



FTIR-BASED CHEMICAL INTERACTION STUDY OF RICE HUSK ASH MODIFIED AGBABU NATURAL BITUMEN

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ABSTRACT

Bitumen is a mixture of hydrocarbons widely used as a binder in road pavements but has certain limitations, including oxidative failure and various surface defects. These challenges led to the modification of Agbabu Natural Bitumen (ANB) using rice husk ash (RHA), with the expected result that it might mitigate the adverse effects of conventional bitumen. The raw ANB was modified in a stainless reactor using the rice husk ash at five different proportions maintaining a temperature of 100-110 °C. The modified bitumen was analyzed using Fourier Transform Infrared (FTIR) spectroscopy. The carbonyl peaks are reduced to 1701 cm⁻¹ while the aliphatic contents are retained both in the raw and modified ANB and the aromatics and sulfoxide peaks are stable. The peaks at 3448.84 cm⁻¹, 2854.74 cm⁻¹, 1716.7 cm⁻¹, 1608.69 cm⁻¹, 1377.22 cm⁻¹, 1033.88 cm⁻¹ corresponds to O-H stretching of alcohol, C-H stretching of alkane, C=O stretching of carbonyls, C=C stretching of aromatics rings, C-H bending of methyl groups and S=O stretching of sulfoxide respectively. The silicates peaks were also observed at 420.5 cm⁻¹, 466.79 cm⁻¹, 570.95 cm⁻¹, and 582.52 cm⁻¹. The interaction of ANB with RHA showed that the silicate components present in RHA can serve as potential antioxidants for improving the performance of ANB in pavements.

Keywords: Bitumen, Rice Husk Ash, Oxidation

INTRODUCTION

Bitumen is a complex mixture of hydrocarbons which occurred naturally or obtained from crude oil distillation (Bakare and Olabemiwo, 2017). In its raw state, bitumen is a sticky and a viscous substance occurring mostly in sands and clays. Bitumen's physical properties are determined by its chemical composition, which consists of asphaltenes and maltenes. The basis of oxidative aging of bitumen is associable with the different types of compound in the substance which include aromatic and hetero atomic (N, S, and O containing organic) compounds, most of which are with varying molecular size, aromaticity, and polarity (Shankaregowda, 2014).

Literatures have reported several agricultural wastes which can be used as a binder including straw, sugarcane bagasse etc. These materials are abundant, renewable, and can reduce the carbon footprint of road construction and maintenance. It was also reported that rice husk can be used as a binder due to its resistance to aging and oxidation. Xue *et al.* 2014 modified bitumen using two biomass ashes (rice husk ash and sawdust ash) to examine the effects on specific physical properties, including viscosity, penetrability, and wear resistance. Their findings revealed that the ash and bitumen combined physically, without undergoing a chemical reaction. They concluded that rice husk ash-modified bitumen exhibited physical properties closer to expected performance values and the modified bitumen demonstrated improved resistance to deterioration at high temperatures. Moreover, the study found that incorporating rice husk ash and sawdust ash enhanced rutting resistance, highlighting the potential benefits of utilizing biomass ashes in bitumen modification.

Rice husk ash (RHA), a waste byproduct of rice milling, in bituminous roadways provides valuable advantages including reduction of environmental degradation, lowering construction costs and refining the overall pavement infrastructure. Rice husk in ashed form, contains porous amorphous silica with high SSA adsorbs light maltene

fractions (oily components) and acidic compounds (e.g., carboxylic acids, 2-quinolone types) in bitumen. This stabilizes the colloidal structure (asphaltene dispersed in maltene), reduces the availability of oxidizable molecules, and limits oxygen access or radical propagation. RHA improves compatibility and dispersion in the bitumen matrix, enhancing thermal/oxidative stability.

This sustainable approach promotes eco-friendly construction practices, enhances road performance and conserves natural resources. It has also been documented in literature that FTIR spectrometry can be successfully used for the identification and quantification of the effects of modifiers on the aging of bitumen as well as for the evaluation of their effects on chemical and physical properties of asphalt (Iliya and Adam, 2021; Olabemiwo *et al.*, 2015; Olabemiwo *et al.*, 2019). Previous studies by Petersen and Harnsberger, also investigated sulphoxide and ketone formation during aging of asphalt and reported that during the oxidation spurt, some of the hydroperoxides formed from the oxidation of aromatic compounds in bitumen e.g. dihydroanthracene are likely to react with aliphatic sulphides to produce sulphoxides or decompose to produce free radicals. Therefore, this study is meant to contribute to knowledge on the novelty of anti-oxidative ability of rice husk ash for the modification of bitumen for pavement applications.

MATERIALS AND METHODS

Materials: Bitumen

Raw Agbabu natural bitumen (ANB) was obtained from one of the observatory wells sunk by the Nigerian Bitumen Corporation (NBC-7) situated opposite Saint Stephen's Primary School, Agbabu, Ondo State, Nigeria. Agbabu is located on the so called bitumen belt of south-western Nigeria, specifically between latitude 006°38'N-006°40'N and longitude 004°34' E-004°37' E. The region falls within the eastern Dahomey Basin and encompasses parts of Edo, Ondo and Ogun States.

Modifier: Rice Husk Ash (RHA)

The rice husk used as a modifier in the study was collected from a local mill situated in Ilorin, Ajasse-Ipo Road, Jimba-Oja, Kwara State, Nigeria, specifically between latitude 8.40° N and longitude 4.68° E and thereafter air dried at room temperature for further use.

Preparation of Rice Husk Ash

The air-dried rice husk was converted into ashes with a muffle furnace at 650 °C. The resultant ashes were sieved through 0.075 mm mesh to eliminate any possible impurities. The sieved ashes were then ground in a planetary ball mill with 400 RPM speed for 3 h to convert the respective ashes to nanomaterial.

Preparation of Rice Husk Ash Modified Bitumen

The Rice husk ash (RHA) modified Agbabu Natural Bitumen (ANB) sample was prepared using melt blend techniques, as described by Kumar and Tanveer (2013). ANB quantities of 40 g, 39 g, 38 g, 37.5g, 37 g, and 36 g were melted at 100-120 °C in a stainless reactor at six modification levels: 0g, 1.0 g, 2.0 g, 2.5 g, 3.0 g, and 4.0 g, respectively. RHA was gradually added to the agitated ANB, maintaining a temperature of 100-110 °C and a mechanical stirrer speed of 28 rpm. The mixture was agitated for 3 hours to ensure homogeneity.

Table 1: Different ANB Samples with their Respective Weights and Modifier Weight

| Sample code | Weight of Reactor (g) | Weight of ANB (g) | Weight of Modifier(g) |
|-------------|-----------------------|-------------------|-----------------------|
| ANB-0 | 74.621 | 40.0 | 0 |
| ANB-1 | 66.715 | 39.0 | 1.0 |
| ANB-2 | 70.841 | 38.0 | 2.0 |
| ANB-2.5 | 87.980 | 37.5 | 2.5 |
| ANB-3 | 74.184 | 37.0 | 3.0 |
| ANB-4 | 90.815 | 36.0 | 4.0 |

Fourier Transform INFRARED (FTIR) Spectroscopy

The functional groups present in the samples were identified using FTIR, an analytical technique that provides information on molecular vibrations and bonding. Fourier Transform Infrared (FTIR) Spectrophotometer FTIR-8400s, SHIMADZU, with spectral range: 4,000-400 cm^{-1} was used. Samples were prepared using the method of Olabemiwo et al.2015. The IR spectra of base and the AgNPs modified base samples were generated by separately scanning each sample. Each sample (1.5 mg) was ground with 150 mg of analytical grade potassium bromide (KBr). The mixture was pressed in a hydraulic press to form a pellet. The pellet was mounted on the spectrophotometer and the infrared spectra of base and modified samples were generated by scanning. The FTIR spectra were analyzed to determine chemical bonding and molecular structure, presence of specific functional groups (e.g., hydroxyl, carbonyl, and alkyl) and changes in molecular interactions due to modification.

RESULTS AND DISCUSSION**FTIR Analysis of Rice Husk Ash**

FTIR analysis of the rice husk ash revealed a broad absorption band was observed around 3441 cm^{-1} and 3271 cm^{-1} , attributed to O–H stretching vibrations, likely from hydrogen-bonded hydroxyl groups (alcohols, carboxylic acids) or moisture as seen in figure 1. Strong absorption peaks appeared at 2916 cm^{-1} and 2854 cm^{-1} , corresponding to the asymmetric and symmetric C–H stretching vibrations of methylene (CH_2) groups in long aliphatic hydrocarbon chains. Furthermore, a strong band was noted at 1701 cm^{-1} , assigned to C=O stretching vibration of a carbonyl group, suggestive of ketones, carboxylic acids, or esters. Absorption bands at 1459 cm^{-1} and 1377 cm^{-1} were assigned to C–H bending vibrations (scissoring of CH_2 and umbrella deformation of CH_3 groups) in the aliphatic chains.

FTIR Analysis of Unmodified Agbabu Natural Bitumen, ANB-0

The FTIR analysis of ANB was recorded in the range of 4000-400 cm^{-1} . The FTIR spectrum of unmodified bitumen shows a C–H stretching of aliphatic hydrocarbons in the range of 3000–2700 cm^{-1} and aromatic hydrocarbons with peaks at

1508.38 cm^{-1} and 1604.83 cm^{-1} (aromatic C=C stretching). There are indications of functional groups such as alcohols at 3448.84 cm^{-1} , carbonyls at 1716.7 cm^{-1} , and possibly phenolic compounds suggested by peaks around 1261.49 cm^{-1} (C–O stretching). The presence of C–H stretching and bending vibrations confirms the hydrocarbon nature of the bitumen, while the carbonyl peak suggests some degree of oxidation or functionalization (Figure 2). These Infrared absorption peaks are similar to the findings of Nivitha *et al.*, 2016.

FTIR Analysis of 1.0g Rice Husk Ash Modified Agbabu Natural Bitumen, ANB-1

The rice husk ash modified bitumen retains the aliphatic peaks in the range of 3000–2700 cm^{-1} , with increased intensity indicating an addition of long-chain hydrocarbons. The peak at 1604.83 cm^{-1} remains prominent, showing that the aromatic character is maintained in the modified bitumen, with increased intensity compared to unmodified bitumen (RHA1). This suggests that the modification enhances the stability or concentration of aromatic structures. The O–H stretching peak at 3433.41 cm^{-1} displays lower intensity compared to RHA1 indicating a balanced incorporation of hydroxyl groups that could enhance the overall bonding and properties of the modified bitumen. There is a notable shift in the carbonyl content, with peaks observed at 1705.13 cm^{-1} and the absence of anhydride peaks. This indicates that the modification alters the carbonyl functional groups, possibly resulting in new interactions without forming anhydrides (Figure 3). The additional peaks in the range 582.52-570.95 cm^{-1} represent new vibrations or structural changes due to the incorporation of rice husk ash, potentially indicating mineral interactions and the formation of new functional groups.

FTIR Analysis of 2.0g Rice Husk Ash Modified Agbabu Natural Bitumen, ANB-2

The peaks at 2727.44 cm^{-1} , 2854.74 cm^{-1} , and 2924.18 cm^{-1} indicate the retention of aliphatic C–H stretching vibrations, suggesting effective preservation of aliphatic content, although with decreased intensity compared to RHA2. The peak at 1608.69 cm^{-1} shows that the aromatic character is maintained. The O–H stretching peak at 3441.12 cm^{-1}

indicates increased hydroxyl groups, enhancing polarity and potential chemical interactions, consistent with similar hydroxyl content observed in previous analyses. Additionally, the lower carbonyl intensity at peak 1701.27 cm^{-1} suggests reduced oxidation, which is similar to results from Olabemiwo et. al., 2017. (Figure 4).

FTIR Analysis of 2.5 g Rice Husk Ash Modified Agbabu Natural Bitumen, ANB-2.5

The FTIR analysis of the 2.5g rice husk ash modified bitumen exhibits key characteristics indicating effective preservation and enhancement of properties. The aliphatic C–H stretching peaks at 2727.44 cm^{-1} , 2854.74 cm^{-1} , and 2924.18 cm^{-1} show similar intensity to those of RHA3, suggesting retained aliphatic content. The aromatic peak at 1608.69 cm^{-1} confirms stability in the aromatic character. A significant peak at 3448.84 cm^{-1} indicates increased hydroxyl groups, enhancing polarity and chemical interactions, which are favorable for performance. The carbonyl peak at 1716.7 cm^{-1} suggests some oxidation, while the presence of a new peak at 2009.89 cm^{-1} likely corresponds to C=O stretching, indicating the formation of new functional groups that may improve reactivity and enhance cross-linking. The 2.5 g modification demonstrates better retention of desirable characteristics compared to the 2.0 g rice husk ash modified bitumen, highlighting its potential for improved chemical stability and durability in various applications. This is shown in Figure 5.

FTIR Analysis of 3.0g Rice Husk Ash Modified Agbabu Natural Bitumen, ANB-3

The presence of aliphatic C–H stretching vibrations at 2723.58 cm^{-1} , 2854.74 cm^{-1} , and 2924.18 cm^{-1} indicates effective preservation of aliphatic content. The aromatic peak at 1604.83 cm^{-1} confirms that the aromatic structure is maintained, which is essential for the material's stability. A notable peak at 3421.83 cm^{-1} indicates the presence of hydroxyl groups, enhancing polarity and improving chemical interactions within the bitumen matrix. Although the intensity is slightly lower than in some previous samples, it still reflects a significant amount of hydroxyl groups. The carbonyl peak at 1716.7 cm^{-1} is similar to that of the unmodified ANB. (Figure 6).

FTIR Analysis of 4.0g Rice Husk Ash Modified Agbabu Natural Bitumen, ANB-4

The aliphatic C–H stretching vibrations are present at 2727.44 cm^{-1} , 2854.74 cm^{-1} , and 2924.18 cm^{-1} , indicating retention of aliphatic content, although the intensity is lower compared to previous samples. The aromatic peak at 1604.83 cm^{-1} suggests that the aromatic structure is maintained, which is crucial for the material's stability. A prominent peak at 3441.12 cm^{-1} indicates the presence of hydroxyl groups, enhancing polarity and potentially improving chemical interactions within the bitumen matrix. The carbonyl peak at 1701.27 cm^{-1} is observed. (Figure 7).

SHIMADZU

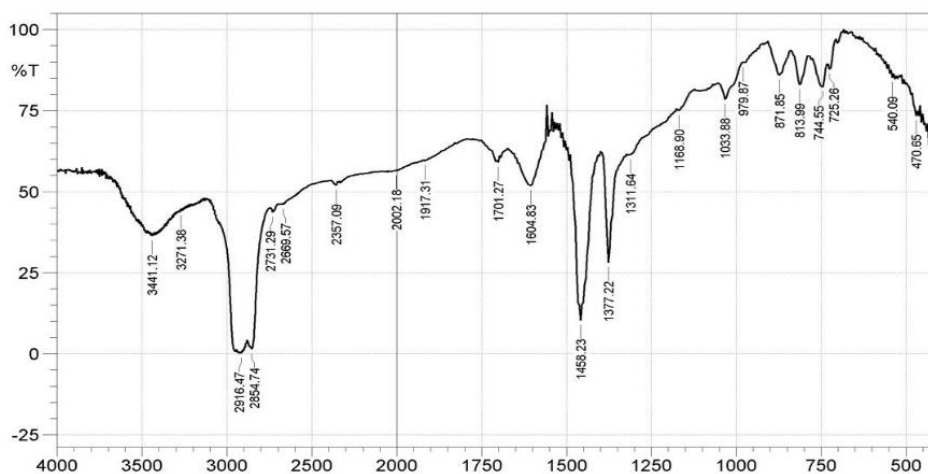


Figure 1: FTIR Spectrum of Rice Husk Ash

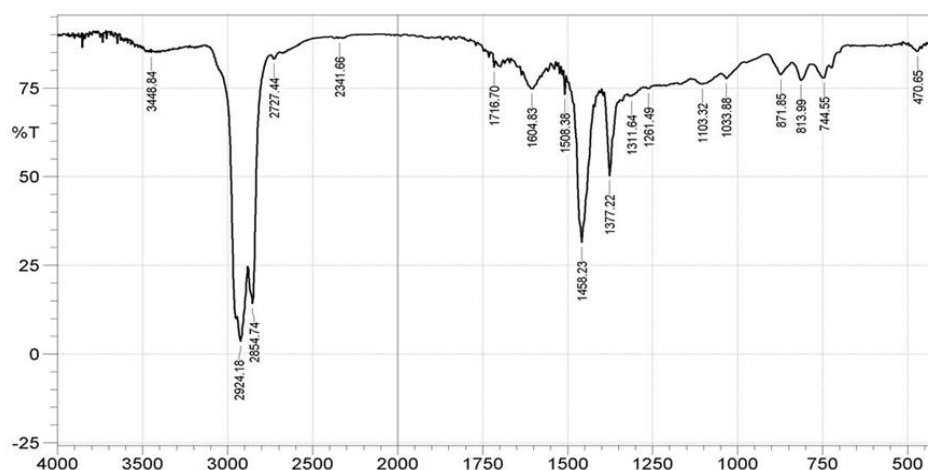


Figure 2: FTIR Spectrum of Untreated Agbabu Natural Bitumen (ANB), RHA1

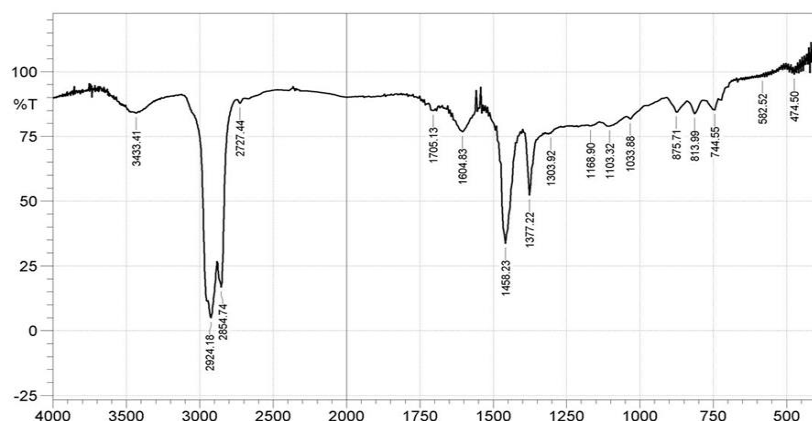


Figure 3: FTIR Spectrum of 1.0g Rice Husk Ash Modified Bitumen, (RHA2)

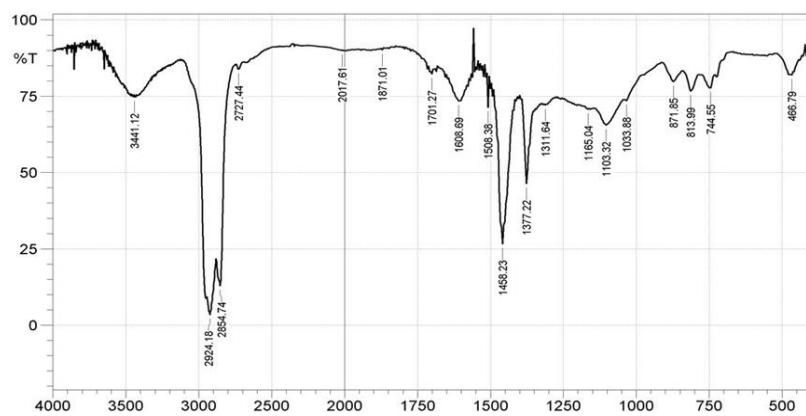


Figure 4: FTIR Spectrum of 2.0g Rice Husk Ash Modified Bitumen, (RHA3)

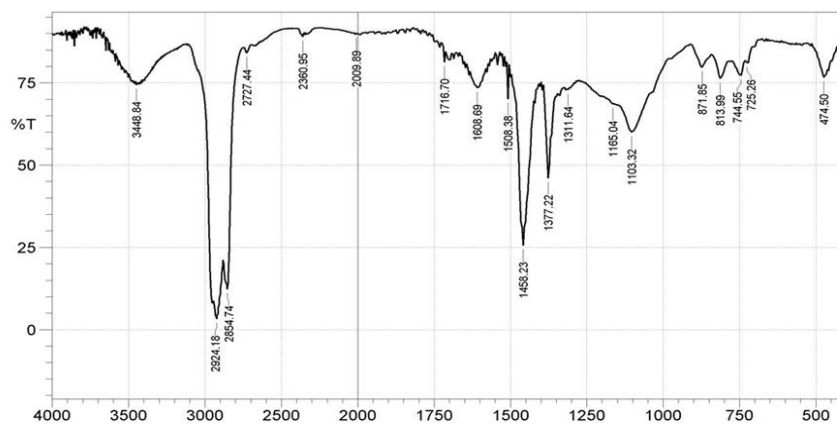


Figure 5: FTIR Spectrum of 2.5g Rice Husk Ash Modified Bitumen, (RHA4)

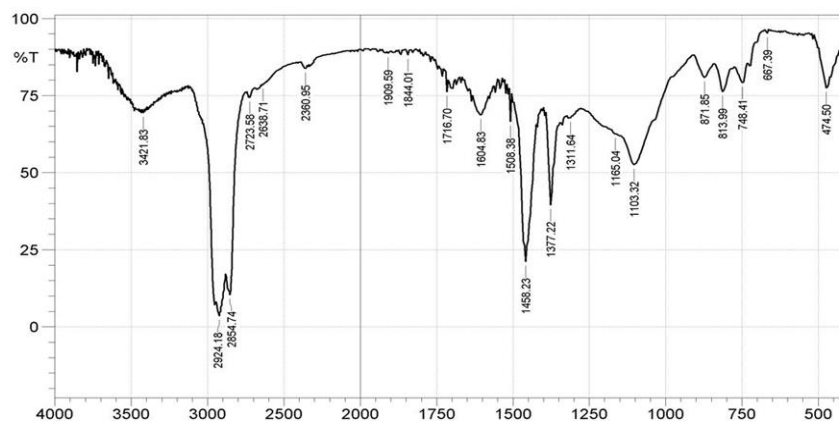


Figure 6: FTIR Spectrum of 3.0g Rice Husk Ash Modified Bitumen, (RHA5)

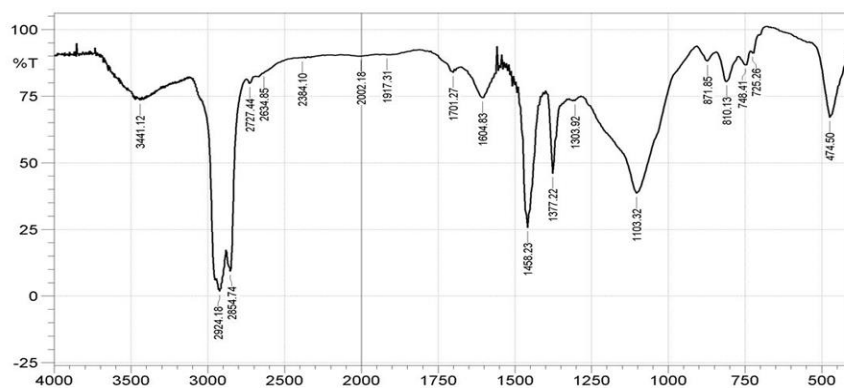


Figure 7: FTIR Spectrum of 4.0g Rice Husk Ash Modified Bitumen, (RHA6)

Table 2: Functional Groups of Agbabu Natural Bitumen ANB-0

| Before Aging | | | After Aging | | |
|-------------------------------|--------------------|---------------------------------------|-------------------------------|--------------------|---|
| Frequency (cm ⁻¹) | Functional Groups | Class of Compound | Frequency (cm ⁻¹) | Functional Groups | Class of Compound |
| 470.65 | C-H (bending) | Aromatics | 470.65 | C-H (bending) | Aromatics |
| 744.55 | C-H (bending) | Aromatics | 547.8 | C-C (bending) | Aromatics |
| 813.99 | C=C (bending) | Alkene | 744.55 | C-H (bending) | Aromatics |
| 871.85 | C-H (bending) | Aromatic ring | 813.99 | C=C (bending) | Alkene |
| 1033.88 | S=O (stretching) | Sulfoxide | 875.71 | C-H (bending) | Aromatic ring |
| 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol | 1033.88 | S=O (stretching) | Sulfoxide |
| 1261.49 | C-O (stretching) | Alkyl aryl ether/ Aromatic ester | 1103.32 | C-O (stretching) | Aliphatic ether/Secondary alcohol |
| 1311.64 | C-N (stretching) | Aromatic amine | 1165.04 | C-O (stretching) | Ester |
| 1311.64 | S=O (stretching) | Sulfone | 1311.64 | C-N (stretching) | Aromatic amine |
| 1377.22 | C-N (stretching) | Aromatic amine | 1377.22 | S=O (stretching) | Sulfone |
| 1377.22 | C-H (bending) | Methyl group | 1377.22 | C-H (bending) | Methyl group |
| 1458.23 | C-H (bending) | Methylene | 1458.23 | C-H (bending) | Methylene |
| 1508.38 | C=C (stretching) | Aromatic rings | 1508.38 | C=C (stretching) | Aromatic rings |
| 1604.83 | C=C (stretching) | Aromatic rings | 1604.83 | C=C (stretching) | Aromatic rings |
| 1716.7 | C=O (stretching) | Aliphatic ketone/ Carboxylic acid | 1701.27 | C=O (stretching) | Conjugated (acid, aldehyde) |
| 2341.66 | O=C=O (stretching) | Carbon dioxide | 1909.59 | C=O (stretching) | Carbonyls Anhydride |
| 2727.44 | C-H (stretching) | Aldehyde | 2364.81 | O=C=O (stretching) | Carbon dioxide |
| 2854.74 | C-H (stretching) | Alkane | 2669.57 | C-H (stretching) | Aldehyde |
| 2924.18 | C-H (stretching) | Alkane | 2727.44 | C-H (stretching) | Aldehyde |
| 3448.84 | O-H (stretching) | Alcohol | 2854.74 | C-H (stretching) | Alkane |
| | | | 2916.47 | O-H | Alcohol |
| | | | | C-H (stretching) | Alkane |
| | | | 3279.1 | C-H (stretching) | Alkyne |
| | | | | O-H (stretching) | Alcohol |
| | | | 3441.12 | O-H (stretching) | Alcohol |
| | | | | N-H (stretching) | Primary amine |

Table 3: Functional groups of 1.0g rice husk ash modified bitumen ANB-1

| Before Aging | | | After Aging | | |
|-------------------------------|-------------------|---------------------------------------|-------------------------------|--------------------------------------|---------------------------------------|
| Frequency (cm ⁻¹) | Functional Groups | Class of Compound | Frequency (cm ⁻¹) | Functional Groups | Class of Compound |
| 474.5 | C-H (bending) | Aromatics | 470.65 | C-H (bending) | Aromatics |
| 582.52 | Si-O (bending) | Silicates | | | |
| 744.55 | C-H (bending) | Aromatics | 570.95 | Si-O (bending) | Silicates |
| 813.99 | C=C (bending) | Alkene | 744.55 | C-H (bending) | Aromatics |
| 875.71 | C-H (bending) | Aromatic ring | 813.99 | C=C (bending) | Alkene |
| 1033.88 | S=O (stretching) | Sulfoxide | 871.85 | C-H (bending) | Aromatic ring |
| 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol | 1033.88 | S=O (stretching) | Sulfoxide |
| 1168.9 | C-O (stretching) | Ester | 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol |
| 1303.92 | C-O (stretching) | Aromatic ester | 1168.9 | C-O (stretching) | Ester |
| 1377.22 | C-H (bending) | Methyl group | 1265.35 | C-O (stretching) | Aromatic ester |
| 1458.23 | C-H (bending) | Methylene | 1303.92 | S=O (stretching) | Sulfone |
| 1604.83 | C=C (stretching) | Aromatic ring | 1377.22 | C-H (bending) | Methyl group |
| 1705.13 | C=O (stretching) | Conjugated (acid, aldehyde) | 1458.23 | C-H (bending) | Methyl group |
| 2727.44 | C-H (stretching) | Carboxylic acid Aldehyde | 1508.38 | C=C (stretching) | Aromatic rings |
| 2854.74 | C-H (stretching) | Alkane | 1604.83 | C=C (stretching) | Aromatic ring |
| 2924.18 | C-H (stretching) | Alkane | 1701.27 | C=O (stretching) | Conjugated (acid, aldehyde) |
| 3433.41 | O-H (stretching) | Alcohol | 1898.02 | C=O (stretching) | Carbonyls Anhydride |
| | | | 2364.81 | O=C=O (stretching) | Carbon dioxide |
| | | | 2673.43 | O-H C-H (stretching) | Carboxylic acid Aldehyde |
| | | | 2854.74 | C-H (stretching) | Alkane |
| | | | 2924.18 | C-H (stretching) | Alkane |
| | | | 3441.12 | O-H (stretching) N-H (stretching) | Alcohol Primary amine |

Table 4: Functional Groups of 2.0g Rice Husk Ash Modified Bitumen ANB-2

| Before Aging | | | After Aging | | |
|-------------------------------|--------------------------------------|---------------------------------------|-------------------------------|--------------------|---------------------------------------|
| Frequency (cm ⁻¹) | Functional Groups | Class of Compound | Frequency (cm ⁻¹) | Functional Groups | Class of Compound |
| 466.79 | Si-O (bending) | Silicate | 420.5 | Si-O (bending) | Silicates |
| | | | | C-C (bending) | Aliphatic/Aromatic |
| 744.55 | C-H (bending) | Aromatics | 466.79 | Si-O (bending) | Silicates |
| 813.99 | C=C (bending) | Alkene | 574.81 | Si-O (bending) | Silicates |
| 871.85 | C-H (bending) | Aromatic ring | 744.55 | C-H (bending) | Aromatics |
| 1033.88 | S=O (stretching) | Sulfoxide | 813.99 | C=C (bending) | Alkene |
| 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol | 871.85 | C-H (bending) | Aromatic ring |
| 1165.04 | C-O (stretching) | Ester | 1033.88 | S=O (stretching) | Sulfoxide |
| 1311.64 | S=O (stretching) | Sulfone | 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol |
| | C-N (stretching) | Aromatic amine | | | |
| 1377.22 | C-H (bending) | Methyl group | 1203.62 | C-O (stretching) | Tertiary alcohol |
| 1458.23 | C-H (bending) | Methylene | 1311.64 | C-O (stretching) | Aromatic ester |
| 1508.38 | C=C (stretching) | Aromatic rings | 1377.22 | C-H (bending) | Methyl group |
| 1608.69 | C=C (stretching) | Aromatic rings | 1458.23 | C-H (bending) | Methyl group |
| 1701.27 | C=O (stretching) | Conjugated (acid, aldehyde) | 1508.38 | C=C (stretching) | Aromatic rings |
| 1871.01 | C=O (stretching) | Carbonyls Anhydride | 1604.83 | C=C (stretching) | Aromatic rings |
| 2017.61 | C=O (stretching) | Ester | 1701.27 | C=O (stretching) | Conjugated (acid, aldehyde) |
| 2727.44 | C-H (stretching) | Carboxylic acid Aldehyde | 2013.75 | C=O (stretching) | Ester |
| 2854.74 | C-H (stretching) | Alkane | 2345.52 | O=C=O (stretching) | Carbon dioxide |
| 2924.18 | C-H (stretching) | Alkane | 2673.43 | C-H (stretching) | Aldehyde |
| 3441.12 | O-H (stretching) N-H (stretching) | Alcohol Primary amine | 2727.44 | C-H (stretching) | Carboxylic acid Aldehyde |
| | | | 2854.74 | C-H (stretching) | Alkane |
| | | | 2924.18 | C-H (stretching) | Alkane |
| | | | 3425.69 | O-H (stretching) | Alcohol |

Table 5: Functional Groups of 2.5g Rice Husk Ash Modified Bitumen ANB-2.5

| Before Aging | | | After Aging | | |
|-------------------------------|--------------------|---------------------------------------|-------------------------------|-------------------|---------------------------------------|
| Frequency (cm ⁻¹) | Functional Groups | Class of Compound | Frequency (cm ⁻¹) | Functional Groups | Class of Compound |
| 474.5 | C-H | Aromatics | 474.5 | C-H | Aromatics |
| | Si-O (bending) | Silicates | | Si-O (bending) | Silicates |
| 725.26 | C-H (bending) | Aromatics | 721.4 | C-H (bending) | Aromatics |
| 744.55 | C-H (bending) | Aromatics | 748.41 | C-H (bending) | Aromatics |
| 813.99 | C=C (bending) | Alkene | 813.99 | C=C (bending) | Alkene |
| 871.85 | C-H (bending) | Aromatic ring | 871.85 | C-H (bending) | Aromatic ring |
| 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol | 972.16 | C=C (bending) | Alkene |
| 1165.04 | C-O (stretching) | Ester | 1033.88 | S=O (stretching) | Sulfoxide |
| 1311.64 | C-O (stretching) | Aromatic ester | 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol |
| 1377.22 | C-H (bending) | Methyl group | 1165.04 | C-O (stretching) | Ester |
| 1458.23 | C-H (bending) | Methylene | 1303.92 | C-O (stretching) | Aromatic ester |
| 1508.38 | C=C (stretching) | Aromatic rings | 1377.22 | C-H (bending) | Methyl group |
| 1608.69 | C=C (stretching) | Aromatic rings | 1458.23 | C-H (bending) | Methyl group |
| 1716.7 | C=O (stretching) | Aliphatic ketone Formates | 1508.38 | C=C (stretching) | Aromatic rings |
| 2009.89 | C=C=C (stretching) | Allene | 1600.97 | C=C (stretching) | Aromatic rings |
| 2360.95 | O=C=O (stretching) | Carbon dioxide | 1701.27 | C=O (stretching) | Conjugated (acid, aldehyde) |
| 2727.44 | C-H (stretching) | Carboxylic acid | 2029.18 | C=O (stretching) | Ester |
| 2854.74 | C-H (stretching) | Alkane | 2677.29 | C-H (stretching) | Aldehyde |
| 2924.18 | C-H (stretching) | Alkane | 2727.44 | C-H (stretching) | Aldehyde |
| 3448.84 | O-H (stretching) | Alcohol | 2854.74 | C-H (stretching) | Alkane |
| | N-H (stretching) | Primary amine | 2924.18 | C-H (stretching) | Alkane |
| | | | 3425.69 | O-H (stretching) | Alcohol |

Table 6: Functional Groups of 3.0g Rice Husk Ash Modified Bitumen ANB-3

| Before Aging | | | After Aging | | |
|-------------------------------|--------------------|---------------------------------------|-------------------------------|--------------------|---------------------------------------|
| Frequency (cm ⁻¹) | Functional Groups | Class of Compound | Frequency (cm ⁻¹) | Functional Groups | Class of Compound |
| 474.5 | C-H | Aromatics | 420.5 | Si-O (bending) | Silicates |
| | Si-O (bending) | Silicates | | C-C (bending) | Aliphatic/Aromatic |
| 667.39 | C-H (bending) | Aromatics | 474.5 | C-H | Aromatics |
| | C-O | Ether | | Si-O (bending) | Silicates |
| 748.41 | C-H (bending) | Aromatics | 721.4 | C-H (bending) | Aromatics |
| 813.99 | C=C (bending) | Alkene | 744.55 | C-H (bending) | Aromatics |
| 871.85 | C-H (bending) | Aromatic ring | 813.99 | C=C (bending) | Alkene |
| 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol | 871.85 | C-H (bending) | Aromatic ring |
| 1165.04 | C-O (stretching) | Ester | 972.16 | C=C (bending) | Alkene |
| 1311.64 | C-O (stretching) | Aromatic ester | 1033.88 | S=O (stretching) | Sulfoxide |
| 1377.22 | C-H (bending) | Methyl group | 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol |
| 1458.23 | C-H (bending) | Methylene | 1165.04 | C-O (stretching) | Ester |
| 1508.38 | C=C (stretching) | Aromatic rings | 1211.34 | C-O (stretching) | Ester |
| 1604.83 | C=C (stretching) | Aromatic rings | 1300.07 | C-O (stretching) | Aromatic ester |
| 1716.7 | C=O (stretching) | Aliphatic ketone Formates | 1377.22 | C-H (bending) | Methyl group |
| 1844.01 | C=O (stretching) | Anhydride | 1458.23 | C-H (bending) | Methylene |
| 1909.59 | C=O (stretching) | Carbonyls Anhydride | 1508.38 | C=C (stretching) | Aromatic rings |
| 2360.95 | O=C=O (stretching) | Carbon dioxide | 1604.83 | C=C (stretching) | Aromatic rings |
| 2638.71 | C-H (stretching) | Aldehyde | 1701.27 | C=O (stretching) | Conjugated (acid, aldehyde) |
| 2723.58 | C-H (stretching) | Aldehyde | 1913.45 | C=O (stretching) | Carbonyls Anhydride |
| 2854.74 | C-H (stretching) | Alkane | 2021.47 | C=O (stretching) | Ester |
| 2924.18 | C-H (stretching) | Alkane | 2384.1 | O=C=O (stretching) | Carbon dioxide |

| Before Aging | | | After Aging | | |
|-------------------------------|-------------------|-------------------|-------------------------------|-------------------|-------------------|
| Frequency (cm ⁻¹) | Functional Groups | Class of Compound | Frequency (cm ⁻¹) | Functional Groups | Class of Compound |
| 3421.83 | O-H (stretching) | Alcohol | 2677.29 | C-H (stretching) | Aldehyde |
| | N-H (stretching) | Primary amine | | | |
| | | | 2727.44 | C-H (stretching) | Aldehyde |
| | | | 2854.74 | C-H (stretching) | Alkane |
| | | | 2924.18 | C-H (stretching) | Alkane |
| | | | 3433.41 | O-H (stretching) | Alcohol |

Table 7: Functional Groups of 4.0g Rice Husk Ash Modified Bitumen ANB-4

| Before Aging | | | After Aging | | |
|-------------------------------|--------------------|---------------------------------------|-------------------------------|-------------------|---------------------------------------|
| Frequency (cm ⁻¹) | Functional Groups | Class of Compound | Frequency (cm ⁻¹) | Functional Groups | Class of Compound |
| 474.5 | C-H | Aromatics | 470.65 | C-H | Aromatics |
| | Si-O (bending) | Silicates | | Si-O (bending) | Silicates |
| 725.26 | C-H (bending) | Aromatics | 725.26 | C-H | Aromatics |
| 748.41 | C-H (bending) | Aromatics | 748.41 | C-H (bending) | Aromatics |
| 810.13 | C=C (bending) | Alkene | 813.99 | C=C (bending) | Alkene |
| 871.85 | C-H (bending) | Aromatic ring | 871.85 | C-H (bending) | Aromatic ring |
| 1303.32 | C-O (stretching) | Aromatic ester | 1033.88 | S=O (stretching) | Sulfoxide |
| 1103.92 | C-O (stretching) | Aliphatic ether/ Secondary alcohol | 1103.32 | C-O (stretching) | Aliphatic ether/ Secondary alcohol |
| 1377.22 | C-H (bending) | Methyl group | 1165.04 | S=O (stretching) | Sulfonate |
| 1458.23 | C-H (bending) | Methylene | 1303.92 | C-O (stretching) | Aromatic ester |
| 1604.83 | C=C (stretching) | Aromatic rings | 1377.22 | C-H (bending) | Methyl group |
| 1701.27 | C=O (stretching) | Conjugated (acid, aldehyde) | 1458.23 | C-H (bending) | Methylene |
| 1917.31 | C=O (stretching) | Carbonyls Anhydride | 1604.83 | C=C (stretching) | Aromatic rings |
| 2002.18 | C=O (stretching) | Ester Anhydride | 1701.27 | C=O (stretching) | Conjugated (acid, aldehyde) |
| 2384.1 | O=C=O (stretching) | Carbon dioxide | 1867.16 | C=O (stretching) | Carbonyls Anhydride |
| 2634.85 | O-H (stretching) | Carboxylic acid | 2669.57 | C-H (stretching) | Aldehyde |
| 2727.44 | C-H (stretching) | Aldehyde | 2731.29 | C-H (stretching) | Aldehyde |
| 2854.74 | C-H (stretching) | Alkane | 2854.74 | C-H (stretching) | Alkane |
| 2924.18 | C-H (stretching) | Alkane | 2924.18 | C-H (stretching) | Alkane |
| 3441.12 | O-H (stretching) | Alcohol | 3448.84 | O-H (stretching) | Alcohol |

CONCLUSION

Rice husk ash was successfully incorporated into bitumen with the aim of improving its resistance to aging. The presence of hydroxyl groups at contributes to increased polarity and chemical interactions, which can further enhance adhesion in various applications. The combination of long aliphatic chains (physical compatibility and barrier) and polar oxygenated groups (OH and C=O — chemical interactions via H-bonding and dipole forces) present in the rice husk ash allows the additive to improve homogeneity and reduce phase separation, limit oxygen ingress and stabilize polar components in bitumen, reducing the rate of carbonyl and sulfoxide formation during aging.

The shifts in carbonyl peaks were observed, these changes may also indicate beneficial reactions, such as cross-linking, due to the formation of new functional groups while some modification may appear suitable due to decreased in carbonyl peaks in ANB-4 and ANB-2, some appears suitable due to retention of the aliphatic peaks and stable carbonyl peaks at 1716.70 cm⁻¹. The incorporations preserve key characteristics of bitumen and promote enhancements that could lead to better performance in harsh environmental conditions. Further analysis like penetration tests, softening points would be beneficial to fully assess the implications of these changes, particularly the consistent reduction in aliphatic content and long-term performances.

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