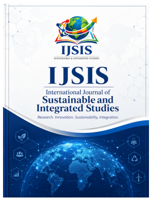

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Investigation on the Effects of Coconut Shell Ash and Husk Fiber as Filler Materials on the Mechanical Properties of Asphalt Concrete

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Abstract

This experimental study investigated the potential of Coconut Shell Ash (CSA) and Coconut Husk Fiber (CHF) as sustainable alternative materials for asphalt concrete, addressing the productive utilization of abundant coconut wastes in the Philippines. Guided by the Input-Process-Output (IPO) model, seventeen asphalt mixtures with varying proportions of CSA and CHF were prepared and compared with conventional asphalt. Their performance was evaluated through aggregate gradation, water absorption, Marshall Stability, Flow and Wheel Tracking tests, with descriptive statistics, Two-Way ANOVA, correlation analysis, and related statistical procedures used to assess the results. The findings showed that CSA and CHF could be incorporated into asphalt mixtures without compromising essential engineering properties. CSA demonstrated a significant influence on water absorption, mechanical properties, and rutting resistance, whereas CHF showed no significant standalone effect on several measured properties. Higher CSA concentrations generally improved moisture and rutting resistance, while the combination of 5% CSA and 5% CHF provided the most balanced modified-mixture performance in terms of strength, deformation, resistance, and durability. The study concluded that coconut-derived agricultural waste has potential as a sustainable alternative material for asphalt pavement and recommended further investigation of higher CSA proportions, other locally available waste ashes, appropriate aggregate gradation, material processing, and silica content. The study supports SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production) by linking agricultural waste utilization with sustainable pavement development. Its sustainability impact is primarily environmental and infrastructure-related, with socio-economic relevance through the productive use of coconut byproducts and the development of alternative road construction materials.

Keywords: Asphalt Concrete, Coconut Husk Fiber (CHF), Coconut Shell Ash (CSA), Coconut Waste, Mechanical Properties, Sustainable Asphalt, Sustainable Pavement

1. Introduction

The growing demand for sustainable infrastructure has encouraged the use of alternative materials in pavement construction. Conventional asphalt depends on mineral aggregates and petroleum-based bitumen, contributing to resource depletion, energy consumption, and harmful emissions (Mazumder, 2016). This study investigates Coconut Shell Ash (CSA) and Coconut Husk Fiber (CHF) as sustainable filler and additive materials in asphalt concrete. Their use is particularly relevant in the Philippines, where coconut production generates almost 5 million tons of organic waste annually (Kyriazopoulos, 2022). The study evaluates asphalt mixtures containing varying proportions of CSA and CHF through aggregate gradation, water absorption, Marshall Stability and Flow, and Wheel Tracking tests. Their performance is compared with conventional asphalt to determine their potential as sustainable materials for flexible pavement.

Sustainable pavement construction increasingly explores waste-derived materials to reduce dependence on conventional resources. Recycled plastics can improve asphalt stiffness and rutting resistance, although concerns regarding segregation, fatigue resistance, and environmental effects remain (Moreno-Navarro et al., 2022; Xu et al., 2023; Diab, 2022). Other waste materials have likewise demonstrated potential as asphalt modifiers (Cao et al., 2025). Coconut-based materials are promising because of their abundance and material properties. CSA can improve Marshall Stability, stiffness modulus, moisture resistance, and elastic modulus (Ahmad et al., 2021; Ekwulo et al., 2021), while CHF can enhance ductility, stability, and binder adhesion when appropriately incorporated (Molvi & Singh, 2023). Pyrolyzed coconut husks and coir ash have also demonstrated improved binder adhesion and moisture resistance (Rafi et al., 2020; Lejano et al., 2024).

The suitability of alternative asphalt materials depends on their ability to maintain structural reliability and durability. Moisture susceptibility, wheel tracking, and related performance evaluations are therefore essential (Ceylan, 2024). Coconut shells have demonstrated potential as partial aggregate replacements at low replacement levels (Amiera Jeffry, 2016; Iturralde & Guerra, 2024), although improper incorporation of coconut fibers may reduce abrasion resistance (Aquino et al., 2021). These findings indicate that the effectiveness of coconut-derived materials depends on their proportions and interaction within the mixture. Evaluating CSA and CHF together can therefore provide evidence regarding their effects on asphalt strength, moisture resistance, flexibility, and resistance to deformation.

Globally, recycled and agricultural waste materials are increasingly investigated as alternatives for more sustainable pavement construction. This approach is particularly relevant to the Philippines because of its substantial coconut production and resulting agricultural waste. Coconut production generates almost 5 million tons of organic waste annually (Kyriazopoulos, 2022), yet only a limited portion of coconut husks is utilized. Transforming coconut shells and husks into asphalt materials provides an opportunity to reduce agricultural waste while developing alternative materials for road construction. It may also create productive uses for coconut byproducts that are otherwise discarded.

The study follows the Input-Process-Output (IPO) model. Inputs include CSA, CHF, aggregates, asphalt binder, and laboratory equipment meeting ASTM/AASHTO standards. The process involves material preparation, gradation, mixing and compaction, water absorption, Marshall Stability and Flow, Wheel Tracking, and statistical analyses. The outputs include a modified asphalt mixture, comparative performance results, feasibility assessment, and evaluation of CSA and CHF as sustainable pavement materials.

Previous research has primarily examined coconut shell ash, coconut husk fiber, and other coconut-derived materials separately. CSA has demonstrated favorable mechanical and moisture-related properties (Ahmad et al., 2021; Ekwulo et al., 2021), while CHF has shown potential to improve stability and binder adhesion (Molvi & Singh, 2023). However, research on their combined use in asphalt mixtures remains limited, particularly in the Philippines. Local studies, long-term performance assessments, and standardized processing methods are also limited. The present study addresses this gap by evaluating different CSA–CHF combinations and comparing their mechanical performance with conventional asphalt.

The study aligns with SDG 9 – Industry, Innovation and Infrastructure by investigating agricultural waste as an alternative material for pavement construction. It also supports SDG 12 – Responsible Consumption and Production through the productive utilization of coconut waste and relates to SDG 11 – Sustainable Cities and Communities through its focus on sustainable road materials.

The study contributes to environmental and infrastructure sustainability by investigating the conversion of coconut waste into useful pavement materials. It also supports socio-economic sustainability by identifying potential productive uses for coconut byproducts. By evaluating CSA and CHF through established asphalt performance tests, the study integrates waste utilization, material innovation, and sustainable infrastructure development.

2. Materials and methods

2.1 Research Design

An experimental research design was used to evaluate the effects of CSA and CHF on asphalt concrete. Asphalt mixtures were prepared using CSA at 2%, 3%, 4%, and 5% and CHF at 2%, 4%, 5%, and 6%. A conventional hot-mix asphalt served as the control specimen for comparing the performance of the modified mixtures.

2.2 Locale of the Study

The study was conducted at the Civil Engineering Laboratory of the College of Engineering at Jose Rizal Memorial State University in Dapitan City, Zamboanga Del Norte.

2.3 Respondents of the Study
The investigation focused on experimentally prepared conventional and CSA–CHF modified asphalt specimens whose proposed respondents are civil engineering researchers and road contractors.

2.4 Sample and Sampling Procedure
The experimental samples consisted of conventional and modified asphalt mixtures containing different combinations of CSA and CHF. The conventional hot-mix asphalt served as the control specimen. The modified mixtures incorporated CSA at varying proportions and CHF at varying proportions to determine their effects on asphalt performance.

2.5 Research Instrument
The study used laboratory materials and equipment for asphalt preparation and performance evaluation, including aggregates, asphalt binder, coconut shells, coconut husks, weighing and temperature-measuring equipment, sieves, molds, an oven, an automatic Marshall compactor, a Marshall Stability machine, and a Wheel Tracker. Testing followed applicable ASTM and AASHTO standards to provide standardized measurements of the mechanical and durability properties of the mixtures.

2.6 Data Gathering Procedure
CSA was prepared by cleaning, drying, crushing, calcining, grinding, and sieving coconut shells to obtain ash within the required particle-size fraction. CHF was produced by shredding, grinding, washing, oven drying, and trimming the fibers to approximately 5 mm. Aggregates, CSA, and 60/70 penetration-grade bitumen were preheated according to ASTM requirements before the prepared CSA and CHF were incorporated into the heated aggregates and binder. The mixtures were compacted using an automatic Marshall compactor and formed into standardized cylindrical specimens. Aggregate gradation was evaluated following ASTM C136M, water absorption following ASTM D2726M, Marshall Stability and Flow following ASTM D6927, and rutting resistance through Wheel Tracking following ASTM D8292 and AASHTO T324. Water conditioning and controlled-temperature testing were applied to support consistent experimental conditions.

2.7 Data Analysis Techniques
Data on stability, flow, density, water absorption, and rut depth were collected and compared across conventional and modified asphalt mixtures. Descriptive statistics, Two-Way ANOVA, and Post Hoc tests were used to determine significant differences among the mixtures. The study also employed Correlation (Pearson) Analysis as part of the statistical evaluation of the effects of CSA and CHF. These analyses provided the basis for assessing the feasibility and performance of CSA and CHF as sustainable modifiers for asphalt pavement.

3. Results and Discussion

3.1 Physical and Mechanical Performance of CSA–CHF Modified Asphalt

3.1.1 Chemical Characteristics of Coconut Shell Ash
Chemical analysis showed that CSA had a rough, irregular, and highly porous microstructure. Its composition included Silicon (Si=4.43%) and Calcium (Ca=2.61%), together with oxygen, carbon, potassium, sodium, and aluminum. The presence of silica and calcium indicates potential cementitious characteristics that may contribute to stronger bonding within the asphalt mixture. These constituents may therefore support the use of CSA as an alternative filler material.

3.1.2 Aggregate Gradation
The aggregate blend generally satisfied the gradation requirements for a 12.5 mm Superpave mix under AASHTO M 323 (2012). The gradual decrease in percent passing across sieve sizes indicated a well-graded distribution of coarse and fine aggregates. The balanced particle-size distribution allows coarse particles to provide structural strength while finer particles fill available voids, promoting better compaction and interlocking. Proper aggregate gradation is associated with improved stability, durability, and resistance to deformation (The Asphalt Handbook, 2007).

3.1.3 Water Absorption
Water absorption varied across the CSA–CHF mixtures. Higher CSA proportions generally resulted in lower water absorption, particularly at 5% CSA, while mixtures containing approximately 3% CSA demonstrated intermediate absorption values. Variations in CHF produced less consistent changes. The lower absorption observed with higher CSA content suggests a denser internal structure with fewer connected voids available for moisture penetration. This is important because moisture can weaken binder–aggregate adhesion and contribute to stripping, rutting, and reduced pavement durability (Hicks, 1991).

3.1.4 Marshall Stability

The conventional control mixture produced the highest Marshall Stability at 92 kN. All CSA–CHF mixtures satisfied ASTM requirements, although their stability values varied considerably. Higher CSA concentrations of 3–5% generally improved stability among the modified mixtures, with 5% CSA and 5% CHF producing the highest modified-mixture stability of 57 kN. The lowest value was 8 kN at 2% CSA and 6% CHF. The results indicate that CSA contributed more consistently to the strength and stability of the modified asphalt mixtures, whereas the effects of CHF varied according to its combination with CSA. Although the modified mixtures did not exceed the control in stability, they maintained the required performance level.

3.1.5 Marshall Flow

The control mixture recorded the lowest Marshall Flow value at 4.16 mm. The CSA–CHF mixtures satisfied ASTM requirements, with higher CSA concentrations, particularly 4%, generally producing greater flow values. CHF showed inconsistent effects across the different mixtures. The results suggest that varying CSA and CHF proportions can influence deformation characteristics while maintaining acceptable flow performance. However, the inconsistent response to CHF indicates that its contribution to mixture flexibility depends on its interaction with CSA.

3.1.6 Rutting Resistance

The control mixture recorded a rut depth of 8 mm, while most CSA–CHF mixtures remained within the ASTM limit of 10 mm. Higher CSA concentrations of 4–5% generally demonstrated better rutting resistance, with several mixtures containing 5% CSA recording rut depths of approximately 2 mm. In contrast, mixtures containing 3% CSA showed inconsistent performance, including one rut depth of 15 mm. The findings indicate that higher CSA concentrations improved resistance to permanent deformation. This suggests that CSA can contribute to a more rut-resistant asphalt structure when incorporated at appropriate proportions.

3.2 Statistical Effects of CSA and CHF on Asphalt Properties

3.2.1 Effects on Water Absorption

Two-Way ANOVA showed that CSA had a significant effect on water absorption and permeability, whereas CHF did not demonstrate a meaningful independent effect. This finding supports the experimental observation that increasing CSA generally reduced moisture absorption. CSA therefore appears to be the more influential material in controlling moisture-related properties and improving the durability of the modified asphalt mixture.

3.2.2 Effects on Marshall Stability

Statistical analysis showed that CSA significantly influenced the mechanical properties and stability of the asphalt mixtures. CHF did not demonstrate a significant standalone effect, although it may provide additional benefits when combined with CSA. These findings indicate that CSA is the primary factor contributing to improvements in strength and stability. The effect of CHF appears to depend more strongly on its interaction with CSA than on its individual proportion.

3.2.3 Effects on Marshall Flow

Neither CSA nor CHF significantly affected Marshall Flow. Changes in their proportions therefore did not produce statistically significant differences in the flexibility or deformation behavior of the mixtures. The statistical findings indicate that CSA and CHF can be incorporated at the tested proportions without significantly altering Marshall Flow. This supports their potential use while maintaining acceptable deformation characteristics.

3.2.4 Effects on Rutting Resistance

CSA significantly affected rutting performance, while CHF showed no significant independent effect. Higher CSA concentrations generally corresponded with improved resistance to permanent deformation. The statistical results reinforce the Wheel Tracking findings, identifying CSA as the principal factor associated with improved rutting resistance. CHF demonstrated a less consistent contribution to this property.

3.3 Overall Performance of CSA–CHF Modified Asphalt

Across the experimental and statistical results, CSA demonstrated the strongest and most consistent influence on water absorption, stability, and rutting resistance, while CHF generally showed no significant standalone effect. The combination of 5% CSA and 5% CHF provided the most balanced modified-mixture performance in terms of strength, deformation resistance, and durability. Overall, the findings demonstrate that CSA and CHF have potential as sustainable alternative materials for asphalt concrete without compromising essential engineering properties. The performance of mixtures with higher CSA concentrations particularly supports the use of coconut-derived agricultural waste as a practical modifier for sustainable pavement construction.

4. Conclusion & Recommendations

The study concludes that Coconut Shell Ash (CSA) and Coconut Husk Fiber (CHF) have potential as sustainable alternative materials for asphalt concrete without compromising essential engineering properties. CSA demonstrated a significant contribution to durability, strength, water resistance, and resistance to permanent deformation, while maintaining adequate flexibility. Although CHF showed no significant standalone effect on several measured properties, its incorporation with CSA remained feasible. Among the modified mixtures tested, the combination of 5% CSA and 5% CHF provided the most balanced performance in terms of strength, stability, deformation resistance, and durability. Overall, the findings demonstrate the potential of coconut-derived agricultural waste as practical and sustainable modifiers for asphalt pavement construction.

Future studies should investigate higher percentages of CSA to determine whether increased concentrations can further enhance asphalt performance and should explore other locally available waste ashes from food-processing activities, such as lechon and bibingka production, as potential asphalt modifiers. Coarse aggregates should follow a gradation passing the 3/8-inch sieve and retained on the No. 4 sieve to improve particle interlocking and mixture stability, while a proper mold extractor should be used to preserve specimen quality during removal. Coconut shells intended for modification should also undergo carbonization before calcination to improve processing and potentially increase silica content, and the silica content of prospective asphalt modifiers should be considered because of its contribution to binding, strength, and durability.

The study was limited to laboratory evaluation of conventional and modified asphalt mixtures containing CSA and CHF within the selected proportions and using gradation, water absorption, Marshall Stability and Flow, and Wheel Tracking tests. The investigation did not include long-term performance assessment, and standardized processing methods for coconut-based asphalt modifiers remain limited. Therefore, the findings are confined to the materials, mixture proportions, preparation procedures, and laboratory performance measures evaluated in the study.

5. Compliance with ethical standards

The authors declare no conflict of interest. No external funding source was specified for this study; the research involved laboratory-based preparation and testing of Coconut Shell Ash (CSA) and Coconut Husk Fiber (CHF) modified asphalt mixtures using standardized procedures. As the study did not involve human participants, voluntary participation, informed consent, participant confidentiality, and non-invasive survey procedures were not applicable. The authors acknowledge Jose Rizal Memorial State University as the institutional affiliation associated with the study.

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