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Reduction of Thermally Induced Cracks in Asphalt Using Thermochromatic Pigments in the Asphalt

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Abstract

The purpose of this research was to establish the significance of adding pigment in the design mix of asphalt concrete. This was achieved using Thermochromatic pigments. Four samples of asphalt concrete containing paint, dye, neat and pigmented were prepared and its volumetric properties established. The degree in which each of the sample was capable of reflecting away solar radiation were however tested by exposing all the four samples to the environment under direct solar radiation and the amount of solar radiation that each of them absorbed were measured and recorded. The pigmented mix after testing registered the lowest temperature change as compared to the other mix. It was therefore recommended that it is very prudent to add the pigment as additive at 25% of the bitumen weight and 25% pigments during the design mix of asphalt concrete as it will assist in reflecting away the solar reflectance of the pavement.

Keywords: Thermochromatic pigment, thermochromics material, asphalt concrete, volumetric properties, thermal cracking

INTRODUCTION

This study investigated the reduction of thermally induced cracks on asphalt concrete containing thermochromics pigment as material used as wearing course for roads, airport runways and any other pavement surfaces made from asphalt concrete. Reduction of thermally induced cracks in asphalt concrete containing thermochromics pigments was achieved using thermochromics pigments that reflect away the solar radiation. These pigments were mixed with asphalt concrete in different proportion; comparison was made according to its behaviours after laboratory test. Comparison was made for the mixes dosed with thermochromics pigments and neat asphalt mix. Two other mixes were also included in the study i.e., an asphalt mix that was painted later and an asphalt mix that was dosed with blue dye. The study used a thermochromics substance which was a grey powder. The research then investigated the behaviours of which after research its behaviour when heat was introduced was investigate. From previous research, thermoplastic pigments changes colour from grey colour to a light blue colour, the pigment is capable of reflecting away more heat thereby reducing the amount of heat absorbed by the concrete and consequently reduces the thermal stress on the bitumen binder. This study was important in the road maintenance; Government of Kenya uses resources in road maintenance especially on potholes which is because of thermal cracking after temperature variation.

The study aimed to investigate the properties of asphalt concrete made of asphalt containing Thermochromatic pigments. The volumetric properties were investigated with the aim of determining whether the thermochromatic pigment negatively affects asphalt mix volumetric properties. Marshall Test of various mixes was carried out. The mixes included a neat mix, mix containing thermochromatic pigments, mix containing a blue dye, and a neat mix that was painted later. The volumetric properties of the asphalt mix containing thermochromatic pigments were compared to those of the other mixes. The thermal performance of the asphalt concrete containing thermochromatic pigments

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was investigated. It was analysed by evaluating the changes in temperature of the asphalt mix in the surface containing thermochromics pigments and compared to changes in surface temperature of the other mixes over a period of eight weeks. Thermochromatic materials addition in production of asphalt concrete would significantly assist in improving safety, decrease unwanted environmental impacts, and help to increase the durability of roads made of asphaltic concrete.

THEORY

Thermochromic materials are ones that react to external stresses namely thermal stresses by changing their optical properties in a reversible chemical transition. They are organic chemicals with optically active molecular structures. The colour change occurs by selective reflection of white light. Certain wavelengths are reflected by the crystal-like structure of the material and this property of thermochromic pigments what makes it a viable method of reducing the thermal stresses in asphalt.

Asphalt pavement materials have low thermal conductivity; therefore, a lot of solar radiations can be absorbed by pavements made of black asphalt. Absorbed heat can be retained within the road; hence temperature is increased. Asphalt pavement surface temperature can easily reach 65oC on a hot day (Jiang et al., 2017). According to Memon et al. (2021), the slight increase in temperature especially in high temperature areas can greatly the asphalt performance. Asphalt shear stress of asphalt mix becomes more than its shear strength, under the repeated load of vehicles, the mix of asphalt undergoes plastic deformation, which in turn results in high temperature rutting problem (Van Thanh & Feng, 2013). Rutting deformation reduces the lifespan of the pavement made of asphalt. However, asphalt pavement service life is reduced, rutting deformation also results in different tire-road contact stress and water drift hence affecting the safety of vehicles (Tian & Yu, 2017; Wang et al., 2012).

Thermochromatic pigments are substances which can change color in response to temperature reversibly. They are potential materials that can change thermal condition of the pavements. This study developed thermochromic asphalt concrete containing dynamic solar reflectance in response to environmental temperature. The study indicated that the coating layer in thermochromic binder gained a temperature decrease as high as 6.4oc under the condition of typical day in summer. A comparison on measurements was made as per the temperature under cold conditions in Cleveland illustrated that thermochromic asphalt binder could remain warmer than neat asphalt binder. This demonstration helps to improve the asphalt pavement resistance to low- temperature cracking, delays ice formation on the road surface and potentially improves durability and safety of asphalt roads.

Thermochromatic materials exhibit a change in colour in their visible optical properties when exposed to changes in temperature. The process of colour change is always noticed at a given transition of temperature (TT) because core in chromogenic (Lima et al., 2022). Therefore, these materials can be used in solar reflective pavements coatings. Reflective pavements can be developed in two main ways. First, they can be developed through application of a layer of thermochromics, reflective infra-red, or highly reflective property. Reflective pavements can also be developed using fly ash and heat reflective coated aggregates pavements (Anupam et al., 2021). The main objective of the research was to establish the properties of asphalt concrete dosed with thermochromatic pigments and make comparisons with conventional asphalt mix. The study was guided by the following specific objectives to achieve the main objectives;

(i) To determine the effects of thermochromatic pigments on the volumetric properties of asphalt mix dosed with the thermochromics pigments.
(ii) To compare the volumetric properties of a neat asphalt mix, an asphalt mix mixed with blue dye, an asphalt mix that is painted, and an asphalt mix dosed with thermochromics pigments.
(iii) To establish the optimum design mix ratio of asphalt containing thermochromics pigments.
(iv) To compare the thermal properties of a neat asphalt mix, an asphalt mix mixed with blue dye, an asphalt mix that is painted, and an asphalt mix dosed with thermochromics pigments.

Problem Statement

Asphalt is globally used in paving due to its flexibility and relatively inexpensive cost as compared to using concrete. However, asphalt is susceptible to thermal stresses induced by the high solar radiation resulting in crack formation Conventional asphalt, due to its black colour. The high quantity of heat energy absorbed by the asphalt increases the surface temperature of the asphalt pavement, especially during periods of high temperatures. A drop in temperature during cold periods accelerates cracking and rutting of the pavements made of asphalt; therefore, impairing its durability.

Study Justification

There was a need to carry out this study as practically roads in kenya are done but within a short period of time thermal cracks start developing. This study is very important as its try to come up with asphalt concrete dosed with the colour changing pigments and therefore alter the solar reflectance which produces thermal stresses in a conventional asphalt concrete. This paper content is organised as follows; Title, Name of the Author, Abstract, Keywords, Introduction, Literature Review / Theory, Research Methods, Results, Discussion of Findings, Conclusion, Recommendations and Cited References.

Figure 1 compares the reflective properties of a conventional asphalt pavement to that of a thermochromics pavement. In the case of conventional asphalt, a lot of this incoming sun energy is retained by the road made of asphalt concrete due to its dark colour. On the other hand, a high amount of incoming solar energy is reflected away from the thermochromics pavement since it has incorporated a thermochromics layer.

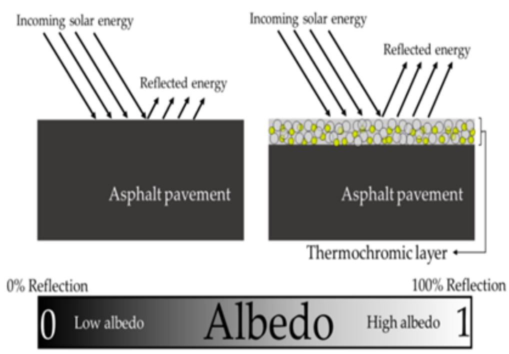

FIGURE 1
Comparison of reflective properties of asphalt pavement and thermochromics pavement
Source: Lima et al, (2022)

To achieve the objective of the study, the following research questions were formulated:

(i) What are the thermochromics pigments effects on the volumetric asphalt mix properties dosed with the thermochromics pigments?
(ii) What are differences in volumetric properties (Percentage Air Voids in compacted mix, bulk Specific Gravity of compacted mix, Percentage Voids Filled with Bitumen) and Voids in Mineral Aggregates, and for a neat asphalt mix, an asphalt mix mixed with blue dye, an asphalt mix that is painted, and an asphalt mix dosed with thermochromics pigments?
(iii) What is the optimum design mix ratio of asphalt mix ratio of asphalt containing thermochromatic pigments?
(iv) What are the differences in the thermal properties of a neat asphalt mix, an asphalt mix mixed with blue dye, an asphalt mix that is painted, and an asphalt mix dosed with thermochromatic pigments?

Scope of the study

Asphalt concrete containing thermochromatic pigment was the aim of this study. Asphalt mix volumetric properties were investigated with the aim of determining whether the thermochromics pigment negatively affects the volumetric properties of the asphalt mix. Marshall Test of various mixes was carried out. The mixes included a neat mix, mix containing thermochromatic pigments, mix containing a blue dye, and a neat mix that was painted later. Asphalt mix containing thermochromatic pigments volumetric properties Also, the thermal performance of the Asphalt Concrete containing Thermochromatic pigments was investigated. The thermal performance was analysed by evaluating the changes in temperature of the asphalt mix in the surface containing thermochromatic pigments and compared to changes in surface temperature of the other mixes over a period of eight weeks.

RESEARCH METHODS

The current study involved analysing the effects of adding a thermochromatic pigment in asphalt mix. Several laboratory tests were conducted. Deductions were made from the results that is, the performance and properties of asphalt containing thermochromatic pigments were measured against neat asphalt mix. Also, for control, the experiment involved two other mixes; an asphalt mix mixed with blue dye and an asphalt mix that is painted later. Conclusions were then made from the results obtained from the laboratory tests and information obtained from secondary sources.

Thika Garissa road was used as a case study for this research. Visual observation of the cracks as a result of thermal stresses was observed.

The pilot test was done in this study to assess the feasibility of methods and procedures to be used in this research; the efficacy of this research was established through the visual observation of the existing pavement made of conventional asphalt concrete on Thika Garissa section.

Overview of Methods

The thermochromatic asphalt binder was prepared by heating the thermochromatic pigments at about 1500C for five minutes. For the pigmented mix, the mix was dosed with 50%, 33.33%, 25%, 20%, and 16.67% by weight of the asphalt binder. The thermochromatic pigments were added to the melted asphalt binder and mixed for approximately five minutes. The modified asphalt binder was then used in casting In addition to the moulds made from the bitumen modified with thermochromatic, other mixes containing other additives were also prepared. The mixes included a neat mix, mix containing thermochromatic pigments, mix containing a blue dye, and a neat mix that was painted later. The volumetric properties of the asphalt mix containing thermochromatic pigments were compared to those of the other mixes. The thermal performance was evaluated by measuring the changes in surface temperature of the asphalt mix containing thermochromatic pigments and compared to changes in surface temperature of the other mixes over a period of eight weeks. The behaviours of the samples were observed under different temperature conditions and conclusions drawn from the results.

Materials

Thermochromatic pigments, blue dye, paint, bituminous binder, and aggregates were the materials used in the laboratory investigations. Apart from the pigments other were sourced from the local suppliers. As required by various codes, materials were prepared and tested.

60/70 pen grade bitumen was used in the research. It was sourced at Kenya Colas Industrial area Nairobi.

Kenya Colas production of bitumen meets all the requirements. Below are some of the test which were conducted

Specific gravity at 25°C (AASHTO Test T228)

(i) Specific gravity, ring and ball
(ii) Penetration at 25oc,100g,5s (ASTM D5 Test)

The fine and coarse aggregates were sourced locally, 14/6 and 0/6 aggregates sizes were used for the design mix. For grade sieve analysis, guidelines in ASTM E11, were carried out on oven-dried sample of aggregates to get a batch that lies within the grading envelop.

Aggregates mechanical properties such as toughness, water absorption, strength, and hardness were researched in this study to evaluate that they were within the limit specified by the standard specification Aggregates having good hardness, strength and toughness were used in this research. Below tests were conducted on the aggregates:

(i) Los Angeles abrasion (ASTM C131)
(ii) Aggregate crushing value (BS812 Part3)
(iii) Aggregate impact value (BS812 Part3)
(iv) Water absorption test (ASTM C127)

Thermochromatic Pigments

This is substances which can change color reversibly in response to temperature. It can be designed to have high solar reflectance at high temperature and low solar reflectance at low temperature. They are potential materials that can change thermal condition of the pavements. This study was to develop thermochromatic asphalt concrete containing dynamic solar reflectance in response to environmental temperature. In this process, the correct proportions of bitumen, fine and coarse aggregate, and sometimes chippings were selected to produce an asphalt pavement having the properties specified. Approximately 1200 grams of aggregates and filler were heated to a temperature of 190°C. Bitumen was then heated to a temperature of 125°C having a content of 4% (whether bitumen was alone or mixed with other components) by weight of the material aggregates.

The bitumen binder was then mixed with the thermochromatic pigment in different ratios (2-5%) at a temperature of least 150oC. The heated aggregates were then thoroughly mixed with bitumen and the pigment at a temperature of 160°C. The mix was then placed in a preheated mould at a temperature of 145oC, the mix was compacted using a standard rammer and given fifty blows on either side. The mixed aggregate weight was taken for specimen preparation and suitably altered to get compacted thickness of 63.5mm. The above procedure was repeated for the remaining four moulds samples with different ratios of bitumen, with ordinary dye for the second specimen, for asphalt without anything added to it and for the asphalt to be painted later. The prepared moulds were then loaded in the Marshall Test setup. The third sample was painted with a blue paint on one side of the sample once it cooled. The samples were exposed to the environment and surface temperatures and were taken in the morning and at midday for each sample.

Marshall Test (Overseas Road Note 19)
Bituminous materials at a loading rate of 50.8mm/min, the Marshall Stability test measured the maximum load sustained in any bituminous materials. Until it reached maximum, the test load was increased. This test is mostly used in routine test for the paving jobs. The objective of the Marshall test was to determine the flow and stability values of the bituminous mix samples. Also, another objective of the test was to evaluate the performance of the various bituminous mixes that had been prepared with different components.

The marshal stability test was conducted in compliance with ASTM 1599 test procedure on all specimen made of various percentages of bitumen, thermochromatic pigments, paint and dye. 1200g should be the total weight of the mix. Sample readings were then recorded and comparison was made. Obtained data on different parameters were graphically analysed with the critical aim being to make comparison of the mixes with different binder composition. The obtained data was then compared to the specification required of the mixes. The following parameters were determined from the Marshall Stability test:

(i) Stability and flow
(ii) Bulk specific gravity of compacted mix
(iii) Voids in mineral aggregates
(iv) Percent air voids in compacted mix
(v) Percent voids filled with bitumen

RESULTS

Flakiness Index (F.I)
Using the following formulae, the Flakiness Index of the aggregates was calculated:

Flakiness Index (F.I)
= M2/M1x 100 %........................(1)
= 451/1895 x 100%
= 23.8%

Table 1 shows the flakiness index values.

TABLE 1
Results for the Flakiness Index

Sample	Weight (g)
Initial test sample, M1	2500
Final test sample, M2	1933

Source: Field survey, 2024

From research, the Flakiness Index of the aggregates used in construction of roads should be between 20% and 30% for optimum road conditions. From calculations above on Flakiness Index giving a result of 23.8% was then concluded to be satisfactory. Therefore, the aggregates were allowed to be included in the mix design.

Los Angeles Abrasion (L.A.A)
Table 2 shows L.A.A values.

The Los Angeles Abrasion was then calculated as follows:

$$\text{L.A. A}= \frac{M_1-M_2}{M1} \times 100\% \ldots\ldots (2)$$

$$\text{L.A. A} = \frac{2500-1933}{2500} \times 100\%$$

$$\text{L.A. A}= 22.68\%$$

TABLE 2
Results of Los Angeles Abrasion

Aggregate Sample	Weight (g)
Initial aggregate sample, M1	1500
Fraction passing through the sieve, M2	255

Source: Field survey, 2024

The maximum allowed Los Angeles Abrasion value for a Water Bound Macadam (WBM) Road is 40%. According to the results, the value of 8.35% L.A.A is satisfactory, and the aggregates can, therefore, be used in production of the asphalt mix.

Aggregate Crushing Value (ACV)

$$\text{Aggregate Crushing Value (ACV)} = \frac{M_2}{M_1} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\text{Aggregate Crushing Value (ACV)} = \frac{255}{1500} \times 100\% = 17\%$$

Table 3 shows Aggregate Crushing Value.

TABLE 3
Results for the aggregate crushing value test

Sieve Size (mm)	Weight Retained, M1(g)	Weight Passing Special Sieve, M2(g)
28	0	
20	863.5	117
14	377.5	75.5
10	301	103.5
5	353	155
Total	**1895**	**451**

Source: Field survey, 2024

Aggregate Gradation

For durable and stable mixes, well-graded materials are needed for densest mix which would require bitumen content at minimum both neat and modified samples used aggregates gradation as shown in **Table 4. Figure 2** shows the grading curve for the blended aggregates (combined fine and coarse aggregates).

The main factors that influence workability include the following:

(i) The surface area of the aggregate which determines the amount of water needed to wet all the solids
(ii) The relative volume occupied by the aggregate
(iii) The tendency to segregate
(iv) The quantity of fines in the mix

From the grading curve, shown in **Figure 2,** the distribution of the particle size of the fine aggregate fell within the upper and the lower limits. Therefore, the grading of the aggregates was satisfactory in the preparation of the asphalt concrete.

Neat Mix

For the Neat Mix, the following materials were used;

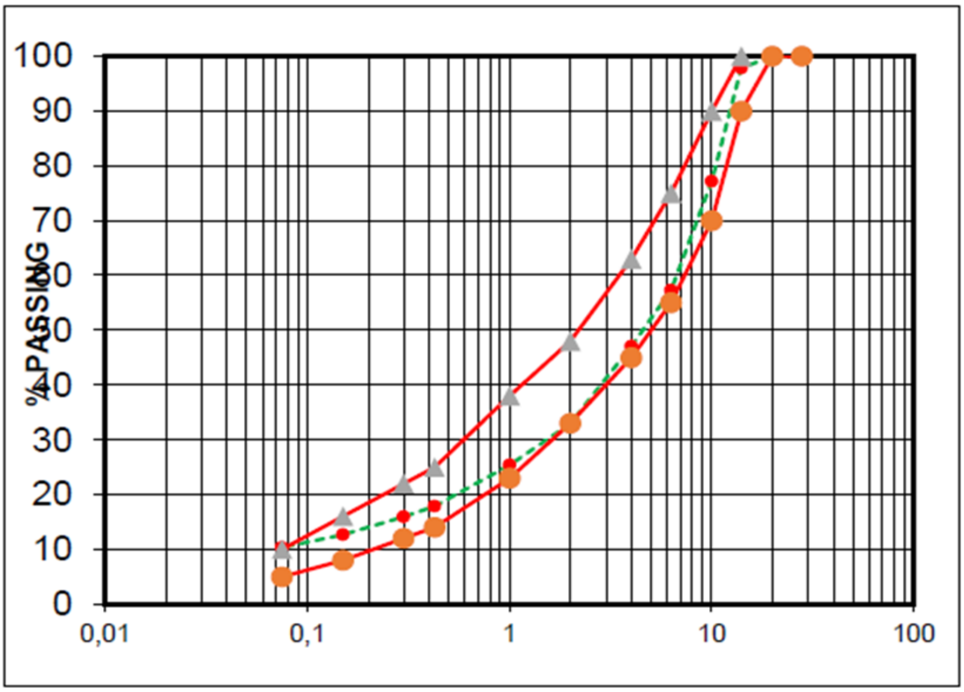

FIGURE 2
Aggregate grading used in the mix design and design specifications
Source: Field survey, 2024

TABLE 4
Aggregate gradation

AGGREGATES					
Sample no	Nominal Size	Description and Source	TRIAL MIX		
			Total Wt.	%	Wt.
2	0	Aggregates	0	0	0
3	0	Aggregates	0	0	0
4	6/14	Aggregates	1100	53	583
5	0/6	Crushed rock	1100	47	517

SIEVE ANALYSIS % PASSING								
Sample Number	1	2	3	4	5	THEO.	DESIGN MIX	
% in Mix 100	0	0	0	53	47	COMBINED	SPEC.	
Sieve Size (mm)						GRADING		
28	100	100	100	100	100	100.0	100	
20	100	100	100	100	100	100	**100**	
14	100	100	100	96	100	98	**90**	**100**
10	100	100	100	57	100	77	**70**	**90**
6.3	100	100	100	23	96	57	**55**	**75**
4	100	100	100	9	90	47	**45**	**63**
2	100	100	100	0	70	33	**33**	**48**
1	100	100	100	0	54	25	**23**	**38**
0.425	100.0	100	100	0.0	38	18	**14**	**25**
0.3	100.0	100	100	0.0	34	16	**12**	**22**
0.15	100.0	100	100	0.0	27	13	**8**	**16**
0.075	100.0	100	100	0.0	22	10	**5**	**10**

Source: Field survey, 2024

- 900g of course aggregate
- 200g of fine aggregate

i. Theoretical Specific Gravity

Specific Gravity, $G_t = \frac{W1+W2+W3+Wb}{\frac{W1}{G1}+\frac{W2}{G2}+\frac{W3}{G3}+\frac{Wb}{Gb}}$ ....(1)

Specific Gravity, $G_t = \frac{900+200+100+40}{\frac{900}{2.7}+\frac{200}{2.1}+\frac{100}{1.7}+\frac{40}{1.03}}$ = 2.36

ii. Bulk Specific Density

Bulk Density, $G_m = \frac{Weight\ of\ mix\ in\ air}{Weight\ of\ Mix\ in\ Air - Weight\ of\ mix\ in\ water}$ .... (2)

Bulk Density, $G_m = \frac{1240}{1240-695}$ = 2.275

iii. Percentage Air Voids

Percentage Air Voids, $V_v = \frac{(G_t - G_m)100}{G_t}$ ....(3)

Percentage Air Voids, $V_v = \frac{(2.36-2.275)100}{2.36}$ = 3.6%

iv. Percentage Volume of Bitumen

Percentage Volume of Bitumen, $V_b = \frac{\frac{Wb}{Gb}}{\frac{W1+W2+W3+Wb}{Gm}} \times 100\%$...... (4)

Percentage Volume of Bitumen, $V_b = \frac{\frac{40}{1.03}}{\frac{900+200+100+40}{2.275}} \times 100\%$ = 7.12%

v. Percentage Void in Mixed Aggregates

Percentage Void in Mixed Aggregates, VMA= $V_v + V_b$ .... (5)
= 7.12 + 3.6
= 10.72%

- 100g of rock dust used as filler material
- 40g of bitumen

The thermal stress in the asphalt concrete with thermochromatic pigment added to it use the following formula:

Thermal Stress, δx= α. Δt. E…. (6)

Where: δx is the thermal stress

α is the linear coefficient of thermal contraction/ expansion

Δt is the change in temperature of the asphalt concrete

E is the elastic modulus

The thermal stress of the Pigmented Mix was compared to the thermal stress of the other three mixes i.e., the Neat Mix, the Painted Mix, and the Dyed Mix. The Young's modulus for bitumen-based road surfaces usually ranges between 2 – 3 Giga-Pascal's and the linear co-efficient for thermal expansion or contraction is 3 × 10-5 per 1oC. Thermal stress is also a factor of both temperature and was calculated as follows:

For Neat Mix:
Thermal Stress, δx = (3 × 10-5/oC × 23.6oC) × (3 × 106 kN/m2 × 0.152)
= 47.8 KN/m2

For Painted Mix:
Thermal Stress, δx = (3 × 10-5/oC × 11.2oC) × (3 × 106 kN/m2 × 0.152)
= 22.68 kN/m2

For Dyed Mix:
Thermal Stress, δx= (3 × 10-5/oC × 8.7oC) × (3 × 106 kN/m2 × 0.152)
= 17.62 kN/m2

For Pigmented Mix:
Thermal Stress, δx= (3 × 10-5/oC × 7.8oC) × (3 × 106 kN/m2 × 0.152)
= 15.8 kN/m2

Painted Mix
The calculated results on the mix properties were therefore like those of the asphalt concrete with nothing added to it and were summarized as follows:

- Specific Gravity, Gt= 2.36
- Bulk Specific Density, Gm= 2.275
- Percentage Air Voids, Vv= 3.6%
- Percentage Volume of Bitumen, Vb= 7.12%
- Percentage Void in Mixed Aggregates= 10.72%

Dyed Mix
For the Dyed Mix, a blue dye was added, and mix volumetric properties investigated to determine any properties changes in the. For this mix, below proportions of materials were used:

- 900g of course aggregate

i. Theoretical Specific Gravity

$$\text{Specific Gravity, } G_t = \frac{W1+W2+W3+Wb+Wd}{\frac{W1}{G1}+\frac{W2}{G2}+\frac{W3}{G3}+\frac{Wb}{Gb}+\frac{Wd}{Gd}} \quad \ldots\ldots\ldots\ldots(8)$$

$$\text{Specific Gravity, } G_t = \frac{900+200+100+40}{\frac{900}{2.7}+\frac{200}{2.1}+\frac{50}{1.7}+\frac{40}{1.03}+\frac{50}{1.3}} = 2.31$$

ii. Bulk Specific Density

$$\text{Bulk Density, } G_m = \frac{\text{Weight of mix in air}}{\text{Weight of Mix in Air} - \text{Weight of mix in water}} \quad \ldots..(4.10)$$

$$\text{Bulk Density, } G_m = \frac{1240}{1240-675} = 2.19$$

iii. Percentage Air Voids

$$\text{Percentage Air Voids, } V_v = \frac{(G_t - G_m)100}{G_t} \quad \ldots\ldots\ldots\ldots\ldots..(4.11)$$

$$\text{Percentage Air Voids, } V_v = \frac{(2.31-2.19)100}{2.31} = 5.19\%$$

iv. Percentage Volume of Bitumen

$$\text{Percentage Volume of Bitumen, } V_b = \frac{\frac{Wb}{Gb}}{\frac{W1+W2+W3+Wb}{Gm}} \times 100\% \quad \ldots\ldots.(9)$$

$$\text{Percentage Volume of Bitumen, } V_b = \frac{\frac{40}{1.03}}{\frac{900+200+50+40+50}{2.19}} \times 100\% = 6.86\%$$

v. Percentage Void in Mixed Aggregates

$$\text{Percentage Void in Mixed Aggregates, } VMA = V_v + V_b = 6.86 + 5.48 = 12.34\%$$

- 200g of fine aggregate
- 50g of rock dust used as filler material
- 50g of blue dye in powder form
- 40g of bitumen

Tests on Bitumen
Ring-and-ball softening point and the penetration test were the tests that were done to evaluate the properties of the binder. They were carried out in accordance to the AASHTO standard procedures. The results are as shown on **Table 5**.

TABLE 5
Results of tests on bitumen

Penetration at 250C, 100g, 5s (ASTM D5 Test)	64
Softening Point, ring-and-ball (ASTM D36 Test)	55.00C
Specific gravity at 250C (AASHTO Test T228)	1.01

Source: Field survey, 2024

Pigmented Mix- Asphalt mix modified with thermochromatic pigment
The thermochromatic pigment was used as an additive in the mix. To determine the optimum ratio of the additives and bitumen, test was carried out. Based on previous similar studies, the following additive percentages were selected: 50%, 33.33%, 25%, 20%, and 16.67%. In addition to the volumetric properties being investigated, the current study also investigated temperature changes in the various mixes by exposing samples to the environment.

The results of the volumetric properties and change in temperature for the five mixes were recorded in **Table 6**.

Analysis of Pigmented Samples

i) Theoretical Specific Gravity of the Mix
As shown in **Figure 3**, Specific gravity values decreased with increasing thermochromatic pigment content from 16.66% up to 50%. This can be as a result of lower specific gravity of the thermochromatic pigments compared to bitumen.

ii) Bulk Density of the Mix
As shown in **Figure 4**, specific gravity values decreased with the rise in bitumen content from 16.66% up to 30% from where it commenced increasing up to 50%.

iii) Percentage Air Voids
Figure 5 shows the value for VIM against percentage thermochromics pigment content.

iv) Percentage Volume of Bitumen
The percentage of volume of bitumen increased with increasing thermochromatic pigments content.

V) Percentage Voids in Mixed Aggregate
As shown in **Figure 7**, the value of percentage voids in mineral aggregates increased with increasing thermochromatic pigments content.

TABLE 6
Volumetric properties and changes in temperatures for the mixes

Mix	Percentage of pigment in mix	Theoretical Specific Gravity, Gt	Bulk Specific Gravity, Gm	Percentage Air Voids, Vv (%)	Percentage Volume of Bitumen, Vb (%)	Percentage Voids in Mixed Aggregate, VMA (%)	Change in Temp. ΔT
Mix 1	50	2.23	2.82	9.63	6.42	16.05	6.1
Mix 2	33.33	2.31	2.10	8.94	6.13	15.07	7.4
Mix 3	25	2.36	2.16	8.47	5.67	13.54	8.0
Mix 4	20	2.40	2.40	7.83	4.61	12.44	10.3
Mix 5	16.67	2.44	2.44	6.91	4.12	11.03	13.8
Neat Mix	0	2.36	2.275	3.6	7.12	10.28	

Source: Field survey, 2024

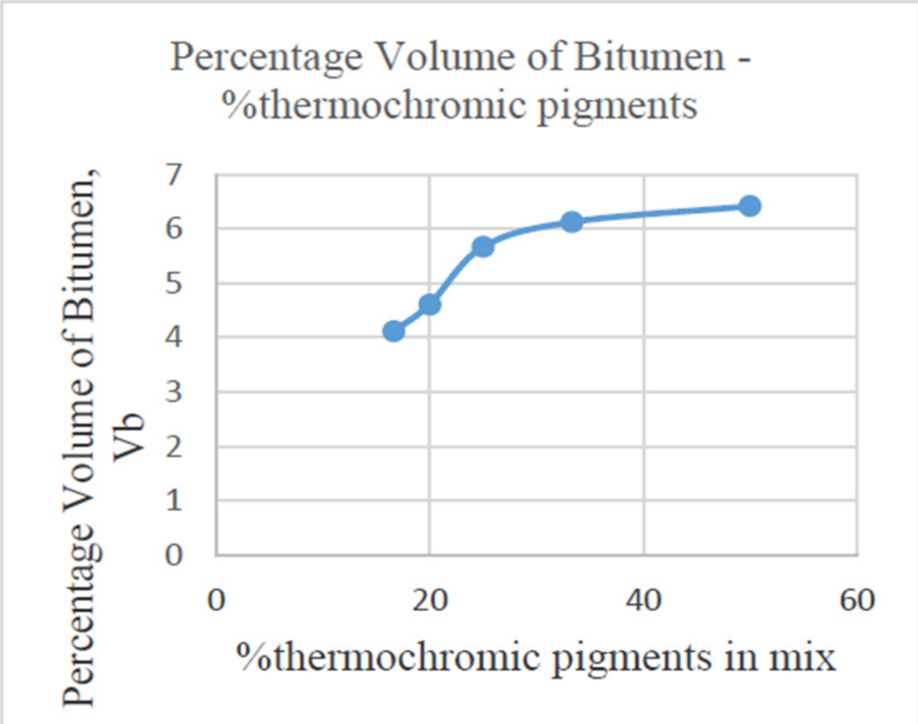

FIGURE 3
Percentage Volume of Bitumen against % thermochromatic content
Source: Field survey, 2024

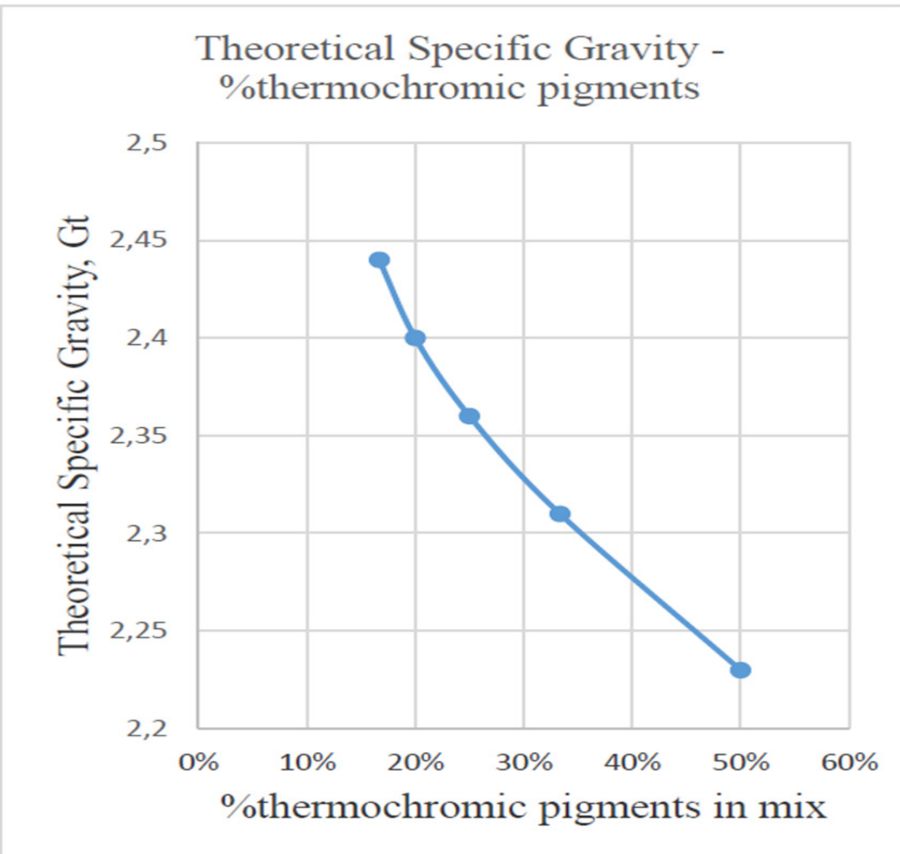

FIGURE 4
Percentage Volume of Bitumen against % thermochromatic content
Source: Field survey, 2024

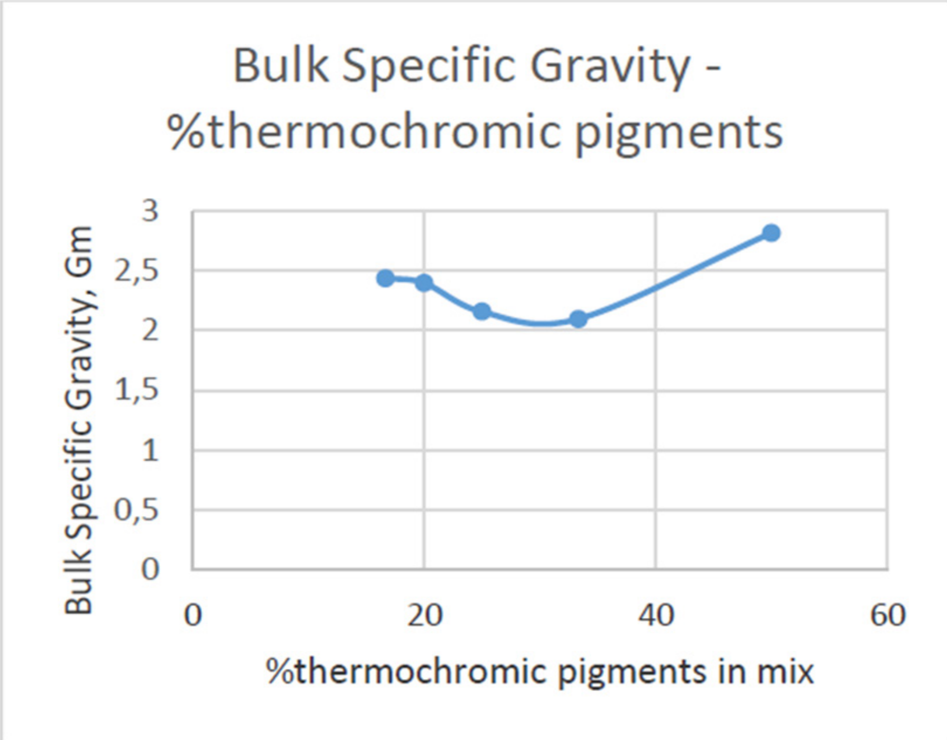

FIGURE 5
Bulk Specific Gravity against %thermochromics content
Source: Field survey, 2024

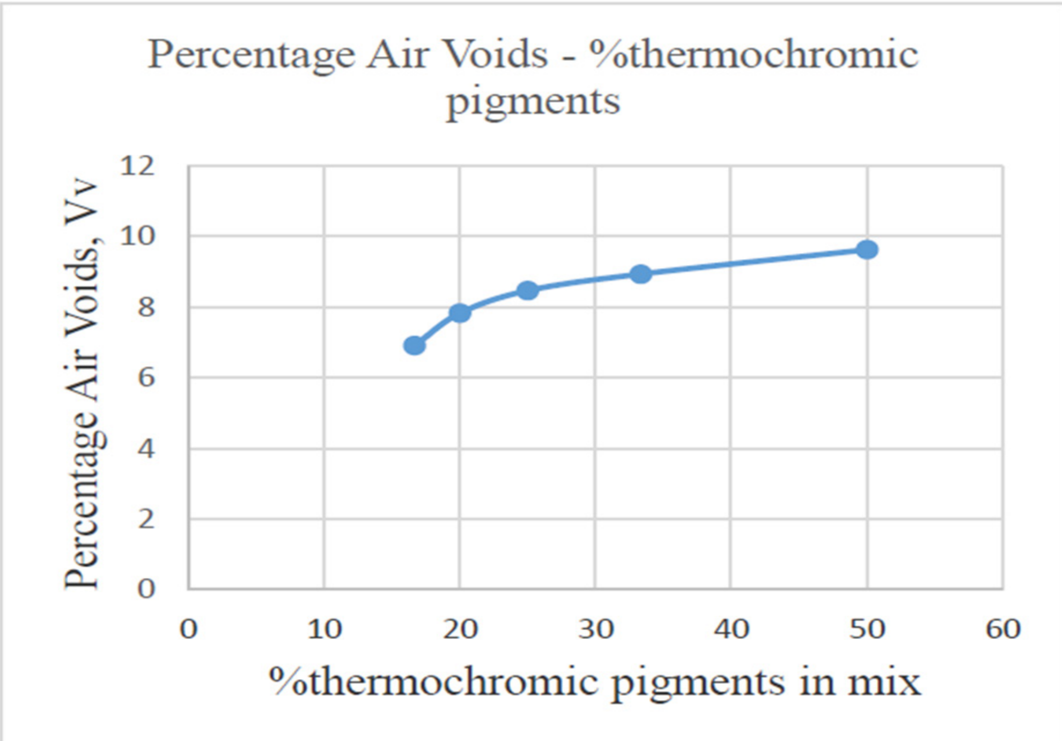

FIGURE 6
Percentage Air Voids against % thermochromics content
Source: Field survey, 2024

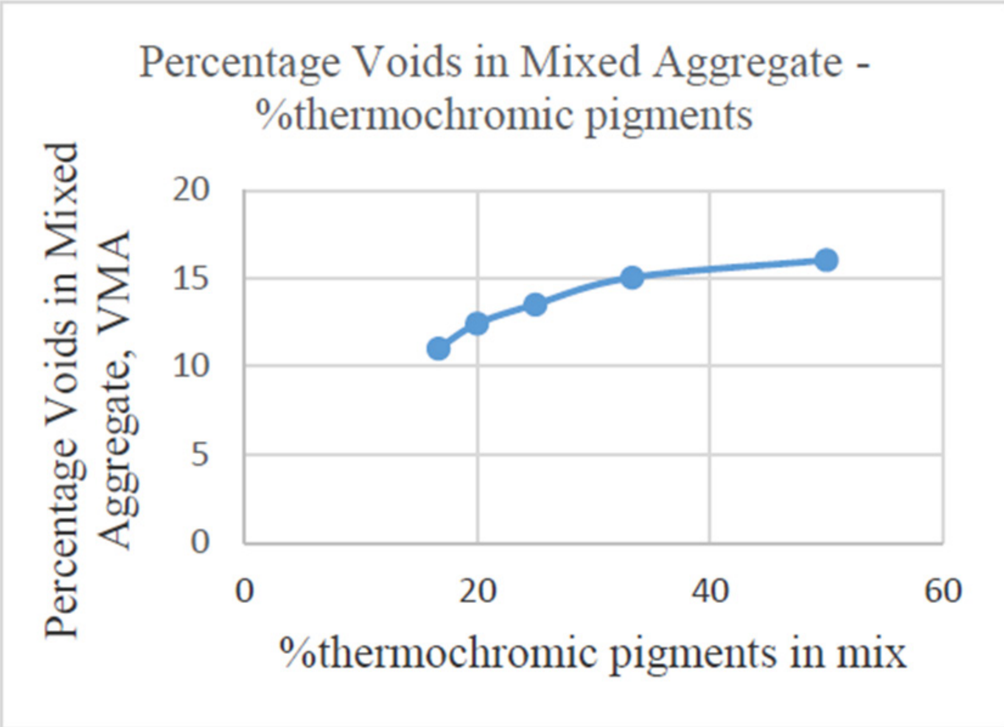

FIGURE 7
Percentage Voids in Mixed Aggregate against % thermochromics content
Source: Field survey, 2024

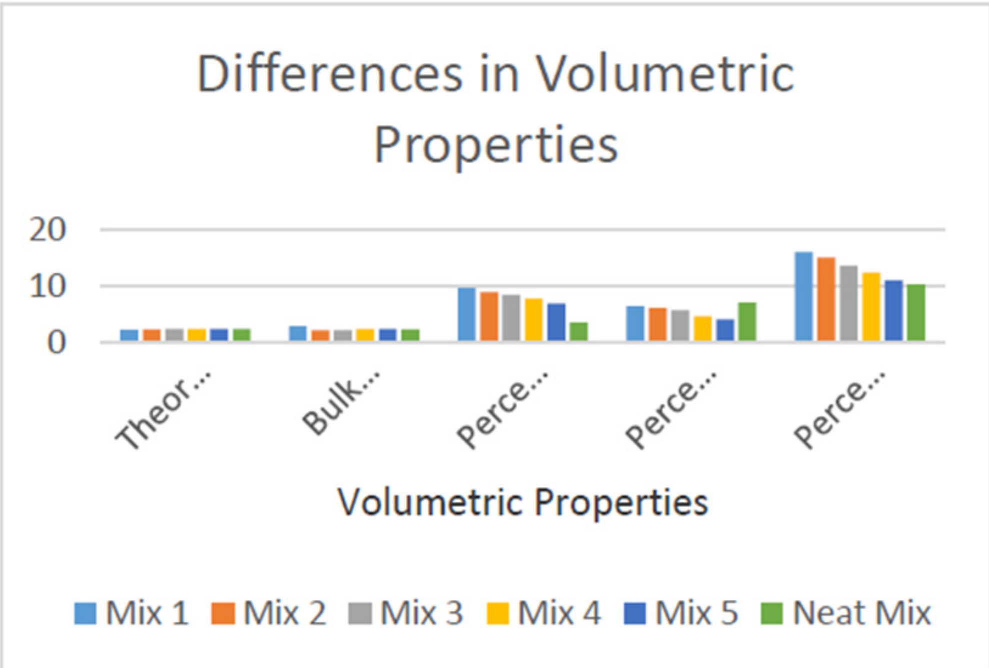

FIGURE 8
Summary of differences in volumetric properties in mixes with varying proportions of thermochromatic pigments
Source: Field survey, 2024

Figure 8 shows the differences in volumetric properties between the neat mix and mixes with varying proportions of thermochromics pigments.

Summary of differences in volumetric properties in mixes with varying proportions of thermochromics pigments

Mix 3 was selected as the mix with the optimum proportion of additive; 25% of the bitumen weight of thermochromics pigments was added to the asphalt mix. Mix 3 was considered to be the optimum mix due to the closeness of its properties to the neat mix. The purpose of the ther-mochromics pigments additive was to improve the reflective properties of the asphalt mix with-out altering much of its volumetric prop therefore also maximum strength. A deviation in the volumetric properties would mean a negative impact on the strength of the bituminous mix. Mix 3 is the closest in terms of volumetric properties. Also, Mix 3 has a low temperature change in-dicating a high reflectivity of solar radiation. Mix 3 was therefore adopted for the rest of the study (henceforth referred to as Pigmented Mix).

DISCUSSION

Table 7 summarizes the volumetric properties and thermal properties of the four mixes with the aim of determining the differences in their performance in road pavements.

From the calculations of average initial and final temperatures of the four mixes (Neat Mix, Painted Mix, Dyed Mix, and Pigmented Mix), it was determined that the Neat Mix underwent the highest change in temperature (24.6oC). The Neat Mix absorbed the largest quantity of solar radiation when exposed to the environment. This means that flexible pavements made from this mix were most susceptible to cracking as a result of high temperatures condition during the day.

The Painted Mix, the temperature was second highest with a value of 10.2oC. however, the difference in temperature change between the Neat Mix and Painted Mix is significant. Therefore, it can be concluded that only a small amount of solar radiation was absorbed by the asphalt concrete. The blue paint provided a cover layer and also reflected away the direct solar radiation from the asphalt concrete. From the temperature results recorded however, it was realized that the final temperatures were very small at the start but as time went by, the temperatures gradually increased. This was because when the paint, which provided a cover layer and a reflective surface, started to peel off hence exposing the asphalt pavement to direct solar radiation. The peeling off of the paint meant the solar radiation was now able to penetrate the paint layer and get absorbed by the asphalt concrete hence resulting in an increase of temperatures over the later weeks of the experiment.

The Dyed Mix registered the second-best temperature change of all the four mixes. The temperature change was determined as 8.8oC. The good performance of the asphalt mix, with regards to temperature change, can be attributed to its colour change. The blue dye changed the colour of the black and dark asphalt mix to from a permanent dark blue colour. The partial blue colour in the Dyed Mix improved the mix's reflective characteristics. Therefore, it was able to reflect away solar radiation hence the mix

TABLE 7

Volumetric properties and changes in temperatures for the mixes

Mix	Theoretical Specific Gravity, G_t	Bulk Specific Gravity, G_m	Percentage Air Voids, V_v (%)	Percentage Volume of Bitumen, V_b (%)	Percentage Voids in Mixed Aggregate, VMA (%)	Change in Temp. ΔT
Neat Mix	2.37	2.285	3.5	7.13	10.18	23.6
Painted Mix	2.37	2.285	3.5	7.13	10.18	11.2
Dyed mix	2.31	2.19	5.18	6.76	12.24	8.7
Pigmented mix	2.36	2.16	8.47	5.07	13.54	7.8

Source: Field survey, 2024

undergo less temperature change compared to the Neat Mix and Painted Mix.

The Pigmented Mix recorded the lowest temperature change of all the four mixes (8.0oC). The grey thermochromics pigment added to the mix changed into a light blue colour when the specimen was exposed to direct solar radiation. The light blue coloured mix was then able to reflect away solar radiation hence resulting in very little heat absorbed by the asphalt mix.

The Dyed Mix, even though produced almost similar results to the Pigmented Mix (8.8oC compared to 8.0oC), was not a desired method in reducing thermally induced cracks in the bitumen-based surfaces. The dyed mix permanently changed colour to blue, therefore, may be confusing to drivers who are used to the dark colour of roads. In contrast, the Pigmented Mix only changed colour when exposed to sunlight. Its light blue colour was better than the dark blue colour of the Dyed Mix in reflecting sunlight.

CONCLUSION AND RECOMMENDATIONS

The project was successfully concluded as all specific objectives of the experiment were achieved.

It was determined that the Pigmented Mix was effective in reflecting away sunlight hence underwent little temperature changes. The little temperature changes meant that the thermochromics pigments were successful in reducing thermal stresses in the mix hence effective in reducing thermal cracking of bituminous mixes.

The optimum percentage of adding thermochromics pigments to asphalt mix was determined as 25% of the bitumen weight. At 25% thermochromics pigments and 75% bitumen, the asphalt mixes still maintained most of its desired volumetric properties and improved the thermal properties of the mix.

It was then concluded that, the probability and degree of future occurrence of thermally induced cracks can be prevented, reduced, or eliminated by mixing the binder material (bitumen) with the thermochromics pigment in the ratio 3:1 respectively during the preparation of the asphalt.

When the addition of thermochromics pigments is done in large scale, the overall objective will be achieved and the thermally induced cracks in the roads, airport runways and any other bitumen-based surfaces will be either prevented completely or reduced.

This study had no advanced equipment's to study the long term stability check for asphalt concrete containing thermochromatic pigments.

When preparing the design mix of asphalt concrete, it is prudent to incorporate thermochromatic pigments as it alters solar reflectance at the rate of 25% and 75% bitumen in order to reduce the rate of thermally induced cracks in asphalts made of concrete.

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