

ECO-FRIENDLY FOAM CONCRETE USING VULCANIZED TIRE WASTE AND RICE HUSK ASH: A CONTRIBUTION TO SUSTAINABLE CONSTRUCTION IN THE SPIRIT OF ISLAMIC ENVIRONMENTAL STEWARDSHIP

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Abstract: *In line with sustainable construction practices and the Islamic principle of environmental stewardship (khalifah fil ardh), this study investigates the use of rice husk ash (RHA) and vulcanized tire waste (VTW) in foam concrete production. By partially replacing cement with RHA (0%, 5%, 10%) and sand with VTW (0%, 10%, 20%), the research aims to reduce environmental waste while contributing to eco-friendly building solutions. A total of 54 cube specimens (10 × 10 × 10 cm) were prepared using sand-cement ratios of 1:2 and water-cement ratios of 0.35 and 0.45. Compressive strength was tested at 28 days. Results indicated the highest strength (12.26 MPa) in the control mix at a 0.35 water-cement ratio, while the lowest (2.12 MPa) occurred with 20% VTW and 10% RHA at a 0.45 ratio. Although the mechanical properties decreased with higher waste content, the study underscores the environmental value and potential of integrating industrial and agricultural waste into concrete, supporting the pursuit of sustainable development inspired by Islamic environmental ethics.*

Keywords: *Foam-Concrete, Vulcanized, Waste Tire, RHA, Sustainable*

Introduction

The construction industry is a significant contributor to global environmental degradation, accounting for approximately 40% of energy consumption and 30% of greenhouse gas emissions worldwide (Siddika et al., 2019). In response to this challenge, sustainable construction practices have gained prominence, emphasizing the use of eco-friendly materials to reduce environmental impact. One promising approach is the incorporation of industrial and agricultural waste into construction materials, such as foam concrete, which offers both structural and environmental benefits (Y. H. M. Amran, Farzadnia, & Abang Ali, 2015).

Foam concrete, a lightweight material characterized by its porous structure, is increasingly recognized for its thermal insulation properties and reduced carbon footprint (Ramamurthy, Kunhanandan Nambiar, & Indu Siva Ranjani, 2009). However, the production of conventional foam concrete still relies heavily on non-renewable resources, necessitating innovative alternatives. This study explores the use of vulcanized tire waste (VTW) and rice husk ash (RHA) as partial replacements for sand and cement, respectively, in foam concrete. VTW, a non-biodegradable material, poses significant disposal challenges, with over 2.9 billion tires

discarded annually worldwide (Siddika et al., 2019). Similarly, RHA, a byproduct of rice milling, is often underutilized despite its pozzolanic properties (Riza, 2011; Riza, Hadipramana, & Rahman, 2022; Riza, Hadipramana, Rahman, & Faisal, 2021), which can enhance concrete performance (Al-Alwan et al., 2024; Siddika, Mamun, Alyousef, & Mohammadhosseini, 2021; Zareei, Ameri, Dorostkar, & Ahmadi, 2017).

From an Islamic perspective, environmental stewardship (Khilafah) is a fundamental principle, urging humanity to utilize resources responsibly and minimize waste (Qur'an 7:31). The integration of VTW and RHA into construction materials aligns with this ethos, offering a practical solution to waste management while promoting sustainable development.

This research investigates the mechanical properties of foam concrete incorporating VTW and RHA, focusing on compressive strength, density, and workability. By addressing the dual challenges of waste management and sustainable construction, this study contributes to the broader goal of eco-friendly infrastructure development in harmony with Islamic environmental ethics.

Literature Review

1. Foam Concrete

Foam concrete is a lightweight construction material known for its thermal insulation, reduced density, and ease of handling. Initially explored for non-structural applications such as roof slopes and floor levelling (Cox & Dijk, 2003), its potential as a structural material has also been investigated, although its compressive strength typically remains lower than that of conventional concrete (M. R. Jones & McCarthy, 2005).

To improve the mechanical and environmental performance of foam concrete, several studies have incorporated recycled and waste materials. Jones et al (Martyn Roderick Jones, McCarthy, & Dhir, 2005) demonstrated that using recycled aggregates could reduce the environmental footprint of foam concrete without significantly compromising performance. Meanwhile, Rum et al (Rum, Jaini, Boon, Khairaddin, & Rahman, 2017) studied the use of rice husk ash (RHA) as a partial sand replacement, finding that RHA improved compressive strength while also contributing to sustainable waste management.

Other agricultural by-products, such as eggshell powder and oil palm ash, have also shown promise. Incorporating these materials can enhance the durability and environmental profile of foam concrete (Hadi, Awang, & Al-mulali, 2015 ; Tiong, Lim, Lee, Ong, & Yew, 2020). Additionally, polypropylene fiber inclusion has been reported to improve tensile strength and crack resistance in foam concrete (Hadipramana, Samad, Zaidi, Muhammad, & Ali, 2013), while a broader review of fiber-reinforced foamed concretes emphasized the benefits of fiber additions for toughness and post-crack behavior (M. Amran et al., 2020).

2. Tire Waste in Concrete

The use of waste tire rubber in concrete has been widely explored as a strategy to address the growing volume of scrap tires while enhancing the sustainability of construction materials. With global tire production expected to increase annually by 3.4% (Evans, 2019), the environmental challenge of managing tire waste continues to grow. As a result, incorporating vulcanized tire waste (VTW) into concrete has attracted significant interest.

Several studies have investigated the mechanical behavior of rubberized concrete. Research has shown that replacing natural aggregates with waste tire rubber can reduce compressive strength but improve ductility, energy absorption, and impact resistance, making it suitable for applications such as roadside barriers and shock-absorbing structures (Aslani, 2016; Elchalakani, 2015). The addition of supplementary materials like silica fume has been found to mitigate some of the strength reductions typically associated with rubberized concrete (Elchalakani, 2015).

The influence of rubber aggregate particle size on mechanical and acoustic performance has also been studied. Angelin et al (Angelin, Miranda, Santos, Lintz, & Gachet-Barbosa, 2019) reported that finer rubber particles generally perform better in maintaining compressive strength while also offering improved acoustic insulation properties. Li et al (Li, Zhang, Wang, & Dang, 2019) further highlighted the potential of using waste tire rubber as aggregate in various cement-based products, noting advantages such as improved toughness and crack resistance.

Rubber powder, in particular, has been identified as a promising material for enhancing concrete workability and reducing unit weight, though its effect on mechanical strength remains a challenge (R. Liu & Zhang, 2015). Additionally, innovative applications such as the automated manufacturing of rubberized blocks and hollow bricks have demonstrated the versatility of tire rubber in prefabricated masonry products (Sodupe-Ortega, Fraile-Garcia, Ferreiro-Cabello, & Sanz-Garcia, 2016).

While these studies confirm the feasibility and environmental benefits of using tire waste in concrete, limited research has combined VTW with agricultural by-products like rice husk ash in foam concrete. This study addresses that gap by examining the effects of integrating both RHA and VTW into foam concrete, offering a dual-waste utilization strategy aligned with sustainable construction principles.

3. Rice Husk Ash in Concrete

Rice husk ash (RHA), a by-product of rice milling, has long been recognized for its pozzolanic properties and potential as a supplementary cementitious material in concrete. Given the vast quantities of rice produced globally, utilizing RHA not only helps reduce agricultural waste but also contributes to more sustainable and eco-friendly construction practices.

Several studies have confirmed the positive effects of RHA on the mechanical and durability properties of concrete. For instance, partially replacing cement with RHA can enhance compressive strength, reduce water absorption, and improve resistance to chemical attack (Al-Alwan et al., 2024) demonstrated that similar improvements in strength and durability were observed (Bixapathi & Saravanan, 2022), especially when RHA was used as a finely ground pozzolan. Optimum RHA content in self-compacting concrete also has been studied (Ameri, Shoaie, Bahrami, Vaezi, & Ozbakkaloglu, 2019).

Further research has also explored the durability of concrete containing various types of RHA. Givi et al. (Chatveera & Lertwattanaruk, 2011) reported that even high-carbon-content RHA could enhance durability characteristics, while Cordeiro et al. (Cordeiro, Filho, & Fairbairn, 2009) emphasized that ultrafine RHA is particularly effective in high-performance concrete applications. The integration of RHA in self-compacting concrete, combined with materials like metakaolin, has also shown improvements in both strength and long-term durability (Gill & Siddique, 2018).

Beyond conventional concrete, RHA has been successfully incorporated into recycled aggregate concrete, offering benefits in mechanical performance and microstructural refinement (C. Liu et al., 2022). In aerated and foam concrete applications, it demonstrated that RHA can positively influence compressive strength, though optimal replacement levels are crucial for maintaining material integrity (Manubothula & Gorre, 2022). The strength properties of concrete with various proportions of RHA have also been systematically assessed, with results consistently showing performance improvements when RHA is finely processed and appropriately dosed (Depaa, Priyadarshini, Hemamalinie, Francis Xavier, & Surendrababu, 2021). Analysis revealed that cement, RHA, and superplasticizers had a positive effect on strength (Kashem, Karim, Das, Datta, & Alharthai, 2024).

Despite these advancements, limited research has examined the combined effect of RHA with other recycled materials such as vulcanized tire waste in foam concrete. This study aims to

bridge that gap by evaluating the performance of eco-friendly foam concrete incorporating both RHA and tire waste, contributing to resource-efficient construction aligned with environmental sustainability principles.

Method

1. Materials

The materials used in this study comprised Portland cement, fine sand, rice husk ash (RHA), vulcanized tire waste (VTW), water, and a commercially available foam agent. The RHA was obtained from the controlled combustion of rice husks and then sieved through a 75 μm mesh to enhance its pozzolanic reactivity. VTW was produced by shredding discarded vulcanized tires into fine aggregate-sized particles with a maximum size of 5 mm. All materials were sourced locally to support sustainable construction practices.

2. Mix Proportions and Sample Preparation

Foam concrete mixtures were designed with a fixed sand-to-cement ratio of 2:1, using two different water-cement ratios (w/c) of 0.35 and 0.45 to examine their influence on the properties of the foam concrete. Nine different mix variations were prepared for each w/c ratio as shown in Table 1, resulting in 54 samples with 3 samples for each mix.

Table 1: Foam Concrete Mix Design

No	Mix	VTW (%)	RHA (%)	FAS	
				0.35	0.45
1	Control	0	0	√	
2	M1	0	5	√	
3	M2	0	10	√	
4	M3	10	0	√	
5	M4	10	5	√	
6	M5	10	10	√	
7	M6	20	0	√	
8	M7	20	5	√	
9	M8	20	10	√	
10	Control	0	0		√
11	M1	0	5		√
12	M2	0	10		√
13	M3	10	0		√
14	M4	10	5		√
15	M5	10	10		√
16	M6	20	0		√
17	M7	20	5		√
18	M8	20	10		√

The percentages of VTW replaced an equivalent weight of fine sand, while the RHA replaced an equivalent weight of cement. The foam was produced by mixing a foam agent with water and then blending it with the mortar to achieve the desired lightweight consistency.

For each mix and w/c ratio, three cube specimens measuring 100 mm × 100 mm × 100 mm were prepared, resulting in 54 total specimens (6 mixes × 2 w/c ratios × 3 specimens).

3. Curing and Testing

After casting, the fresh concrete mixes were immediately tested for workability using a slump flow test based on conventional slump cone procedures adapted for foam concrete. Following a 24-hour initial set at ambient temperature, all specimens were de-moulded and subjected to water curing for 28 days to promote optimal strength development.

Upon completing the curing period, the hardened foam concrete specimens underwent the following tests:

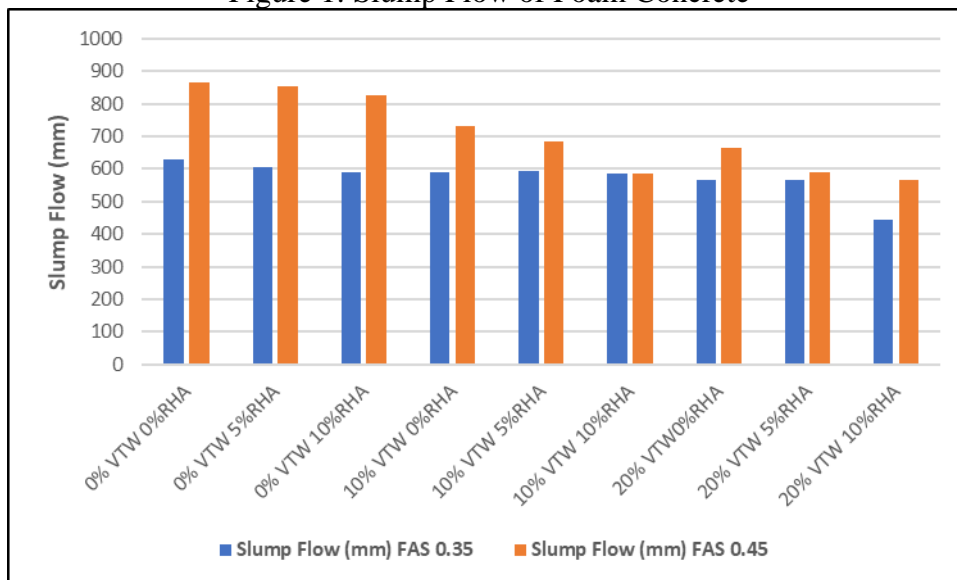
- Density: determined by measuring the mass and volume of each cube.
- Compressive strength: measured using a compression testing machine by applying a continuous load until failure, following standard procedures for cube specimens.

Result and Discussion

1. Slump Flow Test Results

The workability of the fresh foam concrete mixtures was assessed using the slump flow test and the result is shown in Figure 1. The test was conducted to evaluate the influence of vulcanized tire waste (VTW) and rice husk ash (RHA) incorporation at varying percentages, under two water-cement ratios (0.35 and 0.45). The results show a clear trend where the slump flow values decreased with increasing proportions of both VTW and RHA, at both water-cement ratios.

Figure 1: Slump Flow of Foam Concrete



At a water-cement ratio of 0.35, the control mix without any VTW or RHA achieved the highest slump flow value of 630 mm, indicating excellent workability. As RHA content increased from 0% to 10%, a gradual reduction in flowability was observed, dropping to 590 mm. This reduction is attributed to the high surface area and porosity of RHA particles, which increase water demand and reduce free water in the mix. Similar behavior was reported by Ganesan et al. [1], who found that the inclusion of RHA decreased the workability of concrete due to its absorptive nature and pozzolanic activity.

The incorporation of VTW also adversely affected the slump flow. At 10% VTW with no RHA, the slump flow reduced to 590 mm, while at 20% VTW it further declined to 567 mm. This decrease is associated with the irregular shape, rough surface texture, and elastic properties of shredded rubber particles, which increase internal friction and impede flow. The findings are

consistent with those of Thomas and Gupta [2], who noted similar trends in rubberized concrete mixes.

When both VTW and RHA were combined, the reduction in slump flow became more pronounced. At 20% VTW and 10% RHA, the slump flow dropped to 445 mm, the lowest recorded in this study. This combined effect is likely due to the cumulative influence of the absorptive characteristics of RHA and the frictional resistance posed by VTW particles. A comparable reduction in workability was also observed in a study by Al-Tayeb et al. [3], where concrete mixes with combined waste materials exhibited reduced flowability.

At a higher water-cement ratio of 0.45, an overall increase in slump flow values was noted across all mixes. The control mix achieved a maximum slump flow of 865 mm, while mixes containing 10% RHA without VTW decreased to 825 mm. The trends for mixes with VTW and combined VTW-RHA mirrored those observed at the lower water-cement ratio, though the higher water content mitigated the reduction in flowability to some extent. However, the combined effect of both additives at 20% VTW and 10% RHA still resulted in a significant slump flow reduction to 565 mm.

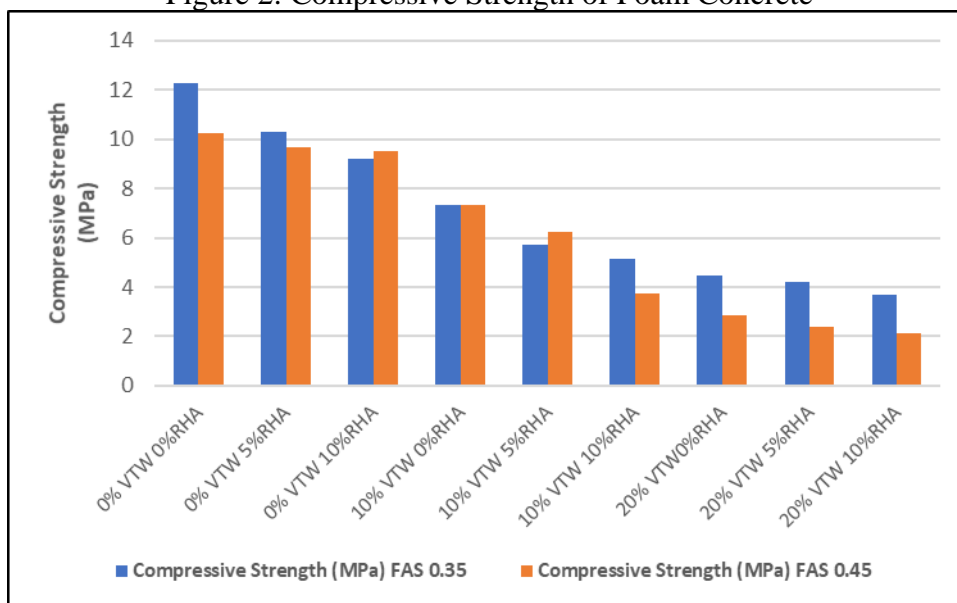
The results confirm that the workability of foam concrete is highly sensitive to both VTW and RHA content. Increasing the water-cement ratio can improve flowability, but its effect is constrained when higher amounts of these sustainable waste materials are incorporated.

2. Compressive Strength Test

The compressive strength results of foam concrete specimens after 28 days of curing are presented in Figure 2. The control mix, without any addition of Vulcanized Tire Waste (VTW) and Rice Husk Ash (RHA), achieved the highest compressive strengths of 12.26 MPa and 10.27 MPa for water-cement ratios (FAS) of 0.35 and 0.45, respectively. This established baseline confirms the expected mechanical performance of conventional foam concrete without alternative materials.

The incorporation of VTW and RHA consistently resulted in a reduction of compressive strength across all mixtures, which is in line with previous research reporting the mechanical limitations associated with replacing conventional fine aggregates with rubber particles (Aslani, 2016; Li et al., 2019). At a fixed water-cement ratio, increasing VTW content from 10% to 20% progressively decreased the compressive strength. For example, at FAS 0.35, the compressive strength dropped from 7.35 MPa at 10% VTW to 4.47 MPa at 20% VTW. This decline is attributed to the inherent low stiffness and elastic nature of rubber particles, which can act as weak zones within the matrix and increase compressibility under loading (Angelin et al., 2019; R. Liu & Zhang, 2015).

Figure 2: Compressive Strength of Foam Concrete



The addition of RHA, known for its pozzolanic activity and micro-filler effects, initially mitigated strength loss at lower replacement levels. At FAS 0.35, the combination of 10% VTW and 5% RHA produced a compressive strength of 5.74 MPa, higher than the 5.16 MPa recorded at 10% VTW and 10% RHA. A similar trend was observed at FAS 0.45. These findings align with prior studies indicating that moderate RHA incorporation can enhance the microstructure of cementitious composites by refining pore structure and contributing additional calcium silicate hydrate (C-S-H) formation (Al-Alwan et al., 2024; Bixapathi & Saravanan, 2022; Manubothula & Gorre, 2022).

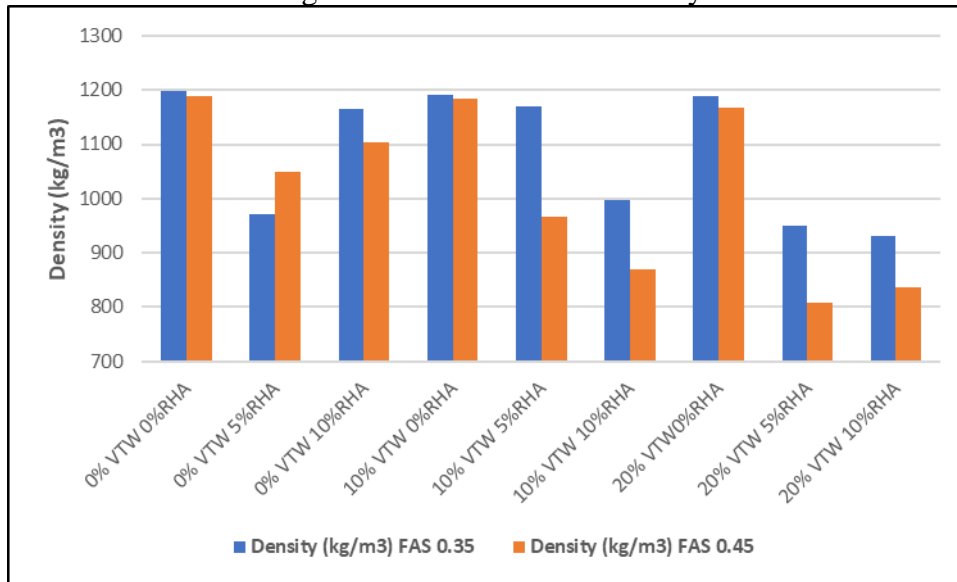
Additionally, compressive strength values were consistently higher for mixtures with a lower water-cement ratio of 0.35 compared to 0.45 across all compositions. Higher water content tends to increase porosity in foam concrete, which weakens the hardened matrix and reduces mechanical strength (Depaa et al., 2021; Hadipramana et al., 2013). For example, at 20% VTW and 10% RHA, compressive strength at FAS 0.35 was 3.68 MPa, whereas at FAS 0.45 it declined to 2.12 MPa.

Although the inclusion of VTW and RHA reduced compressive strength relative to the control, the values achieved remain suitable for certain lightweight and non-structural applications such as partition walls and insulating panels. Moreover, this approach contributes to sustainable construction practices by reducing dependency on cement and natural aggregates, while simultaneously diverting rubber and agricultural waste from landfills, in alignment with Islamic environmental stewardship principles promoting ecological responsibility.

3. Foam Concrete Density

The density values of foam concrete specimens at 28 days are presented in Figure 3. The results indicate the influence of vulcanized tire waste (VTW), rice husk ash (RHA), and water-cement ratio (FAS) on the hardened density of foam concrete.

Figure 3: Foam Concrete Density



The control mix (0% VTW, 0% RHA) produced the highest densities of **1199.3 kg/m³** and **1187.6 kg/m³** for FAS 0.35 and FAS 0.45, respectively. The incorporation of both VTW and RHA generally led to a reduction in density, which is consistent with trends reported in previous research by Thomas and Gupta [2], where lightweight aggregates such as rubber particles reduced the overall weight of concrete.

Increasing VTW content from 0% to 20% at constant RHA showed a slight decrease in density. For example, at 0% RHA, density declined from 1199.3 kg/m³ to 1188.3 kg/m³ for FAS 0.35, and from 1187.6 kg/m³ to 1167.3 kg/m³ for FAS 0.45. This reduction is attributed to the lower specific gravity of rubber particles compared to natural sand [3]. The elastic and lightweight nature of VTW reduces the overall mass per unit volume of the concrete matrix.

The addition of RHA further contributed to density reduction, particularly when combined with higher VTW contents. For instance, at 20% VTW and 10% RHA, densities dropped to 931.0 kg/m³ (FAS 0.35) and 836.0 kg/m³ (FAS 0.45). This outcome is due to the fine, porous structure and lightweight character of RHA, which lowers the mix’s overall density and increases entrapped air voids, as noted by Ganesan et al. [1].

Interestingly, at lower replacement levels (5% RHA), densities occasionally rose slightly or remained comparable due to enhanced packing effects and reduced porosity, as observed in the mix with 0% VTW and 5% RHA at FAS 0.45, which yielded 1049.3 kg/m³, higher than the 970.3 kg/m³ at FAS 0.35.

At a higher water-cement ratio (FAS 0.45), most mixes exhibited slightly lower densities compared to those with FAS 0.35. This is because higher water content introduces additional pore water during mixing and curing, which leaves behind more voids upon evaporation, reducing the final density [3]. For example, at 10% VTW and 10% RHA, density decreased from 998.3 kg/m³ (FAS 0.35) to 868.6 kg/m³ (FAS 0.45).

Conclusion

A comprehensive evaluation was conducted on foam concrete incorporating varying proportions of vulcanized tire waste (VTW) and rice husk ash (RHA), assessed through slump flow, compressive strength, and density tests at two water-cement ratios (FAS 0.35 and 0.45). The key findings are summarized as follows:

- **Slump Flow (mm)**
The workability of foam concrete, indicated by slump flow values, decreased progressively with increasing VTW and RHA contents. The control mix achieved the highest slump flow of 630 mm (FAS 0.35) and 865 mm (FAS 0.45). The lowest workability was recorded in the mix containing 20% VTW and 10% RHA, with slump flows of 445 mm (FAS 0.35) and 565 mm (FAS 0.45). A higher water-cement ratio improved flowability across all mixes but was less effective at higher replacement levels due to the absorptive nature of RHA and the rough, elastic texture of VTW.
- **Compressive Strength (MPa)**
Compressive strength values declined with increasing VTW and RHA content. The control mix achieved maximum strengths of 12.26 MPa (FAS 0.35) and 10.27 MPa (FAS 0.45). Strength reductions were more significant at higher VTW and RHA levels due to increased porosity and weak interfacial bonding. However, moderate RHA inclusion (5%) slightly improved strength relative to higher replacements, confirming its pozzolanic contribution at optimized levels. Higher water-cement ratios consistently resulted in lower compressive strengths for all mix compositions.
- **Density (kg/m³)**
Foam concrete density also decreased with greater proportions of VTW and RHA. The control mix exhibited the highest density of 1199.3 kg/m³ (FAS 0.35) and 1187.6 kg/m³ (FAS 0.45). The mix with 20% VTW and 10% RHA showed the lowest densities of 931.0 kg/m³ and 836.0 kg/m³ respectively. The reduction in density is attributed to the lower specific gravity of VTW and the lightweight, porous character of RHA, which increased internal void content.

In summary, incorporating VTW and RHA in foam concrete results in reduced workability, compressive strength, and density, with performance varying based on the proportions used and water-cement ratio. Despite the reductions, the values achieved remain suitable for lightweight and non-structural applications, contributing positively to sustainable construction by repurposing industrial and agricultural waste in alignment with environmental stewardship principles.

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