Effect of Candle Wax on the Mechanical Properties of Recycled Concretes as Coarse Aggregate in Bituminous Concretes.

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ABSTRACT

All over the world, the need to reduce environmental waste has been emphasized to encourage cleanliness and reduce other environmental risks. One of such ways, however, is through the concept of material re-use technically termed recycling which is a major focus of the present study. A major problem considered in this study was drawn from the concern in the excessive use of gravel as coarse aggregate in the construction of road pavements and other structural works. Secondly, the risk of near depletion of these aggregates is no longer a hearsay rather a concern that requires mitigation especially due to rising population increase that has in turn affected rates of construction on the high. On this basis the present study aimed at using recycled concrete aggregate (RCA) as coarse aggregate in bituminous concrete mixtures to ascertain its suitability. However, on the contrary previous researches have shown that RCA alone does not meet specification requirements. It is on this basis that the present study further sought methods of mitigating the shortfall in using RCA alone by blending with varying amounts of candle wax. The methodology involved preparation of bituminous concrete samples using RCA alone and RCA blended with candle wax and subjecting the samples to indirect tensile splitting test, density, and voids analysis test. The results obtained showed that for optimal performance, a blend of 20% RCA plus 20% candle wax was adequate to meet standard specification requirements. Therefore, it is recommended that RCA be incorporated into bituminous mixtures as revealed in the study.

Keywords: Compaction, Asphalt Concrete, Compressive Strength, Stability, Tensile Strength, Candle Wax;
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1.0 Introduction

A substantial amount of natural resources is consumed during the construction and maintenance of roads making it pertinent to re-use waste as raw material to minimise the use of natural aggregates in road construction. Construction and demolition waste such as recycled concrete aggregate need to be incorporated in the construction and maintenance process.

Several studies have investigated the incorporation of various wastes such as construction and demolition wastes, end-of-life tires, reclaimed asphalt pavement, used motor oils, plastics, and asphalt shingles into road pavement layers (Pasandin, 2015). Demolished construction waste from concrete structures have proven from previous studies to be a good source of construction material. A review of related literature shows that although a lot of research has been conducted with respect to using alternative recycled concrete as materials, modifying it with non-bituminous additives such as candle wax will improve pavement performance.

Recycled concretes are much different from pure natural aggregates and has some amount of cement paste on the surface even after the process of recycling. This high porous cement paste has caused variation in the quality of the recycled concrete, lower particle density, high porosity, and high-water absorption.

To this end, in recent years the need to recycle materials has been emphasizes due to shortage in natural materials and the high cost of reclaiming lands in some countries by refilling it.

1.1 Materials and methods

The following materials were used for the purpose of the study:
a) Bitumen
b) Aggregates

I. Gravel and Recycled aggregate as Coarse
II. Sand as Fine
III. Mineral Fillers: White Cement, Quarry Dust and Crushed Granite Dust

1.2 Methods

For purpose of the research work the following methodology was adopted;

1.2.1 Sampling

The coarse and fine aggregates were both obtained from commercial sources within Port Harcourt.The Recycled concrete aggregate used was obtained from a construction site (NLNG project) at Amadi, Port Harcourt. The bitumen used is of grade 60/70 by penetration and was sourced from Mobil-Oil Nigeria Plc. Port Harcourt. Quarry dust and crushed granite dust were both obtained from MCC Nigeria Limited at their asphalt production site, Port Harcourt.

The Recycled concrete aggregate (RCA) sample consists mainly of an original natural aggregate partially covered by a mortar layer which is more porous and less dense than the natural aggregate.

The Recycled concrete aggregate (RCA) was however crushed and cleaned to remove contaminants such as polyethene, rubber and other soft or friable particles before gradation.

1.2.2 Laboratory Tests and Experiments

The laboratory test and experiments involved material classification and sample preparation.

1.2.3 Material Classification Test

The preliminary tests carried out on materials for this research were in accordance with ASTM Standards, British Standards, and Indian Standards

1.2.4 Blending of Aggregate / Mix Proportion

To meet specifications for aggregate gradation, the proportion of mix for each aggregate was determined using numerical methods. Thus, aggregate blending determines the proportion (or relative masses) in which aggregate batches having different gradations are to be blended to achieve a target mix with a given gradation.

1.2.5 Sample Preparations

Asphalt Concrete Mix design is basically the selection and proportioning of an economic blend of aggregates and asphalt to produce a mix having:

- sufficient asphalt to ensure a durable pavement

- sufficient mix stability to satisfy the demands of traffic without distortion or displacement
- sufficient voids in the total compacted mix to allow for additional amount of compaction under traffic loading without flushing, bleeding or loss in stability; yet low enough to prevent harmful air and moisture.
- sufficient workability to permit efficient placement of the mix without segregation.

Based on these requirements, samples were prepared using the Marshall Design procedures for asphalt concrete mixes as per ASTM D-1559.

2.0 Marshal Design Method

Samples were prepared using the Marshall method of asphalt mix design presented by Asphalt Institute (1997). With the following major steps:

i. Aggregates were blended in proportions that meet the specification for both control mix design parameter and modified concrete.
ii. The asphalt was heated to required temperature after which test on penetration, softening point, viscosity and specific gravity were done. From the control mix design an optimum asphalt content of 4.8% was determined which was used for modification of the concrete.
iii. Briquettes were prepared at optimum asphalt content with a total number of 69 samples for heavy traffic category; compacting effort of 75blows representing heavy traffic category were given on each face of the sample after which the density of the briquettes were measured to allow for calculation of voids properties.

Briquettes were cured at a temperature of 60^0C. Stability and flow values were obtained using the Marshall apparatus to measure strength and flexibility, while other parameters were calculated using various equations.

2.1 Determination of Optimum Binder Content (OBC) (ASTM D6927, 1979)

The determination of Optimum Asphalt Content (OAC) is so critical in the quest for Asphalt Concrete mix. It is essential by setting a bases for the comparison hinged on maximum requirements as the fulcrum in the design procedure for a particular mix design that would stand to be accepted or rejected given the type of traffic in question.

i. The various design properties for each are plotted against Asphalt Content such as
Stability V Asphalt Content (a)
Flow V Asphalt Content (b)
Density V Asphalt Content (c)
a. Percent air voids V Asphalt Content
b. Percent Voids in Mineral Aggregate VMA V Asphalt Content

ii. Determine the Various Parameters
c. Asphalt Content at Maximum Stability
d. Asphalt Content at Maximum Density
e. Asphalt Content at Median Limits of Air Voids (i.e. at 4% air voids)

Optimum Asphalt Content are being determine based on parameter (ii) above, hence they are being sort for.

iii. Then, the arithmetic mean of the Asphalt Content (a-c) from (ii) above equals the designed asphalt content otherwise known as optimum Asphalt Content (OAC) in accordance with (Asphalt Institute 1984, National Asphalt Pavement Association, 1982) as:

$$OAC = \frac{1}{3}(AC_{max\ stability} + AC_{max\ Density} + AC_{max\ median\ Limits\ of\ air\ voids})$$

$$OAC = \frac{1}{3}(a+b+c)$$

iv. Obtain mix design properties for each traffic category that optimum asphalt content.
v. Check for suitability of design parameters in accordance with Marshall Standards.

Table A: Summary of Mix Properties for Unmodified Asphalt Concrete (to get OBC)

Asphalt Content	Gmb	Density (kg/m3)	Stability (N)	Flow (0.25MM)	VMA (%)	Gmm	Air voids (%)
4	2.261	2261	4681.53	12.5	15.05	2.384	5.15939597
4.5	2.313	2313	5108.41	11.96	13.27	2.438	5.1271534
5	2.282	2282	7123.17	10.39	11.63	2.396	4.75792988
5.5	2.28	2280	5911.38	9.57	11.09	2.399	4.96040017
6	2.239	2239	5817.13	10.98	12.00	2.357	5.00636402

Table B: Results of Tensile Strength of Recycled Concrete Blended at various Candle Wax content

	0% CW	5% CW	10% CW	15% CW	20% CW	25% CW
Recycled Concrete (%)	Tensile Strength (N/mm^2) σx	Tensile Strength (N/mm^2) σx	Tensile Strength (N/mm^2) σx	Tensile Strength (N/mm^2) σx	Tensile Strength (N/mm^2) σx	Tensile Strength (N/mm^2) σx
0	1.208	1.210	1.366	1.424	1.444	1.464
5	1.205	1.226	1.443	1.55	1.651	1.635
10	1.202	1.329	1.561	1.706	1.882	1.889
15	1.163	1.454	1.670	1.745	2.053	2.089
20	1.154	1.427	1.732	1.794	2.136	1.936
25	1.026	1.113	1.380	1.502	1.672	1.599

Table C: Results of Compressive Strength of Recycled Concrete Blended at various Candle Wax content.

	0% CW	5% CW	10% CW	15% CW	20% CW	25% CW

Recycled Concrete (%)	Comp Strength (N/mm^2) σy	Comp Strength (N/mm^2) σy	Comp Strength (N/mm^2) σy	Comp Strength (N/mm^2) σy	Comp Strength (N/mm^2) σy	Comp Strength (N/mm^2) σy
0	-3.624	-3.63	-4.098	-4.272	-4.332	-4.392
5	-3.615	-3.678	-4.329	-4.65	-4.953	-4.905
10	-3.606	-3.987	-4.683	-5.118	-5.646	-5.667
15	-3.489	-4.362	-5.01	-5.235	-6.159	-6.267
20	-3.462	-4.281	-5.196	-5.382	-6.408	-5.808
25	-3.078	-3.339	-4.14	-4.506	-5.016	-4.797

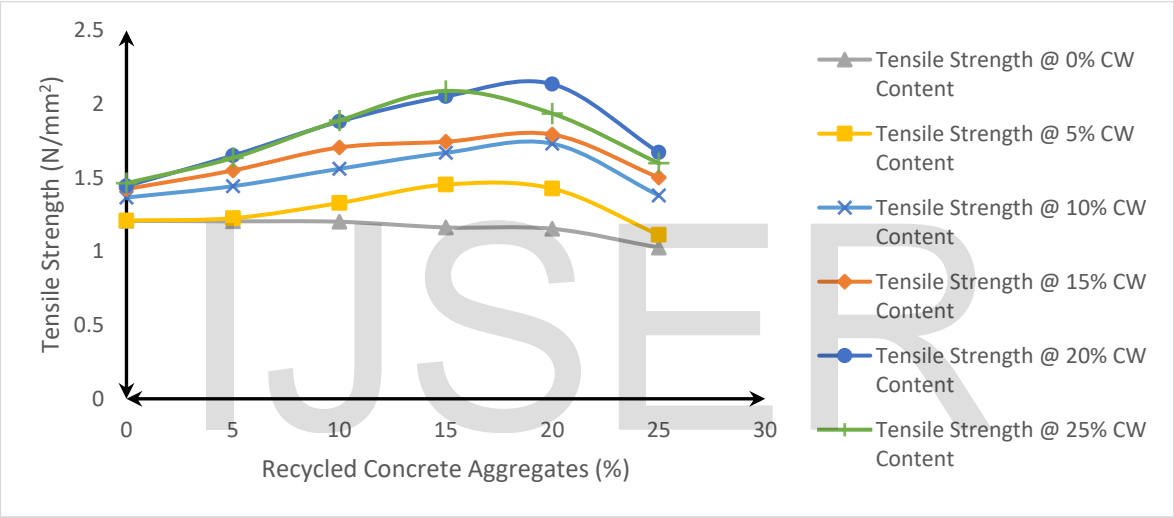

Figure 1: Graph showing the variations of Tensile Strength for Recycled Asphaltic Concrete @ various CW contents

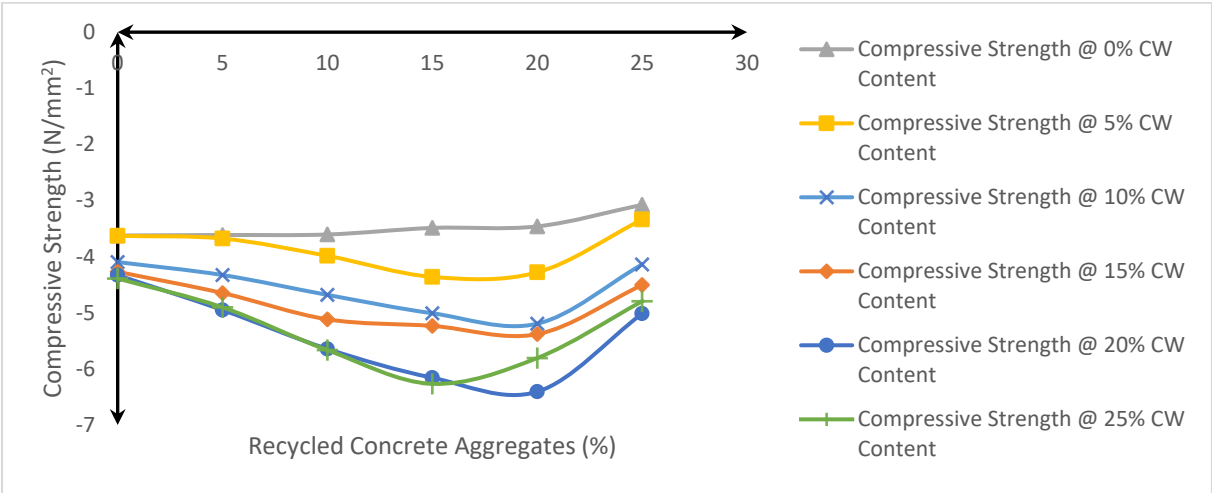

Figure 2: Graph showing the variations of Compressive Strength for Recycled Asphaltic Concrete @ various CW contents

2.2 Discussions

Figures 1 and 2 displays the variations of Tensile and Compressive Strength for Recycled Asphaltic Concrete blended with various candle wax contents.

Tensile Strength.

At 0% CW Content, It reveals that the indirect tensile strength value decreased linearly with increasing Recycled concrete contents. It reduced by 1.27% at 5% RC content. The ITS value reduced further at 25% RC showing that further addition of recycled concrete would cause the mix to become too disbonded.

At 5% CW Content, It reveals that compared with the control mix at 0%, indirect tensile strength value increased linearly when non bituminous additive (candle wax) was introduced with increasing Recycled concrete contents. It increased by 17.6% at 5% RC content, however, at 20% varying recycled concrete contents, ITS value peaked and decreased by 32.6% at 25% recycled concrete contents. This result may be due to fact that as candle wax content additions, there is an increased interlock and internal friction between aggregate particles which causes the mix to have higher internal resistance against external forces as manifested in the increased values of Marshall Stability. However, at 25% recycled content ITS value decreased, indicating that for 5% candle wax contents, further addition of recycled concrete would cause the mix to become too disbonded.

At 10% CW Content, It reveals that compared with the control mix at 0%, indirect tensile strength value increased linearly when non bituminous additive (candle wax) was introduced with increasing Recycled concrete contents. ITS increased by 31.4% at 10% varying recycled concrete contents, ITS value peaked and decreased by 16.4% at 25% recycled concrete contents. This result may be due to fact that as candle wax content additions, there is an increased interlock and internal friction between aggregate particles which causes the mix to have higher internal resistance against external forces as manifested in the increased values of Marshall Stability.

At 15% CW Content, It reveals that compared with the control mix at 0%, indirect tensile strength value increased when non bituminous additive (candle wax) was introduced with increasing Recycled concrete contents. ITS increased by 5.45% at 10% CW content was added, however, at 10% varying recycled concrete contents, ITS value peaked and decreased by 8.51% at 25% recycled concrete contents. This result may be due to fact that as candle wax content additions, there is an increased interlock and internal friction between aggregate particles which causes the mix to have higher internal resistance against external forces as manifested in the increased values of Marshall Stability. However, at 10% recycled content ITS value decreased, indicating that for 15% candle wax contents, further addition of recycled concrete would cause the mix to become too disbonded.

At 20% CW Content, It reveals that compared with the control mix at 0%, indirect tensile strength value increased when non bituminous additive (candle wax) was introduced with increasing Recycled concrete

contents. ITS increased and peaked by 26.9% at 15% varying recycled concrete contents and decreased further. This result may be due to fact that as candle wax content additions, there is an increased interlock and internal friction between aggregate particles which causes the mix to have higher internal resistance against external forces as manifested in the increased values of Marshall Stability. Further addition of recycled concrete would cause the mix to become too disbonded.

At 25% CW Content, It reveals that compared with the control mix at 0%, indirect tensile strength value increased when non bituminous additive (candle wax) was introduced with increasing Recycled concrete contents. ITS increased and peaked by 25.1% at 10% recycled concrete content then the ITS value decreased. This result may be due to fact that as candle wax content additions, there is an increased interlock and internal friction between aggregate particles which causes the mix to have higher internal resistance against external forces as manifested in the increased values of Marshall Stability. However, at 25% recycled content ITS value decreased, indicating that for 10% candle wax contents, further addition of recycled concrete would cause the mix to become too disbonded.

Compressive Strength.

At 0% CW Content, it reveals that the compressive strength of the mix as shown in figure 4.2. Compared with the control mix, Compressive strength increased linearly with by 1.2% at 5% recycled concrete content. However, at 25% recycled concrete content, compressive strength value peaked by 37%. This indicates that further addition of recycled concrete would cause the mix to crack easily and unable to withstand external forces.

At 5% CW Content, it reveals that the compressive strength of the mix as shown in figure 4.2. Compared with the control mix, Compressive strength increased linearly by 17.7% at 5% recycled concrete content; and peaked by 74.8% at 20% recycled concrete content. However, at 25% recycled concrete content, compressive strength value decreased by 11.4%. this indicates that further addition of recycled concrete at 5% candle wax content would cause the mix to crack easily and unable to withstand external forces.
At 10% CW Content, it reveals that the compressive strength of the mix as shown in figure 4.2. Compared with the control mix, Compressive strength decreased linearly and peaked by 31.4% at 10% recycled concrete content. However, at 15% recycled concrete content, compressive strength value increased by 15.6%. this indicates that further addition of recycled concrete at 10% candle wax content would cause the mix to crack easily and unable to withstand external forces.

At 15% CW Content, it reveals that the compressive strength of the mix as shown in figure 4.2. Compared with the control mix, Compressive strength decreased linearly and peaked by 5.32% at 10% CW. However, at 25% recycled concrete content, compressive strength value increased by 8.64%. this indicates that further addition of recycled concrete at 15% candle wax content would cause the mix to crack easily and unable to withstand external forces.

At 20% CW Content, it reveals that the compressive strength of the mix as shown in figure 4.2. Compared with the control mix, Compressive strength decreased linearly and peaked by 26.8% at 15% CW. However, at 25% recycled concrete content, compressive strength value increased. this indicates that further addition of recycled concrete at 20% candle wax content would cause the mix to crack easily and unable to withstand external forces.

At 25% CW Content, it reveals that the compressive strength of the mix as shown in figure 4.2. Compared with the control mix, Compressive strength decreased linearly and peaked by 25.1% at 10% RC. However, at 25% recycled concrete content, compressive strength value increased by 30.6% this indicates that further addition of recycled concrete at 25% candle wax content would cause the mix to crack easily and unable to withstand external forces.

3.0 Conclusions

The conclusions drawn from this research are based on the objectives and general finding of this study. while the aim of this research was based on unraveling the effect of varying candle wax addition on recycled concretes mechanical properties of HMA concrete for suitability, the results obtained were able to help identify these effects. Thus, the following conclusions have been drawn:

i. The tensile and compressive strength obtained from the recycled modified HMA concrete was better than that of the conventional (unmodified) HMA concrete due to the addition of Candle wax (CW). However, 15% - 20% recycled concrete content by weight of aggregates is the range content to attain optimum values of tensile strength.

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