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Colored Pavement for Bicycle Facilities in Oklahoma

Class Three Bike Route

Class One Bike Path

Class Two Bike Lane

Oklahoma Department of Transportation
200 N.E. 21st Street
Oklahoma City, OK 73105

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EXECUTIVE SUMMARY

The mission of the Oklahoma Department of Transportation (ODOT) is to provide a safe, economical and effective transportation network for the people, commerce and communities of Oklahoma. That commitment extends to pedestrians and bicyclists.[1]

At this time, ODOT's long-range transportation plan mentions 989 lane miles of signed bicycle facilities. Within the past decade, a recent development for bicycle facilities to increase bicyclist safety has been the use of green colored pavement.

Beginning in 2011, the FHWA granted interim approval to numerous state and local governmental agencies for experimenting with green (chromatic or saturated) colored pavement for bicycle lanes as a traffic control device.[2] Colored pavement for bike lanes serve to increase visibility for users of the preferential lane and to indicate the purpose of the dedicated lane for all users sharing the roadway.

Since the FHWA term "colored pavement" refers to a wide range of materials, this report divides the term into pavement coatings recognized by the National Association of City Transportation Officials (NACTO), recent developments in the United States, and materials for pigmented pavement used in Europe.

In their Urban Bikeway Design Guide (published March 2014), the NACTO charts the advantages and disadvantages of using pavement coatings. Several examples of pavement coatings include paint, epoxy mixes, and thermoplastic for constructing bicycle lanes on city streets.

Compared to pavement coatings recognized by the NACTO, more recent developments in the United States include Polymer Cement Slurry Surfacing (PCSS) and Colorized Lane Demarcation (CLD). Pigmented pavement used in Europe refers to any asphalt or concrete with pigment added to the mixture.

At ODOT, the mission of the Materials Division is to "provide quality sampling, testing, analysis and inspection programs for the transportation industry, in order to ensure that highway materials meet quality and performance standards."[3]

L. S. Koetsier, M.Sc., coordinator for the Technology Transfer and Technical Writing Program with ODOT, obtained material samples from Europe, synthesized sources of research, and wrote the report. This synthesis explores materials available in the United States to install colored pavements and in Europe to create pigmented pavement.

Research and document requested by Scott Seiter, P.E., Materials Division Engineer, with the Oklahoma Department of Transportation.

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1.0 INTRODUCTION

For over 60 years, transportation agencies throughout the United States have focused on developing efficient transportation for automobiles. Since then, Americans drive automobiles nearly everywhere, resulting in less physical activity with rising rates of obesity and chronic diseases.[4]

Urban planners who recognize these issues are implementing principles of sustainable design to increase active transportation.[5] In numerous cities, transportation officials are researching methods for increasing active transportation.

Active transportation refers to any form of human-powered transportation….such as walking to the bus stop, bicycling to school, or even to work.[6] Offering opportunities for active transportation (in order to increase the number of bicyclists within a given population) means constructing safe and convenient bicycle facilities.

The Federal Highway Administration (FHWA) defines bicycle facilities as "improvements and reasonable amenities and provisions to accommodate, enhance, or encourage bicycling, including but not limited to bicycle lanes and paths, traffic control devices, parking, storage facilities, and bicycle sharing systems."[7]

Federal legislation requires every urbanized area over 50,000 people to have a Metropolitan Planning Organization (MPO). MPOs ensure a comprehensive planning process that considers all surface modes of transportation.[8] In Oklahoma City, transportation officials are considering the needs of drivers, bicyclists and pedestrians in a rapidly evolving urban center.[9]

We're starting a master plan on pedestrian and bike route . . . [so] we can get pedestrians and bikes through downtown.

We have to look at the whole network. Planning is no longer about just cars.

City Planning Director
Aubrey Hammontree

Photo credited to L.S. Koetsier

Figure 1. Dark gray colored pavement used for bike lane in downtown Oklahoma City

The National Association of City Transportation Officials (NACTO) reports that in the United States, methods for coloring bicycle facilities are evolving rapidly. These methods involve material selection, application techniques, and the impact of climatic factors. The NACTO published their Urban Bikeway Design Guide in 2014 to provide this information to state agencies.[10]

Nationwide, transportation officials are recognizing that designing bicycle facilities for active transportation requires more research.[11] Considering safety issues for bicyclists means improving design, including the use of colored pavement for bicycle facilities.

At the Oklahoma Department of Transportation (ODOT), the mission of the Materials Division is to "provide quality sampling, testing, analysis and inspection programs for the transportation industry, in order to ensure that highway materials meet quality and performance standards."[12] This mission includes obtaining more information, guidance and better specifications for colors and for testing materials. This synthesis explores materials available in the United States to create colored pavements and materials obtained from Europe to create pigmented pavement.

2.0 MOVING TRANSPORTATION FORWARD

Before 2000, the FHWA addressed bicycle advocates to assist with planning bicycle facilities at the state and local levels. Since then, transportation officials within state and local agencies have recognized the need for active transportation. Many believe that encouraging public use of bicycles may eventually lead to reduced traffic congestion.[13] Others are interested in exploring the positive effects between active transportation and public health for area citizens.[14]

> **In cities and suburbs, traffic congestion and rising fuel prices are influencing commuters to consider bicycling as an alternative means to access the workplace, a healthier mode of transportation, and a new way to utilize connections to transit modes.**
>
> **U.S. Department of Transportation and FHWA**

In 2004, the National Complete Streets Coalition developed the concept of Complete Streets. A well-designed complete street serves everyone who uses the road, balancing safety and convenience for everyone, including people who cannot drive.[15] As of December 2015, the Florida Department of Transportation has published a guide to complete streets.

For future transportation networks, Complete Streets seeks to "integrate people and place in the planning, design, construction, operation, and maintenance of our transportation networks."[16]

The mission of the Oklahoma Department of Transportation is to provide a safe, economical and effective transportation network for the people, commerce and communities of Oklahoma. That commitment extends to pedestrians and bicyclists.[17] At this time, ODOT's long-range transportation plan mentions 989 lane miles of signed bicycle facilities.[18]

3.0 COLORED PAVEMENT FOR BIKE LANES

In their Policy Memorandum "Interim Approval for Optional use of Green Colored Pavement for Bike Lanes (1A-14)," the Federal Highway Administration (FHWA) defines colored pavement as "colored asphalt or concrete, or paint or other marking materials applied to the surface of a road or island to simulate a colored pavement."[19] Colored pavement currently used for bike lanes consists of numerous materials.

Within the past decade, a recent development for bicycle facilities to increase bicyclist safety has been the use of green colored pavement. In New York City, studies indicate that using solid green colored pavement effectively discouraged motorists from parking in the bicycle lanes.[20]

The FHWA has specified the shade of green in terms of daytime chromaticity and nighttime chromaticity for bike lanes using colored pavement.

Green colored pavement may be retro-reflective, but is not required.

Although this bike lane appears very bright, the shade of green complies with federal guidelines.

The FHWA has approved extending green colored pavement to conflict areas where bicyclists and other roadway traffic may engage in weaving or crossing movements.

Photo credited to L.S. Koetsier

Figure 2. Bike Lane with colored pavement

On 13 May 2014, the FHWA approved a request from the City of Norman, Oklahoma to install green bike lanes in their city.[21] [22] As stated earlier, the FHWA defines colored pavement as "colored asphalt or concrete, or paint or other marking materials applied to the surface of a road or island to simulate a colored pavement."[23]

In their Urban Bikeway Design Guide (published March 2014), the NACTO charts the advantages and disadvantages of using pavement coatings. These pavement coatings include paint, epoxy mixes, and thermoplastic for constructing bicycle lanes on city streets.[24]

In their guide, the NACTO identifies several types of Pavement Marking Materials:

Type of Material	Prices per square foot and Expected Performance
Non-durable Waterborne paint	$0.60 Sq. Ft. for raw materials, $1.20 – $1.60 Sq. Ft. installed…lasts six months to two years based on weather.
Epoxy-based Durable Liquid Pavement Markings (DLPM)	Sunlight and water may reduce color intensity.
Epoxy Pavement Marking	$1 – $3 Sq. Ft. for raw materials. $8 - $11 Sq. Ft. installed….with skid resistance and longevity as long as 3 – 5 years.
Methyl Methacrylate (MMA)	$3 – $4 Sq. Ft. for raw materials. $8 - $11 Sq. Ft. installed…may last as long as 3 - 6 years.
Thermoplastics	$3 – $6 Sq. Ft. for raw materials, $10 – $14 Sq. Ft installed…wears well in conflict areas and spot fixes.
Embedded (Colored Asphalt)	Pigmented asphalt costs are between 30 and 50 percent more than conventional asphalt…layer at least 1 cm thick is expected to last for the life of the pavement.

Figure 3. Material Prices per square foot and expected performance[25]

Since the FHWA term "colored pavement" refers to a wide range of materials, this report divides the term into two additional categories:

- Recent Developments in the United States
- Pigmented pavement used in Europe refers to any asphalt or concrete with pigment added to the mixture

3.1 Recent Developments in the United States

In many European countries, epoxy mix coatings and thermoplastic are preferred for applying intersection spot treatment bikeway color. [26] Cities in the U.S. use thermoplastic for a variety of applications, including spot treatments. With an average lifetime of five years, thermoplastic is ideal for spot fixes.

Compared to thermoplastic, cities reported less use of epoxy and MMA-based materials. Even though DLPM and MMA require special equipment for installation, both products are long-lasting and cheaper than thermoplastic.[27]

Photo credited to L.S. Koetsier

Figure 4. Class Two Green Bike Lane located in southeast Norman

This well-designed street lane with the large thermoplastic arrow provides plenty of notice to motorists and bicyclists alike that the outermost lane is narrowing and the Class Two green bike lane will soon end in a rural area.

Compared to pavement coatings recognized by the NACTO, more recent developments include:

- Polymer Cement Slurry Surfacing (PCSS)
- Pigmented ULTRASEAL® Systems
- Colorized Lane Demarcation (CLD)

3.1.1 Polymer Cement Slurry Surfacing (PCSS)

With improved solar reflectivity, polymer cement slurry surfacing (PCSS) is thermally compatible with concrete and asphalt surfaces, making it an effective choice for durability. PCSS is a system containing a polymer modified cement "slurry" material composed of Portland Cement, blended acrylic modifiers, and a blend of engineered aggregates.[28]

Some epoxy systems can de-bond over time because they respond differently than the substrate under thermal expansion and contraction. Since the PCSS has a coefficient of thermal expansion similar to concrete, the PCSS moves with the underlying concrete. As a system, the PCSS surface can leach out (generally after a rain). Placing a sealer over the recently cured product prevents leaching and provides a glossy appearance.[29]

One company offers PCSS in a variety of colors, including green. Adding pigmented aggregate to the mix can improve skid resistance, increasing durability.

Due to exceptional bonding to both asphalt and concrete surfaces, it is possible to repair spalled or unraveled concrete or asphalt prior to application of the green coating.

Composed of polymer modified Portland cement, pavement coating significantly enhances the service life of crosswalks, bicycle zones and other marked pavement areas.

Thermally compatible with concrete and asphalt surfaces, Polymer Cement Slurry Surfacing is unlikely to degrade under UV exposure.

An innovative-stenciled surface offers a unique riding surface, providing water dispersion during rainstorms.

Photo credited to Endurablend [30]

Figure 5. Portland Cement Slurry Surfacing used in New Jersey

One company located in New Jersey provides a video-recorded step-by-step process for installing PCSS.[31]
To view this video, go to https://www.youtube.com/watch?v=BXnHpckF7hQ&feature=youtu.be

With over half a million square feet installed on America's streets and bridges, numerous state and municipal agencies are choosing PCSS. [32] The service provider nearest to Oklahoma who offers PCSS is located in St. Louis, Missouri. A service provider in Oklahoma City may soon be available.

Compared to paint and epoxy mixes such as MMA, the more durable thermoplastic is cost-prohibitive for large-scale projects such as Class Two bike lanes. However, a durable and economical alternative to thermoplastic would be Pigmented ULTRASEAL® Systems.

3.1.2 Pigmented ULTRASEAL® System

Composed of a polymer modified pigmented asphalt emulsion sealer, Pigmented ULTRASEAL® Systems is designed to protect pavement while increasing visibility.

Pigmented ULTRASEAL® Systems is ideal when cities use pavement markings to increase public safety for bike lanes and crosswalks.

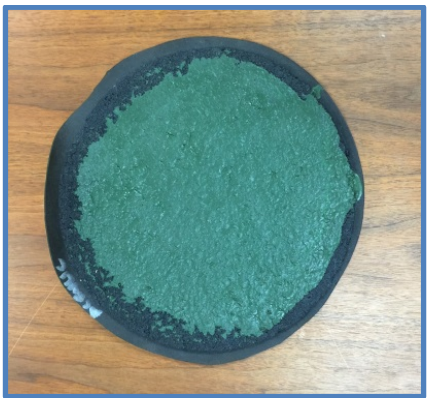

Figure 6. ULTRASEAL® containing green pigment

Pigmented ULTRASEAL® Systems offers:

- toughness
- durability
- high asphalt content
- high softening point
- deep color
- excellent adhesion

Photo credited to Vance Brothers®

Figure 7. ULTRASEAL® containing red pigment applied to existing asphalt surface

Mixing the product at a central plant is best. Once the pavement is free of dirt, dust, clay, sand, vegetation, and all other loose materials, petroleum residues need special treatment.

Once holes, crumbled surface areas, and cracks are repaired, plan for application by brush or squeegee when ambient temperatures are at least 50° F and rising.

Depending on the condition of the surface, a two coat application uses 20 to 25 square feet per gallon.

Available in dark green or dark red, Pigmented ULTRASEAL® Systems offers an attractive surface for asphalt pavements.

Properties	ULTRASEAL®
Solids Content (Non-Volatiles)	48% - 52%
Ash Content of Solids	22% - 24%
Polymer/Asphalt Ratio	3% minimum
Specific Gravity @77 F	1.0 minimum
Adhesion	No Loss
Flexibility	No Cracking
Water Resistance	No Solubility
Heat Resistance	No Blistering / Sagging
Impact Resistance	No Chipping
Homogenity	No Separation
Drying Time	8 Hours

Figure 8. Properties of Pigmented ULTRASEAL® Systems

3.1.3 Colorized Lane Demarcation (CLD)

In 2008, city officials in San Francisco, California tested multiple materials and chose a micro surface binder consisting of a colored synthetic bitumen emulsion, with glass beads added to provide retro-reflectivity.[33] Unfortunately, when bike paths get wet, glass beads can be slippery and dangerous.

Since then, an innovative company located in Hazleton, Pennsylvania has developed a process called Colorized Lane Demarcation®. Instead of using glass beads, the 100% recycled glass aggregate (with added green pigment) is placed over a polymer epoxy binder.

The CLD process uses a high-strength polymer resin for bonding an abrasion resistant high friction aggregate to the pavement surface. The treatment specification requires placing a test area on asphalt concrete pavement, then testing for a 0.65 coefficient of friction.[34]

Manual application is possible, but mechanical application with dispensing vehicles results in a more uniform and durable surface less prone to material failure.[35] The service provider customized an automated application vehicle capable of storing at least:

- 1,200 gallons of polymer resin binder
- 42,000 pounds of high friction aggregate

The applicator vehicle evenly spreads the polymer resin binder over the road surface nearly 1.4 millimeters (or 55 mils) thick. Within seconds, the vehicle uniformly spreads the aggregate over the binder.[36] As the vehicle spreads recycled glass aggregate over the asphalt, the service provider ensures the Portland Concrete near the curb retains its original surface.

Once the polymer resin binder has cured, a vacuum sweeper removes the excess aggregate. Then, the recovered aggregate is recycled and reused.

The company describes Colorized Lane Demarcation as a durable, fade-free, long-term traffic safety solution for high traffic areas that reduces fatalities and potentially saves lives.

As of September 2015, the City of Norman used Colorized Lane Demarcation when installing green bike lanes.

Photo credited to L.S. Koetsier

Figure 9. Excess aggregate laying on Portland Concrete

The majority of the existing bike lanes in Norman are on concrete pavements.

In their plan, city transportation officials estimated $3.60 per square foot for paint compared to DLPM at $13 per square foot for material and application.

However, material costs for Colorized Lane Demarcation are considerably lower, at $3.00 per square foot.

Photo credited to L.S. Koetsier

Figure 10. Road crew installing green bike lanes on Cedar Lane in Norman, Oklahoma

Located near student-focused apartments, the project will eventually connect bicyclists to the nearby Oklahoma University campus.[37] Offering connectivity increases accessibility, one of the goals for moving active transportation forward in Oklahoma.

Photos credited to L.S. Koetsier

Figure 11. Class Two bike lane in Norman as it approaches railroad crossing

Although Colorized Lane Demarcation is a durable and economical safety solution for Class Two bike lanes with high traffic areas, another option for long-term durability would be pigmented pavement.

3.2 Use of Pigmented Pavement

Whereas pavement coatings include paint, epoxy, and other surface treatments such as thermoplastic, pigmented pavement refers to any asphalt or concrete with pigment added to the mixture.

For several decades, Denmark, Germany, and the Netherlands have constructed bicycle lanes using pigmented pavement. As early as May 1997, New York City mentioned pigmented pavement in their Bicycle Master Plan.[38]

In their Urban Bikeway Design Guide (published March 2014), NACTO defines pigmented pavement as a combination of bituminous pitch, sand/gravel, and pigment.[39] Pigmented pavement generally refers to any asphalt or concrete with pigment added to the mix design.[40]

In Oklahoma, one city used asphalt containing red pigment to delineate pedestrian crosswalks. Over the years, the color appears to have faded.

Photo credited to L.S. Koetsier

Figure 12. Asphalt containing red pigment used to delineate pedestrian crosswalk

Nick Brouwer, Manager with Ooms PMB, recommends considering the natural color of the aggregates to achieve the desired pavement color. For example, to obtain a red colored pavement it is best to use red colored aggregates.[41]

One manufacturer located in Acworth, Georgia offers 1-3 millimeter (mm) granite or bauxite aggregate with pigmented binder covering each stone, with a polished stone value over 60. The epoxy resin-based surfacing material (pre-packaged in 50-pound bags) offers rapid installation over existing road surfaces.[42]

A second manufacturer offers a low-dust product named Granufin® In their process, high-speed grinding equipment transforms highly concentrated pigments into a liquid that coats individual pigment particles with color-activating agents.

As the liquid is sprayed, fine droplets form into micro-granules. As it dries, the color-activating agent solidifies, binding individual pigment particles together into nearly perfect spheres, with a water-receptive surface that range in size up to 300 microns. During transportation and storage, granules stay hard. When it is time for application, adding water rapidly dissolves the Granufin® into the mix.[43]

Compared to conventional pavement, pigmented pavement involves these considerations:

- Green Pigment for Pavement
- Clear Binders for Pigmented Pavement
- Installing Pigmented Pavement

3.2.1 Green Pigment for Pavement

As of 2011, the FHWA specified the shade of green for bike lanes in terms of daytime chromaticity and nighttime chromaticity. The daytime luminance factor shall be at least seven but no more than 35.[44]

Chromaticity Coordinates	1		2		3		4	
	x	y	x	y	x	y	x	y
Daytime	0.230	0.754	0.266	0.500	0.367	0.500	0.444	0.555
Nighttime	0.230	0.754	0.336	0.540	0.450	0.500	0.479	0.520

Figure 13. Chromaticity Coordinates for bike lane green as specified by the FHWA

One company (with their green-pigment used in three U.S. cities) describes their Easily Dispersible (ED) pigments as organic, meeting the goals of sustainable development.[45] NACTO reports that San Francisco, Portland, and Chicago currently have bike lanes with FHWA specified green colored pavement.[46] At this time, it is not clear whether these three cities added the pigment to their pavement.

Supplier A located in Madrid, Spain offers Green Chrome Oxide G6 pigment for mixing with concrete as well as Green Chrome Oxide G6PE pigment for mixing with asphalt aggregate. Their pigment is shipped in 25 kg polyethylene bags.

Since the temperature inside the mixer is between 160° and 170°C, the crew can drop the low-melt polyethylene (PE) bag – unopened – into the aggregate, for homogeneous distribution of the pigment.[47] For common commercial grades of medium- and high-density PE the melting point is typically in the range 120 to 180 °C (248 to 356 °F).

Polyethylene absorbs almost no water. However PE can become brittle when exposed to sunlight.

Green Chrome Oxide G6 Pigment for Concrete - Properties	Specification / Unit	European Test Method
Content Cr_2O_3 (min.)	99.3 %	
Content FeO (max.)	0.08 %	ISO 1248
Volatile matter at 105° C (max.)	0.13 %	ISO 787-2
Content Si (max.)	0.12 %	
Content Zn (max.)	0.002 %	
pH	5 – 8	ISO 787-9
Water soluble salts (max.)	0.25 %	ISO 787-3
Predominant particles size	0.32	
Oil absorption	18 – 25 µm	ISO 787-5
Colour strength (matching standard)	95 – 105 %	ISO 787-24
ΔE max. (matching standard)	1.0	

Figure 14. Properties of Green Pigment from Madrid, Spain

Davis Colors obtains powder pigments from Supplier A. Recycled material is used for many of the pigments. Standard colors and custom powder blends include synthetic red, yellow, orange, brown and black iron oxides, carbon blacks, cobalt blues, and chromium oxide greens.

Whereas Davis Colors packages the pigment in 50 lb. PE bags, the Mix-Ready® line offers smaller packaging options.[48] The supplier nearest to Oklahoma is located in Independence, Kansas.[49]

Supplier B located in the Netherlands offers pigments specifically designed for mixing colored asphalt. With a high coloring strength, the durable lightfast pigments are available as powders branded as Ferroxon® and an in-house developed pellet pigment (in a 10 kg bag) branded ColorFalt V®. Composed of Chromium Oxide, the ColorFalt V® manufacturer will customize pigment to match any specific color request.[50]

ColorFalt V ® Pigment	Typical Properties	Characteristics	ColorFalt V ® Green
Pigment content	Ca. 80%		
Pigment	Chromium Oxide	Light Fastness (1 % dosage measured on the Blue Wool Scale, DIN 53387-2-E; 500 hours)	8
Carrier	E.V.A.	Weather Fastness (1% dosage measured on the ISO Grey Scale DIN 53387-1A-X; 3,000 hours)	4 - 5
Granule Shape	Cylindrical	Heat Resistance (1% dosage with a residence time of 5 min.)	300 ° C (DPA – 003)
Granule Size (average)	3 mm x 1 mm		
Melting point	90 – 120° C		

Figure 15. Specifications for ColorFalt V® Pigment

Supplier C located in the United Kingdom offers green chromium oxide PJ GRN01 for pigmenting concrete. They offer a variety of packaging options that include multi ply paper sacks, bulk bags & water soluble bags, suited to the customers dosing criteria. PJGRN01 is also available in liquid form.[51]

For pigmenting asphalt, they offer green pigment PJ GRN10 packaged in either <1000kg bulk bags or <25kg/<55lbs low melting polyethylene bags. The weights can be specifically tailored to the customer's mix design.[52] They charge $ 4,390 per metric ton plus shipping.

Since many other pigments lack tint strength or the heat stability required for coloring asphalts, Supplier C describes their pigments as "lightfast and weather stable." All pigments for coloring pavement are manufactured in accordance with EN12878.[53]

Supplier C expresses their commitment to Health & Safety and protecting the Environment.[54] Whereas synthetic iron oxides react to excessive heat (at mixing temperatures above 160 – 180 °C),[55] chromium green pigments do not.[56]

Conventional Asphalt Binder Conventional asphalt binder is manufactured from crude oils that vary from viscous black liquids to free-flowing straw colored liquids. The source and type of crude oil affects the color of the asphalt.[57] Most conventional asphalt binders are black due to asphaltene found in distillation residue.[58]

Outside of the United States, several manufacturers have developed clear binders that do not contain asphaltene. These clear binders are necessary to:

- Obtain the expected shades of red, white, yellow, blue, and green-pigmented asphalt[59]
- Ensure the chromatic or saturated green-pigmented pavement required by the FHWA[60]

3.2.2 Clear Binders for Pigmented Pavement

Clear binders make it possible to create asphalt of any color by varying the color of the aggregate or by adding pigment.[61] There are two types of clear binder:

- Plant-based binders
- Synthetic binders

Plant-based Binders Two examples of plant-based clear binders are Vegecol® and Floraphalte®. Vegecol® has been used as a surface treatment throughout Europe, including historic buildings in France. As a transparent pigmentable plant-based binder, Vegecol® combines performance, aesthetics and environmental protection.[62] The manufacturer reports that it is easy to apply Vegecol® mixes, even by hand. As a long lasting, pigmented pavement, Floraphalte® is available in 190-liter drums or 1-kilogram (kg) packs.[63] Both manufacturers report that low temperatures for manufacturing their clear binders results in decreased emissions and energy consumption.

Synthetic Binders Whereas Vegecol® and Floraphalte® are plant-based clear binders; Mexphalte C P2® is a synthetic clear binder designed for:

- Bicycle lanes located on a road shoulder (where heavy-duty traffic may occasionally pass over the bicycle path)
- Bicycle lanes that frequently intersect with heavily trafficked roads (intersections, roundabouts, etc.)

Mexphalte C P2® offers a plasticity range similar to conventional bitumen.[64]

Product Features	Unit	ASTM Test Method	EN Test Method	Floraphalte®	Mexphalte C P2®
Penetration at 77° F /25° C	0.1 millimeter	ASTM D5 and AASHTO T49	EN 1426	100 – 150 ° C	35 – 50 ° C
Softening point (Ring & Ball)	° Celsius (C)	ASTM D36 /D36M	EN 1427	≥ 39 ° C	≥ 70 ° C
Density at 77° F /25° C	Kilograms / Cubic Meter	ASTM D1298	EN ISO 3838	Typical Value 990	1.0 – 1.03
Flash point	° Celsius	ASTM D92	EN ISO 2592	≥ 250 ° C	≥ 250 ° C

Figure 16. Specifications for Floraphalte® and Mexphalte C P2®

Mexphalte C P2® allows an extensive color palette, even with small amounts of pigment. Differing UV light intensity may cause the pigmented asphalt to become homogeneous after a few weeks. Working with a homogenized product tank will help maintain a uniform shade. Special laying equipment is not required.

Floraphalte and Mexphalte C P2® include a high quality polymer, enhancing mechanical stability for roads with heavy traffic.[65] At one time, a company located in Houston, Texas advertised Floraphalte® and Mexphalte C P2®. Since then, the manufacturer reports that these clear binders are not available anywhere in the United States.[66] The company located in the Netherlands ships the green pigment as pellets and the clear binder as a liquid product.

A second manufacturer located in Madrid, Spain offers Recofal S100-P®. As a synthetic binder containing a mixture of resins, oils and polymers, Recofal S100-P® allows mixing a variety of colors for paving bicycle lanes in parks and gardens.[67]

Madrid, Spain Product Characteristics	ASTM or AASHTO Test Method	EN Test Method	Recofal S-100P® Specification / Unit
Penetration at 77° F /25° C	ASTM D 5	EN 1426	20 – 50 0.1mm
Softening temperature	ASTM D36 AASHTO T53	EN 1427	≥ 85 ° C
Temperature Fragility Fraass		EN 12593	≤ -20 ° C
Density		EN 15326	0.95 to 1.15 g / cm^3
Brookfield Viscosity at 320° F / 160°C		EN 13303	≥ 400 ° C
Resistance to aging		EN 12607-1	
Retained Penetration			≥ 80 %
Temperature Increment Softening			≤ 10 ° C
Mass variation (value absolute)			≤ 1,5 %

Figure 17. Specifications for Recofal S-100P®

Supplier C located in the United Kingdom offers clear binder Recofal S100-P® packaged in 10 kg and 25 kg low-melt polyethylene bags. In granular or pellet form, it can be stored and handled at room temperature. They charge $3,750.00 per metric ton plus shipping.[68]

Materials donated by Harvey Jackson, Director of Procter Johnson Colors located in the United Kingdom.

Figure 18. Green Powder Pigment and Clear Binder Pellets

This company also offers PJ GRN10 green pigment packaged as a fine powder. Moreover, shipping their product from the United Kingdom to the United States is possible.

Supplier C suggests adding the pigment either with or just after the introduction of the clear binder; otherwise the pigment tends to be absorbed by the aggregates, then coated by the binder, resulting in poor color generation.[69]

A third manufacturer located in the Netherlands offers various grades of clear binders, as shown in the chart below. Clear binders use a reduced amount of pigment, allowing intense colors. The clear binders are suitable as raw material in clear binder emulsions.[70] Whereas Bitucolor® is an unmodified clear binder, Sealoflex Color® is a modified clear binder costing nearly $1,500.00 per metric ton plus shipping. [71]

Netherlands Clear Binder Properties	ASTM or AASHTO Test Method	EN Test Method	Bitucolor 70-100®	Bitucolor 50-70®	Sealoflex Color®
Penetration at 77° F / 25° C	ASTM D 5	EN 1426	70 - 100 (0.1 mm)	50 - 70 (0.1 mm)	70 - 100 (0.1 mm)
Softening point (Ring & Ball)	ASTM D36 AASHTO T53	EN 1427	40 – 46° C 104° to 115° F	44 – 50° C 111° to 122° F	50 – 56° C 122° to 133° F
Fraaβ breaking point of Bitumen		EN 12593: 2007	≤ - 10° C 14° F	~ - 8° C 17.6° F	≤ - 10° C 14° F
Viscosity at 275° F / 135° C	ASTM D 4402	EN 13702-2	150 - 250 mPa-s	160 - 260 mPa-s	400 - 600 mPa-s*
Flash point	ASTM D 92	EN ISO 2592	≥ 230 ° C	≥ 230 ° C	≥ 230 ° C

Figure 19. Product Characteristics for Clear Binders[72]

*millipascal-second (mPa-s)

The company located in the Netherlands ships the green pigment as pellets and the clear binder as a liquid product.

Materials donated by Nick Brouwer with Ooms PMB bv
Photo credited to L.S. Koetsier

Figure 20. Left to Right: Green Pigment Pellets, Sealoflex ® Binder Blend of Pigment and Binder, Green Pigmented Asphalt

3.2.3 Installing Pigmented Pavement

In their guide, NACTO officials briefly describe the advantages and disadvantages of using pigmented pavement for constructing bicycle lanes on city streets. NACTO reports that San Francisco, Portland, and Chicago currently have bike lanes with FHWA specified green colored pavement.[73]

The company that supplied the pigment explains their process: once a reactor stirs the Easily Dispersible® (ED) pigment, a certain amount of additive modifies the pigment. After delivery, a high-speed dissolver simplifies dispersion of the ED pigment, eliminating the need for the traditional bead-milling step.[74] At this time, it is not clear whether these three cities used pigmented asphalt or pigmented concrete.

Installing pigmented concrete requires the additional step of applying a primer or sealant. Several peer cities including New York and Salt Lake City reported that applying colored pavement to concrete in poor condition reduces the lifespan of the treatment. Regardless of the concrete's current state of repair, the presence of roadway grease, particulate, dust, dirt and other debris on any existing pavement resulted in a poor quality installation.[75]

When installing pigmented concrete on existing concrete, city officials in Salt Lake City, Utah estimated a lifetime of six months. For better long-term results, they recommend installing pigmented asphalt on new asphalt.[76]

In the Netherlands, most bikeways with pigmented asphalt are composed of naturally red-colored rock with conventional black bitumen, as opposed to implementing other colors with the more expensive clear bitumen.[77]

One supplier recommends mixing between 30 kg to 50 kg of green pigment per ton of aggregate before adding the clear binder.

In the photo, both samples contain clear binder instead of conventional bitumen.

The sample on the right includes 2% green pigment, sufficient for color saturation.

Photo credited to OOMS PMB bv

Figure 21. Asphalt without pigment (left) and asphalt with green pigment (right)

Preparation for installation of pigmented asphalt is similar to installing standard asphalt. Installing a thin layer of pigmented asphalt over conventional asphalt can be cost-effective, especially during a Pavement Coating operation for existing automobile lanes.[78]

Several cities, including Chicago, New York, and Los Angeles, reported grinding or blasting concrete or asphalt roadways as part of surface preparation, increasing the application's longevity.

City officials in Austin, Texas have determined that applying a fresh asphalt surface (seal coat or micro surface) before installing any proposed thermoplastic is best.

Photo credited to People for Bikes.org [79]

Figure 22. White thermoplastic dashes indicate conflict area

Since asphalt is not retro-reflective, applying a white thermoplastic stripe next to pigmented asphalt improves visibility.[80] Installing pigmented asphalt may require special attention at joints between pigmented and standard asphalt. In their guide, NACTO asserts that pigmented asphalt offers permanent color, durability, skid resistance, and that it requires minimal maintenance.[81]

In one study, investigators used the rolling thin film oven (RTFO) test to determine the aging process of pigmented asphalt. After aging, resins as well as saturate and aromatics content decreased, whereas asphaltene content increased. Researchers used the aging index and the Gastel index to determine that aging led to deteriorated performance of the pigmented asphalt.[82] However, the report does not specify the type of binder used in the pigmented asphalt.

4.0 CONCLUSION: SAFE BIKE LANES USING COLORED PAVEMENT

In numerous cities, transportation officials are researching methods for increasing active transportation. Offering opportunities for active transportation (in order to increase the number of bicyclists within a given population) means constructing safe and convenient bicycle facilities.

One method for planning safe, convenient, and well-designed bicycle facilities would be confirming the effective and economical use of green colored pavement. As a traffic control device, green colored pavement ensures that bicycle lanes and conflict areas are conspicuous to bicyclists as well as motorists.[83] Studies in various cities across the United States provide valuable information for considering the use of green colored pavement.

Prioritizing bicycle facilities will eventually lead to increased personal safety for bicyclists.[84] For several cities in Oklahoma, conflict areas pose the greatest safety hazard for bicyclists.

Whereas pavement coatings include paint and other surface treatments such as thermoplastic, pigmented pavement refers to asphalt or concrete with pigment added to the mixture prior to placement.

Compared to pavement coatings, pigmented pavement is expected to offer superior durability.

Even though three cities in the U.S. report using green-pigmented pavement, it remains unclear as to whether they used pigmented concrete or pigmented asphalt.

Photo credited to L.S. Koetsier

Figure 23. Dashed line indicates conflict area Where motorists must yield to bicyclists in Tampa, Florida

A thin top layer of pigmented asphalt within new construction costs 30% to 50% more than standard asphalt.[a] In an asphalt mill and overlay project, the new surface could be constructed with pigmented asphalt.

At the current time, the use of clear binders and green pigment to mix green-pigmented asphalt is cost prohibitive.

Considering the high cost of clear binder, green pigmented concrete appears to be a better option than green pigmented asphalt.

Comparing costs for various materials is important for cities with limited budgets.

Photo credited to Ooms *PMB* pv

Figure 24. Asphalt Concrete sample topped with thin layer of green pigmented asphalt

Transportation officials have provided several estimates:

- $ 3.00 per square foot for Colorized Lane Demarcation (CLD)
- $ 3.40 per square foot for Methyl Methacrylate (MMA) (material only)*[85]
- $ 3.60 per square foot for green paint
- $12.00 per square foot for Polymer Cement Slurry Surfacing (PCSS)*
- $13.00 per square foot for Durable Liquid Pavement Markings (DLPM)

*Estimates for PCSS and MMA obtained from service provider.

As a system, PCSS contains a polymer modified cement "slurry" material composed of Portland Cement, blended acrylic modifiers, and a blend of engineered aggregates. However, PCSS is labor-intensive. Numerous state and municipal agencies are choosing PCSS.[86] The nearest service provider is located in St. Louis, Missouri.

Composed of a polymer modified pigmented asphalt emulsion sealer, Pigmented ULTRASEAL® Systems is designed to protect pavement while increasing visibility. The nearest service provider is located in Kansas City, Missouri.

Composed of 100% recycled glass, CLD seems to be an economical and effective safety solution for constructing additional bike lanes within Oklahoma.[87] The nearest service provider is located in Oklahoma City.

In the future, as researchers develop a greater variety of innovative materials, there will be more options available for American cities constructing green bike lanes on their city streets.

Appendix A: Techno-Poetry, Starry Night, and Solar Panels

Considering recent developments in the United States and the use of pigmented pavement in Europe, the most unique bike facilities are in the Netherlands. With 35,000 kilometers (or nearly 21,750 miles) of bike lanes, the Netherlands is famous for their advanced bike network and for their innovative design.

Several years ago, architect Daan Roosegaard conceptualized a bike path using solar panels, with the solar surface embedded below the glass/epoxy outer layer. The recently completed bike path has nearly 2000 cyclists per day. Roosegaard defines techno-poetry as combining the technical with human experience.[88]

Photo credited to Roosegaard Studio

Figure 25. Bike Path on solar panels designed by Daan Roosegaard

At night, the Van Gogh-Roosegaard bike path resembles Van Gogh's famous painting "Starry Night." Viewer and space become one in tactile high-tech environments. This connection between ideology and technology, results in what Roosegaarde calls 'techno-poetry.'[89]
For Roosegaard, connecting our poetic past with the pragmatic present offers a hopeful future.
To see the video, go to https://www.youtube.com/watch?v=ZYpO2pJ6afM

In the Netherlands planners resolved a conflict area due to a right turn. Their innovative design includes a colored bike lane that curves as it crosses the street, with room for one car to turn, then stop at a crosswalk, effectively protecting right of way for the bicyclist.[90]
To see the video, go to https://www.youtube.com/watch?v=a6gy-ojmdh8

The advanced bike network offers bicyclists convenience as well as safety. Well-designed cycle tracks offer the disabled and elderly with motorized scooters effective protection from motorized traffic.
To see the video, go to https://www.youtube.com/watch?v=xSGx3HSjKDo

Although solar panels may be one method to consider for building future bike paths in Oklahoma, confirming the effective and economical use of green colored pavement is more likely for planning safe, convenient, and well-designed bicycle facilities in the near future.

Appendix B: Aging Behavior of Colored Paving Asphalt

Abstract:

In this paper, the aging processes of colored paving asphalt conforming to GB/15180-94 standard were studied by rolling thin film oven (RTFO) test. The results show that the established two dynamics models can be used to describe the aging velocity of the two kinds of colored paving asphalt perfectly.

After aging, asphaltene content increased, resins and aromatics content, as well as saturate content, decreased. As a result, the original colloidal structure of colored paving asphalt is destroyed, which deteriorates performance of the colored paving asphalt.

During aging, the Gastel index (*Ic*), which is sensitive to aging conditions, decreased with increase of aging temperature and extension of aging time. Therefore, the Gastel index can be used to evaluate the aging resistance of the colored paving asphalt.[91]

Petroleum Science and Technology, Volume 24, Issue 6, 2006 (pages 689-698);
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Acknowledgments

Nationwide, the primary guides and manuals concerning bicycle facilities are:

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- AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities (2004)
- National Association of City Transportation Officials (NACTO) Urban Bikeway Design Guide (2014)
- Highway Capacity Manual (2010), Highway Safety Manual (2010)
- Manual on Uniform Traffic Control Devices (2009)

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