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AquaShell Paver: Ecofriendly Paving Brick Using Super Absorbent Polymers (SAP) and Eggshells

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Abstract

Urban development has lead to increased use of impermeable materials such as concrete and asphalt, causing significant environmental challenges including urban flooding, reduced groundwater recharge, and elevated carbon emissions. This study introduces an innovative and eco-friendly paving brick named AquaShell Paver Brick, which incorporates eggshell powder (ESP) and Super Absorbent Polymer (SAP) into conventional brick mixtures to address these issues. Eggshell powder, a calcium carbonate-rich waste material, partially replaces cement to reduce cement consumption and environmental impact. Meanwhile, SAP is added in small quantities to enhance moisture retention during curing, promoting better hydration and durability. The research evaluates the effects of varying ESP and SAP contents on the compressive strength and water absorption of the bricks, as well as the impact of different curing methods on structural integrity. Experimental results indicate that incorporating ESP obtain 38.17MPa and SAP improves strength and permeability compared to traditional bricks, although the combination of both additives requires careful curing to avoid strength loss due to excessive internal moisture. The study concludes that AquaShell Paver Bricks offer a sustainable alternative for urban infrastructure by improving water management, reducing waste, and lowering carbon footprint, aligning with goals of greener urban development.

1. Introduction

Urbanization has significantly increased the coverage of impervious surfaces such as roads, pavements, and parking lots, resulting in various environmental challenges including surface runoff, urban flooding, and reduced groundwater recharge [1], [2]. Traditional construction materials like concrete and asphalt worsen these effects due to their impermeability and resource-intensive manufacturing processes, which also contribute to carbon emissions [3]. Concurrently, waste management has become a growing concern, with large volumes of organic waste such as eggshells being discarded despite their potential value. Eggshells, primarily composed of calcium carbonate, possess favorable properties that make them suitable for use in construction materials [4].

This research aims to address these dual concerns of urban water management and waste utilization by developing an innovative and eco-friendly paver brick, named AquaShell Paver, which integrates eggshell powder (ESP) and Super Absorbent Polymers (SAPs). SAPs are known for their exceptional water retention capabilities and have been widely used in environmental and agricultural applications, presenting promising prospects in sustainable building practices [5]. By combining ESP and SAP, this study explores their impact on compressive strength and curing behavior, while evaluating the environmental and structural performance of the resulting paver bricks.

The scope of the project includes the characterization of raw materials, optimization, and economic viability. The findings are expected to offer a sustainable alternative to conventional materials, reduce dependency on cement, promote the recycling of waste, and enhance urban resilence through improved stormwater management.

2. Methodology

The Aquashell Paver Brick is an innovative approach to sustainable construction materials, designed to address pressing issues such as water management, waste recycling, and the environmental impact of traditional building materials. The methodology behind the creation of the Aquashell Paver Brick combines two primary elements: super absorbent polymers (SAP) and eggshells, both of which bring unique properties to the material. The flowchart for the research study as shown in Fig. 1.

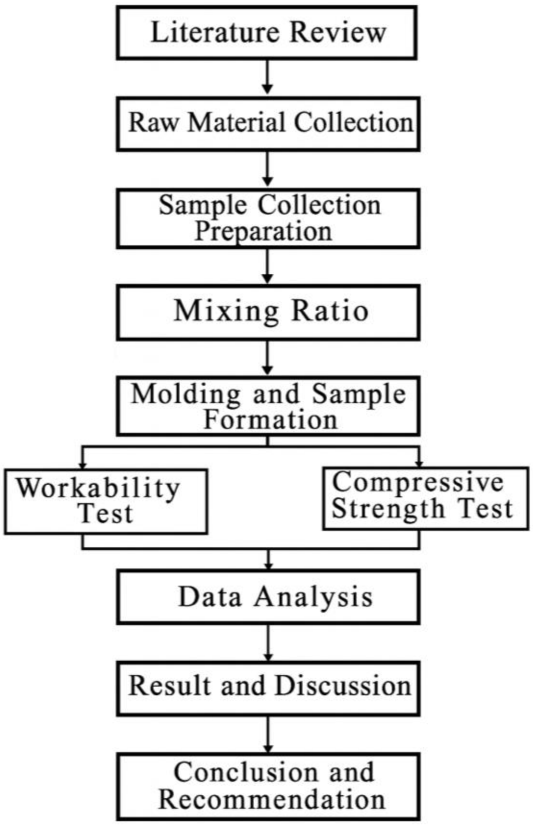

Fig. 1 *The flowchart for the study*

The process of producing paving bricks using Super Absorbent Polymer (SAP) and eggshells begins with the preparation of the eggshells. This involves collecting, cleaning, and drying the eggshells, followed by crushing and grinding them into fine powder. The next stage involves mixing the materials: cement, fine aggregate (sand), coarse aggregate (gravel), eggshell powder (at 10% of the cement's weight), and small amount of SAP (0.3% of the cement weight). After combining the dry materials, water is gradually added and adjusted to achieve the desired consistency. A concrete slump test is then performed to assess the mixture's workability. Once the target consistency is achieved, the mixture is poured into the prepared moulds, ensuring it is compacted thoroughly and evenly to eliminate any air voids. Table 1 represents the concrete mix design parameter with SAP and ESP additives.

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Table 1 *Concrete Mix Design Parameter with SAP and ESP Additives*

Item	Parameter Name	Variable Value	Dimension
Cement	Cement Content	1 part (base)	-
Fine Aggregate	Sand Ratio	2 parts	-
Coarse Aggregate	Gravel Ratio	4 parts	-
Water	Water-to-Cement Ratio	0.60	Ratio (w/c)
SAP	SAP Dosage (Additive)	0.3% of cement weight	Percentage (%)
ESP	ESP Dosage (Replacement)	10% of cement weight	Percentage (%)

2.1 Research Design

The research design employed in this study is an experimental framework aimed at systematically evaluating the influence of eggshell powder (ESP) and Super Absorbent Polymer (SAP) on the mechanical and durability properties of paving bricks. This design integrates controlled preparation of raw materials, precise formulation pf mix proportions, and standardized fabrication and curing procedures to ensure consistency and reproducibility of results. Specimens incorporating varying percentages of ESP and SAP were produced alongside control samples without additives. Comprehensive performance testing, including compressive strength, was conducted in accordance with MS EN 1338, the European and Malaysian standard that specifies requirements and test methods for concrete paving bricks. This standard ensures bricks are suitable for pedestrian and vehicular applications by requiring a characteristic compressive strength of at least 35 MPa. Data collection followed rigorous protocols, with statistical analysis applied to determine the significance of observed differences. The design also includes the implementation of appropriate curing methods to optimize the hydration process and mechanical performance of the modified bricks. This structured approach ensured robust, valid, and reliable findings pertinent to the development of sustainable paving materials.

2.2 Testing Method and Procedures

2.2.1 Slump test

The slump test was conducted to determine the workability and consistency of the fresh concrete mix. The apparatus used includes a standard slump cone and a flat base plate. The paver mixing was placed in the cone in three equal layers, each tamped 25 times with the rod. After filling, the cone was lifted vertically, and the slump height. The difference between the cone height and the top of the slumped concrete was measured in milimeters. Fig. 2 shows the slump test that has been conducted.

Fig. 2 *Slump Test*

2.2.2 Curing Tank Monitoring

The curing process was carried out using a standard curing tank filled with clean water at room temperature. All samples were fully submerged to ensure consistent hydration and proper cementitious reaction. The water level and temperature were monitored daily to maintain optimal curing conditions. Each sample casting date, curing duration, and any visible changes (such as surface cracks or discoloration) were recorded on a curing log sheet.

2.2.3 Compressive Strength Test

The compressive strength test was conducted to measure the load-bearing capacity of the AqualShell Paver Brick. The samples were cast into standard cube molds (100 mm x 200 mm x 60 mm) and cured for 7 and 28 days. After curing, each sample was tested using a Universal Testing Machine (UTM)

3. Result and Discussion

3.1 Compressive Strength Test at 7 Days and 28 Days

To assess the early strength development of the paving bricks, compressive strength tests were conducted on day 7. The 7-day compressive strength test results for paving bricks with SAP and ESP showed notable differences based on material composition. The control sample reached about 33.04 Mpa. Adding 0.3% SAP increased strength to around 37.85 Mpa, likely due to improved moisture retention. Replacing 10% cement with ESP slightly lowered strength to about 32.28 Mpa. However, when both 0.3% SAP and 10% ESP were used together with internal curing, the compressive strength dropped significantly to 11.59 Mpa. This drastic reduction may be due to the excessive internal moisture from SAP combined with the lower cement content from ESP replacement. In contrast, the combination of 0.3% SAP and 10% ESP with external curing showed better performance, yielding a compressive strength pf 29.85 Mpa. Although still lower than the control sample and single additive, this value indicates that external curing helped mitigate the strength loss.

To assess the long-term strength development of the paving bricks, compressive strength tests were conducted on 28 days. The results below reflect different mixtures including SAP and ESP variations, compared to the control sample. The 28-day compressive strength results demonstrated that the material composition and curing methods significantly affected the performance of paving bricks. The control sample reached 35.93 Mpa, serving as a benchmark. The 0.3% SAP mix recorded 34.88 Mpa, indicating effective moisture retention but minimal long term strength gain. In contrast, the 10% SAP mix achieved the highest strength at 36.66 Mpa, reflecting improved performance over time. The combination of 0.3% SAP and 10% ESP under internal curing showed the lowest strength at 18.30 Mpa due to excessive moisture and porosity. However, external curing of the same mix improved strength to 23.43 Mpa.

According to MS EN 1338, concrete paver bricks must reach a minimum compressive strength of 25Mpa at28 days. In this study, the control mix achieved 35.93 Mpa in 28 days, exceeding this requirement. The mix with 10% ESP increased from 32.28 Mpa at 7 days to 36.66 Mpa at 28 days, supporting previous findings that ESP helps improve strength over time. The 0.3% SAP mix showed the highest early strength at 37.85 Mpa but dropped slightly to 34.88 Mpa on 28 days. Despite this reduction, it still met the minimum strength. However, the combined 0.3% SAP and 10% ESP mixed with internal curing performed poorly, achieving only 18.30 Mpa in 28 days, which is well below the standard. This may be caused by delayed hydration and slower strength development. The 0.3% SAP and 10% initially dropped below the required strength for 28 days.

Although 10% ESP enhances long-term compressive strength, the combination of 0.3% SAP and 10% ESP under internal curing conditions resulted in a drastic reduction to 18.30 MPa in 28 days. This finding is consistent with prior research indicating that SAP may impair compressive strength due to increased porosity and water-release effects. Jensen & Hansen (2002) observed approximately 19% strength reduction in SAP-modified concrete, while Craeye et al. (2011) and Liu et al. (2020) reported compressive strength decrements ranging from 22% to over 27%, attributable to voids formed after water desorption by SAP.

The eggshell powder was oven-dried, crushed, and sieved to pass through a 0.075 mm sieve to achieve a fine and uniform particle size suitable for partial replacement of fine aggregate. This sieving process ensures that the eggshell powder meets the required fineness for effective mixing and bonding within the paving brick. Fig. 3 represents the compressive strength test at 7 Days and 28 Days.

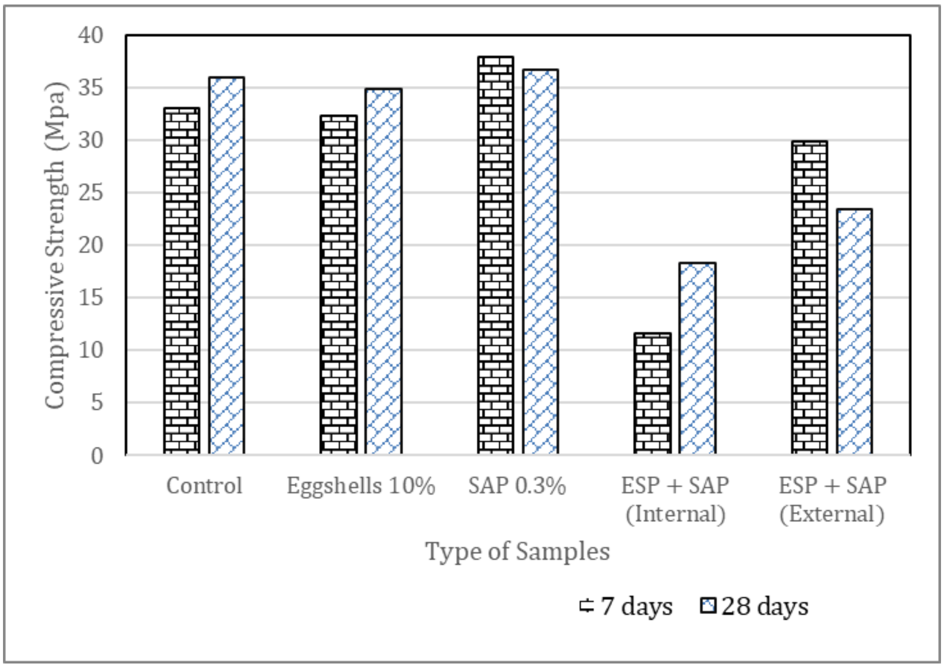

Fig. 3 *Compressive Strength Test at 7 Days and 28 Days*

4. Conclusion

The incorporation of finely ground eggshell powder (ESP) in concrete has demonstrated potential to enhance compressive strength at low to moderate replacement levels, particularly up to 15%. This improvement is attributed to the high calcium oxide content and fineness of ESP, which contributed to improved bonding and matrix densification. However, excessive replacement or coarse particle sizes may adversely affect strength. For Super Absorbent Polymer (SAPs), while they do not directly contribute to compressive strength, their role in mitigation shrinkage and enhancing curing indirectly supports strength development. Optimal dosages and particle characteristics of both ESP and SAPs are critical to achieving desired mechanical performance.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follow: ***study conception and design:*** *Author Dian, Author Aizatul;* ***data collection:*** *Author Dian, Author Aizatul, Author Amin;* ***analysis and interpretation of results:*** *Author Dian, Author Aizatul;* ***draft manuscript preparation:*** *Author Dian, Author Aizatul, Author Siti Nooraiin. All authors reviewed the results and approved the final version of the manuscript.*

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