



Original Research Article

Rice Husk Ash-Bitumen Modification as Sustainable Road Pavement Materials

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ABSTRACT

In recent times, there has been diverse research in finding alternatives or improving the existing bitumen through the utilization of industrial and agricultural wastes due to the demand for green road materials. In this study, the role of rice husk ash (RHA) as a modifier of bitumen for improving the performance of flexible pavements was investigated. The various mechanical properties of bitumen containing different percentages of RHA (0, 2, 4, 6, and 8%) such as penetration, softening point, viscosity, flash, and fire points, loss on heating, and specific gravity were examined. The results show that the penetration decreased from 65 to 46.3 mm, softening point increased from 35 to 42.5°C, and the viscosity increased drastically from 283 to 1395 seconds at 100°C using tar viscometer. It was observed that the weight loss on heating decreases, which indicates high thermal stability, and there was an increase in flash and fire points. Thus, it was concluded that adding RHA increases the strength of bitumen and makes it more resistant to temperature variations, making it a promising modifier for sustainable pavement construction. RHA-modified bitumen was recommended for eco-friendly road construction, especially in tropical regions where bitumen performance is affected by temperature and moisture variations.

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1. INTRODUCTION

Due to the fact that transport needs are growing quickly, especially in developing countries like Nigeria, there is a greater need for road infrastructure that lasts a long time, affordable, and is good for the environment. Bitumen is an important binding agent for flexible pavements, which are what most road systems are made of (Huang, 2017; Yoder and Witczak, 1975). This is because it sticks, keeps water out, and has a viscoelastic quality. Researchers are investigating sustainable and alternative materials for pavement construction due to the increasing costs of petroleum-based products and the escalating environmental concerns associated with their use and production (Roberts *et al.*, 1996; Read and Whiteoak, 2003).

Bitumen has been in use everywhere, but it has some built-in problems such as responding negatively to temperature changes, aging when exposed to air, and soaking up moisture, which all end up causing roads to strip, rut, or crack (Whiteoak, 2003; Hossain *et al.*, 2012). In tropical countries like Nigeria, where high temperatures and heavy rainfall are common, roads tend to deteriorate more quickly. Finding ways to improve bitumen and make it tougher has become an important study in pavement engineering (Behnood and Olek, 2017).

Recently, however, there has been a shift of focus towards the utilization of sustainable and locally sourced materials, such as agro-industrial waste products, as bitumen modifiers. One such material that has gained popularity is rice husk ash (RHA), owing to its higher silica content, pozzolanic properties, and availability as a residue from the processing of rice grains (Zhang *et al.*, 1996). Tons of rice husks are generated annually worldwide due to rice cultivation; unfortunately, a substantial quantity of these husks is either dumped indiscriminately or burned off directly, resulting in environmental contamination (Okafor and Nwaobakata, 2014).

RHA added to bitumen has been found to improve important engineering characteristics of asphalt mixtures. Research findings show that RHA helps increase rigidity, softening point, decreases the penetration value, improves rut resistance, and moisture susceptibility (Amu and Salami, 2010; Jony *et al.*, 2011). All these improvements in the performance of asphalt mixes can be mainly credited to the fine size of particles and increased surface area of RHA, which helps to improve the bonding between the binder and aggregates. Also, RHA has been observed to significantly improve the durability and oxidative stability of modified bitumen (Uche and Onwuka, 2018; Zhang *et al.*, 1996).

Apart from enhancing pavement performance, the use of RHA will aid the achievement of sustainability targets worldwide as it minimizes the dependence on nonrenewable resources while decreasing carbon emissions that result from the processing of bitumen (Behnood and Olek, 2017). The idea of utilizing agriculture waste in constructing roads will facilitate the attainment of circular economy objectives in which the waste produced from various sources is transformed into engineering material resources.

While many benefits have been identified in previous works, several concerns have been raised about the application of RHA. Some of the most significant challenges is the impact of variables like the quality of ash, particle sizes, burning process, and addition method to the performance of the material (Zhang *et al.*, 1996). Besides, lack of standard guidelines to guide the use of RHA in the construction of pavements has discouraged its adoption. Therefore, this study aims to evaluate the suitability of locally available rice husk ash (RHA) as a bitumen modifier by investigating its effects on the engineering properties and performance characteristics of bitumen for sustainable flexible pavement construction.

2. MATERIALS AND METHODS

2.1. Material Collection and Sampling Methods

Rice husk was obtained locally from rice mills in Langtang South Local Government, Plateau State Nigeria and converted to ash by proper combustion to obtain high amorphous silica content in line with recommendations provided by Zhang *et al.* (1996). RHA produced by the procedure was allowed to cool down and sieved to particle sizes less than 0.15 mm using sieving methods before being kept in sealed containers. Traditional 60/70 penetration grade bitumen, normally used in the making of flexible pavements, was selected as the base binder (Huang, 2017; Read and Whiteoak, 2003).

The RHA-modified bitumen specimens were produced through the wet mixing process (Behnood and Olek, 2017). In this process, bitumen was melted to a temperature of between 140-150 °C for fluidity, whereas the RHA was heated to dry off moisture. Ash was then added to the molten bitumen in different concentrations of 0, 2, 4, 6, and 8% of the binder mass. Mechanical stirring was used for the purpose of ensuring proper mixing. The samples were allowed to cool down to room temperature before being preserved for further tests. The above concentrations were chosen based on the findings of previous research (Jony *et al.*, 2011).

2.2. Analytical Methods

The laboratory study evaluated the mechanical, thermal, and rheological characteristics of both regular and modified binders. The penetration value of the binder sample was obtained in accordance with ASTM D5 (2018a). It helped to assess the consistency and hardness of the material. The softening point was obtained in accordance with ASTM D36 (2018b), which is used to evaluate the temperature susceptibility of the material. The viscosity was measured according to (ASTM D4402, 2019; ASTM D88/D88M-07, 2024) using a tar viscometer. The flash and fire points (ASTM D92, 2018d) were estimated to provide information about the safety of heating and manipulating the material. The loss on heating (ASTM D6, 2017) was performed to evaluate the volatility and aging of the material. The specific gravity of the material was measured according to ASTM D70 (2018c) to help with volumetric calculations and mix design (Roberts *et al.*, 1996; Whiteoak, 2003).

All tests were performed several times to achieve reliable results. The average values were calculated to perform analysis. Experimental data were analyzed based on the relationship between engineering characteristics and the amount of RHA added. The main factors included penetration, softening point, and viscosity of the binder sample. They were used to analyze the impact of RHA addition on the stiffness, thermal stability, and workability of the binder material. The trends were evaluated in accordance with previous studies devoted to bitumen modification and sustainable materials (Amu and Salami, 2010; Behnood and Olek, 2017).

3. RESULTS AND DISCUSSION

3.1. Chemical Properties of RHA

The X-Ray Fluorescence (XRF) test results reported by Oyejobe *et al.* (2014) indicated that the summation of the percentage of major oxides (SiO_2 , Al_2O_3 and Fe_2O_3) is 90.71%, which meets the minimum percentage of pozzolana required with regard to those elements. It has been stipulated that the minimum percentage of any pozzolana materials be 70%, according to ASTM C618 (ASTM, (1978); ASTM C618-19, (2019)). The silicon content allows for increased strength and durability of the bitumen. The presence of silicon dioxide (SiO_2) is dominant compared to silicon in the oxidized state, implying adequate burning of the rice husk at controlled temperatures; hence, converting amorphous silica and not quartz. Amorphous silica reacts with the calcium hydroxide ($\text{Ca}(\text{OH})_2$) during hydration and forms secondary calcium silicate hydrate (C-S-H), leading to durability and strength when incorporated into bitumen or cementitious products. The minor oxides including Al_2O_3 and Fe_2O_3 enhance the binding and chemical stability of the material. Presence of moderate amounts of CaO (8.95%) allows for self-cementing effect whereas low LOI (4.084%) ensures cleanliness of the burning process and absence of unburnt carbon.

3.2. Penetration Test Results

Figure 1 shows the results of the penetration test for the unmodified and RHA-modified bitumen samples against percentage RHA content. As the percentage of Rice Husk Ash increased, there was a gradual decline in the penetration value of the bitumen sample from 65 to 46.3 mm. This trend suggests that the bitumen sample becomes less pliable with an increase in RHA percentage due to stiffening in bitumen. The reason behind the decrease in the penetration value of bitumen can be explained by the role of filler in the bitumen sample due to RHA addition. RHA acts as a filler in the bitumen sample because of its finer particles. RHA fills up all the gaps in the bitumen matrix, leading to improved cohesion and density of the bitumen matrix. This is consistent with the results reported by Kumar and Suman (2025). The reduction in penetration is beneficial in tropical environments because of high temperatures on pavements.

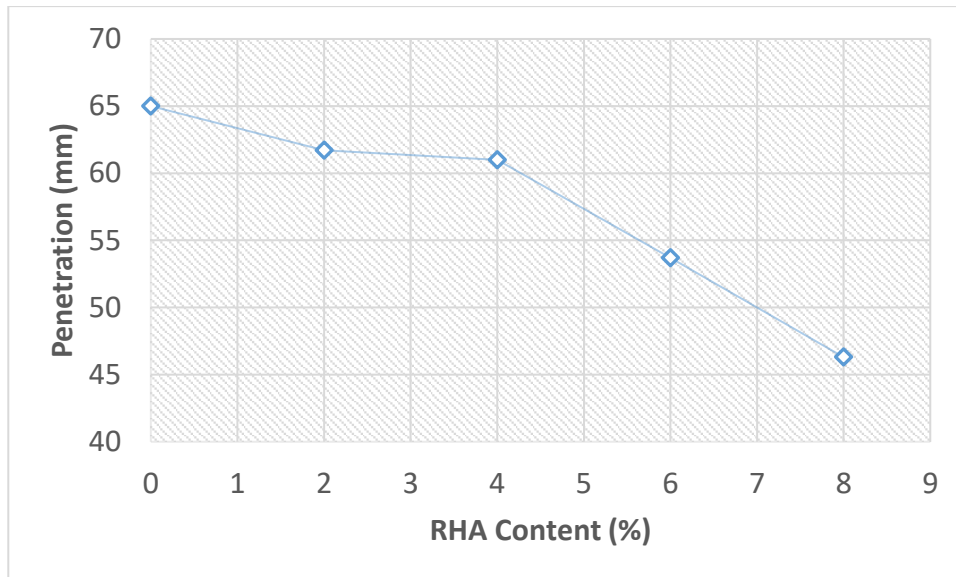


Figure 1: Penetration vs RHA content

3.3. Softening Point Test (Ring and Ball Method) Results

The result of the softening point test for the unmodified and RHA-modified bitumen samples against percentage RHA content is presented in Figure 2. As presented in Figure 2, the softening point increased from 35° to 42.5°C upon adding RHA, meaning that the new formulation of bitumen can be used at a relatively higher temperature before the occurrence of softening. This means that the bitumen possesses better thermal properties for application. This is attributed to the pozzolanic reaction of the silica component present in RHA, which is in line with the report of Salas *et al.* (2007).

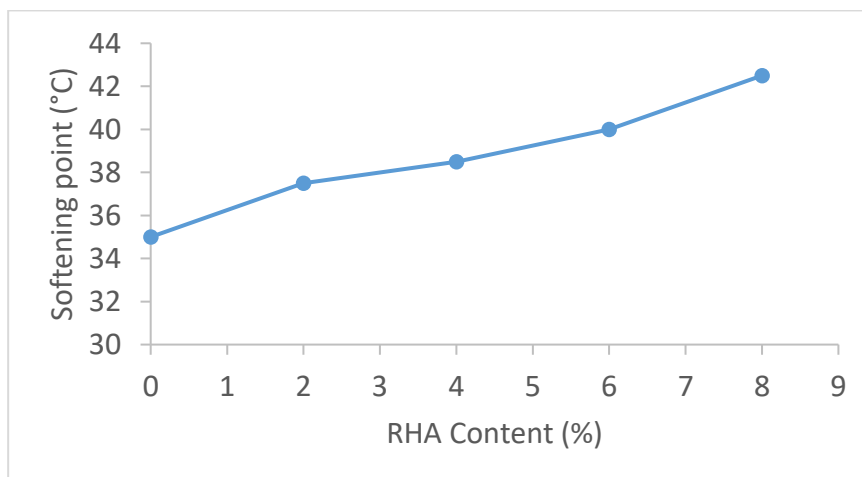


Figure 2: Softening point vs RHA content

3.4. Viscosity Test Results

Figure 3 shows the result of the viscosity test for the RHA-modified bitumen and the trend in variation of viscosity against percentage RHA content. Viscosity was found to increase from 283 to 1395 seconds (using tar viscometer at 100°C), as shown in Figure 3. In other words, the viscosity of the bitumen rose as the percentage of RHA increases, and this is because of the interfacial interactions between silica and asphaltenes, resulting in better matrix formation. This phenomenon correlates with the work done by Huzaifa, *et al.* (2020), who noted that the use of RHA in the preparation of binders results in an increase in their viscosity, thereby increasing resistance to plastic deformation due to traffic load.

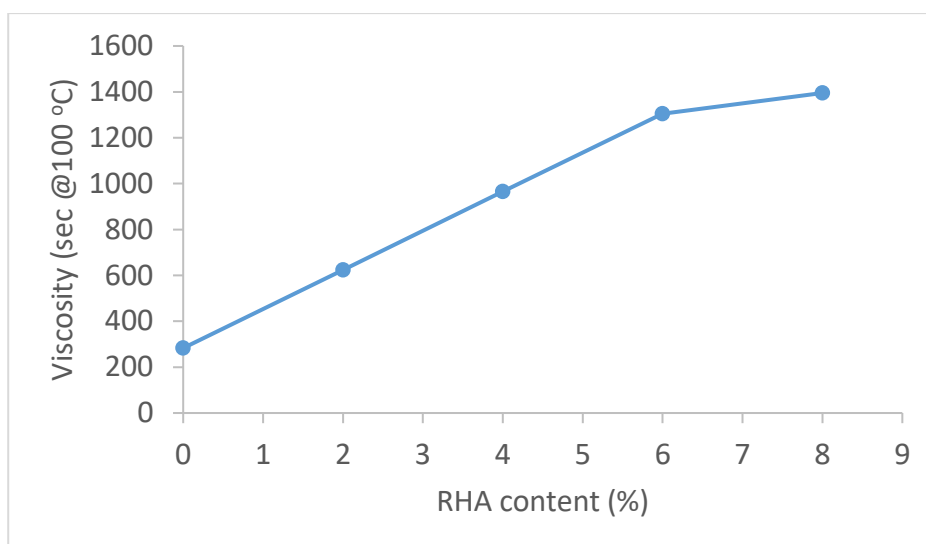


Figure 3: Viscosity vs RHA content

3.5. Flash and Fire Point Test Results

The flash and fire point test results for the unmodified and RHA-modified bitumen samples are plotted in Figure 4 against percentage RHA content. The trend shows that an increase in both the flash and fire points was observed with increase in RHA modification. From Figure 4, it is observed that the increment made to the bitumen by incorporating RHA improves its performance in terms of thermal stability and fire resistance when mixed and laid. This is achieved as a result of oxidation stability imparted into the binder as well as reduction in volatile substances by the silica content in the RHA which agrees with the findings of Ismail and Waliudden (1996).

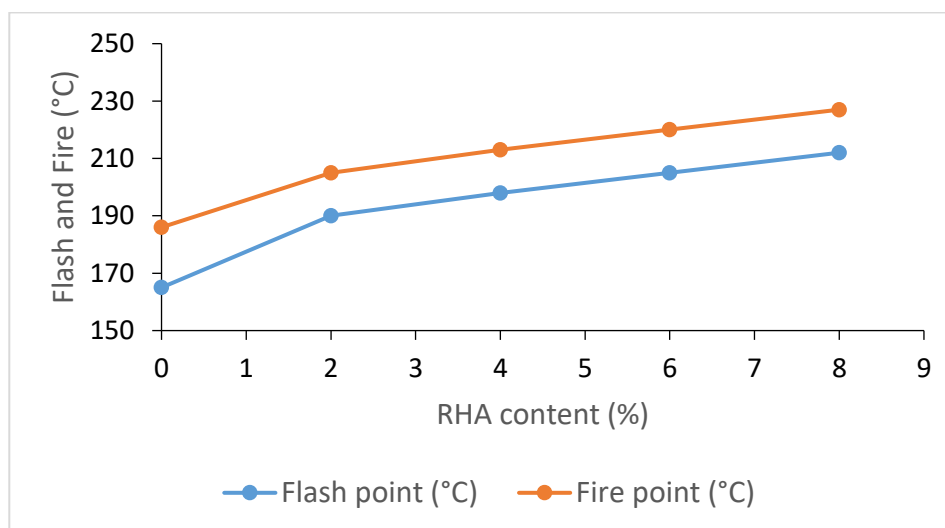


Figure 4: Flash and fire point vs RHA content

3.6. Loss on Heating Test Results

Figure 5 presents the loss on heating test results against percentage RHA content. After six hours of heating, the weight of the bitumen sample reduced, signifying the loss of volatile components during heating. The RHA-modified samples showed less weight loss compared to the unmodified binder, suggesting improved resistance to oxidation and volatilization. This is because the RHA particles act as stabilizers, preventing excessive evaporation of light hydrocarbons. The result agrees with the work of

Kumar *et al.* (2025), who found that ash-modified binders exhibit enhanced resistance to thermal aging, thereby improving their long-term performance in pavement applications.

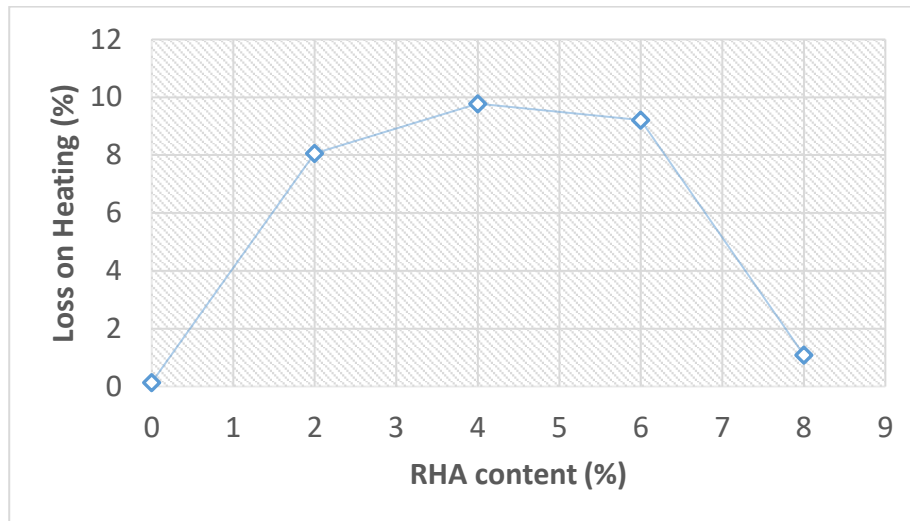


Figure 5: Loss on heating vs RHA content

3.7. Specific Gravity of RHA Modified Bitumen

Figure 6 shows the result of specific gravity test for the unmodified and RHA-modified bitumen and the trend of specific gravity against percentage RHA content. The specific gravity of the bitumen specimens fell within the range of 1.000 to 1.109, revealing a slight rise as the proportion of RHA rose. This implies that the use of RHA improves the density and compactness of the binder matrix, thus improving its bonding with the aggregate. The rise in the specific gravity value is because RHA has a high specific surface area and a high percentage of minerals, which makes the mixture more dense. According to Lee *et al.* (2023), binders with higher specific gravities perform better in coatings and stability tests.

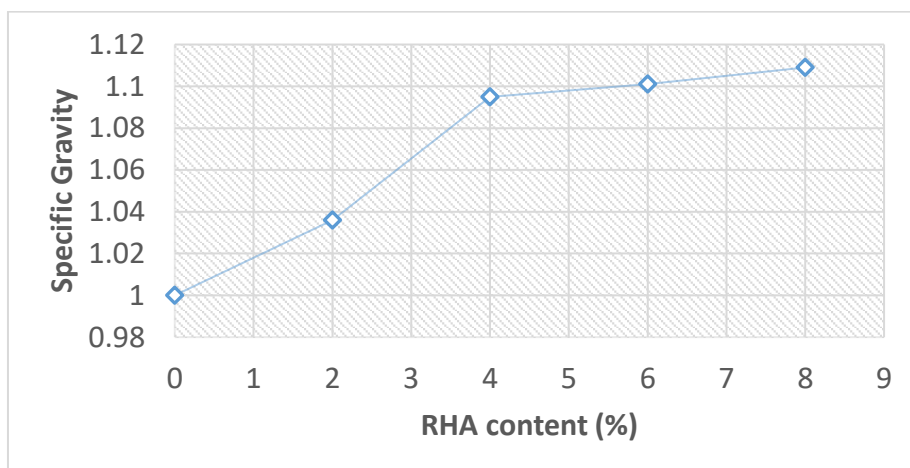


Figure 6: Specific gravity vs RHA content

4. CONCLUSION

From the findings, the following conclusions were drawn:

Rice husk was collected from various rice milling operation centres in Langtan South, Plateau State, Nigeria. The RHA obtained through controlled open-air burning technique was found to have high levels of silica suggesting its suitability to be used as a filling agent or modifier in asphalt binder.

Collection and processing of the RHA provided homogenous and reactive ash, thereby proving the sustainability of the local RHA for pavement construction. From test results it is clear that as the quantity of RHA increases, the value of penetration decreases from 65 to 46.3 mm, implying that the hardness and stiffness of the bitumen would increase. Softening point increases from 35 to 42.5 °C, indicating increased thermal susceptibility and improved high-temperature deformation resistance. Similarly, viscosity increases substantially from 283 to 1395 sec at 100 °C using a tar viscometer.

The results of comparison between control sample and RHA modified bitumen indicated enhanced properties of the latter. RHA modified bitumen showed elevated softening point, decreased penetration value, and increased viscosity, showing higher resistance to rutting, bleeding, and deformation due to the rise of temperatures. Consequently, such properties can improve the durability, stability, and load-carrying capacity of the modified bituminous mixture; hence, it is ideal for application in tropical and hot regions. It should be noted from the obtained experimental data that RHA modified bitumen possesses considerable engineering advantages, providing higher stiffness and strength of the asphalt mixture while being less susceptible to rutting and cracking, having high temperature stability and resistance to aging, and helping save on the consumption of traditional bitumen, which ultimately reduces costs and environmental damage and encourages the recycling of waste materials.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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