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Recycling of Reclaimed Asphalt Pavement (RAP) with Rice Husk Ash (RHA)/Ordinary Portland Cement (OPC) Blend As Filler

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ABSTRACT

Large quantities of agricultural waste are generated daily, and their safe disposal raised much global concern. The popular trends in the stabilization or modification of construction materials, especially soil, have resulted in innovative techniques of utilizing the solid waste materials. This paper presents an experimental investigation into the use of Rice Husk Ash (RHA) as filler to replace Ordinary Portland Cement (OPC) in Reclaimed Asphalt Pavement (RAP). Results of preliminary tests on RAP showed that its properties for pavement mix design were below the standard specification for road works. For correction, RAP was reconstituted with fresh aggregate. Rice Husk Ash (RHA) was used as partial replacement for Ordinary Portland Cement (OPC). Marshall stability tests were performed on various mixes to investigate the pavement performance indices of the blended materials. The most effective combination of mix constituents that meets all design requirements was 70% RAP, 27% fresh aggregate and 3% mineral filler. An optimum value of 25% RHA filler replacement for OPC was obtained. Indirect tensile strength test results indicated that the use of RHA as filler contributes more to crack resistance of recycled asphalt pavement than OPC filler.

KEYWORDS: Rice husk, Reclaimed asphalt, Filler, Aggregate, Bitumen.

INTRODUCTION

Efforts are being made worldwide in the area of recycling waste material from road maintenance and rehabilitation. Removed deteriorated asphalt pavement is now being reclaimed and recycled, especially in the developed countries. RAP is generated when asphalt pavement is removed for the purpose of reconstruction, resurfacing or obtaining access to buried utilities. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated with bitumen. The recycling of asphalt pavement is a valuable technical approach to the friendly economical and environmental atmosphere (Salman, 1998). The use of RAP is not only a beneficial alternative presently and in future, but will also become a necessity to ensure economic competitiveness (Salman, 1998). Both bitumen and aggregates in RAP are non-renewable resources and while asphalt pavement deteriorates with age, any asphalt pavement can be restored to its original or near original consistency by the process of recycling, which can possibly be achieved by blending RAP with fresh aggregate, bitumen and mineral filler.

The mineral filler in asphalt pavement consists of very fine material that is added to hot mix asphalt to improve the density and strength of the mixture. Filler is generally selected on the basis of its ability to increase the stiffness of the binder or improve adhesion between the binders and aggregate (ORN 19, 2002). Typical mineral filler completely passes 0.060 mm (No. 30) sieve with at least 65 percent of the particles

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passing 0.075 mm (No. 200) sieve. Mineral filler serves the following purposes in bituminous mixes:

a) It forms mortar or mastic with the binder and contributes to improve stiffening of the mix.
b) It behaves as mineral aggregate and hence contributes to the contact points between individual aggregate particles.

Some of the commonly used mineral fillers in asphalt pavement mixes are Ordinary Portland Cement (OPC), stone dust, slag dust, hydrated lime and fly ash. These filler materials are not readily available at affordable cost. Consequently, research efforts have gone into waste materials in the construction industry exploring alternative materials at affordable cost. Such materials include industrial, domestic and agricultural waste (Abarshi, 1988). The mineral fillers used in this study are Ordinary Portland Cement (OPC) and Rice Husk Ash (RHA). Ordinary Portland Cement is essentially a calcium silicate cement, which is produced by firing to partial fusion, at a temperature of approximately 1500^0C (Osen and Jackson, 2012; Ahmed et al., 2006). Rice husk is one of the main agricultural residues obtained from the outer covering of rice grains during the milling process. It constitutes about 20% of the 500 million tons of paddy produced in the world (Givi et al., 2010; Bhanomathidas and Mehta). Rice husk ash had usually been dumped as solid waste that caused pollution and contamination of the environment, until it was known to be a useful mineral admixture for concrete. Rice Husk Ash is obtained from the combustion of rice husk (Malzum, 1989). It consists of non-crystalline silicon dioxide (SiO_2) with high specific surface area and high pozzolanic reactivity. It was described as super pozzolana (Malzum, 1989). A pozzolana is a construction material that originally lacks binding properties. However, when such material is exposed to hydrated lime from the hydration of cement, it acquires cementitious property. In this paper, RHA was used as OPC replacement, with proportions of 0% (control), 25%, 50%, 75% and 100% of cement. The chemical composition of OPC and RHA is presented in Table 1.

Table 1. Typical chemical composition of OPC and RHA

Chemical Constituent	Composition in OPC	Composition in RHA (%)
SiO_2	18.24	91.80
Al_2O_3	4.88	0.06
Fe_2O_3	3.47	0.09
Cao	60.82	1.02
MgO	3.20	0.42
Na_2O	0.02	0.06
K_2O	1.73	1.73
LOI	2.04	2.86

Sources: (Rodrigues et al., 2006; Osen and Jackson, 2006).

The utilization of Reclaimed Asphalt Pavement (RAP) as aggregate replacement and Rice Husk Ash (RHA) as cement replacement in hot mix asphalt would reduce the cost of road rehabilitation and combat the problem of solid waste disposal. The study area is Nigeria, where RAP is continuously generated from road rehabilitation by the Federal Roads Maintenance Agency (FERMA) as well as the various state government sister agencies, with little or no effort for its recycling.

MATERIALS AND METHODS

Materials Used in the Investigation

Materials used in this study are fresh coarse aggregate, Reclaimed Asphalt Pavement (RAP), Ordinary Portland Cement (OPC), Rice Husk Ash (RHA) and bitumen. RAP material was obtained from the site of ongoing roads rehabilitation activities along Katsina – Kano Road (5km from Katsina) in Katsina State, Nigeria. The fresh aggregate was obtained from a stone quarry belonging to a Nigeria-based construction company (Mothercat Limited) located along Katsina - Kano road. 60/70 grade cutback bitumen was used. It was also obtained from the asphalt plant of Mothercat Limited. Ordinary Portland cement produced by

Sokoto Cement Company of Nigeria was used in the mix. Rice husk ash was obtained from a local rice mill at Pambegua, Ikara, Local Government Area of Kaduna State, Nigeria.

Methods

Sieve Analysis of the Aggregates

A representative sample of Reclaimed Asphalt Pavement (RAP) and fresh coarse aggregates was first subjected to particle size distribution tests in accordance with (FMWH, 1997; ASTM C136).

Asphalt Binder

60/70 grade cutback bitumen was used as binder. To obtain complete blending between the residual bitumen in the RAP and the virgin bitumen, high temperature blending chart shown in Fig. 1 was used (Imad et al., 2009).

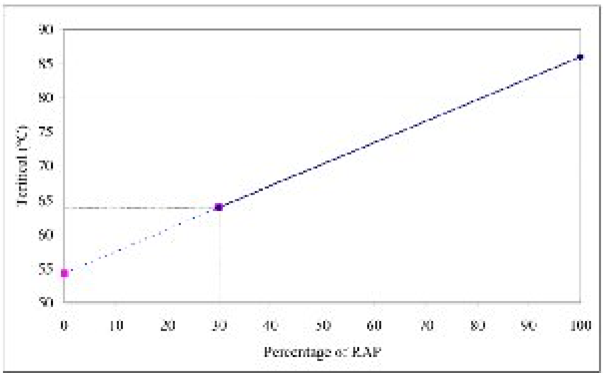

Figure (1): High Temperature Blending Chart (Imad et al., 2009)

Marshal Mix Design

The first step in the utilization of RAP is the determination of appropriate mix design strategy for the various constituent materials. The objective of the mix design is to determine an economical blend through several trial mixes. The gradation of aggregate and the corresponding binder content should be such that the resultant mix should satisfy the following conditions (Shiva et al., 2012):

a. Sufficient binder to ensure a durable pavement by providing a water proofing coating on the aggregate particles and binding them together under suitable compaction.
b. Sufficient stability for providing resistance to deformation under sustained or repeated loads. This resistance in the mixture is obtained from aggregate interlocking and cohesion which generally develops due to binder in the mix.
c. Sufficient flexibility to withstand deflection and bending without cracking. To obtain the desired flexibility, it is necessary to have the proper amount and grade of bitumen.
d. Sufficient voids in the total compacted mix to provide space for additional compaction under traffic loading.
e. Sufficient workability for an efficient construction operation in laying the paving mixture.

Marshal mix design method was adopted in this study. Investigation was conducted on Marshal briquettes prepared by reconstituting RAP with the addition of fresh aggregate, RHA/OPC (filler) and bitumen.

The properties that are of interest in the Marshal test are (Salman, 1989; Heeralal et al., 2009):

a. Marshal stability. This is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60˚C.
b. Flow. This is a measure of flexibility, measured by the change in diameter of the test sample in the direction of load application between the start of loading and the time of maximum load.
c. Compacted density of the mix (CDM).
d. Voids in the mix (VIM), meaning the percentage of air voids by volume in the specimen.
e. Percentage voids in mixed aggregates (VMA), meaning the volume of inter-granular void space between the aggregate particles of a compacted paving mixture, including the air voids and the volume of bitumen not absorbed into the aggregate. VMA-value is expressed as a percentage of the total volume of the mix.

f. Percentage voids filled with bitumen (VFB), meaning the voids in the mineral aggregate frame work filled with bitumen binder. VFB is inversely related to air voids and hence as air voids decrease, VFB increases.

Performance Evaluation

Performance evaluation of the Reconstituted Asphalt Pavement was made using the results of indirect tensile strength test. The indirect tensile strength test was developed to determine the tensile properties of cylindrical concrete and asphalt concrete specimens through the application of a compression load along a diametrical plane through two opposite loading heads (Ahmed et al., 2006).

RESULTS AND DISCUSSION

Particle Size Distribution

The particle size distribution curve for RAP performed based on Federal Ministry of Works and Housing, Nigeria, is presented in Fig. 2.

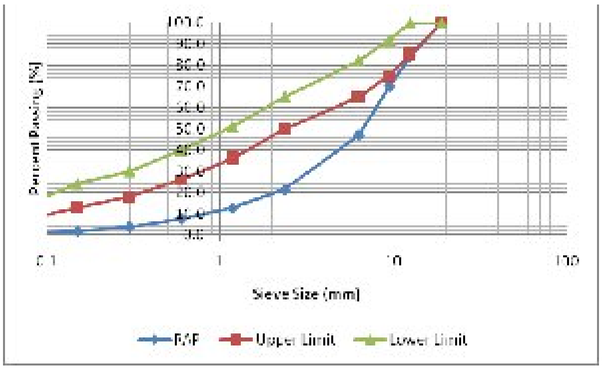

Figure (2): Particle Size Distribution Curve for RAP

The result indicated that the RAP failed to fit within the gradation limit of the FMWH (FMWH, 1997). It therefore requires augmentation with fresh aggregate and mineral filler in order to meet the standard specification. Through trial and error, RAP, fresh aggregate and cement mineral filler blend of 70 % RAP and 27% fresh aggregate as well as 3% cement mineral filler were found to have fully fitted within the FMWH (1997) envelops, as shown in Fig. 3. Blending with 3% mineral filler satisfied the standard limit specified in Road Note 19 (2002).

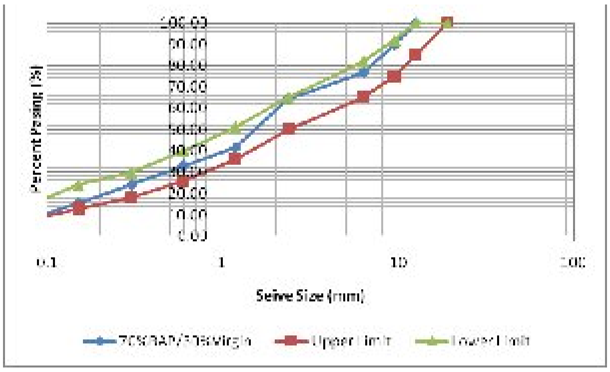

Figure (3): Particle Size Distribution Curve for RAP/Fresh Aggregate Blend

Tests on the Bitumen

The laboratory test results on the physical properties of the bitumen are presented in Table 2. The results show that the binder passed the requirements specified in various standards.

Table 2. Physical Properties of the Asphalt Binder

Property	Test Method	Obtained Result	Standard Value (ASTM)
Penetration at 25^0C (1/10 mm)	ASTM D5	67	60-70
Softening Point, ^{o}C	ASTM D36	47.30	4.52
Specific gravity	ASTM D70	1.03	1.03-1.06
Ductility, cm	ASTM D113	102	Min. 100

Rice Husk Ash Replacement of the Portland Cement

Asphalt reconstitution was made with various percentages of rice husk ash as replacement for the

Ordinary Portland Cement filler. Sieve analysis on Rice Husk Ash (RHA) showed that the material can be used as filler, since the material passing No. 200 sieve satisfied the fineness requirement of filler. Five trial mixes with 0%, 25%, 50%, 75% and 100% Rice Husk Ash (RHA) replacement of Ordinary Portland Cement (OPC) were used.

Marshal Stability Test Results

Stability

For each of the five mixes, samples were prepared for nine different bitumen contents of 4.5%, 5.0%, 5.5%, 6.0%, 6.5%, 7.0%, 7.5%, 8.0% and 8.5%, with three samples for each fraction. Fig. 4 shows the plots of Marshal stability against bitumen content. The stability values increase with increasing bitumen content up to a maximum value, then decreases with increasing bitumen content. The maximum values of the stability for the various mixes are presented in Table 3. It is clear from the results that the use of RHA as OPC mineral filler replacement in Hot Mix Asphalt (HMA) with RAP resulted in a decrease in Marshal stability. The stability dropped from 10.10 kN to 8.5 kN, when OPC was completely replaced with RHS as mineral filler.

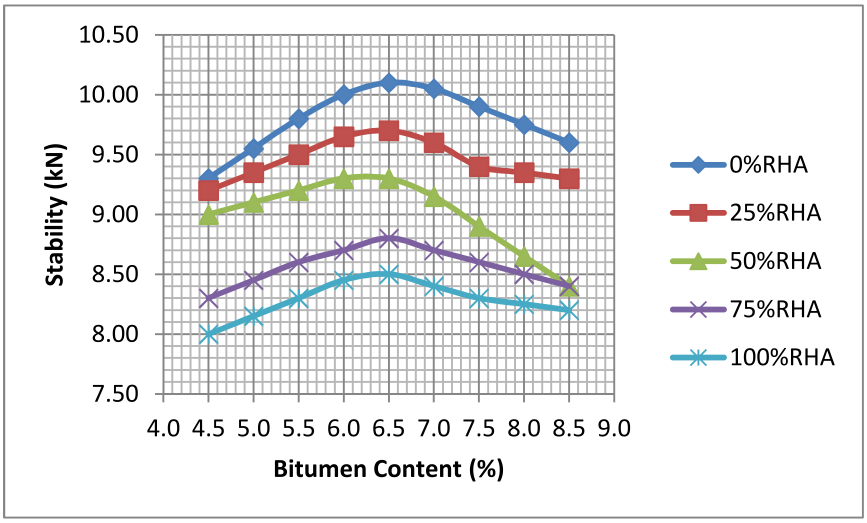

Figure (4): Stabilty against Binder Content

Table 3. Maximum Values of Marshal Stability

Mix	**Maximum Stability (kN)**	**Bitumen Content (%)**
100% OPC Filler	10.10	6.5
25% RHA/75% OPC Filler	9.70	6.5
50% RHA/50% OPC Filler	9.30	6.3
75% RHA/25% OPC Filler	8.93	6.5
100% RHA Filler	8.50	6.4

Flow

Fig. 5 shows the plots of flow against bitumen content. It is clear from the results that increasing the bitumen content leads to a linear increase in the flow values.The plots for 25%-75% RHA replacement of OPC give similar flow values as the control mix. However, for the mix with 100% RHA, the flow value is higher. For all the five considered mixes and at all values of bitumen contents, the flow values are within the standatd limit of 2-4 mm specified by Asphalt Institute.

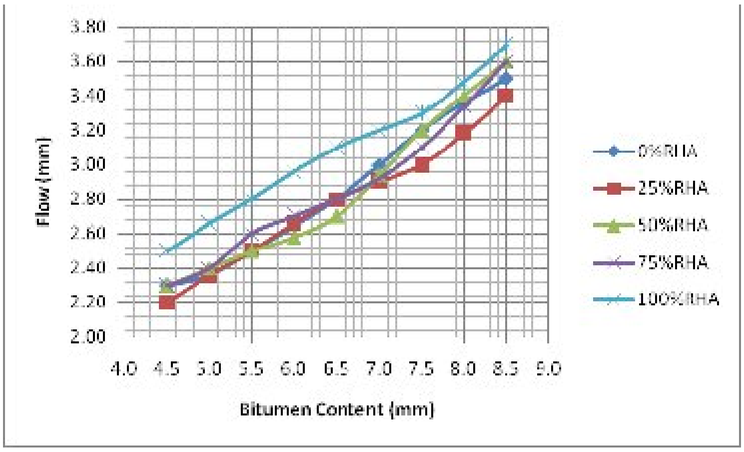

Figure (5): Flow against Binder Content

Compacted Density (CDM)

The relationship between compacted density (CDM) and bitumen content is presented in Fig. 6. It was found that as the RHS content of the filler increases, the value of the compacted density decreases. This may be attributed to the higher air voids created by the substittion of Ordinary Portland Cement with Rice Husk Ash.

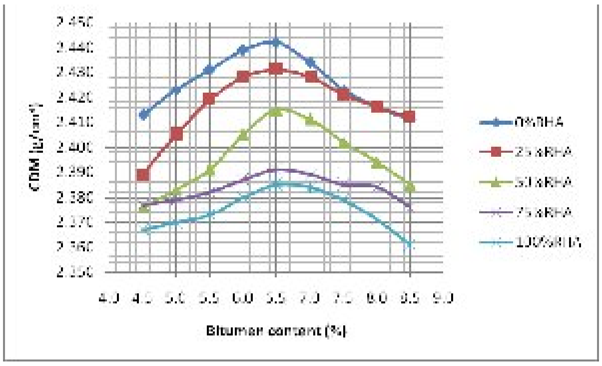

Figure (6): CDM against Binder Content

Voids in Mix (VIM)

In is observed in Fig. 7 that the voids in mix increase with increasing bitumen content. Likewise, an increase in RHA results in an increase in the percentage of air voids. This is in aggreement with the earlier observation made from the CDM plots in Fig. 6, confirming that the addition of RHA as partial replacement for OPC as mineral filler results in an increase in air voids. However, all points were above the lower limit of 3% air voids in the mix specified by Asphalt Institute.

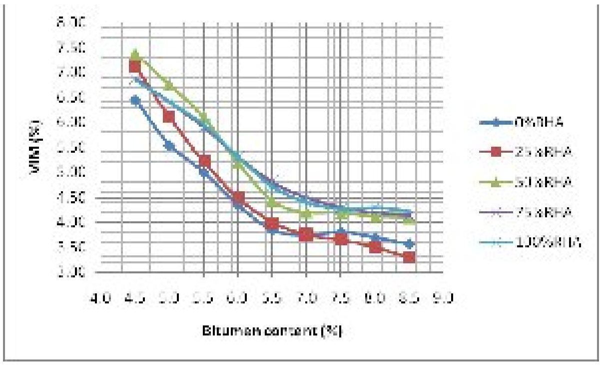

Figure (7): VIM against Binder Content

Voids in Mineral Aggregates (VMA)

Voids in mineral aggregates is the volume of intergranular void space between the aggregate particles of a compacted paving mixture, including the air voids and the volume of asphalt not absorbed into the aggregate (Roberts et al., 1991). The plots of the VMA against bitumen content are presented in Fig. 8. It is observed from the plots that for all the considered mixes, the VMA increase with increasing bitumen content. The control specimen has the least value of VMA beyond. The increase in the VMA as a result of the addition of RHA may be attributed to the increased absorption of bitumenn content by the filler (Sehmen et al., 2013).

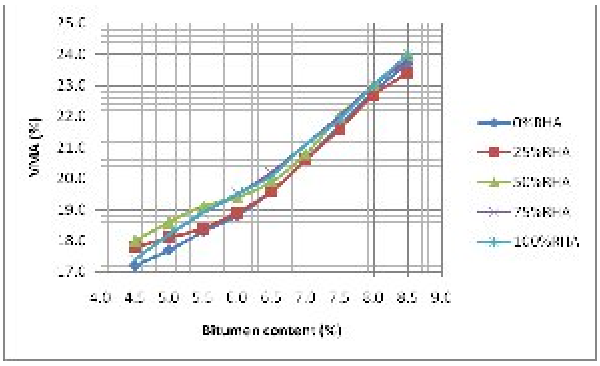

Figure (8): VMA against Binder Content

Voids Filled with Bitumen (VFB)

The relationship between VFB and bitumen content is presented in Fig. 9. It is observed from the plots that VFB increse with increasing bitumen content. The values of VFB for all the mixex containing RHA are lower than for the control mix (100% OPC), implying that the addition of RHA reduces VFB values.

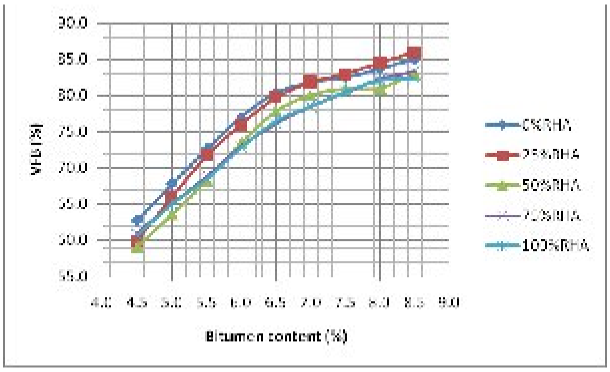

Figure (9): VFB against Binder Content

Optimum Bitumen Content

The optimum bitumen content has been obtained by taking the average of the bitumen contents at which the mix has maximum compacted density, maximum stability and 4% design air voids. The void ratio for all the three mixes containing 50%, 75% and 100% RHA have greater air voids at all bitumen contents. These mixes are therefore considered unsuitable. At 4% air voids, the bitumen contents for the mix containing 25% RHA and the control mix (100% OPC) are 6.3% and 6.5%, respectively. On the ground of the percentage of the voids in mix, 25% RHA replacement is considered in this paper as the upper limit. The overall optimum bitumen content for the mix is 6.5%.

Indirect Tensile Strength Test Results

The indirect tensile strength test was developed to determine the tensile properties of cylindrical concrete and asphalt concrete specimen through the application of a compression load along a diametrical plane through two opposite loading heads. This type of loading produces a relatively uniform stress acting perpendicularly to the applied load plane, causing the specimen to fail by splitting along the loaded plane. The indirect tensile strength has been used in this study to evaluate the maximum resistance of pavement to cracking. Fig. 10 shows the influence of filler on tensile strength. The testing temperature was 30^{0}C. The adopted design mix with 25% RHA has the highest tensile strength of 1150 N/mm^2, while the mix with OPC has the lower tensile strength of 1090 N/mm^2. This implied that the RHA mix has the highest resistance to cracking.

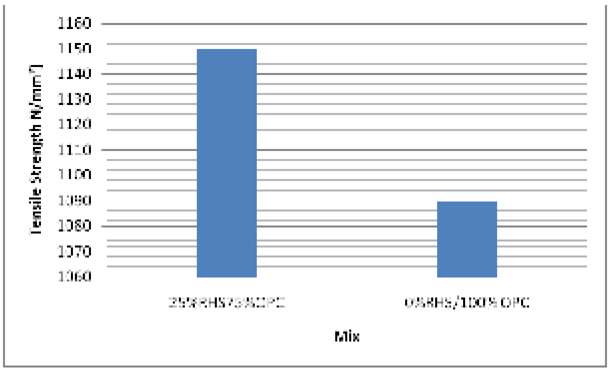

Figure (10): Indirect Tensile Strength Test Results

CONCLUSIONS

This paper presents a laboratory-based study that was conducted to evaluate the performance of Reconstituted Reclaimed Asphaltic Concrete mix design with Rice Husk Ash (RHA) as filler and to establish the best possible combination of RAP, Fresh Aggregate and RHA/OPC that meets the standard specifications for hot-mix asphalt design. The following conclusions were made as the outcome of the study:

a. Scarified Asphalt Pavement generated as waste during road rehabilitation can be reused to provide good results. In this research, the use of RAP alone failed to satisfy the standard specifications. The deficiency was corrected by reconstitution with fresh aggregate. Through trial and error approach, the use of 70% RAP and 27% fresh aggregate gave a good design mix that satisfied the standard specifications for road works in Nigeria and other parts of the world. 3% filler was adopted in line with the recommendation of design standards that the percentage of filler materials should be less than 6%.

b. It was established that Rice Husk Ash (RHA) can effectively be used as OPC replacement for the filler material. The use of 25% RHA and 75% OPC was found to be optimum. The optimum bitumen content is 6.5%.

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