

TONER USED IN THE DEVELOPMENT OF FOAMED CONCRETE FOR STRUCTURAL USE

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Abstract - This paper investigates the effect of toner as a new material on enhancing compressive strength and permeability of foamed concrete (FC). The aim is to develop the FC through testing the reaction of toner with the cement of the FC, to produce a hydrophobic lightweight FC to use for structural elements. Foamed concrete is generally made of ordinary Portland cement (OPC), sand, foaming agent, and water with a well spread pore structure. The experiment was carried out on 100 mm cubes. Results for toner inclusion of all the mixes, when added in the right quantities, showed high improvement for water penetration and compressive strength in comparison to the published data on FC for the use as structural material, which is a step forward in the advancement of FC to meet the aim of this research.

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Keywords: Compressive strength, Foamed concrete, Permeability, Toner.

1.0 INTRODUCTION

Foamed concrete (FC) is a lightweight material made up of Ordinary Portland cement paste (OPC and a filler, usually sand) and water with a well spread air voids or pore structure created by the introduction of air by mechanical means of foaming. The foam can be originated from an agent made of natural surfactants or synthetic materials, and can be added to the concrete mix either as pre foamed (where the foam is prepared in advance by the foaming machine and added later) or as mixed foaming (the foam is added to the mix at the same time as it is prepared) [1]. Foamed concrete is a lightweight material with low densities of between (400 - 1800) kg/m³ [2] incorporating a high volume of air, highly workable, self-flowing, self-compacting and self-levelling with fire resisting, thermal insulating and sound proofing properties. The typical strength value for foamed concrete of densities between (800 – 1600) kg/m³ is between (1–10) N/mm², see *Table 1* [3]. Foamed concrete produced in this range can only be used for general purposes, such as gap fillings. But at a minimum strength of 25 N/mm², foamed concrete has the potential to be used as a structural material [4], [5].

Table 1 Summary of properties of hardened foamed concrete [3]

Density (kg/m ³)	Compressive strength (N/mm ²)
400	0.5 – 1.0
600	1.0 – 1.5
800	1.5 – 2.0
1000	2.5 – 3.0
1200	4.5 – 5.5
1400	6.0 – 8.0

While, *Table 2* shows the maximum compressive strength of 28.5 N/mm² reached [6].

Table 2 Compressive strength of foamed concrete at different densities [6]

Fine aggregate type	Plastic density kg/m ³	28-day compressive strength (N/mm ²)
Sand	1400	13.5
	1600	19.5
	1800	28.5

The protein based foam agents result in a stronger and a more closed-cell bubble structure, which permits the inclusion of greater amounts of air and provides a more stable air void matrix, while the synthetic foam agents yield greater expansion and thus lower density [7]. The content of the foaming agent has a considerable effect on the properties of fresh and hardened concrete. Therefore, the mechanical and physical properties of FC can vary depending on the type of foaming agent and dosage used in the mix [8]. It has been reported that the excessive foam volume results in a drop in flow, decrease in density, and decrease in compressive and tensile strengths [7]. Standard protein based foaming agents are formed by the process of protein hydrolysis using animal proteins from horn, blood, bones of cows or other remainders of animal carcasses. While Synthetic foaming agents are amphiprotic substance that are strongly hydrophilic and easily dissolve in water yielding air bubbles. However, when introducing synthetic agents into concrete, which is a complex chemical environment, the compatibility of surfactant and cement particles is critical to effectively entrain the desired air content and concrete microstructure [8]. The foam should be steady and stable to be able to resist the mortar pressure until the cement initially sets. This helps to build up a strong skeleton of concrete all over the voids filled with air [7].

This paper examines strength and permeability of toner (newly introduced material through this research) in the development of FC to produce a hydrophobic lightweight foamed concrete with enhanced properties to be used as a structural material. Foamed concrete is highly permeable, recently its potential as a semi-structural material came to light. It is generally used in building construction as low strength concrete for foundations, thermal and sound insulations, and in areas where resistance to frost is a requirement [9]. Classification of aerated concrete (AC) based on the method of pore-formation can be summarized as air-entraining method (gas concrete), foaming method (foamed concrete, FC) and combined method [10]. Autoclave is a form of curing, using heat treatment for early gain of concrete strength. The second type of aerated concrete is FC, for which no chemical reactions are involved. The cement content of the foamed concrete for all research studies was kept constant at (500 – 600) kg/m³, which is comparable to other studies [11]-[13]. Addition of toner at 1% or 5% by weight of the cement, had no effect on water demands for the mixes involved.

1.1 TONER

This is a newly introduced material particular to this research, therefore, there is no published data available at all for its usage in this field of FC. This material comes in the form of a powder, which is going to be used as an additive to the experimental mixes, at 1% and 5% of the binding cementitious material (cement). This material is chosen for this research because it is widely available as a waste material for recycling and to help cleaning the environment by reducing buried waste and CO₂ emission around the world. Table (3) shows chemical composition for toner. Also, toner includes the following additives for flow and lubrication purposes: Fumed silica and metal stearates.

Table 3 Chemical composition of toner [14]

Toner Type	Composition
Plastic (Styrene acrylate copolymer, polyester resin)	65-85% or 55-65%.
Iron oxide	6-12% or 30-40%.
Wax, ground sand	1-5%
Amorphous silica	1-3 %
Carbon black	1-10%.

2.0 EXPERIMENTAL WORK

The experiments were carried out in the laboratory in accordance to the relevant British Standards (BS) for each part of the process. Sets of 100 x100 x 100 mm plastic cube moulds were used to cast the normal weight concrete samples, whereas, disposable polystyrene cube moulds were used to cast all concrete samples containing foam to avoid the use of release agent and enabling the sealed curing process of the desired period of 28 days, figures (1 and 2). Eleven batches of different concrete mixes, made with OPC and sand, with a w/c ratio of 0.5. Only 5 out of the 11 batches made with the inclusion of toner at 1% and 5%. The foam was added at different percentages to the mixes to produce the desired densities. The foaming agent used in this project was a protein based foaming agent, dry pre-foaming method was used to generate the foam. All specimens cured for 28 days.

For a target plastic density (D , kg/m^3) and water/cement ratio (w/c), the binder content (Cement, kg/m^3), the total mix water (W , kg/m^3) and fine aggregate content (Sand, kg/m^3) are calculated from the following mix design equation:

$$D = C + W + F$$

Where D = target plastic density, kg/m^3 C = binder (cement content) kg/m^3
 W = water content, kg/m^3 F = filler (fine aggregate, sand) kg/m^3

2.1 COMPRESSIVE STRENGTH AT 28 DAYS

The test was carried out with a digital log keeping and digitally controlled automatic loading machine in accordance with BS EN 12390-3:2009 [15]. The oven dried cubes were placed centrally under the loading plates and positioned to have even surfaces in contact with the loading plates, figures (3A and 3B). Results quoted in each case are the average of six specimens.



Figure 1 Disposable polystyrene cube moulds of the size (100 x 100 x 100) mm.



Figure 2 Sealed cubes in cling film as a method of curing.



Figure 3, A; Cube between plates under compression, B; Cube after crushing.

2.2 PERMEABILITY AT 28 DAYS IS MEASURED THROUGH CAPILLARY WATER ABSORPTION AND TOTAL WATER ABSORPTION

2.2.1 CAPILLARY WATER ABSORPTION

Capillary water absorption test was carried out under 5 bar pressure in accordance with BS EN 12390-8:2009 [16]. Three oven dried specimens put under the 5 bar permeability test apparatus for 72 hours, after which they are taken out and split open to mark and measure water penetration from bottom up, results expressed in millimetres (mm), *Figures 4 and 5*.



Figure 4 Left; Permeability apparatus



Figure 5 Specimens split open and marked

2.2.2 TOTAL WATER ABSORPTION

Total water absorption test was carried out in accordance with BS 1881-122:2011 [17]. Three oven dried were totally immersed in water for at least 72 hours, after which they were taken out to measure weight of absorbed water. The absorbed water was determined from the difference in weight between fully water saturated and dried state of a specimens. Results expressed in (kg/m^3) or in (%) of the dried weight.

3.0 RESULTS AND DISCUSSIONS

3.1 COMPRESSIVE STRENGTH

This part will be analysed based on the emerging results for the different densities, and on the bases of the $28.5 \text{ N}/\text{mm}^2$ compressive strength set as a standard from *Table 2*, see *Figure 6* and *Table 4*:

Through the highest to the lowest density of 1800 to $500 \text{ kg}/\text{m}^3$, S7 to S11 showed higher compressive strength of 49.3 to $5.1 \text{ N}/\text{mm}^2$, compared to those corresponding compressive strengths of S2 to S6 made with no toner inclusion. The reaction between the constituents of the toner i.e. the iron oxide and the silica with the chemical composition of the binding material, results in a strong intercellular bond, in turn, a higher compressive strength.

- The use of toner upgrades the strength to a much higher level, taking S8 of $55.1 \text{ N}/\text{mm}^2$ as an example, the strength has increased by 93% (almost by two folds) over the $28.5 \text{ N}/\text{mm}^2$ set as a standard.
- Looking at the very low densities of the $500 \text{ kg}/\text{m}^3$, S11 of $5.1 \text{ N}/\text{mm}^2$, again, they have shown improvement by about 40 % compared to those figures published within the literature review of ($0.5 - 2.0$) N/mm^2 for those matching densities.

- Most of the above discussed results obtained for foamed concrete with toner inclusion of S7 to S9, closely match that of the sand mix normal concrete of 2000 kg/m³, taken as a controlled concrete mix for comparison.

Table 4 Labelling for fillers of different concrete mixes and their densities

Labeling	Type of concrete cast	Dry density
		(Kg/m ³)
S1	Sand	2000
S2	Sand	1800
S3	Sand	1600
S4	Sand	1300
S5	Sand	1000
S6	Sand	600
S7	Sand and Toner	1800
S8	Sand and Toner (5%)	1700
S9	Sand and Toner (5%)	1600
S10	Sand and Toner (1%)	1100
S11	Sand and Toner (1%)	500

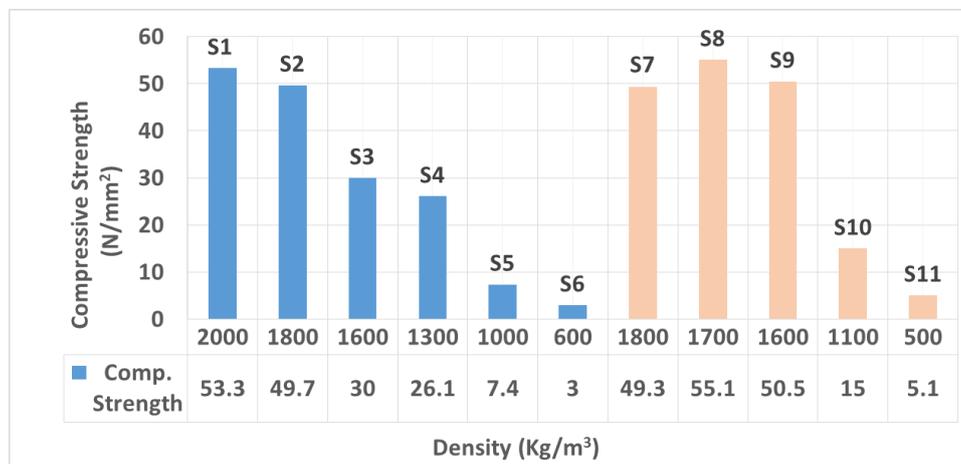


Figure 6 Compressive strength versus density for different mixes contain sand and toner

3.2 PERMEABILITY

3.2.1 CAPILLARY WATER ABSORPTION UNDER 5 BAR PRESSURE

All specimens made with toner inclusion, showed superior qualities over those made with the same corresponding mixtures but without the inclusion of toner, see S7 to S10, *Figure 7* and *Table 4*.

S7 of 1800 kg/m³, 2 mm, S8 of 1700 kg/m³, 1 mm, S9 of 1600 kg/m³, 3 mm, showed less water penetration of 26 mm for the normal concrete of S1 specimen made without toner inclusion of 2000 kg/m³ density.

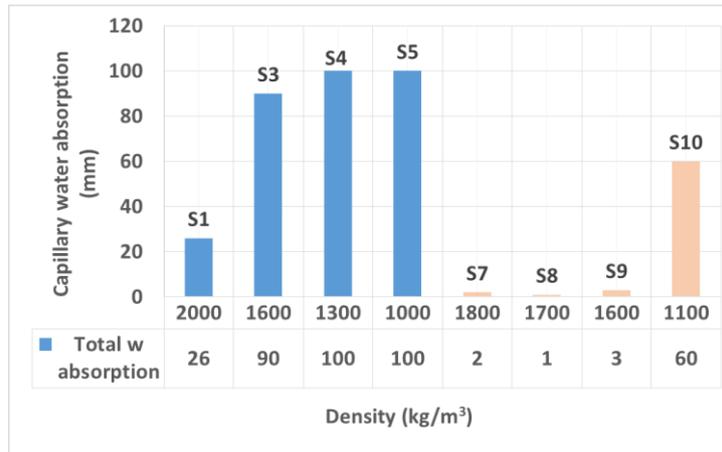


Figure 7 Capillary water absorption (mm) versus density for different mixes with and without toner inclusion

3.2.2 TOTAL WATER ABSORPTION

Looking through *Figures 8 and 9*, all specimens with the inclusion of toner, S7 to S10 recorded permeability of the range between (7 % to 12.5 %) or (115.2 to 138.5) kg/m³ of their dry weight while all the rest of the specimens made without the inclusion of toner show higher permeability of the range between (9.3% to 38.8 %) of their dry weight, or (187.7 to 388.7) kg/m³ water absorption. Specimens S7 to S10 showed less permeability compared to S1 specimen which is 187.7 kg for normal concrete of 2000 kg/m³, therefore, toner inclusion showed improvement in this respect, *Figure 9 and Table 4*.

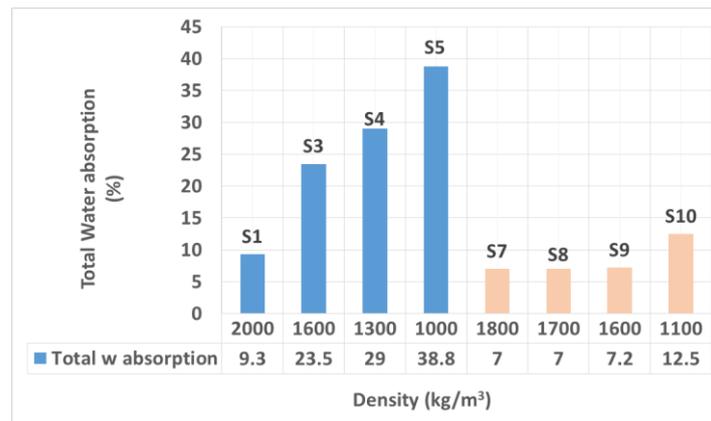


Figure 8 Total water absorption (%) of dry weight versus density for different mixes with and without toner inclusion.

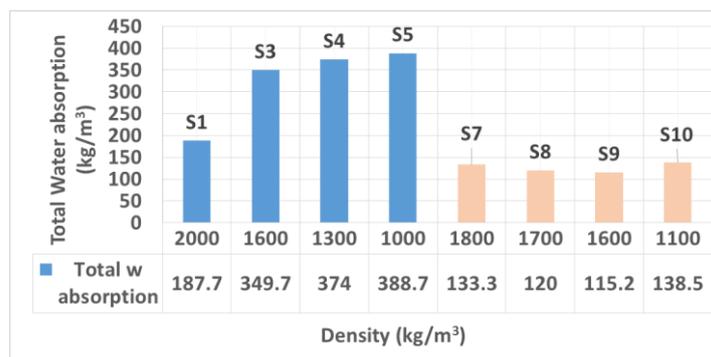


Figure 9 Total water absorption (kg/m³) of dry weight versus density for different mixes with and without toner inclusion

In both cases of the capillary water absorption and total water absorption improvements, the lubricating metal stearates from the toner forming a fine coating film around the binding particles and the voids, resulting in a stronger and closely packed hydrophobic (water repellent) cellular concrete matrix.

4.0 CONCLUSIONS

The following conclusions can be drawn from the present study:

Toner at 5% dose, proved to be an excellent viable material for inclusion in foamed concrete (FC), improving compressive strength almost by up to two folds compared to those demonstrated through figures published by BCA [2]. Permeability test through capillary water absorption is improved to reach a minimum of a few millimetre water penetrations, i.e. close to zero, which cannot easily be obtained even with normal concrete of high densities. Permeability test through total water absorption is also improved to values that only the normal concrete of high densities of 2000 kg/m³ and beyond can reach, i.e. permeability reached the minimum comparative values. Compressive strength is directly related to concrete density; concrete of high density exhibits high compressive strengths. Toner will enhance the compressive strength and permeability when added to the mix at 5%, compared to the 1%. This material can be used in the development of the FC to be used in the construction of light weight structural elements.

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