Production of Sustainable Foam Concrete using Foam Concrete Block Waste as Partial Cement Replacement

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ABSTRACT

As the global population continues to grow, the cost and environmental challenges associated with traditional construction materials, like cement and river sand, are becoming increasingly significant. The present study examines an alternative environmentally friendly approach to typical building materials. It thus aims to evaluate the feasibility of using foam concrete block waste as a partial replacement for cement to create eco-friendly foamed concrete products. The experimental program involved the deployment of specific machines to prepare finely ground foam concrete waste with a particle size equivalent to that of cement. The replacement levels were 0%, 10%, 20%, and 30% by weight of cement. The effects of the different replacement ratios on the foamed concrete properties were investigated and compared with the control cement-foamed concrete.

Keywords-foam concrete; waste; compressive strength; tensile strength

I. INTRODUCTION

Sustainable development treats natural resources as finite emphasizing the logical management of waste. To address the global waste volume, which has approximately reached 2500 million tons on an annual basis [1, 2], researchers have devised innovative methods for waste disposal. Sustainable construction has become increasingly challenging due to several economic and environmental factors. One of these is the consumption of natural resources by the construction sector and the generation of a great amount of waste [3]. Concrete has been extensively used globally throughout the centuries, with the demand for concrete ingredient resources increasing equivalently to these ingredients' growing utilization [4]. Since almost all concrete ingredients come from natural sources, the latter are being depleted [5]. This reduction in accordance with certain environmental and stability considerations has rendered the employment of waste resources in concrete manufacturing utilizing alternative components and the decrease of the Ordinary Portland Cement (OPC) production matters of great importance [6]. Cement, one of the most expensive concrete components, generates significant CO_2 emissions during its production [7]. For instance, the production of one ton of clinker in cement manufacturing releases one ton of CO_2, which represents 7% of the global CO_2 emissions. Therefore, it is essential to analyze the technological and physical components used in concrete preparation to identify eco-friendly solutions that can help reduce this kind of emissions [8]. The decrease of CO_2 emissions in cement manufacturing and the promotion of recycling industrial waste, which significantly contributes to environmental pollution, can be achieved by incorporating sustainable materials into civil engineering projects [9, 10]. Most research on the construction field in Iraq has examined whether locally sourced raw materials can be viable substitutes of the imported substances needed for specific real-world uses, such as sound and thermal insulation [11]. The production of cement requires three primary ingredients: alumina, silica, and calcium, all of which are derived from natural resources. However, the increasing utilization of these ingredients threatens natural resources. This fact along with the rising CO_2 emissions and temperatures, and the disappearance of natural areas has made the construction sector refocus on producing sustainable and eco-friendly concrete [12]. A solution to the aforementioned issues could be the deployment of foamed concrete, which is made by mixing cement, sand, and water with foam. Essentially, it is a combination of mortar and foam [13] by incorporating air into a sand-cement mortar [14]. Lightweight foamed concrete can be produced with a wide range of densities, making it suitable for various applications. These include non-structural uses, such as floor fills, sloping roof screeds, void filling in slabs, and roadways to reduce the lateral loads on wall structures. In addition, the particular concrete type has certain structural applications; for example, it is utilized in load-bearing building components. Foamed concrete is considered an environmentally friendly construction material because it uses fewer natural resources by eliminating coarse aggregates and utilizing waste materials, like fly ash and rice husk ash, whenever possible [15]. The compressive strength of lightweight insulating concrete increases as the density and water-cement ratio rise [16].

II. MATERIALS AND MIX PROPORTIONS

A. Cement

All mixtures involved in this study utilized OPC Type I cement. The chemical and physical properties of the latter are shown in Tables I and II, respectively. Test results demonstrate that the type N 42.5MPa cement deployed meets the Iraqi specification No. 5/2019 [17].

TABLE I. CHEMICAL COMPOSITION AND THE MAIN COMPONENT OF CEMENT

Oxide Compositions	Wt.%	Limits of (IQS No.5, 2019)
Lime (CaO)	63.32	-----
Iron Oxide (Fe_2O_3)	4.16	-----
Alumina (AL_2O_3)	5.22	-----
Silica (SiO_2)	19.84	-----
Insoluble Residue (IR)	0.64	Max (1.5)
Magnesia (MgO)	2.78	Max (5)
Loss on Ignition (LOI)	2.68	Max (4)
Sulfate (SO_3)	2.45	2.8 if C3A>3.5
***Main Compounds of Cement**		
TricalciumSilicate C3S 58.91	58.91	---
Dicalcium Silicate C2S 13.13	13.113	---
Tricalcium Aluminate C3A 6.8	6.8	---
TetraCalcium Aluminate –Ferrite C4AF	12.84	

TABLE II. PHYSICAL CHARACTERISTICS OF THE OPC

Propriety	Test Results	Limits of (IQS No.5, 2019)
Soundness by Autoclave Approach (%)	0.17	≤ 0.80
Setting time (Vicat's approach) Initial setting (min)	130 min	≥ 45 min
Setting time (Vicat's method) final setting time.	260 min	≤ 600 min
Compressive Strength (MPa)		
Compressive Strength (2) days	25.55	≥20
Compressive Strength (28) days	45.48	≥ 42.5

B. Fine Aggregates

The concrete mixes utilized natural sand as fine aggregate. Their physical and chemical properties are detailed in Tables III and IV. The test results indicate that the sand grading complies with the limits specified in the Iraqi Standard No. 45/1984 [18], and is classified in Zone 4 based on its content.

TABLE III. SIEVE ANALYSIS OF FINE AGGREGATES

Sieve no.	Accumulative passing %	(IQS No.45, 2019), Zone Two
10	100	100
4.75	96	90-100
3	84	75-100
1.18	69	55-90
0.6	50	35-59
0.3	15	8-30

TABLE IV. PHYSICAL AND CHEMICAL PROPERTIES OF FINE AGGREGATES

Physical properties	Test results	(IQS No.45, 2019)
Specific gravity	2.67	--
Fineness modulus	2.84	--
Density (kg/m³)	1590	--
Absorption %	1.8	--

C. Foaming Agent

A foaming agent for cellular concrete ASTM C796-97 [19] was utilized to produce Lightweight Concrete (LWC) by entraining a controlled amount of air bubbles into the concrete mix. This foaming agent is a protein-based surfactant the preparation of which is illustrated in Figure 1.

Fig. 1. Preparation of the foaming agent.

D. Mixing Water

Water was used for mixing and curing all concrete mixes in accordance with the requirements of the Iraqi Standard Specification 1703 [20].

E. Foam Concrete Block Waste

The foam concrete block waste was crushed in three stages using specialized machinery to produce finely ground foam concrete waste with a particle size comparable to that of cement, as portrayed in Figure 2.

III. MIXING, CASTING, AND CURING

A. Mix Proportions

LWF mixes were designed with a wet density of 1000 kg/m³ and a dry density of 900 kg/m³, incorporating a waterbinder ratio of 0.45 and a sand-binder ratio of 1:1.3. Four mixes were produced, with foam block waste having been used as a partial substitute for cement at varying percentages of 10%, 20%, and 30%.

(a) (b)

Fig. 2. (a) Grinding and (b) sieving of foam concrete waste.

B. Mixing Procedure and Curing

All materials were prepared, and the foam machine's density and flow rate were verified. A fine aggregate was first added to the mixer with 10% of the calculated water, followed by the cementitious material. The constituents were mixed for 3 to 4 minutes to ensure a thorough blending. The remaining water was then gradually added until the desired mortar consistency was achieved, following the technique outlined in [21]. The desired mortar density was verified by weighing a standard one-liter cup of the base mortar mix. Subsequently, the required amount of foam was injected into the batch and the density of the foam concrete was checked after thoroughly blending the aqueous foam. The density of the freshly mixed foam concrete was measured and the fresh properties of the foam concrete mixes were evaluated. A sealed curing method was employed in this study, where specimens were wrapped in a plastic sheet until the day of testing [22].

TABLE V. FOAMED CONCRETE MIX CONSTITUENTS

Mix*	Replacement ratio	Cement (kg/m^3)	Foam block waste (kg/m^3)	Foam (L)
Mc	0	365	0	66
M1	10%	329	36	67
M2	20%	292	73	65
M3	30%	256	109	66

*Water content 165 kg/m^3, sand content 475 kg/m^3 for all mixtures

IV. RESULTS AND DISCUSSION

A. Compressive Strength Test

The test was conducted on 100 mm × 100 mm × 100 mm cubes using a compression testing machine at a loading rate of 0.1 kN/s, following the procedure detailed in [23]. At 28 days, the average compressive strength from three cubes was determined, as portrayed in Figures 3 and 4.

B. Splitting Tensile Strength Test

The splitting tensile strength test was performed on 100 mm × 300 mm cylindrical specimens, following the procedure outlined in [24]. The specimens were tested at 28 days using an electrical testing machine, as depicted in Figures 5 and 6.

Fig. 3. Specimen under compressive strength test.

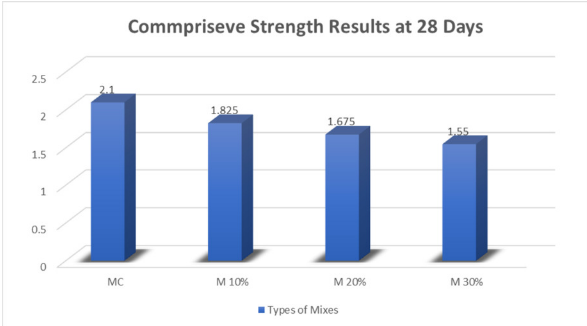

Fig. 4. Compressive strength at 28 days.

(a) (b)

Fig. 5. (a) Specimens of splitting strength before the test, (b) after the test.

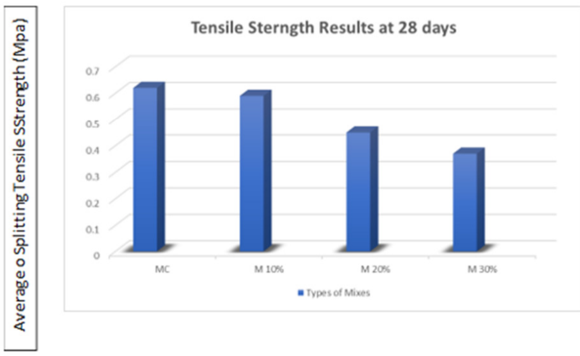

Fig. 6. Splitting tensile strength at 28 days.

C. Dry Density Test

The dry density was determined by measuring the dried weight of the sample at 105 degrees Celsius for 24 hours. Each tested sample involved measuring three cubes. The density was calculated by dividing the weight of the specimens by their measured volume. The dry density was tested at 28 days, as displayed in Figures 7 and 8.

Fig. 7. Cube specimens in the oven.

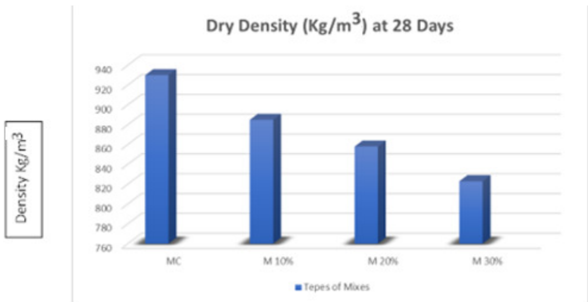

Fig. 8. Density at different replacement ratios.

V. CONCLUSIONS

The present study investigates the feasibility of utilizing foam concrete block waste as a replacement for cement in foamed concrete mixes. This replacement material has shown great potential in saving energy and costs, while it is more environmentally friendly compared to the traditional concrete. The following conclusions were drawn:

- The compressive and tensile splitting strength decreased as the waste content increased. The mix with a 10% replacement level showed 86% lower strength compared to the control mix, while the mix with a 30% replacement level showed 73% lower strength.
- Strength is directly related to the oven-dry density.
- The approach followed in this study tackles two key challenges in construction: minimizing the environmental impact of cement production and managing industrial waste. Although previous studies have explored the use of recycled materials in concrete [25], they have not focused on foam concrete applications, which offer benefits, like lightweight properties and improved thermal insulation. By assessing the mechanical and environmental performance of this innovative material, the current work makes a significant contribution to the development of eco-friendly construction materials, supporting global sustainability objectives.

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