IRAQI Academic Scientific Journals
Al-Rafidain Engineering Journal (AREJ) Vol.29, No.1, March 2024, pp. 94-105

Water Absorption of Foamed Concrete using Recycled Aggregate Derived from Construction and Demolition Waste

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Received: October 1st, 2023 Received in revised form: November 1st, 2023 Accepted: December 18th, 2023

ABSTRACT

Foam concrete (FC) is a type of lightweight concrete that has had many voides added by the foaming agent. This paper investigates the possibility of using two types of construction and demolition waste (CDWs), including thermostone blocks and ceramic tiles, as a partial replacement of sand in foam concrete to test the water absorption performance of foamed concrete. Twenty-one samples with three volume-replacement rates of sand for each waste type were explored (25, 50, and 75%). The effect of these various proportions on workability, fresh density, hardened density, and water absorption, it has been established. The results showed that the workability decreased with increasing replacement, and the density of hardened foam concrete increased. As for water absorption, it decreased at all replacement ratios as a result of filling the pores inside the foam concrete and thus increasing the bulk density. Which, in turn, reduces the permeability of foam concrete. The maximum redection in absorption and permeable voids was in the replacement of 75% of thermostone and ceramic waste powders, where the redection was 20.68% in absorption and 29.2% in permeable voids for thermostone replacement, the absorption value was 15.96%, and the permeable voids were 38.28% for ceramic.

Keywords:

Workability, Density, West Thermostone Block and Ceramic Tiles

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1. INTRODUCTION

Building energy consumption ranks third worldwide [1]. As a result, numerous countries have lately inserted pertinent strategies, which include the utilisation of energy-saving building materials [2,3]. Foam concrete is the key to achieving energy efficiency in buildings, which brings down the thermal conductivity of substances and enhances thermal insulation [4]. Foam concrete is a light cellular concrete composed of a cement paste or mortar, where haphazard air spaces are trapped in the mortar by an appropriate foaming agent, and so it can as well be referred to as aircrete or foamcrete [5,6]. Foam concrete is manufactured in two known manners: the first is the pre-foaming manner with physically foaming, and the second is the combined foam manner with chemically foaming. The typical range of the unit weight of foam concrete is 400–1600 kg/m^3. In addition, it has the following properties: great workability, small self-weight, less aggregate consuming, little controlled strength, superior heat and sound insulation, and great resistance to fire attack [5]. Practically, foam concrete is utilised to a large degree for roof isolation, precast units, road and pavement subbases, and soil stabilisation [7].

Recently, the incorporation of recycled aggregates into concrete manufacturing has grown as a result of the decline in natural aggregates and increased awareness about protecting the environment [8]. Autoclaved aerated concrete, or as it is known in Iraq, "Thermostone," is a material that has been scientifically and virtually efficient in building and has been effectively utilised in Europe, the Americas, Asia, and the Middle East countries [9]. Thermostone waste is a common type of waste generated during construction and demolition works and is created when thermal preservation wall materials are built and torn down [10]. Eliminating thermostone blocks in landfill sites rather than being reused and recycled in new buildings can lead to environmental concerns. For example, leaching of contaminants and alteration in pH in nearby soil and water [11]. This waste powder is commonly used in concrete as a filling material, which in most conditions reduces the concrete strength. Since the amount of this reduction is not large, this is a practicable application of waste powder [12].

Ceramic products belong to the vital building materials utilised in most buildings. Some fabricated ceramics encompass floor tiles, wall tiles, sanitary ware, domestic ceramics, and technical ceramics [13]. According to ceramic world review 2018, the global production of ceramic tiles is around 13.55 billion square metres in 2017, an increase of 2.2% compared to 2016 [14]. Nowadays, numerous kinds of ceramics are utilised in buildings, but some are breakable when fabricated, shipped, or stored [15]. Ceramics presently account for about 40% of construction and demolition waste, and around 30% of its content finds its way into waste through manufacture [16]. This waste not only presents a grave risk to the environment; it also needs a great landfill zone for removal. When ceramic powder comes into contact with groundwater, it leads to severe health issues [17]. The utilisation of ceramic waste in the production of conventional concrete and lightweight mortars has been researched recently. In view of the chemical characteristics of ceramics, some intriguing facts are noted, like the fact that the ceramic powder has a feature of pozzolanic activity that displays the possibility of using it as a supplementary cementing material, or as an aggregate in traditional concrete. She et al. (2018) showed that replacing (50,100)% sand with coarse fly ash (FAc) improves several properties of foam concrete, including workability and mechanical and freeze-thaw resistance, while the opposite is true for water absorption and drying shrinkage properties[18]. Oren et al. (2020) found that foam concretes contained 100% granulated blast furnace slag (GBFS) as a sand replacement develops the physical and mechanical properties compared with the control foam concrete, by exhibiting a lower porosity, bulk density, ultrasound velocity, thermal conductivity, higher compressive strength, and a similar water absorption compared to those of the control foam concrete [19]. Lermen et al. (2020) evaluated the replacement of natural sand with foundry green sand waste in foamed concrete at five levels (0, 25, 50, 75, 100) % of total mass. It was found that the dry density increased by an average of 24%, and the saturated density by an average of 14% when the percentage of waste substitution increased in relation to the amount of natural sand. With an increase in the percentage of substitution, the compressive strength, air void, and water absorption were all reduced by 29.1%, 31.0%, and 43.5%, respectively [20].

In the presen study the performance of foamed concrete containing recycled aggregate derived from various kinds of industrial byproducts or construction and demolition wastes has been studied to a great extent, developing thermostone and ceramic waste powders as lightweight aggregates in foam concrete production should be subject to further research. The influence of the partial substitution of these wastes on the fresh and durability properties (water absorption) of foamed concrete is worthwhile to investigate and needs further deepening.

2. EXPERIMENTAL PROGRAM

2.1 Constituents of foam concrete

2.1.1 Cement

Ordinary Portland cement (OPC) produced by the Badoosh plant, which is of local origin (Iraq), was used in this study. It passed the Iraqi Standard Specification (IQS 5:2019) [21]. The chemical analysis and physical characteristics of the used cement are shown in Tables 1 and 2, respectively.

2.1.2 Fine Aggregate

In this investigation, natural river sand was employed. The following tests were performed to determine the properties of aggregates: sieve analysis – IQS 45:2016 [22]; relative density and water absorption – ASTM C128-15 [23]. Figure 1 depicts the sand's particle size distribution, while Table 3 lists its physical properties.

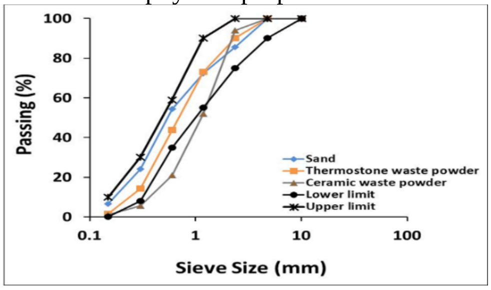

Fig. 1 Gradation of Sand, Thermostone Waste Powder and Ceramic Waste Powder.

Table 1: Chemical analysis of OPC Cement, Thermostone Waste Powder and Ceramic Waste Powder

Chemical Compounds (%)	Cement*	Thermostone Waste Powder**	Ceramic Waste Powder**
CaO	62.99	30.16	7.53
SiO_2	20.69	54.20	52.53
Al_2O_3	5.04	3.64	22.38
Fe_2O_3	2.78	2.71	6.29
MgO	3.51 (5.0 max)	1.28	6.29
SO_3	2.26 (2.8 max)	2.09	0.47
Free Lime	1.09		
Loss on Ignition	1.23 (4.0 max)		
Insoluble Residue	0.6 (1.5 max)		
Solid Solution	15.29		
LSF	0.93 (0.66-1.02)	0.18	0.04
C_3S	50.39		
C_2S	21.45		
C_3A	8.90	5.07	48.68
C_4AF	8.39		

* The chemical analysis was carried out at the Environmental Engineering Laboratory/College of Engineering/University of Mosul.

** The chemical analysis of each sort of waste powder was conducted at the National Center for Construction Laboratories (NCCL)/Baghdad Laboratory.

*** The physical properties were conducted at the Construction Materials Testing Laboratory/College of Engineering/University of Mosul.

Table 2: Physical Properties of Cement***

Property	Result	Limits of Iraqi Standard (No.5, 2018)
Fineness (m^2/kg)	290	≥230
Initial Setting Time (min.)	135	≥45
Final Setting Time (hr.)	4	≤ 10
Compressive Strength (MPa):		
at 3 Days	20.1	≥15
at 7 Days	32.5	≥23

Table 3: Physical Properties of the Sand, Thermostone Waste Powder and Ceramic Waste Powder.

Property	Sand	Thermostone Waste Powder	Ceramic Waste Powder
Fineness Modulus	2.6	.27	3.2
Specific Gravity	2.65	2.0	2.46
Unit Weight (kg/m^3)	1689.2	697.17	1073.67
Water Absorption (%)	1.21	35	4.4

2.1.3 Wastes of Thermostone Blocks and Ceramic Tiles

In this study, waste from thermostone blocks and ceramic tiles was used to partially replace fine aggregate at volumetric amounts of 0%, 25%, 50%, and 75%. Materials for unused blocks and tiles can be found in the manufacturing waste and flaws of thermostone blocks and ceramic tiles. A hammer was used to bbreak both waste types into smaller, 50-100 mm-long bits. Subsequently, the thermostone and ceramic pieces were ground by an originally evolved grinding machine. As can be seen from Fig. 1, the particle size of thermostone waste powder, ceramic waste powder, and sand have been arranged to be almost the same. Therefore, both of these waste powders were sieved into the desired aggregate sizes of 4 mm or less, utilising standard sieves. Table 1 explains the chemical analysis of each sort of waste powder, and Table 3 lists their physical properties.

2.1.4 Water

Potable water was used in the preparation, mixing, and curing of all foam concrete mixtures.

2.1.5 Foaming Agent

A synthetic-based foaming agent under the "CHRYSO® Poresin 88" brand name was adopted during the experimental programme to produce a pre-foamed that is commonly utilised to manufacture foam concrete mixtures. The properties of the foaming agent utilised are listed in Table 4.

Table 4: Properties of Foaming Agent *

Property	Result
Nature	Transparent Liquid
Density at 20°C	1.02 g/ml ± 0.02
pH	8 ± 1
Chloride	Free
Equivalent Na_2O	≤ 1.0%

*Table (4): lists the properties of the foaming agent (CHRYSO®Poresin 88) used, as provided by the manufacturer.

2.2 Research methodology

-Foam concrete mixture constituents were prepared, including ordinary cement, mixing water, sand, and foaming agent.

-Foam concrete mix proportions were designed in accordance with ACI-523.3R-14.

-The study Study were carried out as follows:

-Reference foam concrete mixtures were manufactured by the pre-foam mix method.

-Several alternative foaming agent-to-water ratios were tried, and the one that produced the requisite density was chosen.

-Mixing times were examined for the foam concrete mixture, and the shorter mixing time were selected while keeping the slump flow constant.

-Two types of construction and demolition waste were used, including thermostone blocks and ceramics.

-Three levels of partial replacement for fine aggregate with the recovered aggregate from thermostone and ceramic wastes were used. The suggested replacement levels will be (25, 50, 75%).

-Seven types of foam concrete mixtures were manufactured, including a reference mixture containing fine aggregate, three mixtures containing natural various substitution rates of thermestone waste aggregate, and three mixtures containing various substitution rates of ceramic waste aggregate.

-Fresh properties (density and workability) and hardened properties (density and absorption) were evaluated for each mixture.

2.3 Proportioning According to ACI-523.3R

Generally, the target density in the design of the foam concrete mixture is a major factor in determining the mixing proportions. All mixtures were designed to conform to ACI-523.3R-14 [24]. This mix design methodology starts with the choice of the fresh density of foam concrete and water–cement ratio (w/c). As a result, all mixtures were created with a w/c of 0.5 and a density of 1120 kg/m^3. The sand–cement ratio was also constant for whole foam concretes.

2.4 Preparation of Foam Concrete

In this manner, initially, the foaming agent was dissolved in water with a dilution ratio of 1:60 by weight following the supplier's recommendation, which is equivalent to a density of 1120 kg/m^3. The solution was thereafter charged into a foam generator machine linked with a 300 kPa air compressor. Compressed air is blended with foaming solution in the foam generator to make a preformed steady foam with a density of around 40 kg/m3 (steady foam density varies between 32 and 80 kg/m3) as per ACI-5223R-14 [24]. The foam prepared in this manner is stable through its elevated colloidal activity because of the obstruction of the incorporation of bubbles and can also readily combine with the reference mixture. An unchecked mixing ratio and providing air out of control will have negative impacts on the foam prepared. For foam concrete manufacture, the mixing was done in a tilt drum mixer with a mixing capacity of 100 L. In the beginning, all the powders, including cement, sand, and waste powder (either thermostone or ceramic) were stirred and mixed for 30 seconds. Then, water was added in and stirred for an additional 2 minutes, after which a slurry mix was achieved. The preformed foam was then introduced to the slurry mix within 30 seconds utilizing the foam generating machine's nozzle in accordance with the computed content at the flow rate per second, and after 2 minutes of continuous mixing, a uniform and homogenised mixture was obtained. The overall mixing time of the reference foam mixture took around 5 minutes, and was extended to 6 minutes for foam mixtures containing thermostone or ceramic waste powder. Finally, fresh foamed concrete was cast into the moulds to determine the dimensions for different specified testing methods. No compaction or vibration was carried out during the casting to avoid influencing the stability of the bubbles. The fresh density of the mixture was then measured, and values were agreed to within the tolerance limit of ±50 kg/m3 of the target density. Fresh foam concrete mixtures in the molds were then covered with plastic film to stop the evaporation of water. The specimens were unmolded after 24 h, wrapped with plastic film, and kept under standard conditions at 23 ± 2 ºC and 55% ±2% relative humidity until testing.

3. RESULTS AND DISCUSSIONS

3.1 Workability

Figure (2) show the results of the mini slump flow according to European Standard (EN 12350-8) [25] for all foam concrete mixtures. As shown in Figure (2), the mini slump flow of the RFC was 228 mm. This mixture is flowable and has self-compacting rheology.

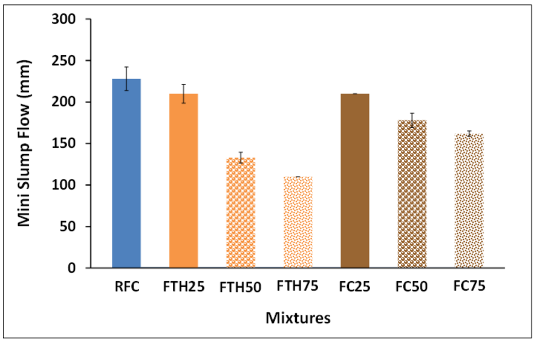

Fig. 2 Mini Slump Flow Values of Foam Concrete Mixtures.

Table 5: Foam concrete materials mixture proportion

Mixture	Replacement Level from Sand	
	Thermostone Waste Powder (%)	Ceramic Waste Powder (%)
RFC	0%	0%
FTH25	25%	
FTH50	50%	
FTH75	75%	
FC25		25%
FC50		50%
FC75		75%

Consistency is mostly determined by the filler's quality [26]. With a higher proportion of this aggregate, the micro slump flow values of foam concrete compositions using recycled thermostone aggregate tended to dramatically decline, for example, from about 210 mm (FTH25) to around 110 mm (FTH75). Due to their porousness and natural particle structure, waste materials frequently increase the amount of water required, which negatively affects their stability and workability [27]. The value of water absorption for thermostone waste aggregate is significantly higher than that of natural fine aggregate, as shown in Table 3. In comparison to natural aggregates, which are more spherical and have a smoother surface, recycled aggregates are more angular and have a larger surface-to-volume ratio as a result of both the crushing and milling processes. In general, more water is needed for the specific workability of the angular fine aggregates [28,29].

The workability of the foamed concrete mixtures comprising recycled thermostone aggregate and recycled ceramic aggregate, as depicted in Figure 2, follows a similar pattern. When compared to the RFC combo, it was determined that the mini slump flow value of FC25 decreased to about 210 mm. This reduction maintained even as the volume of recycled ceramic aggregate increased. The micro slump flow for FC75 was 162 mm. Recycled ceramic aggregate, per Table (3), can absorb more water than natural fine aggregate, which may significantly affect the workability of the mix. There is a tendency that part of the water intended to ensure the workability of the mixture was preserved by ceramic aggregate [30]. These findings correlated with those of Jiménez, Awoyera, and Britto [30,31]. The workability and consistency of mortar decreased when ceramic waste (10–20%) was added as filler, increasing the demand for water [16], according to a study by Vishvakarma et al. Binici asserts that when fine aggregate is substituted for coarse aggregate in concrete, the amount of ceramic powder with angular shapes increases while the value of the mixture slump reduces [32]. Since ceramic aggregate was crushed and milled from tile waste, it was not possible to dominate ceramic aggregate particle angularity to obtain angularity equivalent to that of the fine aggregate particles [33]. The frictional resistance to the workability of foam concrete is also increased by the particle surface roughness, which results in lower values of mini slump flow. The researchers reported that recycled ceramic aggregate has an embedded clay layer on one side and a glassy surface on the other. While the clay layer has the potential to absorb significant amounts of water, reducing workability, the glass surface does not adhere effectively to the other ingredients in the mixture [13,34]. The finer particles in both recycled aggregates are higher than those in natural fine aggregate. In comparison to coarser particles, these tiny particles have a larger specific surface area per volume. Since the finer particles will absorb much more water than the coarser ones, the mini-slump flow will consequently be significantly reduced [35,36].

3.2 Fresh Density

Figure (3) show the results of the fresh density according to BS EN 12350-6 [37], for all foam concrete mixtures. The fresh density of the RFC was 1140 kg/m3. The measured freshness density should be close to the design density in order to produce a stable foamed concrete mixture. All foam concrete mixes investigated were within ±50 kg/m3 of the target density.

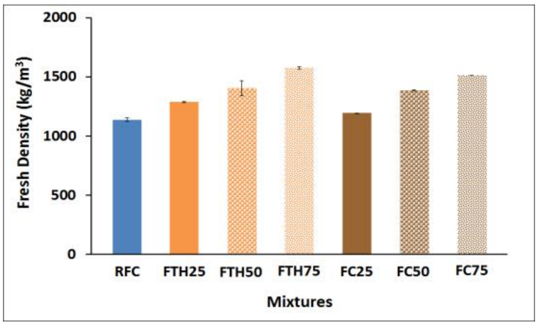

Fig. 3 Fresh Density of Foam Concrete Mixtures.

The fresh density values of foamed concrete mixes using recycled thermostone aggregate tend to increase significantly with a higher proportion of this aggregate; the percentage increase was 13% (FTH25), 23.2% (FTH50), and 38.4% (FTH75), as shown in Figure (3), consecutively. Recycled thermostone waste increases the need for water due to its porous nature, as the higher the replacement ratio, the higher the fresh density compared to natural fine aggregate. Moreover, the fresh density of foam concrete mixtures using recycled ceramic aggregate appears a pattern similar to that of foam concrete containing recycled thermostone aggregates. It was found that the fresh density increased to approximately 5%, 21.6%, and 32.7% for FC25, FC50, and FC75, as shown in Figure (3), respectively, when compared to the mixture of RFC1140 kg/m3. With the increase in the amount of recycled ceramic aggregate, this increase has continued. Recycled ceramic aggregates can absorb more water than normal fine aggregate, which can have a significant impact on fresh density. Therefore, it can be said that both recycled thermostone and ceramic wastes increased the fresh density of all foam concrete mixtures since they have higher absorption compared to natural fine aggregate (volumetric substitution), which caused fracturing of foam bubbles and increased density, which was affected by the quantity and quality of additives [8].

3.3 Hardened Density

Results for the hardened density of the foam concrete mixtures at all curing ages are shown in Figure (4), in accordance with EN 12390–7 [38].

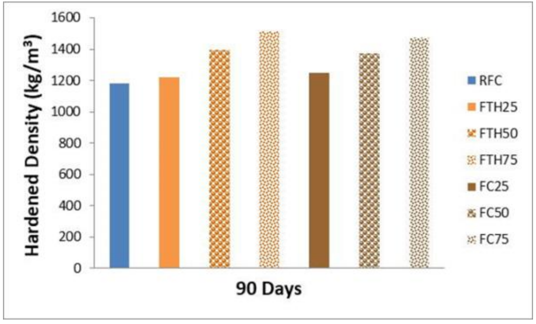

Fig. 4 Hardened Density of Foam Concrete Mixtures.

The findings showed that adding recycled thermostone aggregate increases the hardened density of foam concrete. At 90 days, the increment ratios of the hardened density were reached 3.4, 17.9, and 28% for FTH25, FTH50, and FTH75, with respect to RFC density of 1181 kg/m3. As observed in Table (3), the density of the recycled thermostone aggregate was less than that of river sand. As per the EN 12620 standard, thermostone waste may be utilised as a filling aggregate in cementitious products. The physical effect of the finer particles, which have a filling role in thermostone aggregate, causes pores and voids to get blocked [39,36]. Thermostone waste is a light weight porous material that can be used as the internal curing aggregate of a cement matrix. It could absorb water as it's being prepared and mixed, then slowly release any water that was trapped in the mixture throughout the hardening process. Furthermore, cement paste and aggregate can interlock in these transition zones (interrelated surfaces) thanks to the coarse pore structure and rough particle surface of this aggregate. The matrix density increased as a result of the increased hydration degree and hydrate filling of the pores [40,41,36]. A similar trend was observed for the FC25, FC50, and FC75 mixtures as appeared in Figure (4). At 90 days, the percentages of increase in hardened density were 5.5, 16, and 25% for FC25, FC50, and FC75 respectively, compared to RFC density of 1181 kg/m3. Rubio de Hita discovered that mortar combinations comprising 50% ceramic efficiently decreased the hardened densities of mortars by up to 8% [42] when compared to the reference mortar. Khatib observed a little lowering in density with the increment of fine ceramic powder amount in the mixture for whole curing ages [32]. Jiménez et al., however, found that when the rate of replacement with recycled fine aggregate from ceramic walls increased, the hardened density of masonry mortar decreased

[31]. Recycled ceramic aggregate, as shown in Table 3, has a lower density than natural sand but a higher rate of water absorption. Due to the enhanced density of foam concrete mixtures and the improved interfacial zones in cementitious matrices, recycled ceramic aggregate appears to be the ideal filler material [16]. As with lightweight aggregate concrete, water absorbed by the recycled ceramic aggregate may also offer an internal cure in foam concrete mixtures by enhancing cement hydration and lowering the proportion of accessible pores [43,32]. The delayed pozzolanic reaction of the reactive silica in the fine ceramic aggregate with portlandite produced the supplemental C–S–H gels, and this in turn boosted the density of the mortar matrix and reformed the pores from where their structure and distribution were disturbed [44,36].

3.4 Water Absorption

Figure (5) depicts the results of a water absorption test on foam concrete performed after 90 days on cube samples. Also, Figure (6) depicts the volume of permeable voids. According to ASTM C642-21 [45] using cubic specimens (100 × 100 × 100) mm.

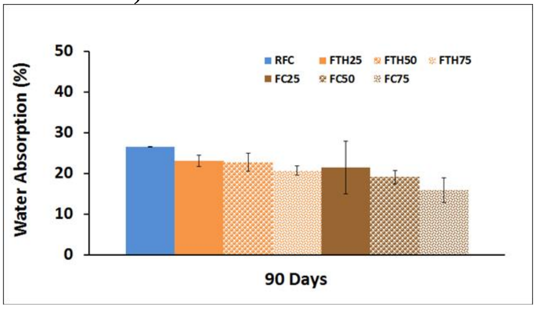

Fig. 5 Water Absorption of Foam Concrete Mixtures.

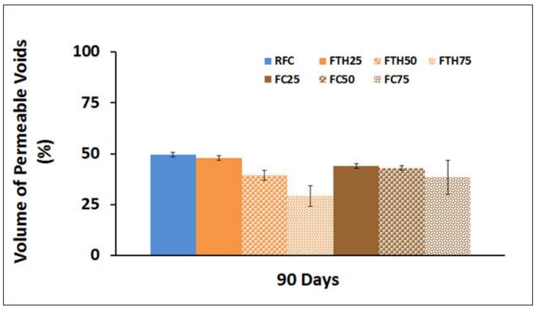

Fig. 6 Volume of Permeable Voids for Foam Concrete Mixtures.

As exhibited in Figure (5), water absorption in the RFC mixture was high at 26.6%. The use of recycled thermostone waste powder reduced foamed concrete absorption to 23.15, 22.79, and 20.68% for replacement ratios of 25, 50, and 75.0%, sequentially. Where the volume of the permeable voids in the RFC reached 49.5% in 90 days and decreased with the increase in the proportion of natural sand replacement with thermostone waste, the permeable voids volumes were 47.8, 39.3, and 29.2% at the replacement rates of 25, 50, and 75%, respectively, Figure (6).

The decrease in water absorption can be attributed to densification of the microstructure as a result of tobermorite formation and filling of the nano-voids as a result of the replacement of natural sand with thermostone waste powder. Where the thermostone powder has the property of filling the pores, which in turn reduces the permeability in the foamed concrete [46, 47]. As the artificial air voids are not interconnected as well as air being trapped in these air voids, they are not taking part in water absorption. Hence, the contribution to water absorption is only made by pores other than artificial air voids present in the sorbing paste [48]. Typically, there are two categories of pores, namely open pores which are connected with each other and the outside, and blind pores which are not connected. Apparently, driven by capillary force, the open pores have water absorption effect [46]. Also, the high water absorption of thermostone powder led to the absorption of part of the foam water and the explosion of some bubbles, which led to a decrease in the volume of foam [8]. This decrease in the volume of foam as a result of the high absorption of the thermostone powder, in addition to the fact that the thermostone powder is pore-filling, led to an increase in the density. The higher the bulk density is, the lower the porosity and the probability of connected pores under the same condition are, and therefore the water absorption is diminished under high bulk density [49]. It can be reported that very well correlation between porosity and absorption and unit weight [50].

Water absorption values for foam concretes containing ceramic aggregate powder were lower than those for RFC, as shown in Figure (5). They were 21.4, 19.1, and 15.96%, for the mixtures FC25, FC50, and FC75, respectively. Moreover, the volume of permeable voids decreased with the increase in the percentage of sand substitution with ceramic waste aggregate, and the permeable voids volumes of 44.07, 42.85, and 38.28% were at the replacement rates (25, 50, and 75%), sequentially, Figure (6). The water absorption decreased with the increase in the percentage of replacing natural sand with ceramic powder waste as a result of filling the pores inside the foam concrete matrix by producing pozzolanic products, in addition to improving the interface transition zone (ITZ) due to the pozzolanic reaction and filling effect of ceramic powder beside the chemical contribution [27,51]. Heidari and Tavakoli reported that the ground ceramic powder has pozzolanic materials provided denser microstructure of concrete [52]. The physical contribution is shown by increasing intensity with an increasing substitution ratio, which leads to decreasing water absorption [27, 51]. Gonzalez-Corominas and Etxeberria confirmed that when they observed that the water absorption and volume of permeable pore decreased for concrete with fine ceramic aggregate in comparison with reference mix. In addition to the good filling of the pore space of the fine ceramic aggregate, the water absorbed in fine ceramic aggregate could as well produce an internal curing in concrete, ameliorating the cement hydration and as a result decreasing the proportion of accessible pores. According to Cusson and Margeson, the cement hydration was improved by internal curing which lead to greater amount of C–S–H [43]. A similar trend was found by Nayana et al. when the water absorption of the mortar containing 15% of ceramic waste powder as a substitute for fine aggregate in 28 days decreased by 1.17% compared to the reference mortar. They stated that reduced pores is the major cause for the reduced water absorption [17]. Elsharief et al., also found less water absorption capacity of concrete containing pre-soaked porous light weight aggregate with respect to traditional concrete [43]. However, Huseien et al. found the oppisite result that when the ceramic tile waste powder grown, less dense C–A–S–H gel was produced which achieved a reduced strength and an enhanced water absorption [53].

4. CONCLUSIONS

- By partially substituting fine aggregate, both thermostone block and ceramic tile waste can be successfully used to produce high-quality foam concrete.
- The workability of recycled thermostone aggregate-based foam concrete mixtures was smaller than that of reference foam concrete. The sharp shape and rough surface of thermostone aggregate particles provided greater inter-particle through their larger surface area that promoted water absorption and relatively less free water for flowability, resulting in reduced workability. In addition to the ceramic aggregate qualities, the glass surface of ceramic aggregate particles did not bind adequately to the other mixed elements, whilst the claly surface could absorb a substantial amount of water, resulting in decreased foam mixture workability.
- The hardened density of foam concretes containing thermostone aggregate increased with increasing thermostone aggregate concentration when compared to the reference foam concrete. Finer thermostone aggregate particles physically acted by closing pores and filling voids. The use of porous aggregate as an internal curing agent also aided in pore structure refinement and transition zone densification. The presence of the crystalline tobermorite phase in the thermostone waste aggregate influenced the density increment positively. Furthermore, the siliceous characteristic of thermostone powder accelerates the hydration reaction and so raises the content of C-S-H, resulting in a compact microstructure and higher hardened density. In comparison to the reference mixture, the foam concretes using recycled ceramic aggregate had higher densities. Ceramic aggregate works well as a filler because it improves the density of foam concrete and the interfacial zone in the cement matrix. More hydration processes were accomplished, and more hydrates were formed, as a result of its higher specific surface area and increased water absorption on the one hand, and its porous feature that serves as a wet curing environment on the other hand. Furthermore, the pozzolanic impact of ceramic aggregate can result in the formation of additional C-S-H and C-A-H secondary hydrates, which fill the micropores of foam concrete and enhance the bond between the cement matrix and aggregate.
- Due to a densification of the microstructure resulting from the forming of tobermorite and the filling of the nano-voids, the use of recycled thermostone waste powder decreased water absorption and the volume of the permeable voids. There is a strong relationship between porosity, absorption, and unit weight, it can be said. Since porosity and the likelihood of linked pores under the same conditions decrease with increasing bulk density, water absorption is reduced in materials with high bulk densities. By filling the pores inside the foam concrete matrix and creating pozzolanic products, ceramic powder waste also improved the interface transition zone (ITZ), which is due to the pozzolanic reaction and filling effect of ceramic powder in addition to the chemical contribution. As a result, the water absorption and the volume of permeable pores decreased with an increase in the percentage of replacing natural sand with ceramic powder waste.

5. RECOMMENDATIONS

The following recommendations suggest future work for further studies:

- Using supplementary cementing materials (SCMs) like fly ash, silica fume, and metakaoline as a partial replacement of cement in the production of foamed concrete.

- Using other construction and demolition wastes, like recycled fine aggregate derived from concrete debris, as a partial substitute for fine aggregate in the foamed concrete.
- Investigating other engineering properties of foamed concrete such as thermal properties (for instance, coefficient of thermal expansion), durability properties (for instance, water and gas permeability), shrinkage deformations, etc.
- Examination of the microstructural measurements of studied foam concrete using techniques such as scanning electron microscopy (SEM).
- For the large-scale commercial exploitation of this type of concrete, greater efforts in terms of process scaling and control of production conditions are still needed.

ACKNOWLEDGEMENTS

This research is the result of the work I did in the Building Materials Testing Laboratory, College of Engineering, University of Mosul. Laboratory employers, technicians, and labors also deserve my thanks, and all fellows for their help provided at laboratory with a positive attitude.

REFERENCES

[1] D. Yang, M Liu, Z. Zhang, P. Yao, Z. Ma, Properties and modification of sustainable foam concrete including eco-friendly recycled powder from concrete waste. Case Stud. Const. Mater. 16 (2022) e00826, https://doi.org/10.1016/j.cscm.2021.e00826.

[2] V. Lesovik, V. Voronov, E. Glagolev, R. Fediuk, A. Alaskhanov, Y. H. M. Amran d, G. Murali, A. Baranov, Improving the behaviors of foam concrete through the use of composite binder. J. Build. Eng. 31 (2020) 101414, https://doi.org/10.1016/j.jobe.2020.101414.

[3] T. Li, F. Huang, J. Zhu, J. Tang, J. Liu, Effect of foaming gas and cement type on the thermal conductivity of foamed concrete. Constr. Build. Mater. 231 (2020) 117197, https://doi.org/10.1016/j.conbuildmat.2019.117197.

[4] H. Gao, W. Wang, H. Liao, F. Cheng, Characterization of light foamed concrete containing fly ash and desulfurization gypsum for wall insulation prepared with vacuum foaming process. Constr. Build. Mater. 281 (2021) 122411, https://doi.org/10.1016/j.conbuildmat.2021.122411.

[5] K. Ramamurthy, E. K. K. Nambiar, G. I. S. Ranjani, A classification of studies on properties of foam concrete. Cem. Concr. Compos. 31 (2009) 388–396, https://doi.org/10.1016/j.cemconcomp.2009.04.006.

[6] E. Eltayeb, X. Ma, Y. Zhuge, O. Youssf, J. E. Mills, Influence of rubber particles on the properties of foam concrete. J. Build. Eng. 30 (2020) 101217, https://doi.org/10.1016/j.jobe.2020.101217.

[7] B. Kado, S. Mohammad, Y. H. Lee, P. N. Shek, M. A. Ab Kadir, Effect of curing method on properties of lightweight foamed concrete. Int. Jour. Eng. Tech. 7 (2.29) (2018) 927-932, https://doi.org/10.14419/ijet.v7i2.29.14285

[8] M. Limbachiya, M. S. Meddah, S. Fotiadou, Performance of granulated foam glass concrete. Construction and Building Materials, 28 (2012) 759-768.
DOI:10.1016/j.conbuildmat.2011.10.052

[9] A. S. Hasan, O. M. Ali, A. A. Hussein, Comparative study of the different materials combinations used for roof insulation in Iraq. Mater. Tod. Proce. 42 (2021) 2285–2289, https://doi.org/10.1016/j.matpr.2020.12.317.

[10] W. Tao1, H. Xingyang, Y. Jin, Z. Huang, S. Ying, Nano-treatment of autoclaved aerated concrete waste and its usage in cleaner building materials. Jour. Wuh. Univ. Tech. Mater. Sci. Ed. 35 (4) (2020) 786–793, https://doi.org/10.1007/s11595-020-2321-6

[11] F. Iucolano, A. Campanile, D. Caputo, B. Liguori, Sustainable management of autoclaved aerated concrete wastes in gypsum composites. Sust. 13 (2021) 3961. https://doi.org/10.3390/su13073961.

[12] Z. Gyurkó, B. Jankus, O. Fenyvesi, R. Nemes, Sustainable applications for utilization the construction waste of aerated concrete. Jour. Clea Prod. 230 (2019) 430–444, https://doi.org/10.1016/j.jclepro.2019.04.357.

[13] P. O. Awoyera, J. M. Ndambuki, J. O. Akinmusuru, D. O. Omole, Characterization of ceramic waste aggregate concrete. HBRC Journal. 14 (2018) 282-287.
https://doi.org/10.1016/j.hbrcj.2016.11.003

[14] R. V. Meena, J. K. Jaina, H. S. Chouhan, A. S. Beniwal, Use of waste ceramics to produce sustainable concrete: A review. Clea Mater. 4 (2022) 100085, https://doi.org/10.1016/j.clema.2022.100085.

[15] Z. Keshavarz, D. Mostofinejad, Porcelain and red ceramic wastes used as replacements for coarse aggregate in concrete. Constr. Build. Mater. 195 (2019) 218–230, https://doi.org/10.1016/j.conbuildmat.2018.11.033.

[16] P. O. Awoyera, B. F. Britto, Foamed concrete incorporating mineral admixtures and pulverized ceramics: Effect of phase change and mineralogy on strength characteristics. Construction and Building Materials. 234 (2020) 117434, doi: 10.1016/j.conbuildmat.2019.117434

[17] L. Gautam, J. K. Jain, P. Kalla, S. Choudhary, A review on the utilization of ceramic waste in sustainable construction products. Materials Today: Proceedings. 43 (2021) 1884-1891, doi: 10.1016/j.matpr.2020.10.829

[18] W. She, Y. Du, G. Zhao, P. Feng, Y. Zhang, X. Cao, Influence of coarse fly ash on the performance of foam concrete and its application in high-speed railway roadbeds. Construction and Building Materials. 170 (2018) 153-166, doi: 10.1016/j.conbuildmat.2018.02.207

[19] O. H. Oren, A. Gholampour, O. Gencel, T. Ozbakkaloglu, Physical and mechanical properties of foam concretes containing granulated blast furnace slag as fine aggregate. Construction and Building Materials. 238 (2020) e01038, doi: 10.1016/j.conbuildmat.2019.117774

[20] R. T. Lermen, G. Bonatto, R. A. Silva, Use of foundry green sand waste in development of foamed concrete. Revista de Arquitetura IMED. 9 (2020) 153-170, doi: https://doi.org/10.55905/revconv.17n.1-060

[21] M. Amran, R. Fediuk, N. Vatin, Y. H. Lee, G. Murali, T. Ozbakkaloglu, S. Klyuev, H. Alabduljabber, Fibre-reinforced foamed concretes: A review. Materials. 13 (4323) (2020) 1-36, doi: **https://doi.org/10.3390/ma13194323**

[22] J. F. Castillo-Lara, E. A. Flores-Johnson, A. Valadez-Gonzalez, P. J. Herrera-Franco, J. G. Carrillo, P. I. Gonzalez-Chi, Q. M. Li, Mechanical properties of natural fiber reinforced foamed concrete. Materials. 13 (3060) (2020) 1-18, doi: **https://doi.org/10.3390/ma13143060**

[23] J. Newman, B. S. Choo, Advanced Concrete Technology-Processes, Elsevier Ltd, 1st edition, 2003.

[24] S. FAlfuady, Y. Idris, Characteristics foam concrete with polypropylene fiber and styrofoam. IOP Conf. Series: Journal of Physics: Conf. Series 1198, SENTEN 2018-Symposium of Emerging Nuclear Technology and Engineering Novelty, (2019) 082020, IOP Publishing, doi: 10.1088/1742-6596/1198/8/082020

[25] G. Calis, S. A. Yildizel, S. Erzin, B. A. Tayeh, Evaluation and optimisation of foam concrete containing ground calcium carbonate and glass fibre (experimental and modelling study). Case Studies in Construction Materials. 15 (2021) e00625, doi: https://doi.org/10.1016/j.cscm.2021.e00625

[26] Y. Peng, X. Yuan, L. Jiang, J. Yang, Z. Liu, Y. Zhao, H. Chen, The fabricating methods, properties and engineering applications of foamed concrete with polyurethane: a review. International Journal of Environmental Science and Technology. (2022) 1-20, doi:

[27] F. K. Abdulhussein, Q. J. Frayyeh, M. S. Al-Shaikhli, Z. F. Jawad, M. M. Salman, Behaviour of thermostone blocks with and without cement mortar plastering exposed to high temperatures. Journal of Applied Engineering Science. 19 (2) (2021), 800, 356-362, doi: https://doi.org/10.5937/jaes0-28742

[28] How to stop 20m tons of construction industry waste going to landfill each year (no date) RMIT University. Available at: https://www.rmit.edu.au/news/all-news/2019/jul/construction-industry-waste-landfill (Accessed: 17 August 2023).

[29] O. Gencel, M. Oguz, A. Gholampour, T. Ozbakkaloglu, Recycling waste concretes as fine aggregate and fly ash as binder in production of thermal insulating foam concretes. Journal of Building Engineering. 38 (2021) 102232, doi: https://doi.org/10.1016/j.jobe.2021.102232

[30] A. A. Jhatial, W. I. Goh, N. Mohamad, L. W. Hong, M. T. Lakhiar, A. A. Abdul Samad, R. Abdullah, The mechanical properties of foamed concrete with polypropylene fibres. International Journal of Engineering & Technology. 7 (3.7) (2018) 411-413.

[31] J. R. Jiménez, J. Ayuso, M. López, J. M. Fernández, J. Brito, Use of fine recycled aggregates from ceramic waste in masonry mortar manufacturing. Construction and Building Materials. 40 (2013) 679-690, doi: https://doi.org/10.1016/j.conbuildmat.2012.11.036

[32] S. Ray, M. Haque, N. Sakib, A. Mita, M. Rahman, B. B. Tanmoy, Use of ceramic wastes as aggregates in concrete production: A review. Journal of Building Engineering. 43 (2021) 1-27, doi: https://doi.org/10.1016/j.jobe.2021.102567

[33] K. W. Shah, G. F. Huseien, Recycled Ceramics in Sustainable Concrete: Properties and Performance, CRC Press and Taylor & Francis Group, 1st edition, 2021, doi: https://doi.org/10.1201/9781003120292

[34] K. Rashid, A. Razzaq, M. Ahmad, T. Rashid, S. Tariq, Experimental and analytical selection of sustainable recycled concrete with ceramic waste aggregate. Construction and Building Materials. 154 (2017) 829-840, doi: https://doi.org/10.1016/j.conbuildmat.2017.07.219

[35] A. M. Barrios, D. F. Vega, P. S. Martínez, E. Atanes-Sánchez, C. M. Fernández, Study of the properties of lime and cement mortars made from recycled ceramic aggregate and reinforced with fibers. Journal of Building Engineering. 35 (2021) 1-10, doi: https://doi.org/10.1016/j.jobe.2020.102097

[36] Z. A. Shareef, S. Y. Ahmed, O. M. Abdulkareem, Potential Use of Wastes of Thermostone Blocks and Ceramic Tiles as Recycled Aggregates in Production of Foam Concrete. Civil Engineering and Architecture. 11 (2023) 1280-1296, doi: 10.13189/cea.2023.110314

[37] BS EN 12350-6: Testing fresh concrete density – part 6, 2019, British and European Standard, doi: https://doi.org/10.3403/BSEN12350

[38] EN 12390-7: Testing hardened concrete density – part 7, 2019, European Standard.

[39]H . El-Didamony, A. A. Amer, M. S. Mohammed, M. Abd El-Hakim, Fabrication and properties of autoclaved aerated concrete containing agriculture and industrial solid wastes. Journal of Building Engineering. 22 (2019) 528-538, doi: https://doi.org/10.1016/j.jobe.2019.01.023

[40] T. Suwan, P. Wattanachai, Properties and internal curing of concrete containing recycled autoclaved aerated lightweight concrete as aggregate. Advances in Materials Science and Engineering. 2017 (2017) 1–11, doi: https://doi.org/10.1155/2017/2394641

[41] M. A. Gawad, N. M. Fawzi, Use of thermostone waste aggregates for internal curing of reactive powder concrete. IOP Conf. Series: Earth and

Environmental Science 877 (2021), Proceedings of the 7th International Conference on Renewable Energy and Materials Technology (ICOREMT 2021), Erbil, Iraq 012043. (2021) 1-16, doi: 10.1088/1755-1315/877/1/012043

[42] P. Rubio de Hita, F. Pérez-Gálvez, M. J. Morales-Conde, M. A. Pedreño-Rojas, Characterisation of recycled ceramic mortars for use in prefabricated beam-filling pieces in structural floors. Materiales de Construcción. 69 (2019) 1-19, doi: https://doi.org/10.3989/mc.2019.04518

[43] A. Gonzalez-Corominas, M. Etxeberria, Properties of high performance concrete made with recycled fine ceramic and coarse mixed aggregates. Construction and Building Materials. 68 (2014) 618-626, doi: https://doi.org/10.1016/j.conbuildmat.2014.07.016

[44] EN 12350: Testing fresh concrete – part 8: Self-compacting concrete – slump flow test, 2008, European Standard.

[45] ASTM C642: Standard test method for density, absorption, and voids in hardened concrete, 1997, American Society for Testing and Materials, doi: 10.1520/C0642-21

[46] R. A. Rahman, A. Fazlizan, N. Asim, A. Thongtha, Utilization of waste material for aerated autoclaved concrete production: A preliminary review. IOP Conf. Series: Earth and Environmental Science 463 (2020) 012035, International Conference on Sustainable Energy and Green Technology, 2019, Bangkok, Thailand. (2020) 1-9, doi: https://doi.org/10.32604/jrm.2021.013296

[47] N. N. Lam, Recycling of AAC waste in the manufacture of autoclaved aerated concrete in Vietnam. International Journal of GEOMATE. 20 (2021) 128-134, doi: 10.21660/2021.78.j2048

[48] E. K. K. Nambiar, K. Ramamurthy, Shrinkage behavior of foam concrete. Journal of Materials in Civil Engineering. 21 (2009) 631-636, doi: https://doi.org/10.1061/(ASCE)0899-1561(2009)21:11(631)

[49] R. Wang, P. Gao, M. Tian, Y. Dai, Experimental study on mechanical and waterproof performance of lightweight foamed concrete mixed with crumb rubber. Construction and Building Materials. 209 (2019) 655-664, doi: https://doi.org/10.1016/j.conbuildmat.2019.03.157

[50] O. Y. Bayraktar, H. Soylemez, G. Kaplan, A. Benli, O. Gencel, M. Turkoglu, Effect of cement dosage and waste tire rubber on the mechanical, transport and abrasion characteristics of foam concretes subjected to H2SO4 and freeze–thaw. Construction and Building Materials. 302 (2021) 124229, doi: https://doi.org/10.1016/j.conbuildmat.2021.124229

[51] N. Tazi, R. Idir, A. B. Fraj, Sustainable reverse logistic of construction and demolition wastes in French regions: Towards sustainable practices. Procedia CIRP. 90 (2020) 712–717, doi: https://doi.org/10.1016/j.procir.2020.01.126

[52] A. Heidari, D. Tavakoli, A study of the mechanical properties of ground ceramic powder concrete incorporating nano-SiO2 particles. Construction and Building Materials. 38 (2013) 255–264, doi: https://doi.org/10.1016/j.conbuildmat.2012.07.110

[53] G. F. Huseien, A. R. M. Sam, K. W. Shah, J. Mirza, Effects of ceramic tile powder waste on properties of self-compacted alkali-activated concrete. Construction and Building Materials. 236 (2020) 117574, doi: https://doi.org/10.1016/j.conbuildmat.2019.117574

امتصاص الماء للخرسانة الرغوية باستخدام الركام المعاد تدويره المشتق من مخلفات البناء والهدم

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تاريخ الاستلام: 1 اكتوبر 2023 استلم بصيغته المنقحة: 1 نوفمبر 2023 تاريخ القبول: 18 ديسمبر 2023

الملخص

الخرسانة الرغوية (FC) هي نوع من الخرسانة خفيفة الوزن التي تحتوي على الكثير من المسام المضافة بواسطة عامل الرغوة. يبحث هذا البحث في إمكانية استخدام نوعين من مخلفات البناء والهدم (CDWs)، بما في ذلك كتل الثرمستون وبلاط السيراميك، كبديل جزئي للرمل في الخرسانة الرغوية لاختبار أداء امتصاص الماء للخرسانة الرغوية. تم استكشاف ثلاثة نسب(25، 50، و75٪) لاستبدال حجم الرمال مع كل نوع من ركام مخلفات الثرمستون او السيراميك. لقد تم إثبات تأثير هذه النسب المختلفة على قابلية التشغيل والكثافة الطرية والكثافة المتصلبة وامتصاص الماء. أظهرت النتائج أن قابلية التشغيل تنخفض مع زيادة نسب الاستبدال، كما تزداد كثافة الخرسانة الرغوية المتصلبة. أما امتصاص الماء فقد انخفض عند جميع نسب الاستبدال نتيجة ملء المسام الموجودة داخل الخرسانة الرغوية وبالتالي زيادة الكثافة الظاهرية. وهذا بدوره يقلل من حجم الفراغات النافذة للخرسانة الرغوية. وكان الحد الأقصى للامتصاص وحجم الفراغات النافذة لنسبة استبدال 75% من ركام الثرمستون والسيراميك، حيث كان 20.68% في الامتصاص و29.2% في حجم الفراغات النافذة لاستبدال كتل الثرمستون، وكانت قيمة الامتصاص 15.96%، و نسبة حجم الفراغات النافذة بلغت للسيراميك 38.28%.

الكلمات الداله :

القابلية التشغيلية، الكثافة، كتل الثرمستون، بلاط السيراميك.