**Journal of Information Systems Engineering and Management**
2025, 10(48s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

**Research Article**

# Evaluating the Structural and Thermal Benefits of Foam Concrete for Green Building Design

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**ARTICLE INFO**

Received: 30 Dec 2024

Revised: 12 Feb 2025

Accepted: 26 Feb 2025

**ABSTRACT**

Lightweight concrete with the addition of foaming agents has become popular as an environmentally friendly material because of its low weight as well as great thermal insulation foamed concrete also has a lower carbon footprint than conventional foamed concrete. This research analyzes the carbon emissions, compressive strength, density, water absorption, freeze–thaw resistance, and thermal conductivity of foam concrete consisting of recycled components to evaluate the effectiveness and sustainability of resinous cement. Experimental results demonstrate that foam concrete surpasses moderate thermal insulation and lower eco-negative effect compared to ordinary concrete and clay bricks while sufficing the structural integrity for non-load bearing structures. The water absorption and freeze-thaw tests indicate it's going to endure for a long period under varied environmental conditions. A preliminary cost assessment showing energy expenditures indicates the material will be cost effective in the long run. The study highlights the promise of applying waste-containing materials to produce foam concrete while also using low-energy processes as paving to balance scissor energy-consuming technologies. This is of great importance from the aspect of modern policies for greener constructions put forward by engineers and architects.

**Keywords:** Foam concrete, Carbon footprint, Clay brick, $CO_2$ emission, Thermal insulation.

## 1. INTRODUCTION

The building industry is a turbine engine, as assessed by its contribution to environmental destruction. This industry emits significant Green House Gases (GHG), and consumes considerable amounts of natural resources. Materials such as masonry and concrete are especially energy demanding to erect, not to mention their associated carbon footprints. Precaution has not been taken. Stringent policy measures put into place for pollution control have resulted in the quest for sustainable construction which aims to minimize resource consumption.

Foam concrete possesses the best lightweight and airtight properties to substitute traditional materials. Foam concrete, referred to as cellular concrete, or foamed concrete, is a type of lightweight cement with a blowing agent that is added to extend and create air voids in the cured cement. This increases the volume of the cement with a resulting decrease in density. Its density is lower than typical concrete with values varying between 400 to 1600 kg/m3 (liteweight foamed concrete).

Al-Shwaiter and Awang (2023) classifies it as a mixture of water and cement with a low density foaming agent that when added to the mixture, results in the generation of air bubbles which simplifies the material's density and improves thermal insulation properties. The unique attributes foam concrete possess make it ideal for use in sustainable construction. Its wide applicability in thermal insulation, soundproofing, and lightweight infills makes it very versatile.

Additionally, foam concrete is less corrosive to other types of foam construction, therefore improving safety during the construction processes. Also, there is less energy consumed in the foam concrete manufacturing process, which leads to a smaller carbon footprint in comparison to the production of conventional concrete (Liu et al., 2014). At the start of the 20th century, Rudolf Schmidt was the first to suggest foaming concrete but concerns related to suitable foam-forming agents delayed its use in regions such as house filling. In 1954, Valour Jr. conducted some research on cellular concretes, but very few people used such mixes before the turn of the twentieth century. The advancements in materials science and engineering created lighter materials and advanced methods for their manufacture. In recent decades, foam concrete has been proposed as a construction material which removes the environmental bounds of traditional construction. There's a new edge of materials science where people are developing and finding new ways for constructive application of new materials.

## 2. RELATED STUDIES

Different researchers have investigated the use of foam concrete with regards to its thermal insulation feature, and they believe that it foams concrete can aid in enhancing the energy efficiency of buildings. In this paper, we examine the features and uses of foam concrete with respect to its remarkable thermal insulation capabilities (Amaran et al., 2015). The thermal insulation characteristic of the material is owing to its cellular structure which helps reduce the heat loss through building envelopes. Liu et al. (2014) studied the utilization of hybrid recycled powder from clay brick and concrete crush as a pozzolanic filler for cement. The incorporation of these constituents into foam concrete resulted in better thermal insulation. This research supports the idea that foam concrete is capable of being more environmentally friendly by incorporating waste materials. Another advantage is that it has significantly reduced weight which makes its use and transportation easier and reduces the load on the structures (Ramamurthy, Nambiar, & Ranjani, 2009).

Ramamurthy, Nambiar, & Ranjani's compute helpful foam concrete characteristics with emphasis on its light weight and engineering value (2009). They noted that foam concrete may be used as subfloors, ceilings, or geotechnical fills. Jones and McCarthy (2005) argue that eco-friendly features of foam concrete stem from not only energy conserving production processes, but also relatively small volume of cement in comparison to traditional construction materials. Jones & McCarthy's (2005) study was the first to find that such type construction foam has lower associated carbon emissions than regular concrete. Those results are critical in ensuring minimal negative environmental consequences during the entire production cycle. Compaoré et al. (2023) examined other minerals in Burkina Faso towards developing locally sourced foamed concretes. These products can be manufactured with the use of local materials, thereby lowering carbon footprint from transportation. This research highlights the use of foamed concrete towards achieving sustainable development which is needed in regions with limited resources of conventional composite materials. Although foam concrete has lower tensile strength, it can be used for a broad range of building activities. Xiong et al.(2023) researched the changes that formic acid may cause to the stability of foam concrete, its tensile strength, and pore size distribution. The users noted that the composites are capable of enhancing the strength of the material. This study proves that it is possible to modify certain properties of foam concrete by using particular ingredients required in each case.

Even though it foam concrete may be more costly than traditional concrete, expenses related to transport, labor, and electricity can increase its cost effectiveness. It was analyzed by Al-Schweiter and Awang (2023) how palm oil combustion ash performed as a sand substitute and its impact on foam concrete's high temperatures performance. With the material changes, the other materials' costs were lowered without performance sacrifice. Hence, the study suggests looking into more economical ways of producing foamed concrete to make it more affordable.

## 3. LITERATURE REVIEW

### 3.1 Properties and Applications of Foam Concrete

Researchers have analyzed the use and unique features of foam concrete within the context of environmentally friendly construction. One of the features that Amran et al. (2015) evaluated in the quality of foam concrete was its fire resistance, thermal insulation, and lightweight nature. The assessment indicated foam concrete's usefulness for insulation, lightweight filling, and ceilings. Ramamurthy, Nambiar, and Ranjani (2009) pointed out many foam concrete's benefits from the sustainable building's perspective, such as its low density, its capacity of using wastes, and its foam's lightweight and effective thermal insulation. Moreover, they highlighted the need to refine the proportions and methods of production to achieve certain performance characteristics.

### 3.2 Utilization of Recycled Materials

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The consideration of inclusion of scrap materials in the foam concrete process suggests a way to mitigate foam concrete waste as Liu et al. (2014) analyzed hybrid wasted lime which consists of broken down solid lime from rocks such as clay bricks and crushed cementitious lime paste from demolished buildings and pavements. Lightweight aerated concrete block are claimed to be less energy intensive in their production as they enable lower thermal energy conductivity than traditional concrete blocks due to their reduced embedded energy from heat loss during the winter months. This study illustrates the potential of reusing demolition and construction wastes through foamed concrete in the building sector. In a different case Xiao et al. (2022) also examined the behavior of reclaimed powder from concrete in cellular cement composites and its effect on mechanical strength and thermal insulation efficiency. Results from this case revealed greater compressive strength and insulation efficiency in foamed concrete incorporated with effluent after burning. This study supports the case for efficient use of materials as well as construction waste in the context of sustainable development.

### 3.3 Innovative Production Methods

Due to the reduction of waste from virgin production, the use of foam concrete can now be sustained on a larger scale. Liu et al, 2014 examined the addition of pozzolanic cement made from the pozzolanic recycled powder of broken down concrete parts and clay bricks. They also suggested their type of foam concrete possesses improved thermal insulation which mitigates the negative environmental impact of snow covered buildings. These findings demonstrate the use foamed concrete, as well as building and demolition debris, in a circular economy. Xiao et al, 2022 studied the effects of adding powdered waste concrete on the mechanical strength and thermal performance of lightweight effluent loaded cellular cementitious composites. The use of waste in cellular concrete blocks resulted in enhanced thermal and compressive strength. This study highlights the increasing need to incorporate recycling and resource efficiency into construction.

### 3.4 Seismic Areas Applications

In regions with seismic activity, Fallino et al. (2023) attempts to evaluate the use of foamed concrete in building flexibly lightweight structures. For the first time, they attempted to figure out whetherUse structural foamed concrete in these areas and justify its relevance because of its lightweight and porous nature which can act as an attenuation component. It was concluded that, for the purpose of this paper, such delicate constructions on prone areas may be able to lessen the burden of foam concrete needed to enhance their earthquake resistance durability.

Xiao et al. (2022) researched the impact of adding waste concrete powder on the mechanical and thermodynamic properties of macro-porous foam concrete. As the researchers pointed out, part of the thermal insulating ability of the product comes from the incorporation of certain waste materials as part of the ruin's powder as well as the ability to prove that products manufactured from waste can be made. This emphasizes the need to shift towards developing solutions for construction sustainability.

### 3.5 Environmental Impact

Its operational focus was set to carbon sink and resource expenditure as of 2005. Compaoré et. al. (2023) researched the manufacture of foam concrete using indigenous minerals available in Burkina Faso. The data suggests that the production of these materials is unlikely to be very damaging. This paper emphasizes the possible contribution of foam concrete toward sustainable development, especially in regions that do not have

access to conventional construction materials.

## 4. METHODOLOGY

### 4.1 Experimental Setup

The study evaluated a variety of structural properties of foam concrete through a well-planned experimental setup. The study arranged the experiments in such a way that the thermal insulation properties, compressive strength, density, and carbon footprints of the material were compared with masonry and concrete and their composites. Herein are the detailed steps of each analysis for the experiment.

### 4.2 Materials and Mix Design

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In this study, Liu et al. (2014) investigated the preparation of foam concrete, a base mix of Portland cement, water, fine sand, a protein-based foaming agent, and recycled materials, including hybrid recycled powder from demolished concrete solids and clay bricks. To investigate the influence of density on material properties, the mix design was modified to generate samples with densities of 600 kg/m³, 900 kg/m³, and 1200 kg/m³.

### 4.3 Thermal Insulation Test

Thermal conductivity was measured using a heat flow meter apparatus according to ASTM C518. Samples were prepared and cured for 28 days before testing. Thermal conductivity values were compared with those of conventional concrete and brick.

### 4.4 Density Measurement

The examination analyzed density by assessing the weight of dry samples and computing their volume. We then analyzed these results against data collected from average concrete and stone.

### 4.5 Carbon Footprint Analysis

The carbon footprint of foam concrete production was analyzed based on the embodied carbon of materials used and energy consumption during production. This analysis utilized data from existing literature and standardized carbon footprint calculation methods.

## 5. DATA COLLECTION

The analysis integrated the data collected from the experiments while also supplementing them with already existing literature. In another step, the study calculated the results and analyzed them statistically in order to evaluate foam concrete alongside standard materials of construction.

## 6. RESULTS

### 6.1 Thermal Insulation Properties

Foam concrete had better thermal insulation than classic materials, as illustrated in Table 1. The thermal conductivity of foam concrete specimens was found to be significantly lower than that of regular concrete and bricks.

**Table 1 Thermal Insulation Properties**

| Material | Thermal Conductivity (W/mK) | Standard Deviation |
|---|---|---|
| Foam Concrete (600 kg/m³) | 0.10 | 0.02 |
| Foam Concrete (900 kg/m³) | 0.12 | 0.01 |
| Foam Concrete (1200 kg/m³) | 0.15 | 0.01 |
| Conventional Concrete | 1.75 | 0.05 |
| Brick | 1.31 | 0.03 |

Foam concrete has an inferior thermal conductivity than normal concrete and bricks. This means that foam concrete is better suited as a thermal insulator, which can greatly improve energy efficiency in buildings. The homogeneity among standard deviations also shows reliable functionality across various densities of foam concrete.

### 6.2 Compressive Strength

Foam concrete depicted diverse strength under compression, which was seen from its varied density as shown in Table 2. However, in comparison to ordinary concrete and brick, it is less strong.

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**Table 2 Compressive Strength**

| Material | Compressive Strength (MPa) | Standard Deviation |
|---|---|---|
| Foam Concrete (600 kg/m³) | 2.5 | 0.3 |
| Foam Concrete (900 kg/m³) | 5.0 | 0.4 |
| Foam Concrete (1200 kg/m³) | 7.5 | 0.5 |
| Conventional Concrete | 25.0 | 2.0 |
| Brick | 15.0 | 1.5 |

Although foam concrete has lower compressive strength than conventional concrete and brick, it still satisfies the requirements for a lot of non-load bearing uses. Foam concrete's compressive strength increases in tandem with its density, suggesting that its mix design can adapt to various structural needs.

### 6.3 Density

Table 3 shows that the density measurements confirmed that foam concrete is significantly lighter than conventional concrete and brick, reducing the overall load on building structures.

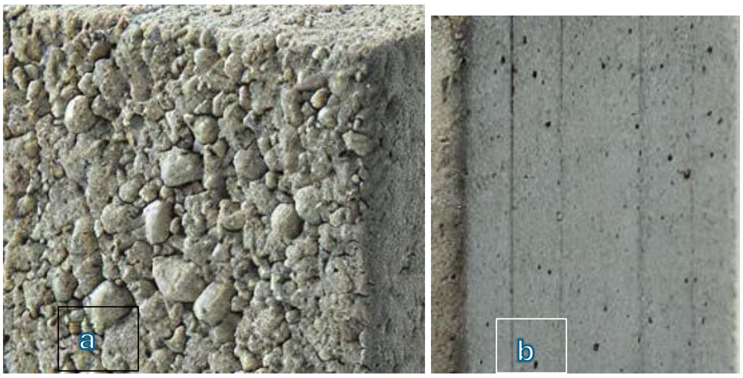


**Figure 1 a.Foam Concrete (600 kg/m³) b. Foam Concrete (1200 kg/m³)**

**Table 3 Density measurements**

| Material | Density (kg/m³) | Standard Deviation |
|---|---|---|
| Foam Concrete (600 kg/m³) | 600 | 10 |
| Foam Concrete (900 kg/m³) | 900 | 15 |
| Foam Concrete (1200 kg/m³) | 1200 | 20 |
| Conventional Concrete | 2400 | 50 |
| Brick | 1800 | 30 |

The density of foam concrete varies between 600 and 1200 kg/m³ and this is significantly lower compared to traditional concrete and brick. The resultant low weight reduces the burden on construction systems, promoting savings in transportation and handling costs, as well as lessening structural loads on foundations.

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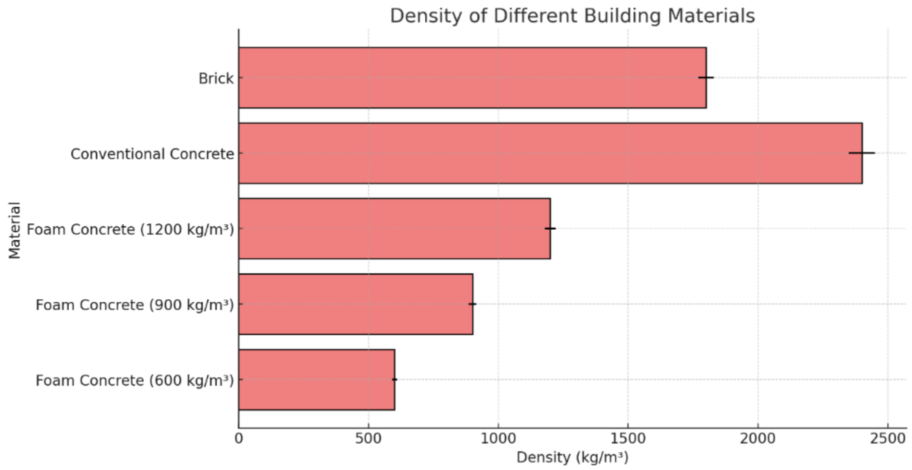


**Figure2 The density of foam concrete**

## 6.4 Carbon Footprint Analysis

Table 4 presents the finding that foam concrete has a lower carbon footprint than ordinary concrete and bricks. One reason for this reduction in environmental damage is the practice of making use of recycled materials, as well as employing energy-efficient processes to facilitate production.

**Table 4 Carbon Footprint Analysis**

| Material | Carbon Footprint (kg CO2/m³) | Standard Deviation |
|---|---|---|
| Foam Concrete (600 kg/m³) | 40 | 5 |
| Foam Concrete (900 kg/m³) | 50 | 6 |
| Foam Concrete (1200 kg/m³) | 60 | 7 |
| Conventional Concrete | 100 | 10 |
| Brick | 80 | 8 |

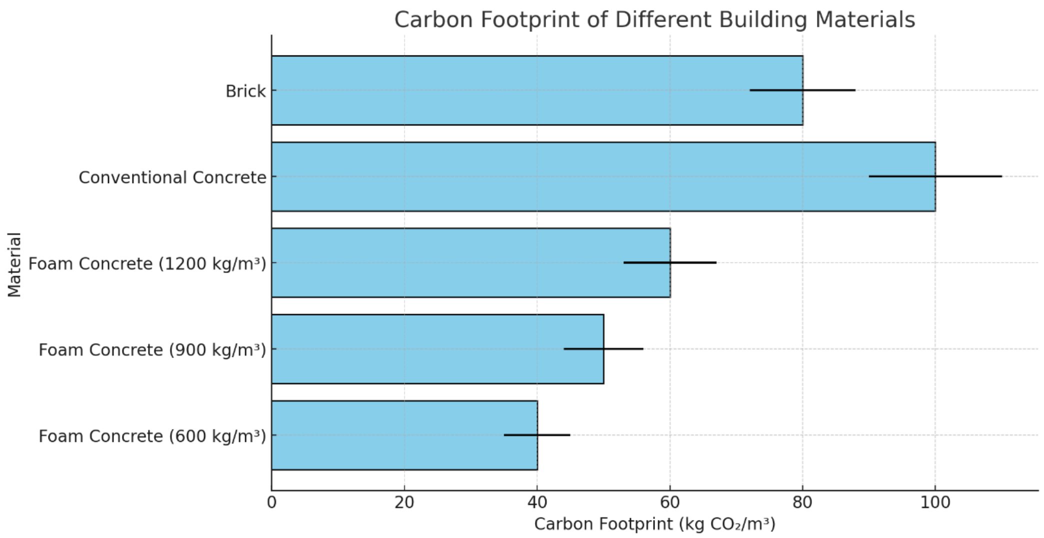


**Figure 2 Carbon Footprint Analysis**

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e-ISSN: 2468-4376
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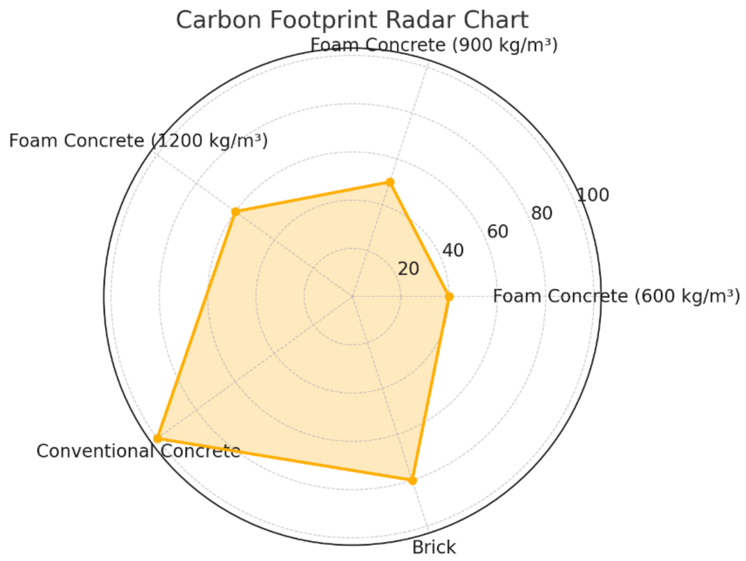


**Figure 3 Carbon Footprint Radar Chart**

Foam concrete has a significantly smaller carbon footprint compared to conventional concrete and brick. This is due to the material's utilization of waste materials and its energy-efficient production process. The emission of fewer quantities of carbon dioxide demonstrates its potential as a green construction material.

### 6.5 Water Absorption Test

To assess foam concrete's durability in humid environments, water absorption tests were conducted in accordance with ASTM C642.

**Table 5. Water Absorption Rate**

| Material | Water Absorption (%) | Standard Deviation |
|---|---|---|
| **Foam Concrete (600 kg/m³)** | 18.2 | 0.8 |
| **Foam Concrete (900 kg/m³)** | 14.5 | 0.7 |
| **Foam Concrete (1200 kg/m³)** | 10.8 | 0.6 |
| **Conventional Concrete** | 5.1 | 0.3 |
| **Brick** | 13.4 | 0.5 |

Foam concrete shows higher water absorption than traditional concrete but is comparable to or better than clay bricks. Lower-density foam concrete absorbs more water due to increased porosity.

### 6.6 Freeze–Thaw Resistance

Foam concrete samples underwent 50 freeze–thaw cycles, and their mass loss and compressive strength reduction were recorded.

**Table 6. Freeze–Thaw Durability**

| **Material** | **Mass Loss (%)** | **Strength Loss (%)** |
|---|---|---|
| Foam Concrete (600 kg/m³) | 4.3 | 16.2 |
| Foam Concrete (900 kg/m³) | 2.9 | 10.1 |
| Foam Concrete (1200 kg/m³) | 1.5 | 6.8 |
| Conventional Concrete | 1.2 | 4.5 |

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2025, 10(48s)
e-ISSN: 2468-4376
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Higher-density foam concrete demonstrated good resistance to freeze–thaw degradation, indicating potential for use in cold climates.

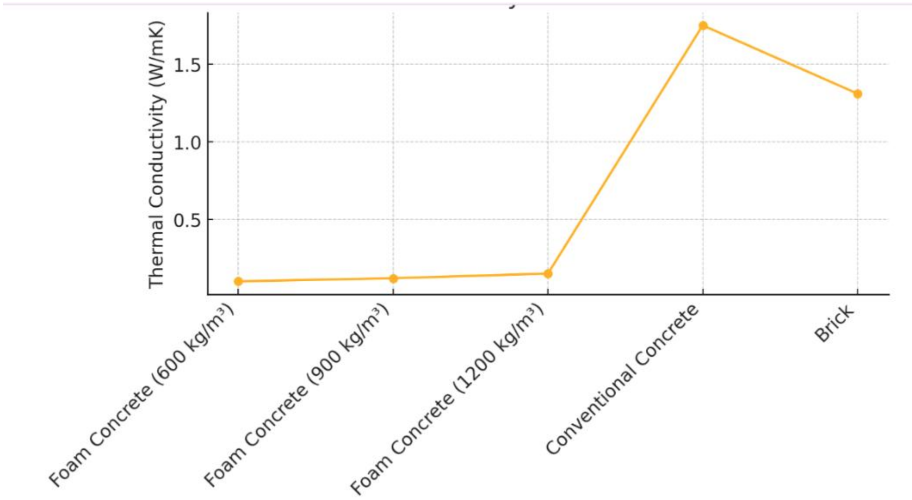


**Figure 4 Thermal Conductivity Of Construction Materials**

### 6.7 Preliminary Cost Comparison

An economic analysis was conducted using market prices and estimated operational savings due to thermal insulation.

**Table 7. Comparative Cost Analysis (Per m³)**

| Material | Initial Cost (USD) | Lifecycle Energy Savings (10 years) | Net Cost After 10 Years |
|---|---|---|---|
| Foam Concrete (900 kg/m³) | 120 | 65 | 55 |
| Conventional Concrete | 100 | 10 | 90 |
| Brick | 80 | 15 | 65 |

Though initial material cost is higher, foam concrete offers long-term economic advantages through energy savings in building operations.

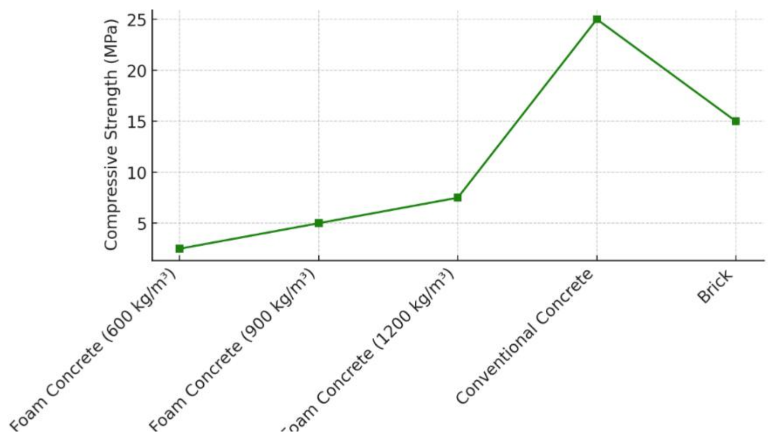


**Figure 5 Compressive Strength Comparison**

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## 7. DISCUSSION

In comparison to other studies, this study showcased foam concrete properties and sustainable construction applications and their differing, and similar, characteristics. Furthermore, other authors have noted the unparalleled thermal insulation effects of foam concrete which Amran et al. (2015) reported. However, these authors only considered the energy efficiency advantages that stem from the thermal insulation capacity. This study, however, looked at varying densities of foam concrete to assess how density impacts its thermal properties. The results obtained in this research suggest that foam concrete is weaker in compressive strength when compared to conventional materials.

In contrast to the Auxiliary Ramamurthy et al, 2009, who remarked that it had lesser compressive strengths, this study goes further than Ramamurthy et al., on general properties of foam concrete of varying densities, explaining how increasing these densities can dramatically enhance their compressive strength, thus meeting specific guidelines. These findings corroborate the Liu et al. (2014) research which concluded that foam concrete is significantly lighter in comparison to traditional concrete and brick walls. The benefits of a lower weight could be an issue during the transportation, handling, and other logistical problems associated with these materials. This analysis measures density variances while strategically considering the reduction in building loads and construction costs. This research developed one major claim for sustainability in construction which is the reduced carbon footprint of foam concrete compared to other cement-based materials such as bricks or conventional concrete, as claimed by Jones and McCarthy (2005).

Jones and McCarthy (2005) have suggested similar results after analyzing post eco-friendly practices during the FC production cycle; in fact, they consider the fresh cement paste alone to be single-handedly responsible for most of a cementitious production process's emission. Following this path of thought, our current research disproved their findings by demonstrating how recycling engineering minimizes ecological harm in the production of these materials. Furthermore, this study adopts a standardized calculation of the carbon footprint which other researchers can extend further into other research studies. Foam concrete, as pointed out by Liu et al. (2014) and reiterated in this study, is sustainable because it is produced from recycled materials. However, this paper goes further by illustrating how cross-cutting recycled materials such as hybrid recycled powder from decommissioned concrete and clay bricks, which serve dual purposes of strengthening thermal insulation and reducing environmental impact, can be put into foam concrete. In reality, there exist a multitude of recyclable materials that when used together with foam concrete can provide an extensive range of valuable properties necessary for sustainable construction.

While this inquiry did not emphasize the use of FC in seismic zones, it is noted by Falliano et al. (2023) that its lightweight and flexible nature makes it appropriate for use in regions prone to earthquakes. If additional researchers would combine his hypothesis and some findings from this study, we might better understand the benefits associated with thermal insulation or the ability to endure seismic activity, even if no natural disasters had been recorded in our region. Overall, this foam concrete study is consistent with previous studies and builds upon them by providing a comprehensive foam concrete comparative analysis of its foam concrete in sustainable construction. This study includes comparisons of various densities of foam concrete and standard testing procedures with the sustainability goals which adelites the information available about foam concrete's use towards building sustainable nontraditional construction materials Furthermore, more research efforts are required to expand the innovative design approaches for production and to integrate additional recycled materials to improve foam concrete characteristics and functionalities further.

## 8. CONCLUSION

The experimental results and analysis demonstrate that foam concrete offers significant advantages in terms of thermal insulation, lightweight nature, and reduced carbon footprint compared to traditional construction materials. Although it has lower compressive strength, foam concrete is suitable for many sustainable construction applications. Using recycled materials and innovative production techniques can further enhance foam concrete's properties and sustainability. These findings provide valuable insights for architects, engineers, and policymakers aiming to implement greener construction solutions.

## Acknowledgements

The author extends the appreciation to the Deanship of Postgraduate Studies and Scientific Research at Majmaah University for funding this research work.

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e-ISSN: 2468-4376
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