Investigation of Physical and Mechanical Properties for Interlocking Paver Block from Foam Waste Binder

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Abstract

This study investigates the feasibility of producing interlocking paver blocks using a mixture of sand and dissolved foam binder at varying contents ranging from 10 to 50 wt%. The results indicate that paver blocks could be successfully formed without edge fractures when the foam binder content was within the range of 20 - 40 wt%. As the foam content increased, the samples exhibited improved densification, while porosity and water absorption significantly decreased due to the infiltration of foam into the micropores. Consequently, the compressive strength of the paver blocks improved with higher foam content, reaching a maximum at 40 wt% foam binder. These findings confirm that interlocking paver blocks produced with 20 - 40 wt% foam binder meet the required strength standards, demonstrating the potential of foam waste as an effective alternative binder in sustainable construction applications.

Keywords: Foam Binder; Paver Block; Waste; Environment

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Introduction

The increasing volume of waste aligns with the rapid population growth, presenting a critical environmental challenge that demands urgent attention (Ganivet, 2020). The escalating amount of waste arises from various factors, including consumption behaviors and inadequate waste separation at the source (Guven et al., 2023). Inefficient waste management practices have resulted in environmental pollution. Additionally, there exists a lack of sufficient knowledge and capability in reusing materials, further exacerbating environmental issues, such as the greenhouse effect caused by the incineration of waste and the consequent release of carbon dioxide (Mishra, 2024). These ongoing problems adversely affect the environment and living organisms, both terrestrial and aquatic. A significant portion of this waste consists of materials that are resistant to decomposition, with foam or plastic waste being a prominent example (Hollerova et al., 2021).

Foam is extensively utilized in contemporary society, especially as food packaging. Vendors selling ready-to-eat meals and various food products commonly use foam containers for their convenience and efficiency. On average, a Thai individual generates approximately 2.3 foam containers daily (Hu and Meng, 2024). Foam waste is recognized as a non-polar material, rendering it insoluble in polar solvents such as water. However, studies have indicated that foam can dissolve in non-polar solvents, including benzene, thinner, and alcohol, forming a viscous liquid that solidifies upon solvent evaporation (Lozano et al., 2025). This property suggests the potential use of dissolved foam as a binding agent for sand particles, resulting in a solid product post-evaporation. Exploring methods to repurpose foam waste represents a promising strategy for reducing waste volume and creating value-added products.

Interlocking pavers are widely used for both aesthetic and functional purposes, such as preventing water accumulation in residential areas. Conventionally, these pavers are manufactured using cement as the primary material, following stringent production standards and quality testing protocols (Sojobi et al., 2018). Interlocking pavers are available in various sizes and shapes, designed to meet specific standards of strength and durability. The diverse colors and forms facilitate different layout patterns, allowing for rapid construction and the option of relocation without the need for demolition (Chumprom et al., 2024; Palanikumar and Kumar, 2016). Color differentiation can also assist in defining boundaries and designating specific areas to prevent water pooling. Nevertheless, the cement industry significantly contributes to carbon dioxide emissions, a leading factor in global warming. Additionally, the transportation of cement and emissions from factory stacks generate particulate matter, which adversely impacts both communities and the environment. Consequently, reducing cement usage is imperative, necessitating the exploration of alternative solutions.

Addressing the dual issues of waste management and the reduction of cement consumption, this study proposes the production of interlocking pavers using foam waste as an alternative binder to cement. This approach aims to mitigate the volume of foam waste and decrease the reliance on cement in paver manufacturing. If the development of foam-based interlocking pavers fulfills the intended objectives, it could provide an effective means to curtail greenhouse gas emissions while addressing the persistent problem of non-biodegradable waste. The research involves blending fine sand with a dissolved foam solution to determine the optimal ratio that ensures adequate strength, durability, and lightweight properties. Additionally, this method seeks to add new value to foam waste, contributing to the creation of high-quality building materials. Moreover, this study presents a novel approach to foam waste disposal, potentially alleviating environmental concerns.

Research Methodology

1. Materials preparation

The foam solution (Figure 1) was prepared by dissolving foam in gasoline at a ratio of 30 wt%. Natural sand from the river with a specific gravity of 2.49 was applied in aggregate. Sand was transferred into a hot-air oven at 110 °C which all moisture in the aggregate is eliminated through oven drying until the aggregate attains a constant weight. The moisture content of dried sand was about 3.9 %. Figure 2 presents cumulative passing graph of sand particles that passes through a particular sieve size. The curve on the graph illustrates the distribution behaviour of sand particle sizes. A gradually sloping curve suggests a wider range of particle sizes (< 4 mm.).

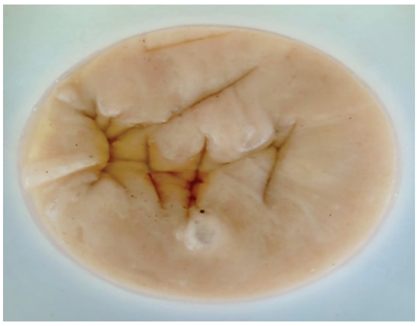


Figure 1 Mixed foam solution from 30 wt% foam waste in gasoline.

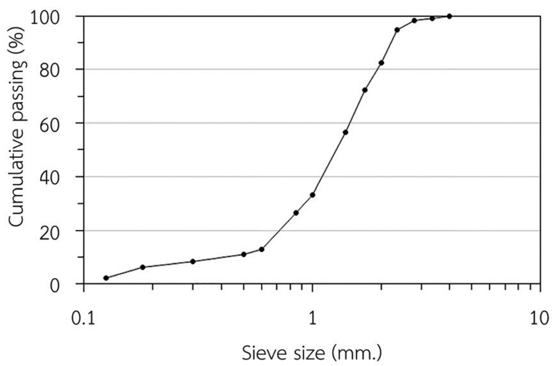


Figure 2 Cumulative passing of sand particle in sieve analysis.

2. Samples preparation and Testing method

Foam binder was prepared from mixed foam solid waste at 30 wt% in gasoline. Foam binder was then used as a bonding agent in the different ratio of 10, 20, 30, 40 and 50 wt% by mixed with sand. The mixtures were pressed in the cubic mold with the length of 5 cm. After molding, the workpieces are removed from the mold and left for 3 hours in a fume hood to eliminate gasoline in binder. Physical properties of the samples were measured by Archimedes method in accordance with ASTM C373-14a (ASTM C373-14a, 2014). This method was applied to determine the relationship between bulk density (D), porosity (P) and water absorption (W) by calculated from dry weight (M_D), wet weight (M_W) and submerged weight (M_S) as follows (Equation (1) - (3)):

$$D = \frac{(M_D)}{(M_W - M_S)} \quad (1)$$

$$P = \frac{(M_W - M_D)}{(M_W - M_S)} \times 100\% \quad (2)$$

$$W = \frac{M_W - M_D}{M_D} \times 100\% \quad (3)$$

Compressive strength refers to ability of the samples to withstand axial loads without failing when subjected to compression. It is defined as the maximum compressive stress that can bear before failure. It is important mechanical property, which ensure to support expected loads safely. It was tested using the methods specified in ASTM C140 (ASTM C773-88, 2011). All sample tests were repeated 10 times to ensure the accuracy of the results.

Results and Discussions

1. Forming samples

In this study, sand was mixed with a saluted foam binder in varying proportions ranging from 10 to 50 wt%, as illustrated in Figure 3. The effect of binder content on the cohesion and formability of the sand mixture was clearly observable across this range. At lower binder concentrations specifically 10 wt%, the adhesion between sand particles was noticeably weak (Figure 3(a)). This insufficient binding resulted in a loosely structured mixture with poor integrity, making it unsuitable for effective molding or shaping. As the foam binder content increased to within the range of 20 to 40 wt%, a significant improvement in particle cohesion was observed. The enhanced inter-particle bonding allowed the material to retain a well-defined cubic shape upon molding, as evidenced in Figure 3(b) through (d). This indicates that the foam binder at this concentration range successfully penetrated the interstitial spaces between sand grains, creating a stable internal matrix capable of maintaining form without collapse or cracking. However, when the foam binder concentration of 50 wt% (Figure 3(e)), the mixture became excessively fluid, leading to a slurry-like consistency. This over-saturation not only compromised the structural integrity of the molded specimen but also resulted in practical processing issues, such as poor demolding due to surface adhesion within the mold. The high moisture and binder content interfered with shape retention and significantly hindered sample removal. Given these observations, binder concentrations of 20, 30, and 40 wt% were identified as the most promising for further investigation. Samples within this optimal range exhibited desirable forming behavior, with successful molding outcomes and no evidence of crack formation. Consequently, these compositions were selected for subsequent testing to evaluate their physical and mechanical properties, including density, compressive strength, and durability, to determine their suitability for construction or material applications.

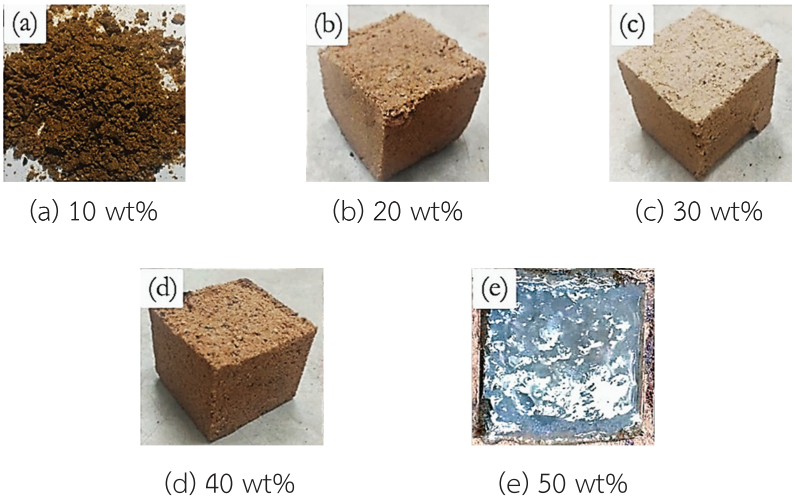
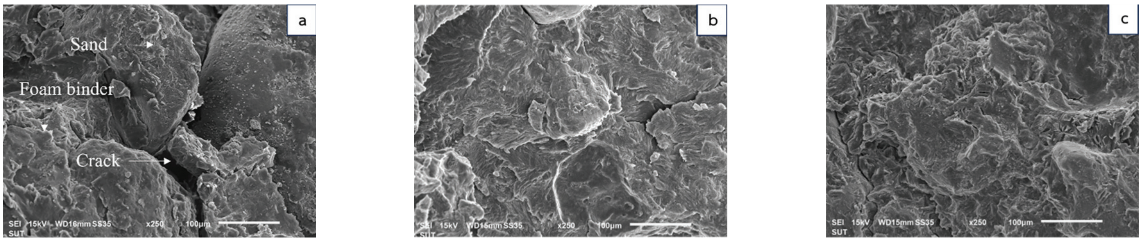


Figure 3 Interlocking pavers with a different foam binder.

2. **SEM analysis**

SEM micrographs presented in Figure 4 provide valuable insights into the microstructural development of paver block samples fabricated with varying foam binder contents, ranging from 20 to 40 wt%. These high-resolution images offer a deeper understanding of the interface characteristics and internal bonding behavior resulting from different binder concentrations. In the sample containing 20 wt% foam binder (Figure 4(a)), the microstructure reveals distinct micro-cracks and loosely packed sand particles. These cracks are primarily located at the inter-particle interfaces, suggesting that the foam binder was insufficient to form a continuous and cohesive matrix. The limited binder content failed to effectively bridge the sand particles, leading to poor particle adhesion and internal stress concentrations, which could compromise the material's mechanical integrity during handling or under loading conditions. In contrast, with an increase to 30 wt% foam binder content (Figure 4(b)), a marked improvement in microstructural cohesion is observed. The binder uniformly coats the sand grains and thoroughly infiltrates the interstitial voids between particles. This suggests a well-distributed foam network that enhances interparticle bonding and promotes densification, thereby minimizing the formation of micro-cracks and discontinuities. At a 40 wt% binder content (Figure 4(c)), the microstructure shows an even more robust and homogeneous distribution of the foam matrix throughout the sand framework. The foam binder not only permeates the particle interfaces but also appears to partially fill the micro-pores, contributing to a denser, more compact structure. The improved contact and cohesion at the microscopic level are expected to significantly enhance the material's mechanical properties, such as compressive strength and resistance to water infiltration, making this composition particularly suitable for structural and outdoor applications. These observations highlight the critical role of foam binder content in shaping the internal structure and performance of paver blocks. The progression from micro-cracked, under-bound structures to well-bonded, compact matrices demonstrates a clear correlation between binder dosage and material integrity at the micro level.



(a) 20 wt% (b) 30 wt% (c) 40 wt%

Figure 4 SEM microstructures of fracture surfaces of interlocking paver samples with a different foam binder.

3. **Physical property**

To understand the influence of foam binder content on the microstructure and physical integrity of paving block samples, a systematic investigation was conducted, focusing on key parameters of apparent density, porosity, and water absorption. These physical properties are critical in determining the mechanical performance and long-term durability of construction materials, particularly those derived from unconventional or recycled inputs. Figure 5 illustrates the variation in apparent density of samples containing different proportions of foam binder (ranging from 20 to 40 wt%). It was observed that the apparent density of the sample incorporating 20 wt% foam binder was approximately 1.41 g/cm^3. At this concentration, the binder initiates bonding among sand particles, contributing to a moderately compact structure. However, the extent of pore filling remains limited, and a significant proportion of interstitial voids persists. An increase in foam binder content to 30 wt% resulted in a notable improvement in densification, with the apparent density rising to 1.51 g/cm^3. This enhancement can be attributed to more effective inter-particle bonding facilitated by the foam matrix, which acts as a bridging medium between sand grains. The increase in density at this stage indicates more efficient packing and reduced internal porosity, suggesting that the foam solution aids in closing micropores and enhancing particle cohesion. Interestingly, at 40 wt% foam binder, the apparent density increased further to 1.68 g/cm^3. This result may appear counterintuitive at first, given the inherently low-density nature of foam; however, it implies that the binder extensively infiltrated and occupied the void spaces within the granular matrix. The penetration of foam at this concentration appears to contribute to a more homogenized microstructure, effectively reducing large air voids and distributing the binder uniformly across particle surfaces. Despite the increase in apparent density, it is important to consider that excessive binder content may lead to over-saturation and a loss of granular skeleton integrity, which, in some cases, can manifest as higher porosity in the solidified structure if not properly cured. Therefore, the relationship between foam content and densification is not merely linear but depends heavily on the microstructural balance between binder infiltration and aggregate skeleton preservation. These findings underscore the critical role of binder optimization in achieving the desired performance characteristics in foam-based construction composites. The observed trends suggest that a binder concentration of approximately 30 wt% may offer an optimal balance between density enhancement and structural stability, while higher concentrations should be evaluated cautiously due to potential changes in pore architecture and mechanical behavior.

Figure 6 presents the apparent porosity values measured in the interlocking paver specimens, providing insight into the microstructural evolution resulting from varying foam binder contents. The observed porosity levels were directly linked to the presence of open pore defects within the matrix. These defects are indicative of incomplete particle packing and insufficient binder infiltration. Both are key determinants of the degree of densification in the composite system. The reduction in apparent porosity with increasing foam binder content can be primarily attributed to the enhanced infiltration capability of the liquid foam. The foam binder effectively penetrates the interstitial voids between sand particles, forming a continuous matrix that bridges and seals the open pore structures. As the foam content increases, it more thoroughly coats the sand grain surfaces and fills micropores, resulting in a more compact and cohesive matrix. This microstructural refinement minimizes unfilled spaces and significantly reduces the occurrence of open pores, thereby promoting improved densification.

Water absorption measurements, also shown in Figure 7, provide complementary evidence regarding the permeability and internal structure of the samples. The ability of water to penetrate the material is directly influenced by pore volume, pore interconnectivity, and surface adhesion characteristics. It was observed that water absorption consistently decreased as the foam binder content increased, further validating the role of the foam solution in reducing porosity and enhancing structural integrity. This trend was visually corroborated by the internal surface analysis in Figure 7, which displayed a notable reduction in visible voids commonly referred to as air pockets in specimens with higher foam content. As the foam solution infiltrated the granular matrix, it effectively displaced entrapped air and filled void regions, thereby limiting the ingress pathways for water. The depletion of these voids through foam infiltration not only reduced water absorption but also contributed to the overall mechanical stability and moisture resistance of the hardened paver blocks. Moreover, the enhanced adhesion between sand particles, facilitated by the foam binder, further restricted water movement through the matrix by eliminating capillary channels and increasing surface contact among the grains. This synergistic effect of pore sealing and particle bonding demonstrates that foam binder content is a key variable in tailoring both porosity and water resistance in composite paving systems.

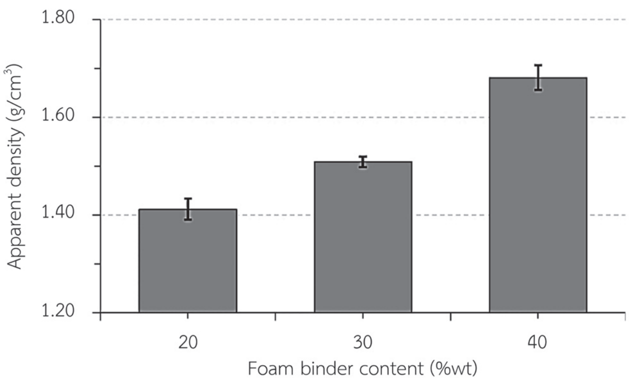


Figure 5 Densification of the interlocking pavers with different foam binder contents.

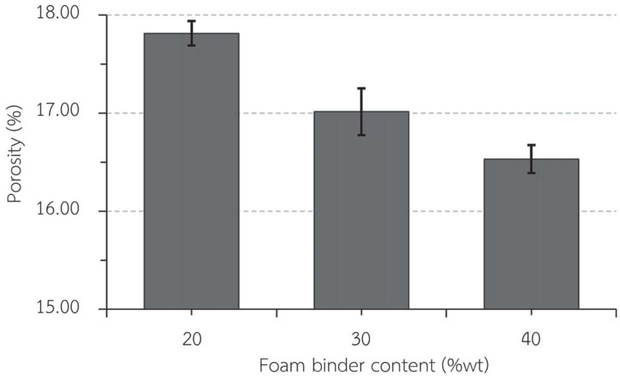


Figure 6 Porosity of the interlocking pavers with different foam binder contents.

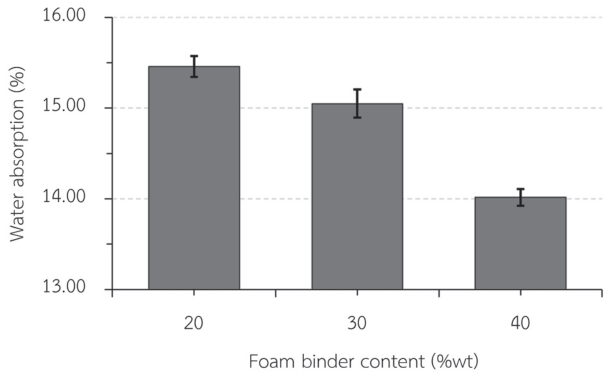


Figure 7 Water absorption of the interlocking pavers with different foam binder contents.

Compressive strength is a critical mechanical property used to evaluate the ability of interlocking paver blocks to resist compressive forces without failure. As these blocks are frequently employed in pavement and structural applications, where they are subjected to both static and dynamic loading conditions of compressive strength serves as a key indicator of their overall quality, durability, and structural suitability. Figure 8 illustrates the compressive strength of interlocking blocks fabricated with varying foam binder contents, ranging from 20 wt% to 40 wt%. The results demonstrate a clear correlation between binder content and the mechanical performance of the composite system. At 20 wt% foam binder, the blocks exhibited a compressive strength of approximately 23.68 MPa, which already exceeds the standard minimum threshold of 20 MPa commonly required for load-bearing paver applications (Oluwarotimi et al., 2021). As the foam binder content increased beyond 30 wt%, a progressive enhancement in compressive strength was observed. This improvement can be attributed to increased matrix densification and enhanced microstructural cohesion resulting from more effective binder distribution. The foam binder, acting as both a filling agent and an adhesive, promotes stronger interfacial bonding between sand particles, reduces internal porosity, and improves load-transfer efficiency throughout the granular skeleton. These factors collectively contribute to improved mechanical integrity and higher load-bearing capacity. The highest compressive strength was recorded in the samples containing 40 wt% foam binder, suggesting that this concentration may represent an optimal balance between particle packing and matrix continuity. This composition likely facilitated maximum particle encapsulation and void reduction, resulting in a reinforced and uniform structure capable of withstanding higher compressive loads without microcracking or brittle failure. It is important to note, however, that while increasing foam content can enhance strength up to a point, excessive binder may lead to diminishing returns due to over-saturation and a potential reduction in rigidity. Nevertheless, within the investigated range of 20 - 40 wt%, all samples maintained compressive strength values above the standard engineering requirement, confirming their structural viability for practical use in interlocking paver applications. In summary, the findings confirm that foam binder content is a decisive factor in optimizing the compressive performance of interlocking pavers. The behavior observed in this study highlights the synergistic relationship between binder-induced densification and microstructural integrity. These results support the use of optimized foam-binder formulations as a sustainable, high-performance alternative for the production of eco-friendly and structurally reliable paving blocks. The findings from this study suggest that the approach can be applied at the community level through the implementation of planned waste separation systems and the establishment of community groups to produce low-cost and environmentally friendly products.

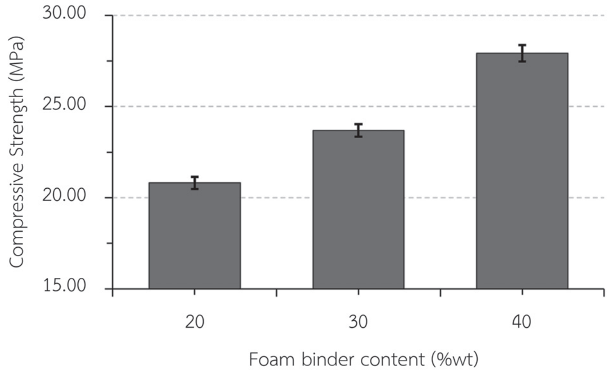


Figure 8 Compressive strength of the interlocking pavers with different foam binder contents.

Conclusions

In this study, interlocking paver blocks were fabricated using mixtures of sand and dissolved foam binder at varying proportions from 10 to 50 wt%. The experimental results showed that paver blocks could be molded successfully without edge fractures when the foam binder content ranged between 20 - 40 wt%. As the foam content increased, the samples demonstrated improved densification, accompanied by a significant reduction in porosity and water absorption. This improvement is attributed to the foam effectively filling the micropores within the matrix. Furthermore, compressive strength values increased with higher foam content, reaching the maximum strength at 40 wt% binder. Notably, paver blocks produced with 20 - 40 wt% foam binder met the standard requirements for structural performance, confirming the potential of foam waste as a viable alternative binder to cement in the production of sustainable interlocking pavers.

Acknowledgements

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