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The re-use of palm kernel shell and steel slag as partial replacement of coarse aggregate in asphaltic concrete

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Abstract

This study investigates the potential of using palm kernel shell (PKS) and steel slag (SS) as partial replacements for conventional coarse aggregates in asphaltic concrete to reduce construction costs and improve sustainability. Various percentages of PKS and SS (0% to 25%) were incorporated into asphaltic concrete mixtures, and their effects on stability, flow, bulk density, air voids, voids in mineral aggregates (VMA), and voids filled with bitumen (VFB) were evaluated using the Marshall Stability test. The results showed that a 5% replacement of PKS and SS (A2) yielded the highest stability value of 6.54 kN, which was higher than the conventional mixture. However, the flow value of 5.47 mm exceeded the recommended range of 2–4 mm, likely due to the angular shape of PKS and SS. The bulk density ranged from 1.82 g/cm^3 to 2.22 g/cm^3, with the highest value observed for the A2 mixture. The air voids, VMA, and VFB were within acceptable limits, indicating that PKS and SS can be used as partial replacements without compromising the volumetric properties of the mixture. The study concludes that PKS and SS are viable alternatives for low-traffic roads, offering environmental and economic benefits. Further research is recommended to optimize the mix design and evaluate long-term performance under different traffic conditions.

Keywords: Palm Kernel Shell (PKS); Steel Slag (SS); Asphaltic Concrete; Marshall Stability; Sustainable Construction

1. Introduction

The construction industry is a cornerstone of economic development, providing essential infrastructure such as roads, bridges, and buildings. However, this sector is heavily reliant on conventional materials like granite, sand, and cement, which are becoming increasingly scarce and expensive due to rapid urbanization, population growth, and the depletion of natural resources [1]. The high cost of these materials poses a significant challenge, particularly in developing countries where budget constraints often limit the scope of infrastructure projects [2]. Moreover, the extraction and processing of these materials have detrimental environmental impacts, including habitat destruction, soil erosion, and increased carbon emissions [3]. In light of these challenges, there is a growing need for sustainable alternatives that can reduce construction costs while minimizing environmental harm.

One promising approach is the utilization of agricultural and industrial waste materials, which not only offer economic benefits but also contribute to waste management and environmental preservation [4]. Among these waste materials, palm kernel shell (PKS) and steel slag (SS) have emerged as viable candidates for use in construction applications. PKS, a by-product of the palm oil industry, is abundantly available in Nigeria, with an estimated annual production of 1.5 million tons [5]. Similarly, SS, a by-product of steel manufacturing, is generated in large quantities, with approximately 150–190 kg of slag produced per ton of steel [6]. Despite their potential, these materials are often discarded as waste, leading to environmental pollution and resource wastage. However, their physical and mechanical properties make them suitable for use in construction, particularly as partial replacements for coarse aggregates in asphaltic concrete [7].

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The re-use of PKS and SS in road construction offers several advantages. First, it reduces the demand for natural resources, thereby conserving the environment and promoting sustainable development [8]. Second, it provides a cost-effective solution for road construction, especially in rural areas where conventional materials are often inaccessible or prohibitively expensive [9]. Third, it addresses the problem of waste disposal, transforming what would otherwise be environmental liabilities into valuable resources [10]. These benefits align with global efforts to promote circular economy principles, where waste materials are reintegrated into production processes to create value and reduce environmental impact [11].

The primary objective of this study is to evaluate the feasibility of using PKS and SS as partial replacements for coarse aggregates in asphaltic concrete. Specifically, the study aims to determine the physical, chemical, and mechanical properties of these materials and assess their impact on the performance of asphaltic concrete. The study also seeks to identify the optimum percentage of PKS and SS that can be used as replacements without compromising the structural integrity of the pavement. By doing so, this research contributes to the growing body of knowledge on sustainable construction practices and offers practical solutions for reducing the environmental and economic burden of road construction [12].

Previous studies have explored the use of PKS and SS in various construction applications. For instance, Apeh and Adejoh (2020) investigated the use of PKS as a partial replacement for coarse aggregates in highway pavements and found that it could replace up to 20% of conventional aggregates without significant loss of performance [13]. Similarly, Arabani and Azarhoosh (2012) demonstrated that SS improved the mechanical properties of asphalt mixtures, including stability and resistance to deformation [14]. However, there is limited research on the combined use of PKS and SS in asphaltic concrete, particularly in the context of rural road construction. This study seeks to fill this gap by evaluating the performance of asphaltic concrete mixtures containing varying percentages of PKS and SS.

In summary, this study addresses a critical need for sustainable and cost-effective materials in road construction. By exploring the potential of PKS and SS as partial replacements for coarse aggregates, it offers a practical solution to the dual challenges of resource scarcity and environmental degradation. The findings of this research have the potential to inform policy decisions and promote the adoption of sustainable construction practices, particularly in developing countries where the need for affordable and durable infrastructure is most acute [15].

2. Material and methods

The materials used in this study were carefully selected to ensure consistency and reliability in the experimental results. Fine aggregate, commonly referred to as sharp sand, was sourced locally and subjected to preliminary tests to determine its moisture content, specific gravity, and particle size distribution [16]. Coarse aggregate, consisting of natural granite with particle sizes of 10 mm and 12 mm, was obtained from construction sites within Osun State University, Osogbo campus. These materials were chosen for their widespread use in road construction and their availability in the study area [17]. Palm kernel shell (PKS), an agricultural waste product, was collected from local sources within Osun State, while steel slag (SS), an industrial by-product, was sourced from Owode Onirin, Lagos State. Both PKS and SS were subjected to rigorous testing to evaluate their suitability as partial replacements for conventional coarse aggregates [18].

Bitumen, a key component of asphaltic concrete, was obtained from Slava Bogu Construction Company. The bitumen used in this study was of grade 60/70, conforming to the American Society for Testing and Materials (ASTM) standards [19]. Its properties, including penetration, ductility, softening point, flash and fire point, and specific gravity, were tested to ensure compliance with the required specifications. These tests were conducted in accordance with ASTM D5, D113, D36, D92, and D70, respectively [20]. The results of these tests provided a baseline for evaluating the performance of the asphaltic concrete mixtures.

The methodology for this study was designed to systematically evaluate the effects of PKS and SS on the properties of asphaltic concrete. The first step involved conducting preliminary tests on the aggregates, including moisture content, specific gravity, sieve analysis, and aggregate crushing value (ACV). These tests were performed in accordance with British Standard (BS) 812: Part 110 and Part 2, ensuring the accuracy and reliability of the results [21]. The sieve analysis, in particular, provided valuable information on the particle size distribution of the aggregates, which is critical for achieving the desired gradation in asphaltic concrete mixtures [22].

The next step involved preparing asphaltic concrete samples with varying percentages of PKS and SS as partial replacements for coarse aggregates. The replacement percentages ranged from 0% to 25%, with increments of 5%, to assess the impact of these materials on the performance of the mixtures [23]. The samples were prepared using the

Marshall mix design method, which is widely recognized for its effectiveness in designing and evaluating bituminous paving mixes [24]. The Marshall method involves compacting cylindrical specimens of asphaltic concrete and subjecting them to stability and flow tests to determine their load-bearing capacity and deformation characteristics [25].

The Marshall Stability test was conducted in accordance with ASTM D1559, with each sample subjected to a compressive load at a rate of 50.8 mm/min until failure occurred [26]. The stability, flow, bulk density, air voids, voids filled with bitumen (VFB), and voids in mineral aggregates (VMA) were determined for each sample. These parameters are critical for evaluating the performance of asphaltic concrete, as they provide insights into the mixture's resistance to deformation, durability, and overall structural integrity [27]. The results of these tests were analyzed to identify the optimum percentage of PKS and SS that could be used as partial replacements for coarse aggregates without compromising the performance of the asphaltic concrete.

In addition to the Marshall Stability test, other laboratory tests were conducted to evaluate the properties of the materials used in this study. For instance, the specific gravity and water absorption of the aggregates were determined to assess their suitability for use in asphaltic concrete [28]. The specific gravity of the bitumen was also measured to ensure consistency in the mix design. These tests were conducted in accordance with established standards, ensuring the reliability and accuracy of the results [29].

The experimental design for this study was carefully planned to minimize variability and ensure the reproducibility of the results. Three samples were prepared for each mix proportion, and the average values were used for analysis. This approach not only enhanced the reliability of the results but also provided a robust basis for drawing conclusions and making recommendations [30]. The data obtained from the laboratory tests were analyzed using statistical methods to identify trends and correlations, providing valuable insights into the performance of asphaltic concrete mixtures containing PKS and SS.

3. Results and discussion

The results of this study provide a comprehensive evaluation of the performance of asphaltic concrete mixtures containing palm kernel shell (PKS) and steel slag (SS) as partial replacements for conventional coarse aggregates. The laboratory tests conducted on the materials and mixtures yielded valuable insights into their physical, mechanical, and volumetric properties, which are critical for assessing their suitability in road construction.

3.1. Properties of Materials

The bitumen used in this study had a penetration grade of 68.90 mm, a specific gravity of 1.04, and a softening point of 48°C, all of which conformed to ASTM standards. These properties ensured that the bitumen was suitable for use in asp haltic concrete, providing the necessary binding and waterproofing characteristics. The fine aggregate had a specific gravity of 2.38 and a moisture content of 3.11%, while the coarse aggregate exhibited a specific gravity of 2.41 and an aggregate crushing value (ACV) of 28.05%, which is within the acceptable limit for road construction. The PKS and SS, which were used as partial replacements for coarse aggregates, had specific gravities of 1.095 and 2.18, respectively, and ACV values of 6.47% and 50.01%. These results indicate that PKS and SS possess properties that make them viable alternatives to conventional aggregates, particularly in applications where lightweight and durable materials are required.

3.2. Marshall Stability Test Results

The Marshall Stability test results revealed significant variations in the performance of the asphaltic concrete mixtures depending on the percentage of PKS and SS used as replacements. The highest stability value of 6.54 kN was achieved with a 5% replacement of PKS and SS (A2), which was higher than the stability value of the conventional mixture (A1). This suggests that a small percentage of PKS and SS can enhance the load-bearing capacity of asphaltic concrete. However, the flow value of 5.47 mm for the A2 mixture exceeded the recommended range of 2–4 mm specified by the Nigerian General Specifications for Roads and Bridges (1997). This increase in flow may be attributed to the angular shape and lower density of PKS and SS, which could affect the mixture's resistance to deformation under traffic loads. Figure 1 illustrates the relationship between bitumen content and Marshall properties, while Figure 2 shows the effect of PKS and SS content on stability and flow.

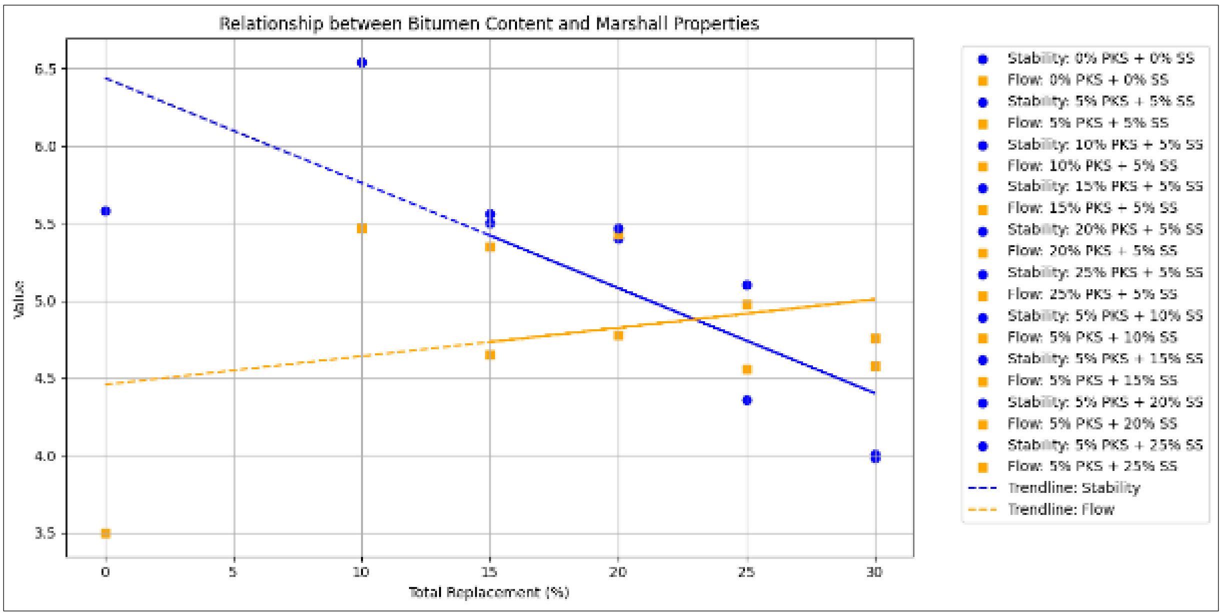

Figure 1 Relationship between bitumen content and Marshall properties

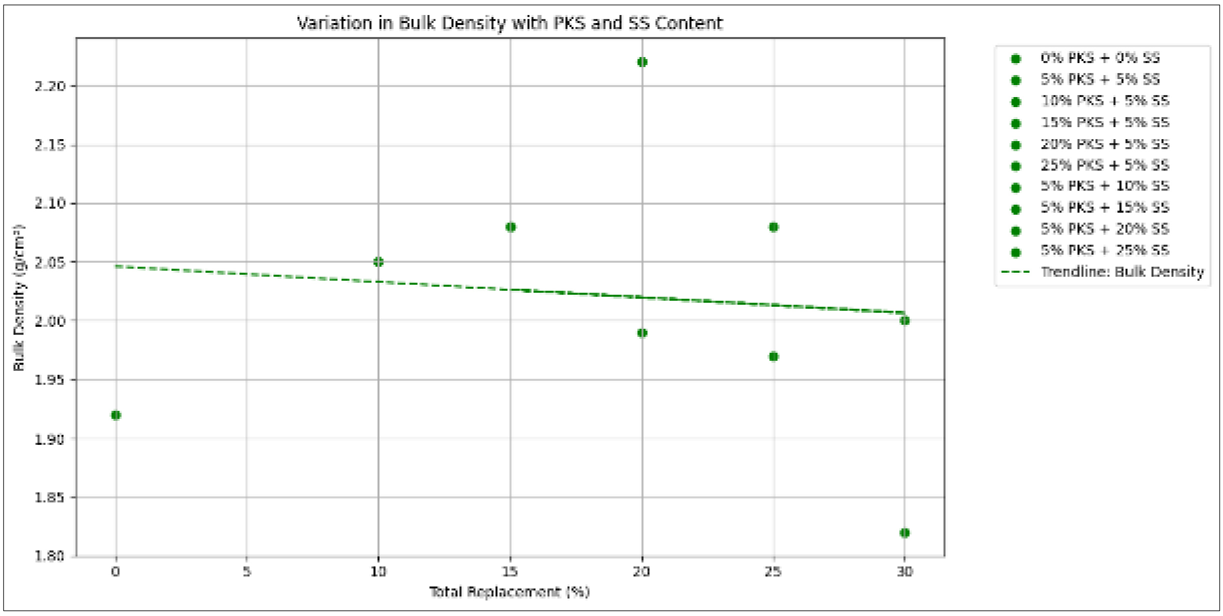

Figure 2 Effect of PKS and SS content on stability and flow

The bulk density of the mixtures ranged from 1.82 g/cm^3 to 2.22 g/cm^3, with the highest value observed in the A2 mixture. This indicates that the inclusion of PKS and SS at low percentages does not significantly compromise the density of the asphaltic concrete. The air voids in the mixtures varied between 3.2% and 3.64%, with the highest value recorded for the A2 mixture. While this exceeds the air void content of the conventional mixture, it remains within the acceptable range for road construction. The voids filled with bitumen (VFB) ranged from 75.55% to 79.02%, with the highest value observed in the A4 mixture (15% PKS and 5% SS). These results suggest that the mixtures containing PKS and SS have adequate bitumen content to ensure durability and resistance to moisture damage. Table 1 summarizes the Marshall Stability test results for all mixtures.

Table 1 Marshall Stability Test Results

Sample	PKS (%)	SS (%)	Stability (kN)	Flow (mm)	Bulk Density (g/cm^3)	Air Voids (%)	VMA (%)	VFB (%)
A1	0	0	5.58	3.50	1.92	3.50	15.50	76.68
A2	5	5	6.54	5.47	2.05	3.64	15.56	76.61
A3	10	5	5.56	5.35	2.08	3.60	15.50	76.50
A4	15	5	5.40	5.43	2.22	3.57	15.45	79.02
A5	20	5	4.36	4.56	1.97	3.51	15.30	77.21
A6	25	5	4.01	4.76	2.00	3.38	15.32	77.10
A7	5	10	5.50	4.65	2.08	3.20	15.28	77.30
A8	5	15	5.47	4.78	1.99	3.32	15.20	77.00
A9	5	20	5.10	4.98	2.08	3.25	15.16	74.46
A10	5	25	3.98	4.58	1.82	3.50	15.10	75.55

3.3. Effect of PKS and SS on Mixture Properties

The inclusion of PKS and SS had a noticeable impact on the voids in mineral aggregates (VMA), which ranged from 15.1% to 15.56% across the mixtures. The highest VMA value was observed in the A2 mixture, indicating that the angular shape of PKS and SS may have contributed to increased inter-particle voids. While this could enhance the mixture's resistance to rutting, it may also reduce its stability under heavy traffic loads. The results also showed that the unit weight of the mixtures decreased as the percentage of PKS and SS increased, with the lowest value recorded for the A10 mixture (5% PKS and 25% SS). This reduction in unit weight is consistent with the lower specific gravity of PKS and SS compared to conventional aggregates. Figure 3 illustrates the variation in bulk density with PKS and SS content, while Figure 4 shows the effect of PKS and SS on VMA and VFB.

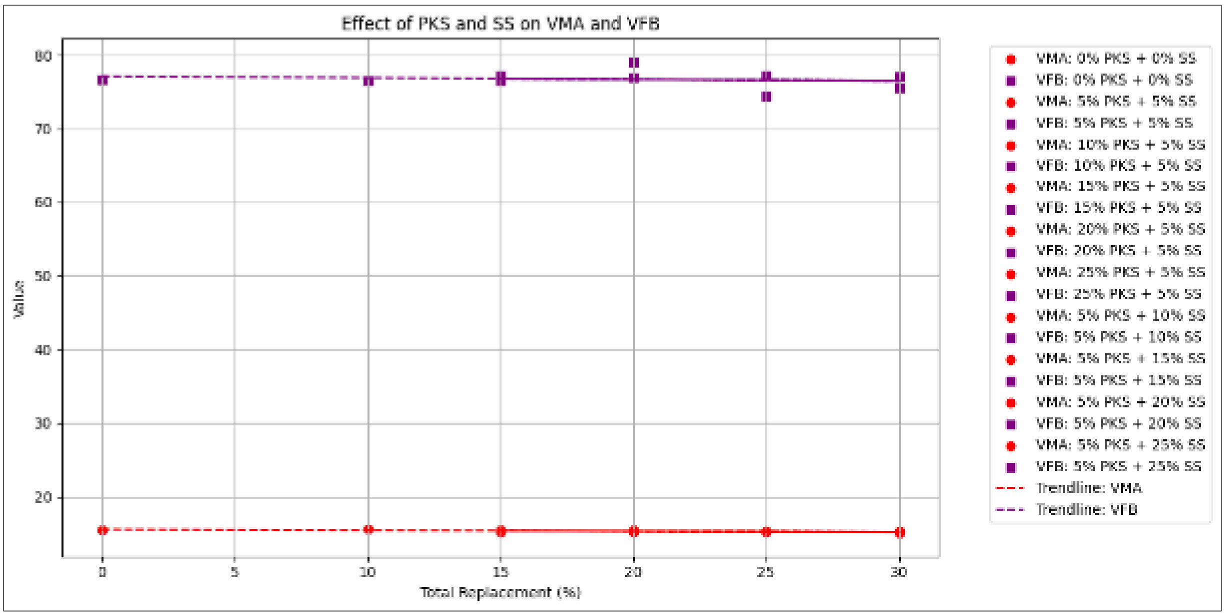

Figure 3 Variation in bulk density with PKS and SS content

3.4. Comparison with Previous Studies

The findings of this study are consistent with previous research on the use of PKS and SS in construction materials. For instance, Apeh and Adejoh (2020) reported that PKS could replace up to 20% of coarse aggregates in highway pavements without significant loss of performance [31]. Similarly, Arabani and Azarhoosh (2012) found that SS improved the mechanical properties of asphalt mixtures, including stability and resistance to deformation [32].

However, the higher flow values observed in this study highlight the need for further research to optimize the mix design and address potential limitations in the application of PKS and SS in high-traffic areas.

3.5. Implications for Sustainable Construction

The results of this study demonstrate that PKS and SS can be used as partial replacements for coarse aggregates in asphaltic concrete, offering a sustainable and cost-effective solution for road construction. The use of these materials not only reduces the demand for natural resources but also addresses the problem of waste disposal, contributing to environmental preservation. However, the higher flow values observed in mixtures containing PKS and SS suggest that these materials may be more suitable for low-traffic roads or as supplementary materials in combination with conventional aggregates. Further research is needed to explore the long-term performance of these mixtures under different traffic and environmental conditions.

4. Conclusion

This study explored the potential of using palm kernel shell (PKS) and steel slag (SS) as partial replacements for conventional coarse aggregates in asphaltic concrete, with the aim of reducing construction costs, improving sustainability, and addressing environmental concerns related to waste disposal. The findings demonstrate that PKS and SS can be effectively utilized in road construction, offering both environmental and economic benefits. A 5% replacement of PKS and SS (A2) yielded the highest stability value of 6.54 kN, which was higher than the stability of the conventional mixture (5.58 kN). This indicates that small percentages of PKS and SS can enhance the load-bearing capacity of asphaltic concrete. However, the flow values for mixtures containing PKS and SS exceeded the recommended range of 2–4 mm, with the highest flow value of 5.47 mm observed for the A2 mixture. This increase in flow is likely due to the angular shape and lower density of PKS and SS, which may affect the mixture's resistance to deformation under traffic loads.

The bulk density of the mixtures ranged from 1.82 g/cm^3 to 2.22 g/cm^3, with the highest value observed for the A2 mixture. This suggests that the inclusion of PKS and SS at low percentages does not significantly compromise the density of the asphaltic concrete. The air voids, voids in mineral aggregates (VMA), and voids filled with bitumen (VFB) for mixtures containing PKS and SS were within acceptable limits for road construction. The highest VFB value of 79.02% was observed for the A4 mixture (15% PKS and 5% SS), indicating adequate bitumen content for durability and moisture resistance. These results highlight the potential of PKS and SS as viable alternatives to conventional aggregates, particularly in applications where lightweight and durable materials are required.

The use of PKS and SS as partial replacements for coarse aggregates offers significant environmental benefits by reducing the demand for natural resources and addressing the problem of waste disposal. Additionally, these materials provide a cost-effective solution for road construction, particularly in rural areas where conventional materials are often inaccessible or prohibitively expensive. However, the higher flow values observed in mixtures containing PKS and SS suggest that these materials may be more suitable for low-traffic roads or as supplementary materials in combination with conventional aggregates. Further research is needed to optimize the mix design and evaluate the long-term performance of these mixtures under different traffic and environmental conditions.

In conclusion, this study demonstrates that PKS and SS can be used as partial replacements for coarse aggregates in asphaltic concrete, offering a sustainable and cost-effective solution for road construction. The findings of this research contribute to the growing body of knowledge on sustainable construction practices and provide practical recommendations for the use of PKS and SS in road construction projects.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Federal Ministry of Works and Housing. (1997). General specification for roads and bridges volume II.

[2] Chandra, S., & Berntsson, L. (2002). Lightweight aggregate concrete science technology and application. Noyes Publications.

[3] Apeh, O., & Adejoh, S. (2020). Assessment of palm kernel shells as partial replacement of coarse aggregates in highway pavements. Department of Civil Engineering, The Federal Polytechnic Idah, North Central, Nigeria.

[4] Nuhu-Koko, M. K. (1990). The use of palm kernel shells as aggregates for concrete. Paper presented at 21st Annual Conference of Materials Testing, Control and Research, Federal Ministry of Works, Lagos, Nigeria.

[5] Devi, V. S., & Gnanavel, B. K. (2014). Properties of concrete manufactured using steel slag. Procedia Engineering, 97, 95–104. https://doi.org/10.1016/j.proeng.2014.12.239

[6] Arabani, M., & Azarhoosh, A. R. (2012). The effect of recycled concrete aggregate and steel slag on the dynamic properties of asphalt mixture. Dept. of Civil Engineering, University of Guilan.

[7] Okobia, E. (2016). Evaluation of saw dust ash as mineral filler in asphalt mixture. Department of Civil Engineering, Ahmadu Bello University Zaria, Nigeria.

[8] Oyedepo, J. O., Olanitori, L. M., & Olukanni, E. O. (2015). Investigation of palm kernel shell as partial replacement for aggregate in asphaltic concrete. Malaysian Journal of Civil Engineering, 27(2), 223–234.

[9] Mohammed, H., Afolabi, K. O., & Umoru, L. E. (2014). Crushed palm kernel shell as a partial replacement of fine aggregate in asphaltic concrete. International Journal of Materials, Methods and Technologies, 2(1).

[10] Osei, D. Y., & Jackson, E. N. (2012). Experimental study on the palm kernel shells as coarse aggregates in concrete. International Journal of Science and Engineering Research, 3(8), 1–6.

[11] Kandahl, P. (1992). Waste materials in hot mix asphalt. National Center for Asphalt Technology, NCAT Report, 92–06.

[12] ASTM D5. (2005). Standard test method for penetration of bituminous materials. American Society for Testing and Materials.

[13] ASTM D113. (2005). Standard test method for ductility of bituminous materials. American Society for Testing and Materials.

[14] BS 812: Part 110. (1990). Methods for determination of moisture content. British Standards Institution.

[15] BS 812: Part 2. (1975). Methods for determination of specific gravity. British Standards Institution.

[16] ASTM D1559. (1989). Standard test method for resistance to plastic flow of bituminous mixtures using Marshall apparatus. American Society for Testing and Materials.

[17] ASTM D70. (2005). Standard test method for specific gravity and density of semi-solid bituminous materials. American Society for Testing and Materials.

[18] ASTM D36. (2005). Standard test method for softening point of bitumen. American Society for Testing and Materials.

[19] ASTM D92. (2005). Standard test method for flash and fire points by Cleveland open cup tester. American Society for Testing and Materials.

[20] ASTM D2042. (2005). Standard test method for solubility of bituminous materials. American Society for Testing and Materials.

[21] ASTM D6. (2005). Standard test method for loss on heating of oil and asphaltic compounds. American Society for Testing and Materials.

[22] ASTM D4402. (2005). Standard test method for viscosity determination of asphalt at elevated temperatures using a rotational viscometer. American Society for Testing and Materials.

[23] ASTM D1559. (1989). Standard test method for resistance to plastic flow of bituminous mixtures using Marshall apparatus. American Society for Testing and Materials.

[24] ASTM D70. (2005). Standard test method for specific gravity and density of semi-solid bituminous materials. American Society for Testing and Materials.

[25] ASTM D36. (2005). Standard test method for softening point of bitumen. American Society for Testing and Materials.

[26] ASTM D92. (2005). Standard test method for flash and fire points by Cleveland open cup tester. American Society for Testing and Materials.

[27] ASTM D2042. (2005). Standard test method for solubility of bituminous materials. American Society for Testing and Materials.

[28] ASTM D6. (2005). Standard test method for loss on heating of oil and asphaltic compounds. American Society for Testing and Materials.

[29] ASTM D4402. (2005). Standard test method for viscosity determination of asphalt at elevated temperatures using a rotational viscometer. American Society for Testing and Materials.

[30] ASTM D1559. (1989). Standard test method for resistance to plastic flow of bituminous mixtures using Marshall apparatus. American Society for Testing and Materials.

[31] Apeh, O., & Adejoh, S. (2020). Assessment of palm kernel shells as partial replacement of coarse aggregates in highway pavements. Department of Civil Engineering, The Federal Polytechnic Idah, North Central, Nigeria.

[32] Arabani, M., & Azarhoosh, A. R. (2012). The effect of recycled concrete aggregate and steel slag on the dynamic properties of asphalt mixture. Dept. of Civil Engineering, University of Guilan.