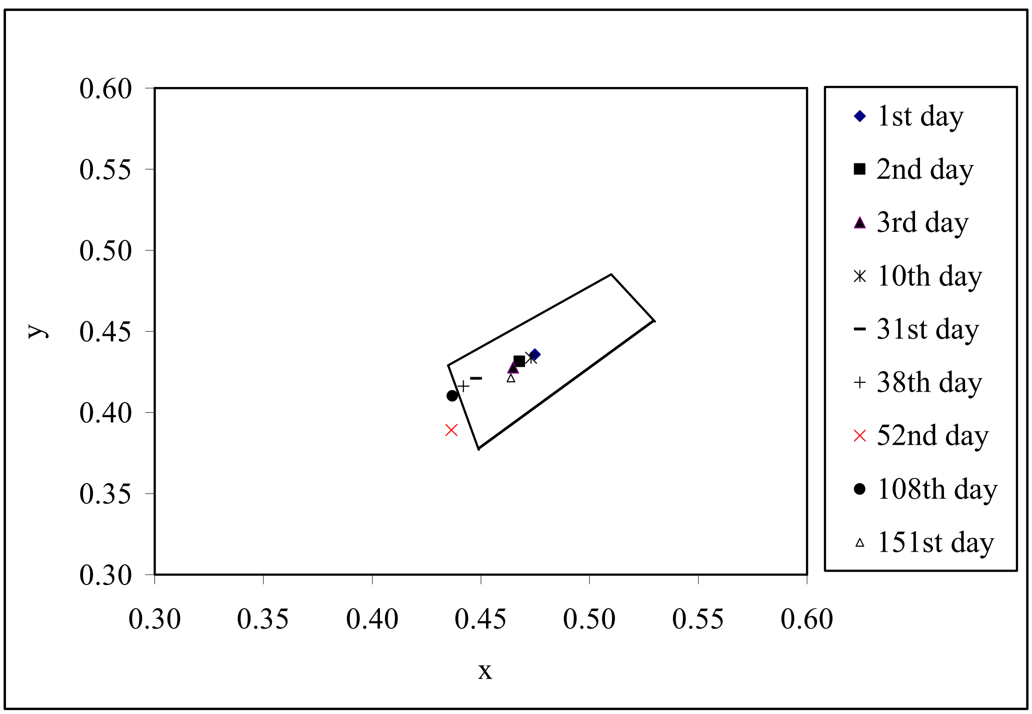

Figure 3-34. Change of Average Chromaticity over Time (Product: D, Color: Yellow, Glass Beads: No)

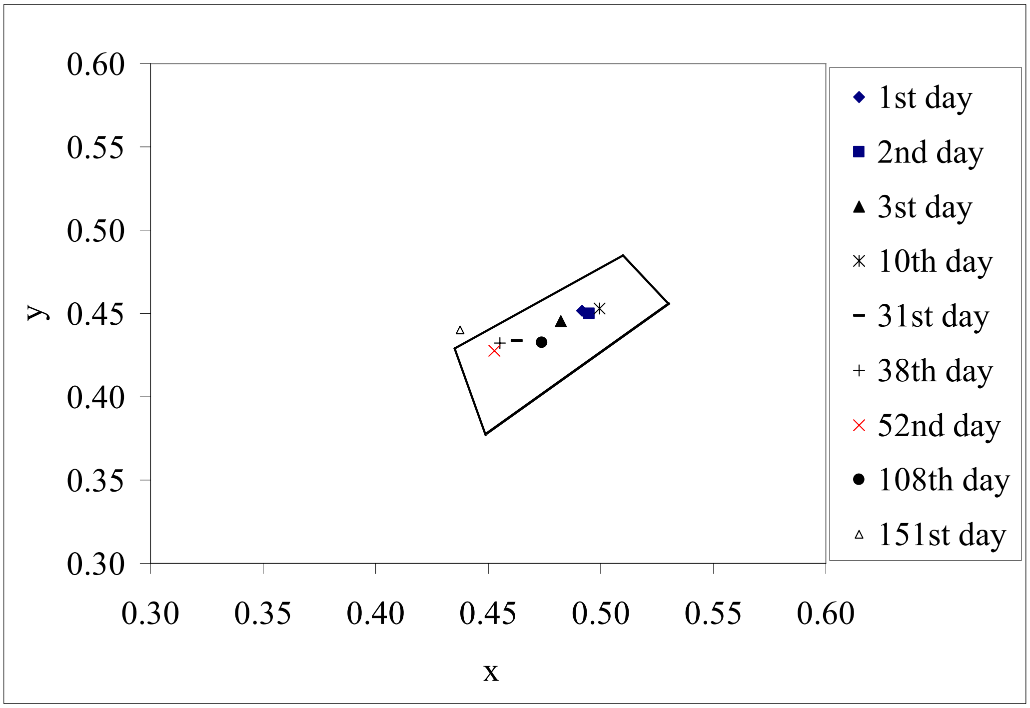

Figure 3-35. Change of Average Chromaticity over Time (Product: R, Color: Yellow, Glass Beads: Yes)

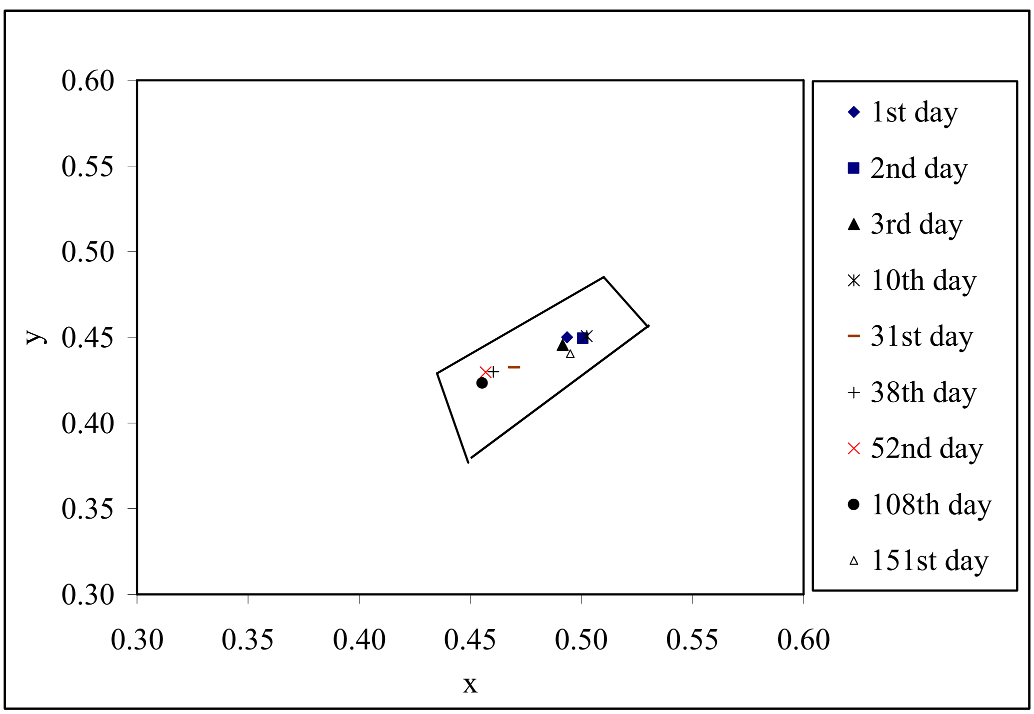

Figure 3-36. Change of Average Chromaticity over Time (Product: C, Color: Yellow, Glass Beads: Yes)

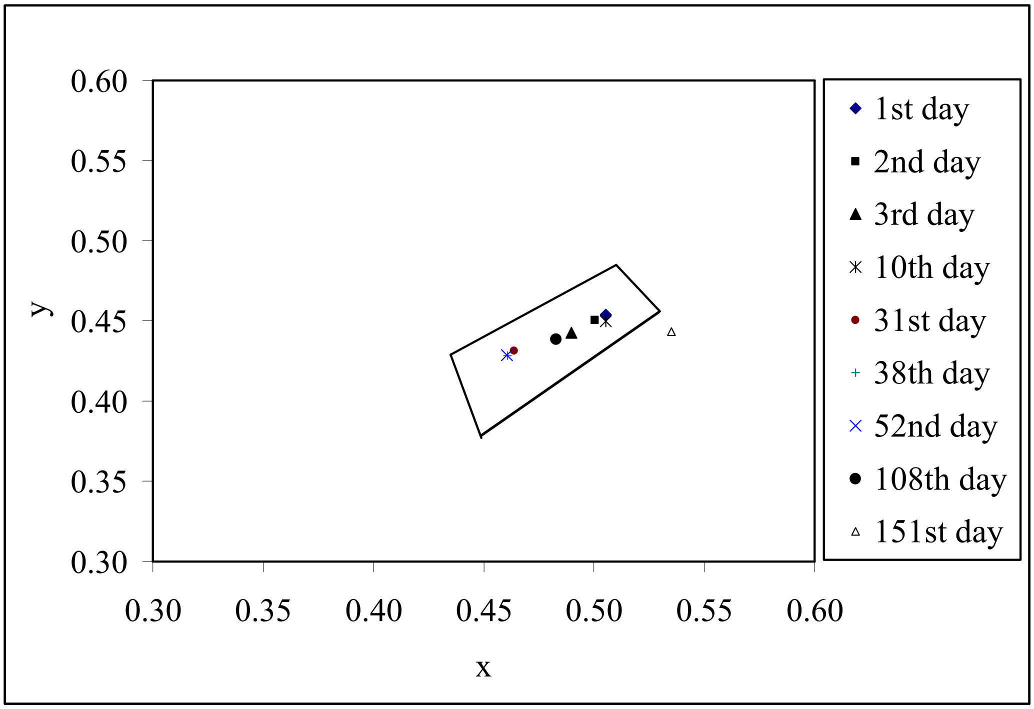

Figure 3-37. Change of Average Chromaticity over Time (Product: E, Color: Yellow, Glass Beads: Yes)

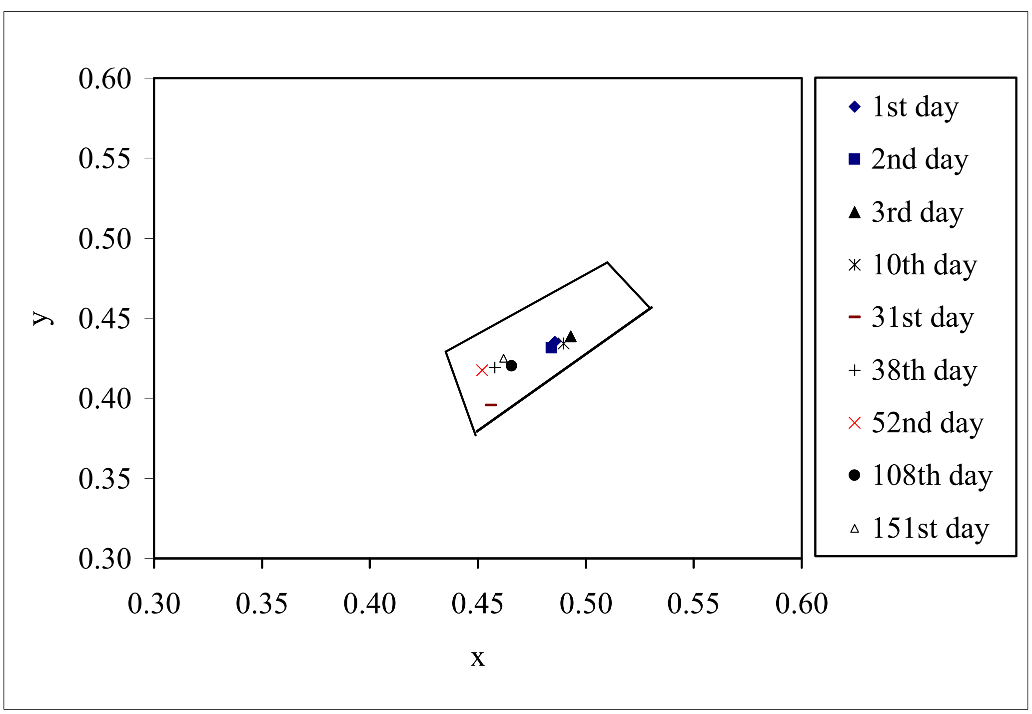

Figure 3-38. Change of Average Chromaticity over Time (Product: D, Color: Yellow, Glass Beads: Yes)

Table 3-9. Color Differences at Different Times during Study Period
(Color: Yellow, Glass Beads: No)

Products	# of Days	CIE 1931 and 1964 x	y	Y	CIE 1976 L* a* b* (CIELAB) L*	a*	b*	ΔE*	ΔE*94
R	1	0.49	0.45	45.76	73.39	17.86	77.59	0.00	0.00
	31	0.46	0.43	24.25	56.34	12.53	47.77	34.77	18.30
	108	0.46	0.43	24.01	56.10	12.49	47.61	35.03	18.54
	151	0.43	0.44	25.46	57.52	2.95	44.70	39.45	18.13
D	1	0.47	0.44	52.02	77.29	15.95	68.73	0.00	0.00
	31	0.45	0.42	41.06	70.22	15.14	50.91	19.19	8.41
	108	0.44	0.41	31.59	63.00	14.06	41.52	30.79	15.88
	151	0.46	0.42	35.42	66.07	17.12	50.92	21.09	12.26
C	1	0.49	0.46	44.43	72.51	14.77	81.82	0.00	0.00
	31	0.46	0.43	37.8	67.87	14.53	55.38	26.84	7.56
	108	0.46	0.43	32.84	64.03	13.86	52.85	30.20	10.66
	151	0.48	0.44	36.38	66.81	16.77	64.16	18.67	7.19
E	1	0.49	0.46	49.83	75.96	15.35	85.01	0.00	0.00
	31	0.46	0.44	38.38	68.30	11.72	59.13	27.23	9.36
	108	0.46	0.43	36.53	66.92	14.36	54.75	31.59	11.16
	151	0.47	0.42	40.16	69.58	20.63	55.79	30.37	10.05

Table 3-10. Color Differences at Different Times during Study Period
(Color: Yellow, Glass Beads: Yes)

Products	# of Days	CIE 1931 and 1964			CIE 1976 L* a* b* (CIELAB)				
		x	y	Y	L*	a*	b*	ΔE*	ΔE*94
R	1	0.49	0.45	40.36	69.73	17.13	74.41	0.00	0.00
	31	0.46	0.43	21.03	52.98	11.95	45.55	33.76	18.02
	108	0.42	0.39	22.61	54.67	12.95	28.66	48.35	18.70
	151	0.44	0.44	22.58	54.64	5.20	45.02	35.12	16.91
D	1	0.49	0.44	43.81	72.10	20.59	71.90	0.00	0.00
	31	0.46	0.40	28.93	60.72	21.68	41.67	32.32	14.20
	108	0.47	0.42	25.14	57.21	17.65	47.73	28.54	16.01
	151	0.46	0.42	22.82	54.89	14.78	43.98	33.31	18.45
C	1	0.49	0.45	41.88	70.79	17.34	75.33	0.00	0.00
	31	0.47	0.43	25.90	57.94	15.19	51.28	27.35	14.02
	108	0.46	0.42	24.93	57.01	15.22	45.29	33.12	15.52
	151	0.50	0.44	24.44	56.53	20.21	64.16	18.34	14.68
E	1	0.51	0.45	37.63	67.75	21.80	81.76	0.00	0.00
	31	0.46	0.43	22.64	54.70	12.25	46.68	38.62	15.08
	108	0.48	0.44	23.87	55.96	14.58	55.75	29.45	13.06
	151	0.50	0.44	23.43	55.51	19.93	63.27	22.25	12.90

Table 3-11. Color Differences at Different Times during Study Period
(Color: White, Glass Beads: No)

Products	# of Days	CIE 1931 and 1964			CIE 1976 L* a* b* (CIELAB)				
		x	y	Y	L*	a*	b*	ΔE*	ΔE*94
R	1	0.33	0.34	69.46	86.73	3.10	6.67	0.00	0.00
	31	0.33	0.35	57.39	80.40	-1.12	9.41	8.09	7.71
	108	0.33	0.35	48.06	74.86	-1.05	8.87	12.76	12.58
	151	0.33	0.35	49.18	75.56	-1.06	8.94	12.13	11.93
D	1	0.32	0.34	69.32	86.66	-1.45	4.96	0.00	0.00
	31	0.33	0.35	57.61	80.52	-1.12	9.42	7.60	7.15
	108	0.33	0.34	52.92	77.83	2.83	6.09	9.88	9.72
	151	0.33	0.35	53.18	77.98	-1.09	9.18	9.66	9.35
C	1	0.32	0.34	68.43	86.22	-1.45	4.94	0.00	0.00
	31	0.33	0.35	59.39	81.51	-1.13	9.52	6.58	6.03
	108	0.33	0.35	45.21	73.03	-1.03	8.69	13.72	13.55
	151	0.33	0.35	51.42	76.93	-1.08	9.07	10.17	9.89
E	1	0.32	0.34	69.13	86.57	-1.45	4.96	0.00	0.00
	31	0.33	0.35	56.83	80.08	-1.11	9.38	7.86	7.44
	108	0.33	0.35	54.48	78.74	-1.10	9.25	8.94	8.59
	151	0.33	0.35	51.29	76.85	-1.08	9.07	10.55	10.29

Table 3-12. Color Differences at Different Times during Study Period
(Color: White, Glass Beads: Yes)

		CIE 1931 and 1964			CIE 1976 L* a* b* (CIELAB)				
Products	# of Days	x	y	Y	L*	a*	b*	ΔE*	ΔE*94
R	1	0.33	0.35	60.24	81.97	-1.13	9.56	0.00	0.00
	31	0.33	0.35	38.13	68.12	-0.97	8.21	13.92	13.88
	108	0.33	0.35	33.86	64.85	-0.94	7.89	17.20	17.16
	151	0.34	0.35	29.42	61.15	2.42	8.85	21.13	21.06
D	1	0.32	0.34	58.99	81.29	-1.38	4.70	0.00	0.00
	31	0.33	0.35	28.91	60.70	-0.89	7.49	20.78	20.72
	108	0.33	0.35	34.44	65.31	-0.94	7.94	16.31	16.21
	151	0.33	0.35	34.00	64.96	-0.94	7.90	16.64	16.54
C	1	0.32	0.34	61.15	82.46	-1.39	4.76	0.00	0.00
	31	0.33	0.35	35.83	66.39	-0.95	8.04	16.41	16.30
	108	0.33	0.35	33.74	64.76	-0.94	7.88	17.98	17.90
	151	0.34	0.35	32.01	63.35	2.49	9.11	19.98	19.76
E	1	0.33	0.35	66.50	85.25	-1.17	9.88	0.00	0.00
	31	0.33	0.35	26.32	58.34	-0.86	7.26	27.04	0.00
	108	0.35	0.34	37.30	67.50	9.70	8.28	20.88	20.11
	151	0.33	0.35	38.74	68.56	-0.98	8.26	16.77	16.73

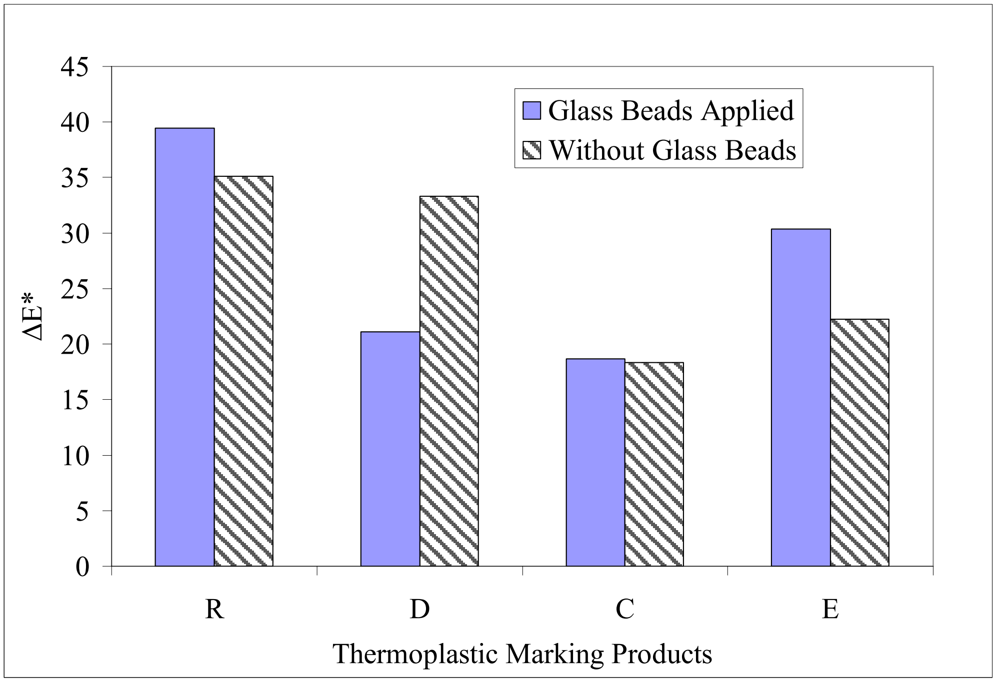

Figure 3-39. ΔE* Values for Yellow Markings (151st day)

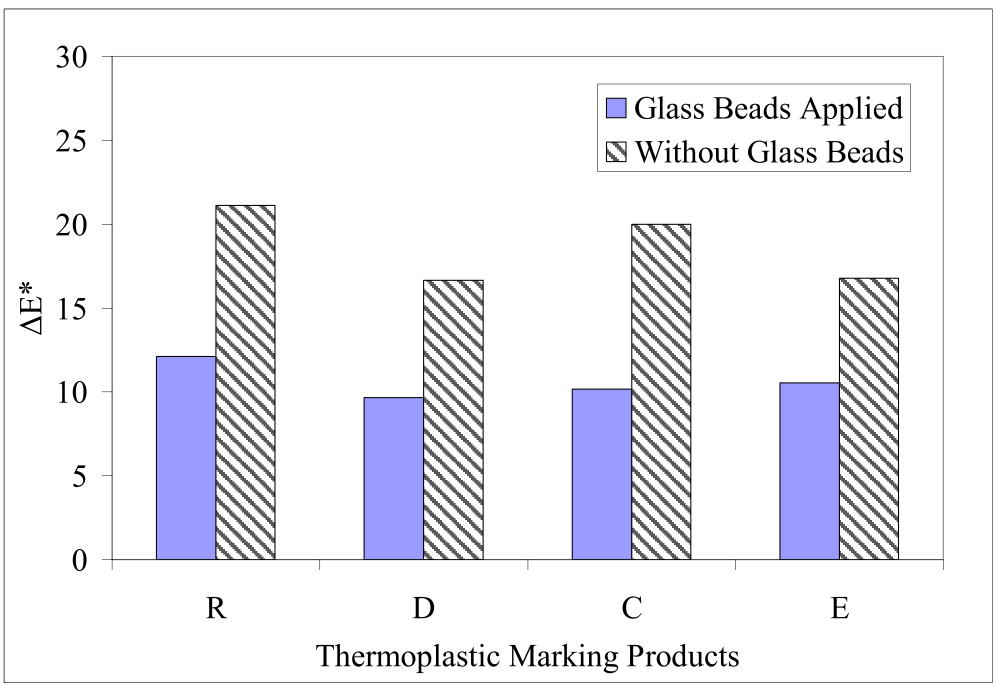

Figure 3-40. ΔE* Values for White Markings (151st day)

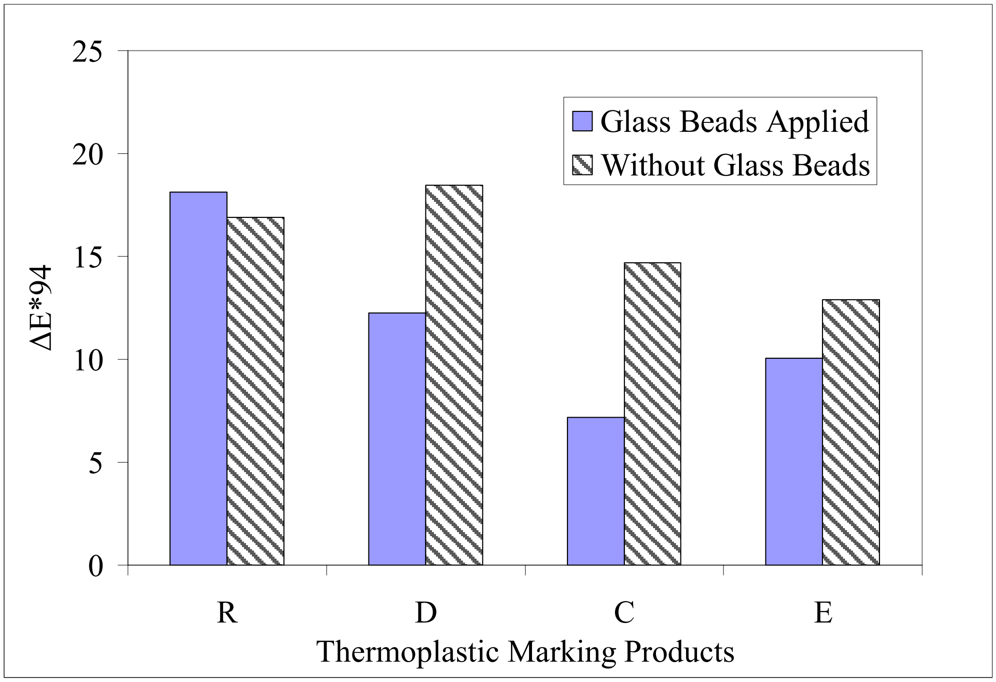

Figure 3-41. ΔE^*_{94} Values for Yellow Markings (151st day)

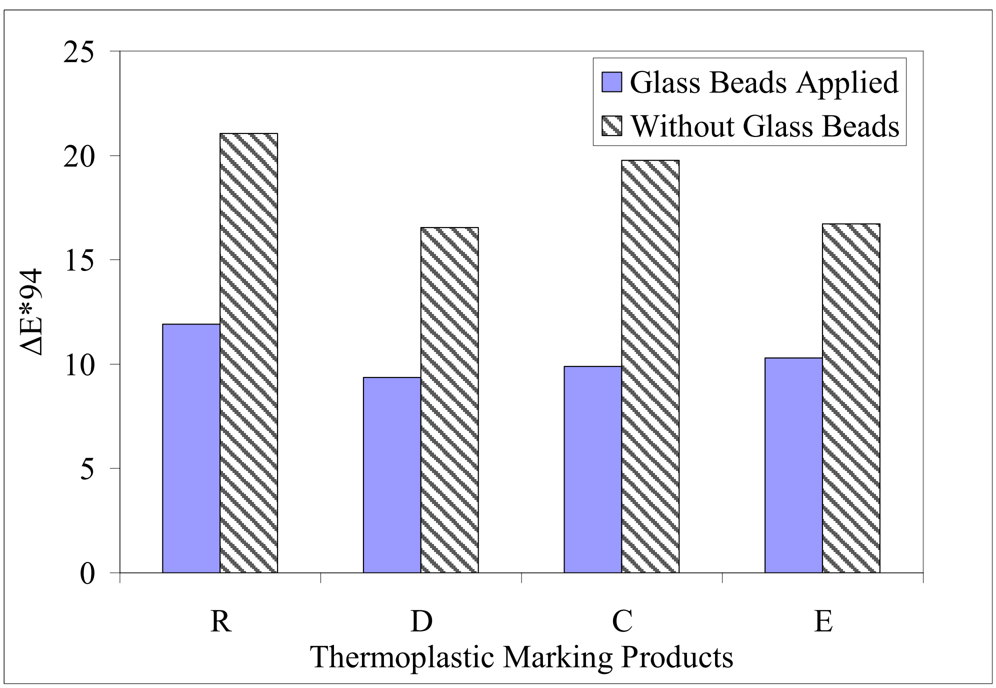

Figure 3-42. ΔE^*_{94} Values for White Markings (151st day)

4 SUMMARY AND CONCLUSIONS

4.1 Summary

Thermoplastic material is a durable traffic marking material which has been widely used in the State of Florida. To install thermoplastic markings on newly constructed pavement, the roadway needs to be closed and traffic has to be stopped. This would cause significant delay to traveling public. Recently, a new type of thermoplastic material called “no track” thermoplastic has been introduced in practical applications. The main benefit of a no track thermoplastic marking is that it can be placed on a fresh asphalt surface. Thus, the roadway can be opened to traffic with a minimum wait time as compared to traditional thermoplastic markings.

Recent practices have indicated a problem associated with some so called no track thermoplastic markings. The problem is that with new asphalt being placed into service, bitumen tracks onto the thermoplastic markings. Thus, during the final asphalt cure time, the markings become discolored with the asphalt materials, resulting in discoloration and reduced retroreflectivity performance. In order to be a no track thermoplastic marking, the marking is supposed to provide resistance to tracking of asphaltic materials onto the marking. Similar to other traffic marking materials, a no track thermoplastic marking should also meet the initial requirements, including shape, adhesion, color, and reflectance for a certain time period as specified by the Florida Department of Transportation.

The main objectives of the research are (1) to search and review existing practices for installing and evaluating no track thermoplastic markings; (2) to develop a test method/procedure to determine whether a thermoplastic marking is a no track marking; and (3) to run field tests and experiments to obtain the performance data (such as reflectivity and color performance) through real applications of no track thermoplastic markings.

To achieve the research objective, real thermoplastic installation projects were arranged and test equipment/instruments were used onsite to measure the performance of industry proclaimed and marketed no track thermoplastic markings. The field tests started on March 26th, 2007 and lasted five months. The last field visit was made on August 23rd, 2007. Four thermoplastic marking materials were selected for the field tests, including three proclaimed no track thermoplastic markings and one regular thermoplastic marking. For convenience, the three no track thermoplastic marking products were named as product C, D, and E, respectively, and the regular thermoplastic marking was named as product R. Factors considered in field tests include color of traffic markings and the use of glass beads. It total, sixteen transverse lines were installed at the test section for the field tests, including four yellow lines with glass beads applied on the surfaces of traffic markings, four yellow lines without glass beads, four white lines with glass beads applied and four white lines without glass beads.

The research team randomly selected 15 points from each transverse line and measured both initial and in service performance data for the applied thermoplastic markings. Retroreflectivity was measured using a MX-30 handheld retroreflectometer. Color was measured using a BYK Gardner Handy colorimeter. When measuring retroreflectivity, procedures provided by the ASTM standard E 1710 were followed. The color measurements followed the test methods provided by the ASTM standard E 1347. Pictures were also taken in the field to illustrate the change of appearance of traffic markings over time. Data measurements were taken during clear daylight hours and were not collected when the pavement was wet. In total, the research team conducted nine field visits to collect performance data, and took 1463 retroreflectivity measurements and 2230 color measurements at the test section.

The appearance of traffic markings by visual inspection in the field showed that the selected no track thermoplastic markings were not completely resistant to the wheel tracking of asphalt on to the traffic marking surfaces. In fact, with visual inspection one could not distinguish between no track and regular thermoplastic markings.

The mean initial retroreflectance for selected thermoplastic markings varies from 189 to 255 mcd/lx·m^2 for yellow traffic markings, and from 330 to 440 mcd/lx·m^2 for white traffic markings. For yellow traffic markings, only product C and product D meet the FDOT requirements for initial retroreflectance. Products R and E did not meet the initial requirements. For white markings, all selected thermoplastic marking products successfully meet the initial requirements for retroreflectance.

Based on the collected retroreflectivity data, degradation curves were developed to illustrate the change of retroreflectivity over time. The curves show that the retroreflectances of traffic markings increase with time and reach the maximum values after the markings have been installed on the road for three days. After three days, the retroreflectances of selected thermoplastic traffic markings reach a relatively steady state. The mean initial retroreflectance for selected thermoplastic markings varies from 189 to 255 mcd/lx·m^2 for yellow traffic markings, and from 330 to 440 mcd/lx·m^2 for white traffic markings. For yellow traffic markings, only product C and product D meet the FDOT requirements about initial retroreflectance. Products R and E were not found to meet the requirements. For white markings, all selected thermoplastic marking products successfully meet the requirements about initial retroreflectance.

The retroreflectivity degradation curves were used to compare the no track and regular thermoplastic markings. For yellow traffic markings, the selected no track thermoplastic markings were found to be superior to the selected regular thermoplastic marking in terms of the higher in-service retroreflectivity. For white traffic markings, even though the selected no track thermoplastic markings meet the FDOT initial and in-service requirements for retroreflectance of white traffic markings, they do not provide better retroreflectivity as compared to the selected regular thermoplastic marking.

Color measurements were represented on the CIE 1931 chromaticity diagram to check if the in-service color is outside the chromaticity limits established by the FDOT, and to illustrate the discoloration of traffic markings over time. It was found that most of the color measurements fall within the box created by the coordinates provided by the FDOT. The data points fall outside of the box represent the points on traffic markings that are badly stained by wheel tracking of asphalts. By looking at these figures, however, it is difficult to identify the pattern of discoloration over time and to quantify the color differences between initial and in-service traffic markings.

In this study, two parameters were used to quantify the discoloration of traffic markings during the asphalt curing time and to compare the discoloration of no track thermoplastic markings to that of the regular thermoplastic marking. These two parameters include the ΔE^* value which is calculated based on the L*, a*, b* values from the CIELAB color space, and CIE94 color tolerance ΔE^*_{94}. It was found that both ΔE^* and ΔE^*_{94} values increase with the time, indicating the fact that these two parameters can be used to quantify the discoloration of traffic markings over time. The selected no track thermoplastic marking materials are found to be more resistant to the tracking of asphalt as compared to the regular thermoplastic marking material in terms of the lower ΔE^* and ΔE^*_{94} values. The data also show that the assumption about the impacts of glass beads is not true. Traffic markings with glass beads dropped on the surfaces were not found to be more resistant to the tracking of asphalt. In fact, for most of the test lines, traffic markings with glass beads dropped on the surfaces have larger ΔE^* and ΔE^*_{94} values as compared to those without glass beads.

4.2 Conclusions

Based on the data analysis results, the following conclusions are made:

1. The selected no track thermoplastic traffic marking materials are not completely resistant to wheel tracking of asphalt. Visual inspection of the appearance of traffic markings in the field cannot distinguish between no track and regular thermoplastic markings.

2. For yellow traffic markings, the selected no track thermoplastic markings were found to be superior to the selected regular thermoplastic marking in terms of the higher in-service retroreflectivity. For white traffic markings, even though the selected no track thermoplastic markings meet the FDOT initial and in-service requirements for the retroreflectance of white traffic markings, they do not provide better retroreflectivity as compared to the selected regular thermoplastic marking.

3. It is difficult to use CIE color coordinates (x, y) to identify if a thermoplastic marking is a no track marking. By plotting color measurements at different times during the

study period on the CIE 1931 chromaticity diagram, it is difficult to identify the pattern of discoloration over time and to quantify the color differences between initial and in-service traffic markings.

4. The CIELAB ΔE^* value which is calculated based on the L*, a*, b* values from the CIELAB color space, and the CIE94 color tolerance ΔE^*_{94} can be used to quantify the discoloration of traffic markings during the asphalt curing time and to compare the discoloration of no track thermoplastic markings to that of the regular thermoplastic marking. The selected no track thermoplastic marking materials are more resistant to the tracking of asphalt as compared to the regular thermoplastic marking material in terms of the lower ΔE^* and ΔE^*_{94} values.

5. Traffic markings with glass beads dropped on the surfaces were not found to be more resistant to the tracking of asphalt. In fact, for most of the test lines, traffic markings with glass beads dropped on the surfaces have larger ΔE^* and ΔE^*_{94} values as compared to those without glass beads.

This study developed a test method and conducted field tests to measure the performance of three industry proclaimed no track thermoplastic markings and one regular thermoplastic marking. It was found that the best parameter that can be used to identify if a particular thermoplastic marking is a no track marking is the color differences between the newly installed marking and the marking that has been opened to traffic for a certain period of time. The difference between initial and in-service color can be quantified by using either the CIELAB ΔE^* value or the CIE94 color tolerance ΔE^*_{94}. It was found that the selected no track thermoplastic marking materials have lower ΔE^* and ΔE^*_{94} values as compared to the regular thermoplastic marking, implying that the selected no track thermoplastic markings are more resistant to the tracking of bitumen as compared to the ordinary thermoplastic striping.

The study provided some quantified results about the change of retroreflectivity and color over time for both no track and regular thermoplastic marking materials. The quantified results can help the FDOT develop technical specifications for the use of no track thermoplastic marking materials. The limitation of this study is that the test lines are transverse lines installed in an exclusive right-turn lane where heavy vehicles will pass over the test lines. The research team was not able to test the performance of longitudinal lines such as edge lines and lane lines. In addition, the study period of the field tests is five months. From the authors' stand point, the study period is still relatively short, and the optimum study period shall be greater than one year. The authors suggest that a larger scale study should be conducted in the future to test more products with a longer study period.

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