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Partial Substitution of Asphalt Concrete Filler with Eco-Friendly Burnt Sawdust

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Abstract
This paper investigates the impacts of burnt sawdust as a partial replacement in asphalt concrete, with the aim of enhancing the material's properties. The study sourced redwood sawdust from a carpentry workshop in Djelfa state, Algeria, and obtained filler, binder, and fine and coarse aggregates from the Public Works Laboratory for the South in Ghardaïa state, Algeria. The sawdust was burned at 200°C in a furnace, cooled, and sieved through an 80 µm sieve. Standard procedures were employed to determine the material properties. Samples of the asphaltic mixture were then prepared with treated sawdust at varying weight percentages of 0%, 5%, 15%, 20%, and 25% for the filler. The Marshall Stability test was conducted to assess the mixtures' density, air voids (AV), voids filled with bitumen (VFB), voids in mineral aggregate (VMA), Marshall Stability, and flow. The results indicated an optimal sawdust content of 15%, showcasing improved properties when burnt sawdust was added to asphaltic concrete. Additionally, the utilization of sawdust contributes to preserve nonrenewable materials and reduces pollution from mineral filler manufacturing. Furthermore, utilizing this fine sawdust, which is typically regarded as waste, offers an environmentally efficient disposal solution.
Keywords: Burnt sawdust. Asphaltic concrete. Marshall stability test. Mineral filler.

Nomenclature
VMA: Voids in Mineral Aggregate.
VFB: Voids Filled with Bitumen.
AV: Air Voids.
ASTM: American Society for Testing and Materials.

1. Introduction

In recent decades, the road network in many countries has experienced an increase in traffic volume. As traffic intensifies, the pavements undergo elevated stress. The substantial number of vehicles, overloaded trucks, and significant temperature fluctuations in pavements have primarily contributed to issues such as surface deterioration, groove formation, and structural fatigue in asphalt road surfaces (Ravindra *et al*., 2013).

Strength, durability, and resistance to fatigue and permanent deformation are crucial factors in properly formulating asphaltic concrete. Moreover, it should also prioritize environmental sustainability and cost-effectiveness. The utilization of appropriate material combinations and modified asphaltic concrete has shown the potential to prolong the lifespan of surface layers, depending on the specific type and proportion of mineral filler employed (Ravindra *et al*., 2013).

The construction sector worldwide is currently experiencing notable progress (Ucol-Ganiron, 2012). Numerous structures, both non-residential and residential, are being erected in response to the growing demand for new buildings, particularly in developing countries (Ganiron, 2013).

Various researchers have initiated efforts to reduce construction costs by examining the feasibility of utilizing local materials. These materials, frequently sourced from agricultural or industrial byproducts like sawdust, concrete debris, fly ash, and coconut shells which originate respectively from milling stations, thermal power plants, waste treatment facilities, and comparable sources. Escalating costs of construction materials, particularly cement, crushed stone (coarse aggregate), and fine sand (fine aggregate), have necessitated the exploration of alternative building materials that are conveniently accessible within the local area (Tomas, 2013).

Adding polymers, glass, fly ash, and furnace slag are some of the modifications that can enhance the performance of asphaltic concrete. Numerous studies have been conducted to incorporate diverse byproducts as fillers aiming to improve the properties of asphaltic concrete (Sobolev, 2003). The role of mineral filler is significant. Traditionally, materials like stone dust, cement, and lime have been included as fillers to enhance the engineering properties of asphaltic concrete (Ravindra *et al*., 2013). The study by Elinwa *et al*. indicates that the use of sawdust ash in concrete initially has a negative impact on strength development, which can be alleviated by incorporating small amounts of metakaolin (Elinwa *et al*., 2005).

Shape, texture, size, and angularity are all indicators of filler geometry. Several chemical substances influence the asphalt and filler interaction. Reactivity, encompassing factors like calcium compound reactivity and water solubility, along with the presence of detrimental fines such as active clay content and organic material constitute the pivotal attributes governing these interactions (Bahia *et al*., 2011; Elinwa *et al*., 2005). Initially, mineral fillers were incorporated into dense graded asphalt concrete to fill voids in stone structures and reduce gaps within the mixture (Prowell *et al*., 2005). It is widely recognized that filler impacts significantly the properties and functionality of the asphaltic concrete mix. Properly arranging the coarse and fine aggregates along with the filler establishes a robust foundation for the mixture (Zulkati *et al*., 2012).

Increased internal stability and cohesiveness of asphalt result from higher filler content, leading to a more robust pavement. Nevertheless, excessive filler content could potentially weaken the mixture as it requires additional asphalt to coat the particles (Kandhal *et al*., 1998).

In a research conducted by Sobolev and Faheem (2014), sawdust ash was collected from various origins revealing that the primary oxides identified were as follow: SiO_2, CaO, Al_2O_3, K_2O, Fe_2O_3, MgO, K_2O, Na_2O, SO_3, TiO_2, and P_2O_5. The prevailing observation indicated a predominant presence of CaO, with values spanning from 28.10% to 51.0%, SiO_2 (5.80 - 25.20 %), Al_2O_3 (4.70 - 14.20 %), Fe_2O_3 (1.20 - 4.50 %), MgO (2.20 - 4.70 %), K_2O (0.20 - 0.50 %), Na_2O (0.40 – 2.50 %), SO_3 (17.10 - 33.30 %), TiO_2 (1.00 - 1.00 %) and P_2O_5 (0.40 - 1.00 %).They substituted 5, 10, and 15% by weight of the filler for the mastic's original filler (a mixture of bitumen and particle filler). The conducted assessments encompassed intricate examinations of shear modulus and stiffness. The results revealed a noteworthy influence of CaO on asphalt performance. The researchers asserted that elevating the levels of CaO, SO_3, and loss on ignition (LOI) led to heightened complex shear modulus and stiffness of the mastic. This impact led to a reduction in pavement raveling, mitigated moisture-induced stripping, and improved resistance to aging. (Sobolev & Faheem, 2014).

2. Materials and methods

This study included bitumen, along with coarse and fine aggregates, as well as mineral filler, as its fundamental components. The bitumen used in the research was of 40/50 penetration grade and was obtained from the Public Works Laboratory for the South in Ghardaïa state, Algeria. The used sawdust in this study was sourced from a carpentry workshop in Djelfa city, Djelfa state, and specifically from redwood. For the fine aggregate, granite dust passing 4.25 mm and retained on 80 µm BS sieves was utilized. The mineral filler was composed of granite dust passing 80 µm BS sieve. As for the coarse aggregate, it consisted of granite particles that passed through 12.5 mm sieves and were retained on 9.5 mm BS sieves. Sawdust was incinerated using a furnace at 200°C, and once cooled, the resultant burnt sawdust was subsequently sifted through an 80 µm sieve. The coarse aggregates in the mix design percentage were 12.50 mm (10.00%) and, 9.50 mm (30.00%), the fine aggregate was 04.75 mm (55.00%) and the mineral filler was 0.075 mm (5%). The ASTM C136 (2003) was followed for conducting the gradation test.

2.1 *Sawdust treatment*

Sawdust was collected from carpentry workshops in Djelfa, then ground using a spice grinder and sieved through an 80 µm sieve. The sawdust was subjected to combustion in a furnace at a temperature of 200°C for a duration of 2 hours. After cooling, the burnt sawdust was further sieved through an 80 µm sieve.

2.2 Specimen Preparation

To attain the optimal bitumen content (OBC) of 5.9%, asphaltic concrete specimens were meticulously prepared using the ASTM D1559 Test Method. This involved varying levels of bitumen application (Transportation Research Board, 2003). These steps were conducted for the control samples. Additionally, samples with sawdust replacements of 0%, 5%, 15%, and 20% for the filler were prepared, resulting in a total of 4 samples based on the sawdust percentages.

2.3 Marshal Test

The results of the Marshal test were used to calculate the values for Marshall Stability, flow, density, voids filled with bitumen (VFB), voids filled with air (VA), and voids in mineral aggregate (VMA).

3. Results

3.1 Physical Properties of Aggregates

The outcomes of flakiness index, elongation index, the aggregate crushing value, and water absorption tests are presented in Table 1. All these values fall within acceptable thresholds, affirming that the aggregates meet the necessary quality standards.

Table 1. Physical Properties of Granite Aggregate and Sawdust.

Properties	values
Aggregate crushing (%)	22.90
Flakiness (%)	25.50
Elongation (%)	27.90
Water absorption (%)	0.340
Specific gravity	2.690
Specific gravity of sawdust	2.270

3.2 Physical Properties of Binder

The findings of the bitumen's specific gravity, penetration, and softening point are displayed in Table 2. The penetration, specific gravity, and softening point measurements yielded values of 61.8, 1.01, and 51.1, respectively.

Table 2. Physical Properties of Bitumen.

Properties	Test method	Result
Penetration at 25°C (0.1mm)	ASTM D5	61.8
Specific gravity	ASTM D70	1.01
Softening point (°C)	ASTM D36	51.1

3.3 Aggregate Gradation

The aggregate gradation for asphalt concrete is a crucial aspect of its design and performance. Proper gradation ensures that the mixture of aggregates used in the asphalt concrete is well-balanced, providing the necessary stability, durability, and performance characteristics. The gradation refers to the distribution of different particle sizes of aggregates in the mixture. The aggregate gradation curve is shown in Figure 1. The presented gradation curve indicates a well-balanced mixture, with the potential to attain the maximum aggregate volume within the mix.

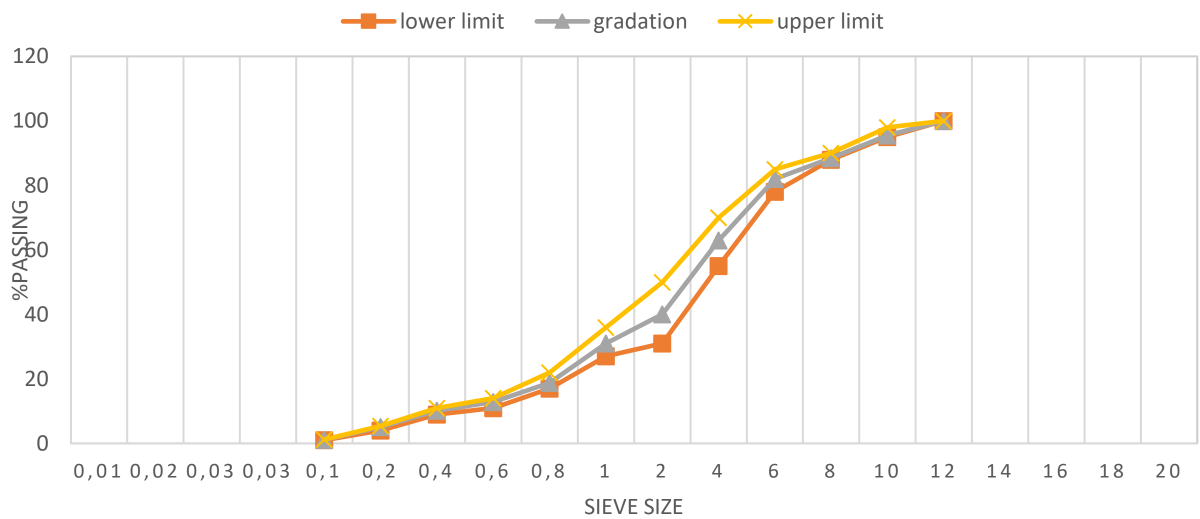

Figure 1- The Aggregates Gradation Curve.

3.4 Marshall Properties for samples with sawdust

3.4.1 Marshall Stability

The stability curve of an asphalt mixture with fine sawdust powder as a partial replacement for filler was displayed in Figure 2. Different percentages of sawdust powder (0%, 5%, 15%, 20%, and 25%) were used in the mixture.

Figure 2- Variation of stability with sawdust (%).

The results showed that 15% sawdust content provided the highest stability, indicating good resistance to deformation and favorable performance. However, a higher percentage of sawdust (25%) led to the lowest stability, suggesting reduced performance and increased susceptibility to deformation. The optimal balance was found at 15% sawdust content in the mixture. Further testing is needed to ensure the suitability of the mixture for specific construction projects and conditions.

3.4.2 Flow Value

In Figure 3, flow values for different percentages of sawdust in the asphalt mixture (0%, 5%, 15%, 20%, and 25% of filler weight) are presented.

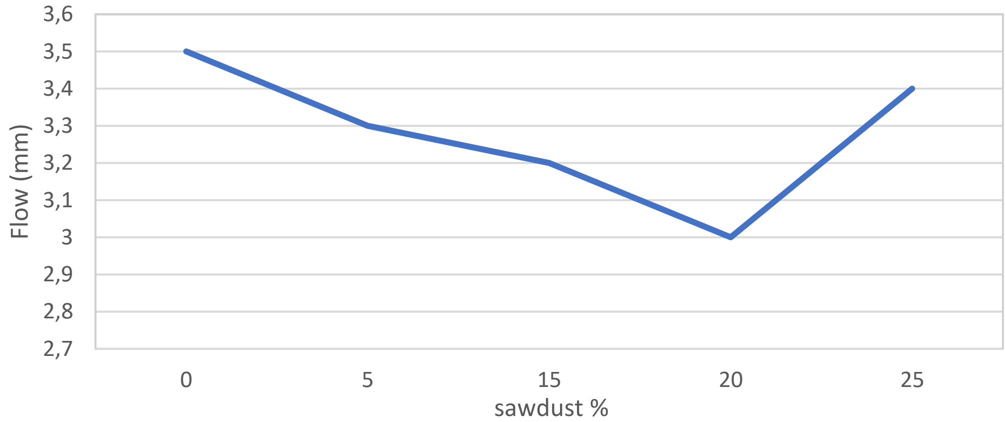

Figure 3- Variation of flow values with sawdust (%).

The results show that the lowest flow value of 3 mm, indicating good stability, is achieved with 20% sawdust content. Conversely, the highest flow value of 3.5 mm, indicating reduced stability, is observed with 0% sawdust. Hence, the inclusion of 20% sawdust in the mixture produces optimal Flow performance, whereas the absence of sawdust results in diminished performance. It is crucial to choose the appropriate sawdust percentage to optimize the asphalt mixture's properties.

3.4.3 Voids filled with Bitumen

Illustrated in Figure 4 are the Voids Filled with Bitumen (VFB) across different sawdust proportions in the asphalt mix (0%, 5%, 15%, 20%, and 25% with filler weight). VFB quantifies the volume occupied by bitumen within the mixture.

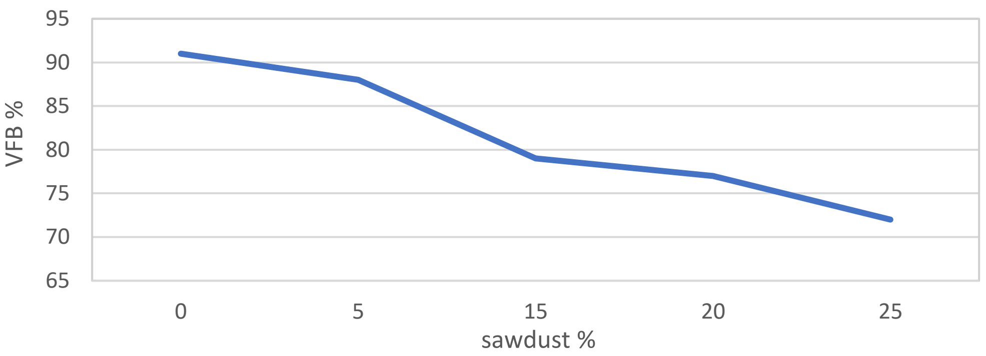

Figure 4- Voids Filled with Bitumen change with increasing treated sawdust.

The results show the asphalt mix with 0% sawdust has the highest VFB, indicating potential drain-down issues and reduced long-term performance. Nevertheless, the blend containing 25% sawdust exhibits the least Voids Filled with Bitumen (VFB), offering advantages such as reduced drain-down concerns and improved resistance against moisture-induced deterioration. Furthermore, the incorporation of sawdust leads to a decrease in surplus bitumen content, potentially resulting in cost savings while maintaining optimal performance.

3.4.4 Air Voids

Figure 5 illustrates the variation of air voids in asphalt mixture specimens with different sawdust percentages (0%, 5%, 15%, 20%, and 25% of filler weight).

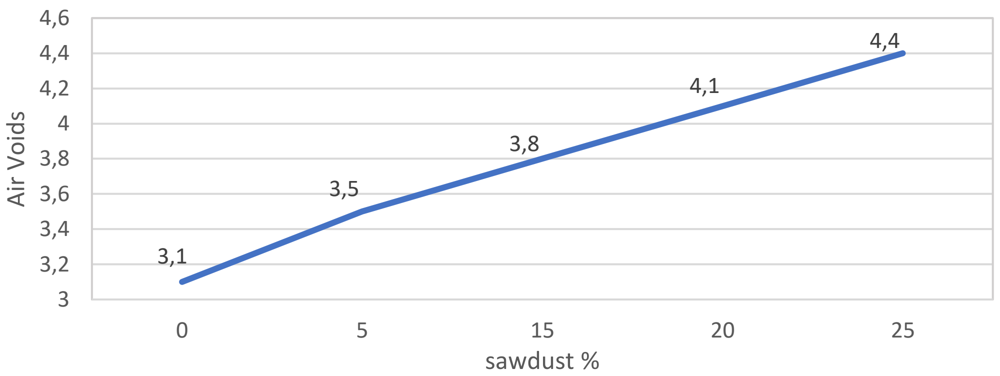

Figure 5- Variation of Air Voids with Sawdust.

The results indicate that asphalt mixtures with 20% and 25% sawdust content have air void percentages of 4.1% and 4.4%, respectively. However, both of these values fail to meet the acceptance criteria specified in the Algerian norms for asphalt mixtures. High air voids may result reducing in the strength and durability of the pavement. Adjustments to the mix design or sawdust content may be necessary to achieve the desired air void level and comply with the specified norms for optimal asphalt mixture performance.

3.4.5 Voids in Mineral Aggregate

Voids in Mineral Aggregate (VMA) are a crucial parameter in asphalt mix design and construction. It refers to the volume of void spaces present between the aggregate particles in an asphalt mixture. The role of VMA is significant for the durability and performance of asphaltic pavement. Figure 6 illustrates the relationship between the increase in sawdust ratios within the asphalt mixture (ranging from 0% to 25% of filler weight) and the Voids in Mineral Aggregate (VMA).

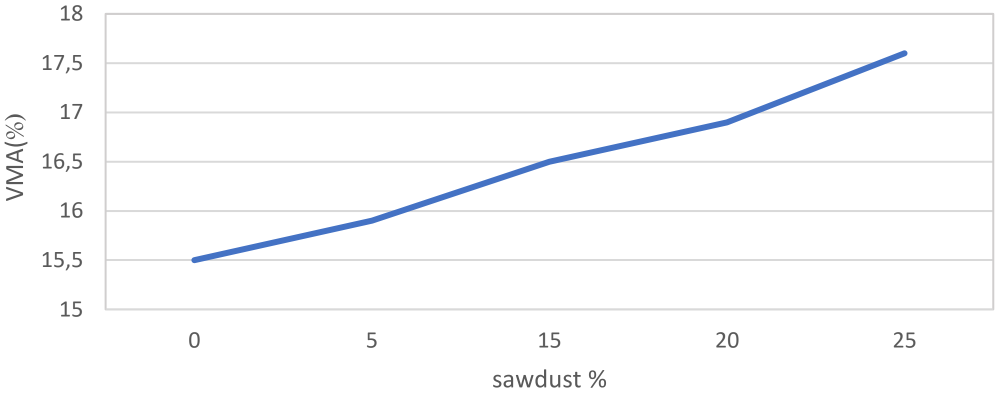

Figure 6- VMA with Increasing Sawdust.

The results show that as the sawdust percentage increases, VMA also increases. However, all VMA values remain within the acceptable range specified in the mix design guidelines. This suggests that the addition of sawdust does not negatively impact the mixture's performance. Proper mix design and adherence to VMA specifications are crucial for ensuring the asphalt mixture's optimal performance under traffic loads and environmental conditions.

4. Discussion

The discussion section offers a thorough evaluation of the findings from the investigation into the impact of treated sawdust on asphalt mixtures. The following are the main points raised. As compared to the control mix, stability values rose for mixtures containing 5% to 20% treated sawdust, as shown in Figure 2. This improvement in stability is attributed to sawdust's elastic properties, which have a good impact on the mixture's performance.

Flow Value in Figure 3 illustrates a decline in flow value at 5% sawdust, reaching a minimum, and then rising again at 20% sawdust. The introduction of lime might contribute to the decreased flow value, improving moisture resistance and minimizing cracking. The subsequent upturn in flow value at 20% sawdust could potentially stem from other influences.

In Figure 4, a discernible reduction in Voids Filled with Bitumen (VFB) values is evident, indicated by the decline from 5% to 25% sawdust content. This decline might possibly be attributed to the increased porosity and calcium particle composition present in the sawdust.

Figure 5 illustrates Air Voids, depicting a consistent rise from 5% to 25% sawdust content. This escalating air voids trend could be attributed to the porous nature of calcium particles in treated sawdust, which potentially enhances bitumen absorption at higher temperatures and consequently leads to an increase in air voids within the mixture.

Figure 6 illustrates Voids in Mineral Aggregate (VMA), demonstrating a gradual increase in VMA values from 5% to 25% treated sawdust content. Once more, the pronounced porosity of calcium particles within treated sawdust could play a role in heightened bitumen absorption, thereby driving the elevation in VMA values.

The discussion offers valuable perspectives on how treated sawdust impacts different characteristics of the asphalt mixes. The elastic nature and porosity of treated sawdust appear to positively impact stability but may influence other properties, such as flow value, VFB, air voids, and VMA. The findings contribute to a better understanding of how treated sawdust can be utilized as a potential alternative material in asphalt mixtures and highlight areas for further research and optimization.

5. Conclusions

The conclusions drawn from the study on the utilization of treated sawdust in asphaltic concrete are as follows:

Lightweight Nature: The recorded specific gravity of 1.09 for the treated sawdust signifies its lightweight nature. This attribute has the potential to lower the overall density of the asphalt mixture, which could have advantageous implications for pavement performance.

Presence of Calcium Oxide: The analysis reveals that calcium oxide is the predominant component in the treated sawdust. This presence of calcium oxide likely contributes to the improvements observed in the properties of asphaltic concrete made with treated sawdust.

Positive Impact on Asphaltic Concrete: The addition of treated sawdust to the asphaltic concrete led to significant improvements in various properties of the mixture. These enhancements suggest that the sawdust treatment has potential for improving the performance of asphaltic concrete.

Enhancement of Properties: The progressive increase in the proportion of treated sawdust within the mixture yielded a favorable impact on the characteristics of the asphaltic concrete. The specific properties that saw improvements were likely discussed in previous sections of the study, such as stability, flow value, VFB, air voids, and VMA.

Potential Application: The study's findings indicate that treated sawdust can be a viable alternative material to enhance the properties of asphaltic concrete. It has the potential to contribute to improved performance and durability of asphalt pavements.

In conclusion, the study highlights the positive impact of incorporating treated sawdust in asphaltic concrete mixtures. The properties of the mixture are likely improved by both the lightweight quality of sawdust and the presence of calcium oxide. These findings offer potential avenues for employing treated sawdust as an alternative and sustainable material in asphalt construction. This encourages additional research and exploration of its practical applications in the field.

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References

ASTM, D. (1989) 1559 (1989). “Test Method for Resistance of Plastic Flow of Bituminous Mixtures using Marshal Apparatus”. American Society for Testing and Materials, Philadelphia, USA.

ASTM, D36. (2001). “Standard Test Method for Softening Point of Bitumen (ring and ball apparatus)”. American Association of Testing and Material. Annual Book of ASTM Standard, Philadelphia, Pennsylvania, USA

ASTM, D5. (2001). Standard Method of Test for Penetration of Bituminous Mixtures, American Association of Testing and Materials, Annual Book of ASTM Standard. Philadelphia, Pennsylvania. USA.

ASTM, D70. (2001). Standard Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials (Pycnometer Method). American Association of Testing and Materials, Annual Book of ASTM Standard, Philadelphia, Pennsylvania, USA

Bahia, H. U., Faheem, A., Hintz, C., Al-Qadi, I., Reinke, G. and Dukatz, E. (2011). Test Methods and Specification Criteria for Mineral Filler used in HMA. NCHRP Research Result Digest, 357, Transportation Research Board, Washington D.C

Elinwa, A. U., Ejeh, S. P., & Akpabio, I. O. (2005). Using metakaolin to improve sawdust-ash concrete. Concrete International, 27(11), 49-52.

Ganiron Jr, T. U. (2013). Effects of rice hush as substitute for fine aggregate in concrete mixture. International Journal of Advanced Science and Technology, 58. http://dx.doi.org/10.14257/ijast.2013.58.03

Kandhal, P. S., Lynn, C. Y., & Parker, F. (1998). Characterization tests for mineral fillers related to performance of asphalt paving mixtures. Transportation research record, 1638(1), 101-110. https://doi.org/10.3141/1638-12

Prowell, B. D., Zhang, J., & Brown, E. R. (2005). Aggregate properties and the performance of superpave-designed hot mix asphalt (Vol. 539). *Transportation Research Board*.

Ravindra, T., Jain, R. K., & KOSTHA, M. (2013). Effect of fillers on bituminous paving mixes. *International Journal of Engineering Research & Science & Technology*, 2(4), 137-142.

Sobolev, K. (2003). Sustainable development of the cement industry and blended cements to meet ecological challenges. *The Scientific World Journal*, 3, 308-318.

Sobolev, K., & Faheem, A. (2014). Application of coal combustion products (CCP). *In Mid–Continental Transport Symposium Center for By-product Utilization (CBU).*

Tomas, U. (2013). Ganiron Jr. Influence of Polymer Fiber on Strength of Concrete. *IJAST*, 55, 53-66.

Transportation Research Board of the National Academies. (2003). Moisture sensitivity of asphalt pavements. *Transportation Research Board Miscellaneous Report*.

Ucol-Ganiron Jr, T. (2012). Concrete Debris as Alternative Fine Aggregate for Architectural Finishing Mortar. *Architecture Research*, 2(5), 111-114. DOI: 10.5923/j.arch.20120205.06

Zulkati, A., Diew, W. Y., & Delai, D. S. (2012). Effects of fillers on properties of asphalt-concrete mixture. Journal of transportation engineering, 138(7), 902-910.