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Innovation in the Production of Tactile Paving (Guiding Block) from A Biochar Mixture as a Direction Indicator for Visually Impaired Individuals

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ABSTRACT: This research examines the innovation of creating tactile paving (guiding block) based on a biochar mixture as a directional aid for visually impaired individuals. Biochar is used as an additive to replace a portion of the sand volume with variations of 0%, 5%, 10%, and 20% relative to the concrete volume. The aim of the research is to evaluate the effect of adding biochar on the physical and mechanical properties of concrete, specifically compressive strength, water absorption, slump, and its suitability for non-structural tactile paving applications. The methods used include testing the characteristics of aggregates and biochar according to SNI, planning a concrete mix with a target strength of 25 MPa using the SNI 7656:2012 method, creating cylindrical test specimens of 15×30 cm, and testing slump, compressive strength at 7, 14, and 28 days, and water absorption at 28 days. The results show that the addition of biochar reduces the average compressive strength compared to normal concrete; at 28 days, the compressive strength of normal concrete is 21.703 MPa, while the variations of 5%, 10%, and 20% are 18.495 MPa, 17.929 MPa, and 13.399 MPa, respectively. Water absorption increased from 1.04% (0%) to 1.79% (20%), while the slump value decreased but remained within the planned range of 75–100 mm. Overall, biochar-based tactile paving with 5–10% variation still meets the compressive strength requirements for non-structural elements, while offering potential weight reduction and the use of environmentally friendly materials for accessible infrastructure for the visually impaired.

KEYWORDS: Tactile Paving (Guiding Block), Biochar, Directional Indicators, Blind Disability

INTRODUCTION

Concrete is the most widely used construction material in the world, but its cement production contributes more than 7% of global CO_2 emissions and threatens efforts to achieve the 2050 net zero target (Aneja et al., 2022). On the other hand, the world's population and the need for urban infrastructure continue to increase, significantly driving up concrete consumption and greenhouse gas emissions (Murali & Wong, 2024). At the same time, visually impaired individuals face mobility barriers in public spaces, necessitating accessible infrastructure such as tactile paving as directional indicators and safe, independent navigation aids (Y. Ma et al., 2023). This global challenge demands innovation in materials and infrastructure design that is both environmentally friendly and inclusive.

In Indonesia, the fulfillment of the rights of persons with disabilities to access safe and equitable public spaces still faces many obstacles. A study in DKI Jakarta found that guiding blocks and ramps are often installed below standard, hindering mobility and increasing the risk of accidents for people with disabilities, particularly the visually impaired (Raflis et al., 2025). These findings are reinforced by a study of inclusive practices in Indonesian higher education institutions, which shows that there are still limitations in physical accessibility and stakeholders' understanding of disability needs (Diny Sujannah et al., 2025). This condition indicates that in addition to improving the design and arrangement of facilities, the development of sustainable accessible infrastructure elements is also necessary, such as environmentally friendly tactile paving that is contextually appropriate.

The selection of biochar as a treatment in the development of tactile paving is based on its characteristics as a negative carbon material capable of substituting part of the cement while sequestering CO_2. Biochar is a solid carbon-rich material resulting from the pyrolysis of biomass, which has the potential to be a cheap, low-emission cement substitute and contributes to carbon absorption in concrete (Lin et al., 2023). Several studies have shown that the addition of biochar as a partial cement substitute at low levels (around 1–4%) can improve compressive strength, flexural strength, sulfate attack resistance, and permeability, while also reducing water absorption due to microstructure densification (Patel et al., 2025; Aneja et al., 2022). On the other hand, biochar allows for the utilization of local biomass waste, making it relevant in the context of Indonesia, which is rich in biomass resources and is promoting low-carbon construction.

At the state of the art, international research on biochar in concrete is rapidly advancing in aspects of mechanical properties, durability, and carbon sequestration capacity. Comprehensive reviews show that replacing 1–2% of cement with biochar generally increases compressive and flexural strength and improves resistance to sulfate, chloride, shrinkage, and permeability thru enhanced hydration and the physical filling effect that densifies the microstructure (Lin et al., 2023; Zaid et al., 2024). Scientometric reviews emphasize that adding 1–2% biochar can improve mechanical performance, while replacements above 5–6% tend to decrease strength compared to concrete without biochar (Room & Bahadori-Jahromi, 2024). On the other hand, studies on biochar concrete also position this material as a key component in the development of carbon-negative concrete that can simultaneously enhance performance and reduce the carbon footprint of construction (Chen et al., 2022; Barbhuiya et al., 2024).

Research on tactile paving emphasizes its role in enhancing the travel effectiveness of visually impaired individuals, revealing various design and implementation limitations. A study in Nanjing shows that tactile paving, ramps, and pedestrian signals generally improve travel effectiveness, but their discontinuity, obstruction by vehicles, and lack of further guidance significantly reduce their accessibility function (Y. Ma et al., 2023). On the technological side, smart guiding systems based on mobile phone cameras and TWSI pattern recognition extend the function of tactile paving into visual markers that can be translated into audio or vibration feedback, even allowing for the replacement of raised bricks with stickers or flat pattern paint that are more comfortable for other users (Chen et al., 2022). The "Virtual Paving" innovation also demonstrates that tactile paths can be realized in the form of multimodal feedback that keeps walking paths safe and efficient for the visually impaired (Xu et al., 2020).

Some research gaps are still evident. The literature on biochar concrete is rich in aspects of general structural concrete, mortar, and carbon-negative concrete, but it hardly discusses its specific applications for small paving elements such as paving blocks or guiding blocks that must meet mechanical criteria, durability, foot comfort, and tactile readability. The mechanical properties of biochar concrete have been extensively studied, but long-term durability tests in various environments and practical field applications are still limited (Lin et al., 2023). Disability infrastructure studies in Indonesia mostly evaluate the performance of existing facilities and their compliance with standards, but have not yet touched on the aspect of developing innovative, environmentally friendly materials for guiding blocks (Raflis et al., 2025). This research aims to develop and test tactile paving based on a biochar mixture as an innovative material solution that integrates directional functions for the visually impaired with the principles of green concrete, thereby introducing novelty in the realm of biochar concrete and accessible infrastructure.

The urgency of this research lies in the simultaneous need to reduce emissions in the construction sector and improve the quality of disability-friendly infrastructure in Indonesia. The use of biochar as a partial substitute for cement has the potential to reduce the carbon footprint of concrete while also adding value to biomass waste (Aman et al., 2022). At the same time, improvements in the design and materials of guiding blocks have the potential to directly enhance the safety, independence, and quality of life for visually impaired individuals, considering that the quality of installation and the availability of accessibility facilities significantly affect the effectiveness of their travel (Y. Ma et al., 2023). The development of biochar tactile paving not only contributes to strengthening the scientific basis of biochar concrete but also supports the agenda of inclusive and sustainable cities in Indonesia.

LITERATURE REVIEW

This research combines two main themes: (1) the function of tactile/guiding blocks for the mobility of the visually impaired, and (2) the performance of concrete/paving with biochar or other substitute materials (compressive strength, water absorption, sustainability). Here is a summary of previous research that can support each group of findings. Functions and Benefits of Tactile Paving for the Visually Impaired: Improving crossing performance: The installation of tactile paving at zebra crossings helps visually impaired individuals maintain a straight path, reduce directional deviation, decrease crossing time, and improve the regularity and symmetry of their steps (Y. Ma et al., 2021). Design innovation & supporting technology: The concept of "Virtual Paving" shows that tactile paths can be replaced by multimodal guidance (vibration and audio) for safe and smooth navigation (Xu et al., 2020). Camera-based guiding systems can detect tactile paving patterns and provide audio/vibration guidance, allowing tactile patterns to be applied as stickers/flat paint (Chen et al., 2022). Another study proposed a unidirectional tactile paving design to ensure one-way circulation remains accessible for the visually impaired (Fernández González & Gongal, 2022).

Biochar as a partial replacement for cement (green concrete): The addition of biochar 0–5% by weight of cement, with an optimum around 2%, can increase compressive, split tensile, and flexural strength while simultaneously reducing water absorption (porosity) before excessive levels decrease durability (Patel et al., 2025). According to Aman et al. (2022), replacing cement with small amounts of biochar (±0.08–5%) generally improves the strength and other properties of concrete while being more environmentally friendly. Other research shows that replacing part of the cement with 10% rice husk ash in natural and recycled aggregate concrete can slightly increase the 28-day compressive strength (W. Ma et al., 2023). Overall, previous research shows that tactile paving has been proven to enhance the safety and independence of the visually impaired, especially when crossing streets, and the quality of installation is crucial for success. Biochar and other waste materials can be used in concrete and paving blocks with optimum doses that can maintain or enhance compressive strength, control water absorption, and reduce carbon footprint.

MATERIALS AND METHODS

The methods used align with cutting-edge biochar-concrete research practices: material characterization, concrete mix design, compressive strength testing, and water absorption/porosity are widely employed to assess the performance and sustainability of concrete with partial cement replacement by biochar (Patel et al., 2025; Qin et al., 2021). Research Materials: The selection of Portland cement, fine-coarse aggregates, water, and biochar as primary materials follows common practices in low-carbon concrete development, where biochar is positioned as a partial cement substitute to reduce CO_2 emissions (Lin et al., 2023; Abbas & Thapa, 2025). The initial characterization of biochar and aggregates (particle size, specific gravity, water absorption) is crucial as these properties significantly influence the workability and strength of biochar concrete (Abbas & Thapa, 2025; Haris Javed et al., 2022).

Biochar Concrete Mix Design: The use of several variations in the percentage of cement replacement with biochar (e.g., 5–20%) aligns with experimental studies that test a wide range of doses to find the optimum content and the performance decline threshold (Patel et al., 2025; Abbas & Thapa, 2025). The establishment of one control mix (without biochar) and several modified mixes allows for direct comparison of mechanical properties and durability, as done with normal concrete, mortar, and biochar-based pervious concrete (Tan et al., 2022; Akhtar & Sarmah, 2018).

Specimen Preparation and Curing: The preparation of 15×30 cm cylindrical test specimens or cubes/beams for compressive, split tensile, and flexural strength tests is standard in biochar concrete studies. Wet curing until the age of 7, 14, and 28 days allows for the evaluation of short- to medium-term strength development, as it has become the focus of meta-analysis and biochar–concrete experiments (Zhao et al., 2024; Gupta et al., 2020).

Concrete Compressive Strength Testing: Compressive strength testing at 7, 14, and 28 days for each biochar variation is important to capture the "up then down" pattern with increasing dosage, which has been widely reported: optimum around 1–3% or <≈5% and a decrease above that (Ling et al., 2023; Patel et al., 2025; Zhao et al., 2024). Interpretation of the results (for example, a 10% variation that still meets the paving compressive strength target) can be supported by findings that certain doses of biochar are still suitable for non-structural applications such as concrete blocks (Abbas & Thapa, 2025). Water Absorption / Porosity Testing: The measurement of water absorption in biochar tactile paving serves as an indicator of porosity and durability, in line with numerous studies linking biochar content to water absorption and pore structure (Patel et al., 2025; Haris Javed et al., 2022; Tan et al., 2022). The combination of compressive strength and water absorption data in the method allows for the classification of biochar paving performance both mechanically and in terms of durability, in line with the comprehensive performance approach for biochar pervious concrete (Qin et al., 2021).

Design of Shape and Function of Tactile Paving: The design of dimensions, protrusion patterns (dot/bar), and layout of tactile paving is based on its function as a directional and warning indicator for the visually impaired. Accessibility studies show that the presence of tactile paving enhances the travel effectiveness of low vision users, and the quality of installation (continuity, obstacle-free) is crucial (Y. Ma et al., 2023). The contribution of this method combines tactile function with biochar material, in line with the concept of accessible infrastructure innovation that also considers material sustainability. Data Analysis: The use of descriptive and comparative statistics (e.g., comparing average compressive strength and absorption between variations) follows the analysis practices in biochar concrete experimental studies, which assess the dose effect thru response curves and discuss the optimum dose (Ling et al., 2023; Zhao et al., 2024). By emphasizing each subsection (materials, mix design, production & curing, compressive strength test, water absorption test, tactile paving design, and data analysis) in detailed paragraphs and grounding them in the aforementioned international literature, your methods are already at the standards commonly used in reputable journals for the topic of biochar concrete and accessible infrastructure.

Table 1: Comparison of biochar composition and main effects on concrete/paving

Aspect	**Reported Optimum Composition**	**Main Effect**	**Source**
Normal concrete (cement replaced with biochar)	2% cement weight	strong compression & tension, water absorption	(Patel et al., 2025)
Cement paste/mortar with various biochar	2% cement weight	Best values for compressive strength & porosity	(Javed et al., 2022)
Pervious concrete with biochar cement	1–3% cement weight	compressive/flexural strength; >3% decrease	(Tan et al., 2022)
Paving block: cement 5% biochar + sand 2% PP	5% biochar + 2% PP	Compressive strength 52.11 MPa; water absorption	(Paoleng et al., 2025)

Overall, previous research shows that tactile paving has been proven to enhance the safety and independence of the visually impaired, especially when crossing streets, and the quality of installation is crucial for success. Biochar and other waste materials can be used in concrete and paving blocks with optimum doses that can maintain or enhance compressive strength, control water absorption, and reduce carbon footprint.

RESULTS

Previous research has extensively discussed why the addition of biochar can alter the compressive strength, water absorption, and microstructure of concrete. In essence, biochar affects cement hydration, pore structure, and the interfacial transition zone (ITZ), which ultimately explains the observed performance improvements or declines. At low concentrations (e.g., 5% vol), the gel/capillary pore structure remains almost unchanged, but biochar helps reduce the formation of large pores; at high concentrations, biochar can become a "micro-defect" that weakens the concrete. Hydration actually decreases when biochar increases (the dilution effect is more dominant), resulting in reduced compressive strength at higher compositions. In addition to finding the optimum content of 2% with the lowest water absorption (decreased porosity), higher content worsens durability. Here is the mix-design table using the SNI 7656:2012 method and the water absorption graph:

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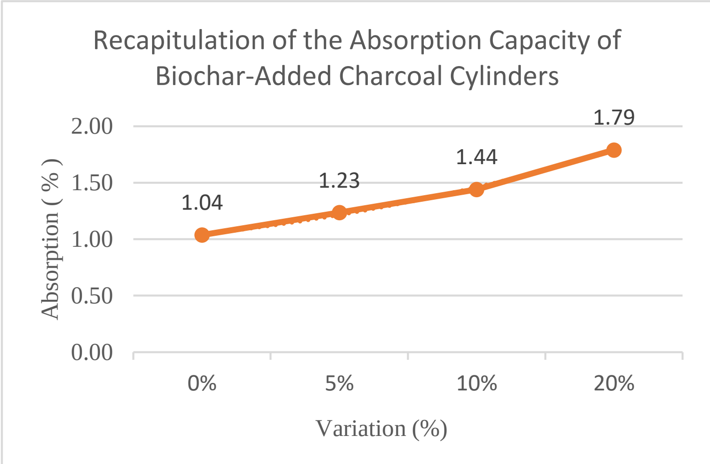
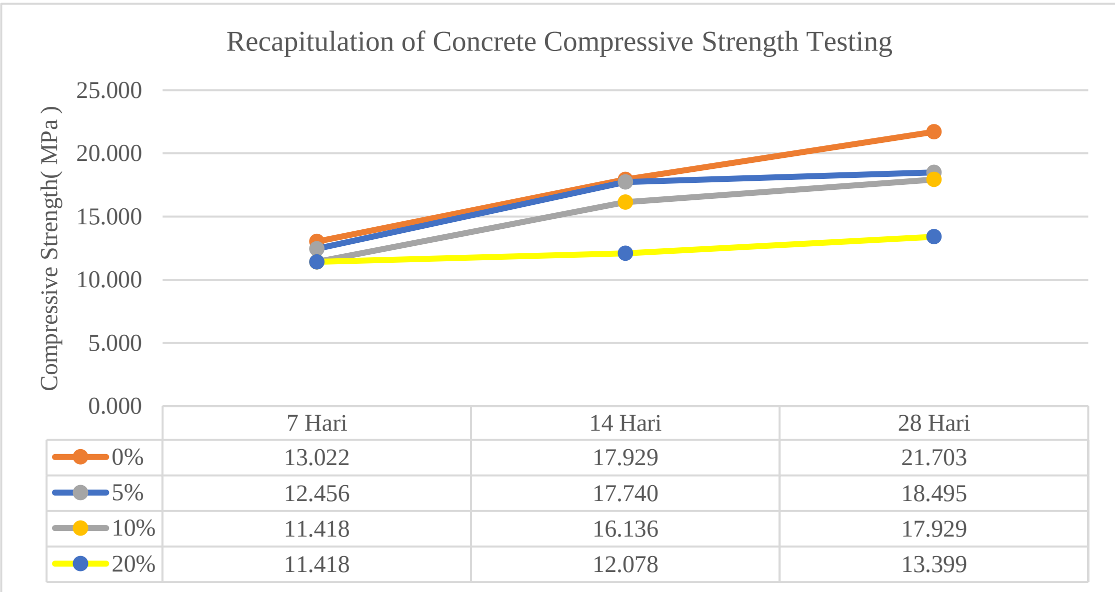
Table 2: Mix-Design Method SNI 7656:2012

Concrete Quality	25 Mpa
Slump	75 – 100 mm
Maximum aggregate size	20
Dry weight oven Ag. Coarse	1,706
Specific gravity of cement without air-entraining agent	3,1
Modulus of Smoothness Fine	2,65
Specific gravity (SSD) Fine Aggregate	2,63
Specific gravity (SSD) Coarse Aggregate	2,66
Water absorption Ag. Fine	1,79%
Water absorption Coarse Aggregate	0,66%
Fine Ag Water Content	3,85%
Water Content Coarse	4,22%
Specific Gravity of Charcoal	1,71



Figures 1: Water Absorption Graph

Mechanistically, these findings (changes in compressive strength, water absorption, and possibly carbonation/durability) can be explained by: (1) water absorption and the internal curing effect of biochar, (2) the role of biochar as a hydration nucleus and pore filler, (3) the formation of a dense ITZ around biochar particles, and (4) the transition from beneficial to detrimental effects as the biochar content exceeds the optimum dosage. Here is the graph of the compressive strength test of concrete for tactile paving (Guiding block):



Figures 2: Graph of Concrete Compressive Strength Testing

DISCUSSION

Experiments show practical recommendations: use 1–2% biochar for improved mechanical performance/durability, avoid replacement >5–6% if structural strength is a priority (Maljaee et al., 2021; Room & Bahadori-Jahromi, 2024). This research on biochar tactile paving shows the presence of an optimum limit; variations of 5–20% reduce compressive strength relative to normal concrete and indicate the need to determine the optimum content for paving applications. A study on lightweight concrete with biochar and incinerated sludge ash shows that 3–5% biochar can improve compressive/flexural strength and water resistance, while also mobilizing heavy metals (Zhang et al., 2022). This can be used as a practical analogy that biochar tactile paving has the potential to meet certain mechanical/durability criteria if the concentration and type of biochar are controlled.

Practical implications of the Nanjing study: regulations are needed to prohibit parking on tactile surfaces, routine checks for continuity, and the installation of alignment cues on medians/road islands (Y. Ma et al., 2023). These findings on the technical feasibility of biochar tactile paving can be translated into practical recommendations: environmentally friendly materials and good installation and maintenance standards. The Virtual Paving concept shows the opportunity to combine physical biochar tactile paths with a multimodal guidance system (audio/vibration) to address coverage limitations or physical disruptions. For theoretical implications, use reviews and mechanistic studies of biochar–concrete as the theoretical foundation (microstructure, hydration, optimum limits, and carbon sequestration) as well as studies on tactile paving as the basic theory for blind navigation. For practical implications, refer to studies that discuss biochar content recommendations, concrete/paving performance, accessible facility management, as well as green concrete and carbon-negative policies to link biochar tactile paving innovations with design practices, regulations, and sustainable development policies.

Previous research in line with this shows that the addition of biochar in small to moderate amounts (around 1–2, sometimes up to 5% cement replacement) generally increases compressive and tensile/flexural strength, while reducing water absorption and permeability, and simultaneously improving resistance to chloride/sulfate and high temperatures (Patel et al., 2025; Gupta et al., 2020; Lin et al., 2023). Analysis and reviews also confirm that compositions <±2–2.5% are very likely to maintain or enhance compressive strength, and biochar has great potential as an environmentally friendly material to partially replace cement (Zhao et al., 2024; Aman et al., 2022). On the tactile function side, tactile paving has been proven to help visually impaired individuals maintain direction, reduce crossing time, and enable smart guiding systems (camera/phone) to read surface patterns as safe directional indicators (Chen et al., 2022).

The findings of reduced water absorption and increased durability at low doses are also consistent with the mechanisms of blocking and purifying pore networks. At concentrations of 1–2%, biochar reduces water permeability and salt ion absorption; this is consistent with the increase in compressive strength and resistance to chloride/sulfate. Comprehensively concluding that up to 5% biochar can improve durability due to more intensive hydration and physical filling, resulting in a denser microstructure that inhibits the penetration of water and ions. On the other hand, if the content is too high, the pore network carried by biochar forms interconnected transport channels, leading to increased carbonation and water absorption; the ITZ acts as a partial barrier, but the high pore connectivity still increases permeability. Some experiments also show that when real fine/coarse aggregates are included (full concrete, not just paste/mortar), the effect of biochar on compressive strength can diminish or even become insignificant, marking the limitations of scale and mix composition.

Practically, findings and related literature suggest that the design of biochar tactile paving should set the biochar composition within an optimal range (around 1–2% cement replacement for normal concrete, or a narrow equivalent range for paving blocks), in order to maintain/optimize compressive strength and water absorption while still utilizing carbon absorption capabilities and reducing the environmental footprint. The design of biochar particles and size distribution can be optimized to balance carbonation channels (for CO_2 sequestration) and the upper limit of water permeability, according to the functional needs of the paving in the field. For use as a guiding block, results on tactile paving detection based on cameras and cellular guidance systems indicate that the surface pattern of biochar paving must not only be comfortable and readable by cane/foot but also visually contrasting and consistent to be easily recognized by computer vision algorithms, enabling integration with smart guidance systems and expanding its benefits for the visually impaired in modern urban environments.

CONCLUSION

This study concludes that the addition of biochar as an additive in tactile paving (guiding block) results in systematic changes to the fresh and hardened properties of concrete. All aggregates, cement, and biochar were first characterized according to SNI and proven to meet the requirements as concrete mix materials, so the results obtained reflect the influence of biochar variation, not the quality of the materials. The mix design for the planned strength of 25 MPa was prepared using the SNI 7656:2012 method, and four mixtures were made: normal concrete and concrete with 5%, 10%, and 20% biochar relative to the volume of sand. The slump values of all mixtures were within the planned range (75–100 mm) and tended to decrease with the increase in biochar (from 86.7 mm for normal concrete to 75 mm at 20% biochar), indicating a reduction in workability but still manageable in the field. Water absorption increased from an average of 1.04% in normal concrete to 1.23%, 1.44%, and 1.79% in the 5%, 10%, and 20% variations, indicating greater porosity with higher biochar addition. The compressive strength of all biochar mixtures meets the criteria for non-structural use, but it is lower compared to normal concrete at 7, 14, and 28 days. The average 28-day compressive strength of normal concrete is 21.703 MPa, while the 5%, 10%, and 20% variations are 18.495 MPa, 17.929 MPa, and 13.399 MPa, respectively. Overall, this study indicates an optimal limit for biochar use: the addition of 5–10% still results in a compressive strength suitable for tactile paving, while also reducing the weight of the concrete. However, the 20% composition significantly reduces compressive strength and increases water absorption, making it less recommended for applications with higher mechanical demands.

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