**E**VALUATION OF RICE HUSK ASH AS MINERAL FILLER IN HOT MIX ASPHALT

**Paul, V. S.1, Kolo, S. S.2, Alhassan, M.3**

 1,2,3Department of Civil Engineering, Federal University of Technology, Minna, Niger State, Nigeria

Corresponding author email: moh.shehu@futminna.edu.ng +2348133768999

**ABSTRACT**

The development of sustainable and cost-effective road construction materials is a pressing challenge in the realm of infrastructure development. Traditional road construction relies heavily on granite materials, which are not only costly but also deplete valuable natural resources and contribute to environmental degradation. To address these challenges, there is a need to explore alternative filler materials that not only enhance sustainability but also maintain or improve the mechanical and durability properties of asphalt mixes. Specifically, the inclusion of rice husk as a filler in hot-mixed asphalt remains largely unexplored. The moisture content, specific gravity, bulk density, void ratio and porosity of RHA were found to be 0.11, 2.38, 0.88kg/cm3, 0.19, and 11.54% respectively, while the chemical composition shows that it contains over 82% of Si2O4. The result shows that the maximum stability using 0% RHA (100% Fine) was 5.5kN with the corresponding flow of 4.5mm at a BC of 5.33% and a density of 6g/cm3. Out of the percentage replacement with RHA (25, 50, 75 and 100%), only 75% of RHA shows a higher stability value of 3.14kN but was about 42% lower compare to the control value. Hence, RHA is not a good replacement to the conventional material

***Keyword: Flow, Hot Mix Asphalt, Rice Husk Ash, Stability,***

**1.0 INTRODUCTION**

The development of sustainable and cost-effective road construction materials is a pressing challenge in the realm of infrastructure development. Traditional road construction relies heavily on granite materials, which are not only costly but also deplete valuable natural resources and contribute to environmental degradation (Kumar and Kumar, 2018). **B**urning rice husk is one of the most environmental problems in Nigeria . It has negative effects on human health and life. Burning the rice husk is the main cause of what is called "black cloud", which has negative influences on the environment and human health.

The traditional production of hot-mixed asphalt relies on conventional mineral fillers, often derived from non-renewable sources. This practice raises environmental concerns and contributes to rising costs in the construction industry. To address these challenges, there is a need to explore alternative filler materials that not only enhance sustainability but also maintain or improve the mechanical and durability properties of asphalt mixes. Specifically, the inclusion of rice husk as a filler in hot-mixed asphalt remains largely unexplored. The following key problems prompt the initiation of this research:

Roads are fundamental components of modern infrastructure, serving as crucial arteries for transportation and economic growth (Kumar and Kumar, 2018). They provide essential connectivity for people, goods, and services, fostering societal development and enhancing quality of life (NCHRP, 2016). To accommodate the escalating demands of traffic and trade, road construction must uphold durability, safety, and efficiency. It typically consists of a prepared surface, known as pavement, located on a leveled area. The primary purpose of a road is to facilitate the transportation of people, vehicles, and goods efficiently and safely. Pavements, as the uppermost layers of roads, face rigorous challenges from traffic loads, climatic variations, and environmental stressors (Ongel *et al.*, 2017).

Engineers have developed various pavement types to address these challenges; pavement refers to the durable and prepared surface of a road that provides a smooth and safe passage for vehicles. It acts as a platform for load-bearing, offers sufficient friction for vehicle tires, and enhances vehicle stability and control. Pavement types vary based on the materials used and design specifications. The two primary types of pavement are rigid and flexible pavement. Rigid pavements include materials such as concrete, reinforced concrete, or asphalt concrete. They have a relatively high flexural strength, which enables them to distribute heavy loads effectively. On the other hand, flexible pavements are made up of multiple layers of materials, including a sub grade layer, base course, and surface course. They are designed to distribute loads through the layers and allow for more significant deformation without cracking.

Flexible pavement is a prominent choice due to its ability to distribute loads over a wider area, ensuring prolonged service life (Mamlouk and Zaniewski, 2019). The materials used in flexible pavement typically consist of aggregates, binders, and fillers. Aggregates provide strength and stability to the pavement structure, binder, usually in the form of asphalt, holds the aggregates together, and filler, such as limestone dust or Portland cement, fills the voids in the aggregates to enhance the stability. Flexible pavements rely heavily on Hot Mix Asphalt (HMA), a composite material comprising aggregates, binders, and mineral fillers (Tigdemir and Guler, 2014). The selection of appropriate materials profoundly influences the mechanical and performance characteristics of HMA (Kassem *et al.,* 2015).

Rice husk ash (RHA) is a biomass ash that comes from burning rice husk in powerhouses and furnaces (Rauch *et al.* 2016). Currently, rice husk ash, because of having proper characteristics, is widely used in the concrete production industry, and has the potential of being used as filler in the pavement industry, too. The significance of introducing Rice husk ash (RHA) into asphalt mixes lies in its potential to enhance pavement performance and address sustainability concerns (Kassem *et al.,* 2015). As traditional mineral fillers have limitations, exploring alternative materials like RHA aligns with sustainable practices and addresses waste utilization (Sadek and Berekete, 2019).

This study seeks to comprehensively evaluate the utilization of rice husk ash/powder as mineral filler in Hot Mix Asphalt (HMA). Through a thorough investigation of the effects of Rice husk ash (RHA) on Hot Mix Asphalt (HMA) properties; this research aims to contribute to the development of innovative and sustainable road construction materials.

**2.0 MATERIALS AND METHODS**

This chapter outlines the materials, experimental procedures, and methodologies employed in the investigation of Rice Husk Ash (RHA) as mineral filler in Hot Mix Asphalt (HMA) for road pavements. The comprehensive characterization of Rice Husk Ash (RHA), the mixture design process, and the testing protocols are detailed to provide a thorough understanding of the research methodology.

* 1. **Materials Used**

Materials used for this project includes: 12.5mm of coarse aggregate, 9.5mm of coarse aggregate, Mineral Filler (Fine Sand), Dust (fine aggregate), Bitumen Emulsion and Rice Husk Ash (RHA)

**2.2 Research Method**

The methods/approach adopted are classified under the methods for determining the physical properties of fine and coarse aggregates, methods for determining the crushing and impact strength of the coarse aggregates. The methods include

* + 1. **Determination of the physical properties of aggregates.**

The following tests were carried out to determine the physical properties of the aggregate used: Sieve Analysis, Specific Gravity, Bulk Density and Moisture Content

* + 1. **Determination of hardened properties of the coarse aggregate**

The following tests were carried out to determine the hardened properties of the coarse aggregate used. This includes; Impact Test and Crushing Test.

**2.2.3 Determination of physical properties of the bitumen**

The following tests were carried out to determine the physical properties of the bitumen used. This includes; Flash and Fire Point Test, Penetration Test, Softening Point Test and Specific gravity Test

**2.2.4 Marshall stability test**

The Marshall Stability test (in ASTM D1559) is conducted to evaluate the mechanical properties and performance characteristics of bituminous mixtures. Marshall Samples with bitumen contents ranging from 4.5% to 6.5% by weight of the aggregate, increased by 0.5%, were prepared for the tests. For each of bitumen content, three samples were made, and the optimal bitumen content (OBC) was found. It is conducted on a prepared cylindrical specimen of asphalt mix to assess its load-carrying capacity and resistance to deformation under specific conditions. A standard dry specimen of 1200g of aggregate and filler was heated at a temperature of 175℃ - 190℃. The dry mix and bitumen was heated in the right proportion according to the mix composition to a temperature of 150℃ - 170℃ and was then placed in an oiled marshal apparatus mold. The mixture is subjected to compaction with a total number of seventy-five blows of a 4.54kg compaction hammer falling through 457mm on the either side of the mold containing the hot mix asphalt. Allow to cool for twenty-four hours, demold and weigh and record the sample separately in air and water. Obtain the values for stability (which represents the maximum load the specimen can withstand before failure) and flow (which is deformation or flow of the specimen. Flow is the amount of vertical displacement experienced by the specimen at the point of maximum load. Flow measurement).

**2.2.5 Filler Replacement**

The RHA was sieved through 2.6mm and 0.075mm BS sieve (No.200), the physical properties like moisture content, bulk density, specific gravity using stated procedure was determined. Using the obtained optimum bitumen content value determined from control specification, hot mix asphalt mould sample was prepared and RHA was partially replaced for mineral filler in ranges from 25, 50, 75, and 100%. The asphaltic mix sample was subjected to marshal stability test to obtain the value for stability and flow.

**3.0 RESULTS AND DISCUSSION**

**3.1 Sieve Analysis Results**

The results for the fine aggregate 75µm ̶ 2.36mm, Coarse aggregate 75µm ̶ 14mm and Rice Husk Ash 75µm ̶ 2.36mm as present in Figure 1 and 2 and was observed that the fine aggregates shows normal distribution.

**Figure 1:** Grading curve for cumulative % passing of Crushed aggregates (Coarse)

**Figure 2:** Grading curve for cumulative % passing of Rice Husk Ash

**3.2 Moisture Content**

Tables 1 present the moisture content results for river sand, 10mm aggregates, 14mm aggregates, stone dust and RHA. It was observed that the value for moisture content 0.10%, 0.12%, 0.13%, 0.11% for 10mm aggregate, 14mm aggregate, stone dust and rice husk ash were low compared to fine aggregate of 0.21%. Which suggest that the rice husk ash need more moisture for the production to avoid reduction in strength.

**Table 1:** Moisture content for aggregate

|  |  |
| --- | --- |
| **Materials**  | **Moisture Content**  |
| Stone dust  | 0.13 |
| Coarse Aggregate  | 0.1 |
| RHA  | 0.11 |

Table 1 shows that the filler material, 9.5mm aggregates, 12.5mm aggregates and RHA have respective moisture content value of 0.21, 0.13, 0.10 and 0.11% respectively and they all falls within the standard specification.

**3.3 Aggregate Impact and crushing test**

The impact values gotten for pure aggregate and rice husk ash were compared with the specification and it was found that the impact value for coarse aggregate is within the specification range of 20-30% value by BS 812, while impact value for rice husk ash did not meet the requirements. The average AIV for the coarse aggregates, and RHA are presented in Table 2

**Table 2:** AIV and ACV

|  |  |
| --- | --- |
| **Other Tests**  | **Result (%)** |
| AI V  | 8.78 |
| ACV  | 20.06 |

**3.4 Bitumen Test**

**Table 3:** Bitumen test results

|  |  |  |
| --- | --- | --- |
| **Bitumen Result**  | **Result**  | **Standard Range**  |
| Flash Point  | 3510C | 2320C Minimum |
| Fire Point  | 3710C | 2320C Minimum |
| Penetration  | 64mm  | 100mm Maximum  |
| Specific Gravity  | 1.03 | 1.01-1.06  |
| Softening Point  | 52.35 | 560C Maximum |

From the test conducted, the value for flash and fire test was 351°C and 371°C respectively and the standard values are 351°C and 371°C, thereby making the material suitable for use. Also, the value for penetration test was 98.67mm which is below the standard maximum value of 100, thereby making the material suitable for use. The value for specific gravity was 1.03 and it falls within the standard range of 1.00 – 1.05, hence, the Bitumen is suitable for road application. The softening point value was 52.15°C which is below the maximum standard value of 56°C.

**3.5 Specific Gravity**

Tables 4 shows the specific gravity results for fine aggregate, stone dust and rice husk ash. The results were found to be 2.65 for fine aggregate which falls within the standard limit of (2.50 - 2.65), 2.40 for stone dust which is also within the standard range of (2.20 – 2.80, and 2.38 for RHA which is also within the standard range of (2.1 to 2.4) respectively. The range for rice husk ash is relatively low compared with the range of values for the other aggregates. Most aggregates have a specific gravity ranging between 2.5 and 3.5 (Neville 1977). The specific gravity of aggregates is used to calculate the quantity in mix design. It is however not a measure of the quantity of aggregate.

**Table 4: S**pecific gravity for aggregates

|  |  |  |
| --- | --- | --- |
| **Materials**  | **Specific Gravity**  | **Range**  |
| Sand  | 2.65 | 2.50-2.65  |
| Stone dust  | 2.4 | 2.20-2.80  |
| RHA  | 2.38 | 1.50-2.55  |

The specific gravity values obtained for mineral filler, stone dust and carbon powder as shown in Table 6 are respectively 2.65 (2.5-2.65 standard range), 2.40 (2.20-2.80 standard range) and 2.53 (1.50-2.55 standard range)

**3.6 Bulk Density**

**Table 5:** Bulk density result for the aggregates

|  |  |  |
| --- | --- | --- |
| **Materials**  | **Bulk Densities**  | **Result(kg/cm3)**  |
| Sand  | Uncompacted  | 1.43 |
|   | Compacted  | 1.53 |
| RHA  | Uncompacted  | 1.74 |
|   | Compacted  | 2.05 |
| Stone dust  | Uncompacted  | 1.65 |
|   | Compacted  | 1.86 |
| Coarse Aggregate  | Uncompacted  | 1.66 |
|   | Compacted  | 1.68 |

The bulk density of a material is the weight of material that would fill a container of unit volume. The bulk density of natural aggregate is generally between 1600 kg/m³. This indicates that the bulk density of rice husk ash which was found to be an average of 460kg/m³ for Un-compacted and 520 kg/m³ for compacted are 28.75% and 32.50% of natural aggregate. The Un-compacted bulk density is used in this work; this is because in practical application the material will not be compacted before being used in the mix.

$$Ratio of compacted to un-compacted Bulk density=\frac{1.43}{1.53}=0.935$$

**3.7 Void Ratio**

Table 6 shows the result for rice husk ash. The result shows that the void ratio was found to be 0.19, this means that the particles of RHA are closely packed together and will require less sand and binder in mix thus, resulting in an economic material. While the void for the stone dust and river sands were found to be as large as 69% and 54%.

$$Void ratio=1-\frac{Uncompacted Bulk Density }{Specific gravity\*Unit weight of water}$$

**Table 6:** Void Ratio Result

|  |  |
| --- | --- |
| **Materials** | **Void ratio** |
| River sand | 0.54 |
| Stone dust | 0.69 |
| RHA | 0.19 |

**3.8 Porosity**

From the results obtained in Table 7, the porosity of rice husk ash was 11.54% when compared with the porosity of common rocks, rice husk ash exhibit rather high percentage porosity. This property of rice husk ash will make it vulnerable to frost action. It is advisable to wet rice husk ash prior to being used in asphalt concrete mix.

**Table 7:** Result of Porosity

|  |  |
| --- | --- |
| **Materials** | **Percentage Porosity (%)** |
| River sand | 6.54 |
| 10mm Aggregates | 1.2 |
| 14mm Aggregates | 4.5 |
| Stone dust | 11.29 |
| RHA | 11.54 |

**3.9 Chemical Composition of RHA**

Table 8 shows the chemical composition result of the RHA. From the result, it was found that RHA contains a higher value from silicon iv oxide (SiO2) about 82%. Hence the RHA is a good replacement for sand which also contains a very large percentage of sand.

**Table 8:** Result of chemical composition of RHA

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Chemical Composition | SiO2  | Al2O3 | Fe2O3 | CaO | MgO | Mn2O3 | Others |
| Percentage % | 82.3 | 4.05 | 1.64 | 9.54 | 2.08 | 0.25 | 0.14 |

**3.10 Physical Properties of Rice Husk Ash**

The results of XRD test of RHA is shown in Figure 1. XRD patterns of the prepared samples show a crystalline sharp peak at 2ɵ = 22 with a number of less intense peaks at 2ɵ = 28, 32, 47, 43, 47, 54 and 58. All the peaks are well described by the cristobalite pattern superimposed on a broad background caused by the remaining amorphous phase.



**Figure 1:** RHA XRD Image

**3.11 Mix Design**

Table 9 shows the combined mix proportion for the asphaltic concrete production. From the percentage passing for the components, it was observed that 7, 18, 15 and 60% of stoned dust are needed to have a total blend that will be satisfactory and will results to the mix that falls within the standard design range.

**Table 9:** Result of Mix Design (gradation of aggregate using trial and error method)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sieve****Size****(mm-µm)** | **Fine Aggregate****7%** | **14mm** **Aggregate****18%** | **10mm****Aggregate****15%** | **Stone Dust****Aggregate****60%** | **%Total****Blend** | **Design****Range****Values** |
| **%Pass** | **%Blend** | **%Pass** | **%Blend** | **%Pass** | **%Blend** | **%Pass** | **%Blend** |
| 20mm | 100 | 7 | 100 | 18 | 100 | 15 | 100 | 60 | 100 | 100 |
| 14mm | 100 | 7 | 100 | 18 | 96.82 | 14.52 | 100 | 60 | 99.52 | 90-100 |
| 10mm | 100 | 7 | 78.30 | 14.09 | 66.34 | 9.95 | 100 | 60 | 91.04 | 90max |
| 6.3mm | 100 | 7 | 9.89 | 1.78 | 33.23 | 4.99 | 100 | 60 | 73.77 | - |
| 2.36mm | 95.60 | 6.69 | 2.60 | 0.67 | 22.18 | 3.33 | 78.05 | 46.83 | 57.52 | - |
| 1.18mm | 87.38 | 6.12 | 2.40 | 0.434 | 17.32 | 2.59 | 57.20 | 34.32 | 43.46 | - |
| 600µm | 69.95 | 4.90 | 2.17 | 0.39 | 13.58 | 2.04 | 39.31 | 23.59 | 31.23 | 19-38 |
| 300µm | 32.82 | 2.30 | 1.96 | 0.35 | 9.97 | 1.496 | 28.98 | 17.39 | 21.54 | - |
| 150µm | 4.93 | 0.35 | 1.42 | 0.26 | 4.59 | 0.69 | 13.81 | 8.29 | 9.59 | - |
| 75µm | 2.35 | 0.165 | 1.14 | 0.21 | 3.02 | 0.45 | 9.02 | 5.412 | 6.24 | 1-7 |

**3.12 Marshal Stability Result**

The Marshall Stability and flow result obtained from the control and the various replacement ratios were found to be within the specification. It was observed that on the average as the fine aggregate (mineral filler) were reduced and rice husk ash added, the Marshall stability reduced while the flow increased. This is to be expected because a reduction in flow implies more strength for the mix. Marshall Stability value of 5.5kN was obtained using fine aggregate alone as mineral filler and 3.14kN for using 75% by weight of rice husk ash as partial replacement for mineral fillers. According to specification, Marshall Stability range for road surfaces carrying between 1 and 6000 commercial vehicles per day should be between 2kN and 10kN.

**Figure 2:** Stability Vs Bitumen content

Figure 2 represent the stability versus Bitumen content graph. Initially, as the bitumen content increases, the stability increases until at 5.5 where the maximum stability was achieved and then continues dropping just above 5.5% Bitumen content.

**Figure 3:** Flow Vs Bitumen content

On the other hand, when BC was 4.5%, the flow was high as 10mm and then dropped to as little as about 5.1mm at 5.5% and then increases at a BC just above 5.5%. Hence, the highest stability and least flow occur at 5.5% BC.

**Table 10:** Strength characteristics of Asphalt concrete

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Mix** | **Control** | **25%** | **50%** | **75%** | **100%** |
| Density (g/cm3) | 6 | 2.42 | 2.42 | 2.42 | 2.42 |
| Marshal stability (kN) | 5.5 | 2.97 | 2.99 | 3.14 | 3.07 |
| Flow (mm) | 4.5 | 6.99 | 7.06 | 7.12 | 6.99 |
| Optimum B.C (%) | 5.33 | 4.13 | 4.16 | 4.23 | 4.16 |

Table 10 clearly summarizes the properties of RHA as a replacement to sand. The result shows that the maximum stability using 0% RHA (100% Fine) was 5.5kN with the corresponding flow of 4.5mm at a BC of 5.33% and a density of 6g/cm3. It was observed that RHA is not a good replacement to the conventional material, in that across the percentage replacement, the stability was far below that of the control. In fact, only at 75% of RHA shows a higher stability value of 3.14kN but was about 42% lower compare to the control value.

**4.0 CONCLUSION**

The physical and chemical properties of Rice Husk Ash (RHA) were ascertained and found that it was suitable as mineral filler in Hot Mix Asphalt (HMA). The moisture content, specific gravity, bulk density, void ratio and porosity of RHA were found to be 0.11, 2.38, 0.88kg/cm3, 0.19, and 11.54% respectively, while the chemical composition shows that it contains over 82% of Si2O4. The result shows that the maximum stability using 0% RHA (100% Fine) was 5.5kN with the corresponding flow of 4.5mm at a BC of 5.33% and a density of 6g/cm3. Out of the percentage replacement with RHA (25, 50, 75 and 100%), only 75% of RHA shows a higher stability value of 3.14kN but was about 42% lower compare to the control value. Hence, RHA is not a good replacement to the conventional material

**REFERENCES**

Ahmad, N. H., Johari, N. A., &Azmi, N. N. M. (2017). Review on Rice Husk Ash in Self-Compacting Concrete. IOP Conference Series: Materials Science and Engineering, 271(1), 012013.

Ahmedzade, P., &Khodaii, A. (2017). Investigating the effects of rice husk ash on the properties of asphalt binder. Construction and Building Materials, 145, 635-643.

Aldubaisi, M. A., Wang, H., & Huang, Y. (2020). Investigation of Moisture Damage and Healing Characteristics of Asphalt Mixtures Incorporating Lime and Hydrated Lime. Construction and Building Materials, 252, 119002.

American Association of State Highway and Transportation Officials (AASHTO). (2020). AASHTO Highway Safety Manual. Washington, D.C.

ASTM International. (2015). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete (ASTM C618/C618M-19). ASTM International.

ASTM International. (2021). Standard Terminology Relating to Pavement Engineering. ASTM D4125-19.

Azenha, M., Guedes, M., Sá, A. S., &Arroja, L. (2019). Environmental and Health Performance of the Portuguese Aggregates Production—A Case Study. Journal of Cleaner Production, 235, 171-182.

Basha, E. A., &Gayathri Devi, L. (2007). Effect of Silica Fume on Properties of Rice Husk Ash Concrete. Construction and Building Materials, 21(2), 356-361.

Braham, A., Buttlar, W. G., &Peshkin, D. G. (2015). Influence of Aggregate on Aging Behavior of Laboratory-Compacted Asphalt Mixtures. Journal of Materials in Civil Engineering, 27(7), 04014216.

Brown, E. R., Kim, Y. R., & Kim, Y. R. (2016). Materials for Sustainable Sites: A Complete Guide to the Evaluation, Selection, and Use of Sustainable Construction Materials. John Wiley & Sons.

Cai, L., Xie, J., & Huang, Y. (2016). Performance Evaluation of Asphalt Mixtures Containing Basalt and Granite Aggregates. Construction and Building Materials, 111, 1-9.

Cai, J., Cao, M., & Huang, W. (2021). Effect of Rice Husk Ash on Properties of Cement Mortar and Microstructure of ITZ. Construction and Building Materials, 293, 123553.

Chandrappa, A. K., Muthadhi, A., & Srinivasan, V. (2019). Life Cycle Assessment of Concrete with Rice Husk Ash as a Supplementary Cementitious Material. Journal of Cleaner Production, 235, 1374-1387.

Chen, J., & Liao, M. (2017). Road Pavement Type and Its Characteristics Based on Rough Set Theory. Advances in Civil Engineering, 2017.

Federal Highway Administration (FHWA). (2015). Pavement Types. U.S. Department of Transportation.

Flintsch, G. W., Choubane, B., & Brown, S. F. (2013). Pavement Engineering: Principles and Practice. CRC Press.

Huang, Y., Bird, R. N., & De Larrard, F. (2018). Influence of Aggregate and Binder Characteristics on Asphalt Mixture Performance. Construction and Building Materials, 167, 217-227.

Jahromi, S. G., Taherkhani, H., &Aghayan, M. (2019). Moisture Damage Evaluation of Asphalt Mixtures Containing Nanosilica and Rice Husk Ash. Journal of Materials in Civil Engineering, 31(9), 04019164.

Ji, T., Zhang, Z., Ling, T. C., & Wang, L. (2019). Influence of Semi-Rigid Base and Subgrade on the Performance of Flexible Pavement. *Journal of Materials in Civil Engineering*, 31(1), 04018384.

Jullien, A., Roux, P., &Morandeau, F. (2017). Quantitative Characterization of the Environmental Impact of Road Construction Using Life Cycle Assessment. Transportation Research Procedia, 25, 1529-1542.

Kassem, E., Mahmoud, E., &Shahin, M. Y. (2015). Engineering properties and environmental impacts of rice husk ash stabilized base course material. Construction and Building Materials, 94, 693-703.

Kim, N. M., Jung, Y. J., & Lee, S. J. (2018). Performance Evaluation of Rice Husk Ash for Modification of Asphalt Binder. Construction and Building Materials, 165, 787-795.

Kumar, N. A., & Kumar, P. (2018). An overview of flexible pavement. *International Journal of Innovative Research in Science, Engineering and Technology*, 7(10), 13580-13589.

Kumar, S., Kumar, R., Singh, A. B., & Singh, S. (2019). Rice Husk Ash as a Supplementary Material for Sustainable Construction: A Comprehensive Review. Construction and Building Materials, 213, 16-32.

Lee, S. J., Lee, Y., & Yoon, S. H. (2021). Performance Evaluation of Warm Mix Asphalt Mixtures Modified with Rice Husk Ash. Materials, 14(4), 832.

Maher, K., Xiao, F., &Amirkhanian, S. (2020). Evaluation of Mechanical Properties of Warm-Mix Asphalt Modified with Nano-Silica and Rice Husk Ash. Journal of Cleaner Production, 258, 120652.

Mamlouk, M. S., &Zaniewski, J. P. (2019). Materials for civil and construction engineers. Pearson.

Morsy, M. S., & Ibrahim, K. I. (2020). The Use of Rice Husk Ash as a Cementitious Material in Mortar Mix. IOP Conference sssSeries: Materials Science and Engineering, 736(1), 012047.

Nasly, M. A. M., Mohamed, A. A., & Ibrahim, N. A. (2019). Potential of Rice Husk Ash in Reducing the Environmental Impact of Cement Production. IOP Conference Series: Earth and Environmental Science, 292(1), 012020.

National Cooperative Highway Research Program (NCHRP). (2011). Mechanistic-Empirical Design and Analysis Guide: A Manual of Practice (Final Report). Transportation Research Board.

National Cooperative Highway Research Program (NCHRP). (2019). Guide for Sustainable Practices for Building and Maintaining Pavements. Transportation Research Board.

NCHRP. (2016). NCHRP synthesis 478: Pavement management systems for airports. National Cooperative Highway Research Program.

Ongel, A., Guler, M., Kilic, A., & Bilge, N. (2017). Structural evaluation of asphalt pavement layers using nondestructive testing methods. *Arabian Journal for Science and Engineering*, 42(9), 3895-3903.

Ozer, H., &Haghshenas, H. F. (2017). Evaluation of the Effect of Rice Husk Ash on the Performance Properties of Asphalt Mixtures. Construction and Building Materials, 150, 200-208.

Pulastya, A., Wijayarathna, D. R., & Kumar, S. (2020). Life-Cycle Cost Analysis of Warm Mix Asphalt Containing High Percentage of Reclaimed Asphalt Pavement. Journal of Cleaner Production, 261, 121097.

Pirzada, B. M., & Siddiqui, M. N. (2017). Laboratory evaluation of asphalt mixes containing rice husk ash. *International Journal of Pavement Research and Technology*, 10(2), 113-120.

Sabat, A. K., &Akbari, K. (2020). Rice Husk Ash: A Potential Material in Building and Construction Industry. Journal of Cleaner Production, 254, 120071.