Porosity and Sorptivity of Aerated Concrete with Different Aluminium Powder Content

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***Abstract*—** The purpose of this paper is an investigation of porosity and sorptivity of aerated concrete with varying percentage additions of aluminium powder between 0.25% and 0.75%. The bulk density, porosity and sorptivity were determined after 28 days of water curing. The results show that the highest density of aerated concrete was with 0.25% aluminium powder. The porosity values obtained by vacuum saturation were consistently formed to be higher than those obtained by soaking which suggests that the soaking method does not access all the pore space. Also, the capillary suction of aerated concrete as assessed by sorptivity was significantly higher than that measured by coefficient of water absorption method.

***Keywords*—**Aerated concrete, density, porosity, sorptivity and aluminium powder content.

I. Introduction

Aerated concrete (AC) is a significant construction material. 60% to 90% of its volume is pore space. Pores are categorised as micro, macro-capillaries and artificial air voids with diameters between 100 nm to 4 mm [1, 2]. The properties of strength, durability, toughness, heat transfer and moisture transport are influenced by the pore size and microstructure. [3-5]. A very porous material will produce excellent acoustic insulation and thermal properties. However, as the pore volume increases, the strength decreases. As a result, characterization of porosity and its effect on the mechanical strength of cellular concrete is an extremely important factor to be analysed in the manufacture of this kind of material [6]. The porosity and sorptivity of a concrete are affected by water content; for that reason a clearly defined condition must be used for testing [7]. Furthermore, incomplete drying results in retaining residual water in the pore system, particularly in the smaller pores. Day and Marsh used methods for assessing porosity by oven drying or re-saturation after oven drying which are equivalent methods. They studied the pore structure characteristics of cement paste containing fly ash. They concluded that the pozzolanic reaction of fly ash can lead to substantial reductions in porosity and that oven drying is the preferred process for assessing porosity [8]. Struharova and Rousekova studied the effect of the pore structure on density and compressive strength of cellular concrete. Their results showed that the pore structure is the main influence on these properties with the total pore size distribution range between 5 to 47 nm. The change in the values of porosity are small and there is no significant influence on compressive strength, wetting of the surface or absorbency of the cellular concrete [9]. Kearsley and Wainwright studied the porosity of foam concrete with the larger volume of cement replacement by classified and unclassified fly ash (up to 75%). It was noted that porosity is mainly dependent on the dry density of aerated concrete rather than the content or the type of fly ash. The volume of water absorbed by foamed concrete was twice that of the cement paste [10]. The influence of aluminium powder (0.2% - 0.8%) on porosity, density and compressive strength of autoclaved clayey cellular concrete was studied by Gugliemir *et al.* It was noted that the porosity increases by an increase in aluminium powder up to 0.4% and then decreases significantly between 0.6% - 0.8%. The mixtures with high aluminium powder content presented pores with a coalescence and non-uniform shape which were larger than those with low aluminium content. By contrast, density and compressive strength decreased slightly up to 0.4% and then increased as the porosity decreased. With a high amount of aluminium powder, part of the hydrogen gas was not effective in producing pores when the reaction between hydroxides and aluminium took place [11]. Raj and John studied the effect of different aluminium powder percentages (0.1, 0.2, 0.5, 1, 2 and 5%) on the bulk density and compressive strength of aerated concrete blocks. Their results showed that the dry density and compressive strength increased by increasing aluminium powder. Addition of more than 5% aluminium powder caused the compressive strength and density to decrease drastically [12]. The aim of the current study is to investigate the effects of varying the aluminium powder content on the density, porosity and sorptivity of aerated concrete after 28 days of water curing.

II. Materials

A. Materials and Mix Design

Ordinary Portland Cement CEM I/52.5N with Leighton Buzzard Sand (0-2mm) were mixed in proportion 1:2. The cement dosage was 350 kg/m^3 and water/cement ratio was 0.5. Daracem 215 superplasticizer (SP) was added by 1% of cement weight and aluminium Powder (Al) purity 99.7% as shown in table 1. Warm water at 55 °C was added to accelerate the reaction throughout the experiment.

B. Mortar Preparation

Sand and cement were put into a rotating drum mixer and

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mixed for 1 min; 70% of the water together with the SP were added and mixed for another 5 min. Then, aluminium powder was incorporated and mixed for an extra 30 seconds. Finally, the remaining water was added and mixed for 10 min. The specimens were demoulded approximately 24h after casting and then placed under water in a curing tank. For each combination of the parameters, two specimens were tested and the mean value is reported.

C. Test specimens

Rectangular specimens with dimensions 50 × 50 × 100 mm were used for studying the bulk density of aerated concrete. Disks with a diameter 75 mm and thickness 70±1 mm [13] were used to determine the porosity and sorptivity. The bulk density of the aerated concrete was determined according to the BSI. 992 [14]. Porosity was measured according to BSI.1881-122 and by vacuum saturation as recommended by Hall [13, 15]. The capillary suction was measured according to BSI. 772-11 and by the sorptivity according to Neville [16, 17].

TABLE I
MIX PROPORTION OF CONTROL AND AERATED CONCRETE WITH DIFFERENT ALUMINIUM POWDER CONTENTS

Material	kg/m^3			
	Mix 1	Mix 2	Mix 3	Mix 4
Cement	350	350	350	350
Sand	700	700	700	700
Water	175	175	175	175
Aluminium powder	0	0.875	1.75	2.63
Superplasticizer (SP)	4.2	4.2	4.2	4.2

III. EXPERIMENTAL PROCEDURES

A. Bulk Density

Bulk density is the density of aerated concrete in its "as-cast" form where the overall volume of the material includes the air in between the particles [18]. The dry weight (w_{dry}), water density (P_w), saturated weight (w_{sat}) and Archimedean weight (w_A) were used to determine the bulk density.

$$P_{Bulk} = w_{dry} \times P_w / w_{sat} - w_A \qquad (1)$$

B. Porosity

The porosity of aerated concrete was determined by two methods: water soaking and vacuum saturation.

B.1. Porosity by Soaking

The porosity measurement by soaking is termed "water absorption". The terminology used here is somewhat confusing. Porosity means the amount of water in the pore space, the term "water absorption" in this context suggests a capillary suction measurement. The porosities of the control and aerated concretes were measured according to BS 1881-122 by drying the specimen at a controlled temperature of 105°C ± 5 °C for 72 ± 2h. On removal from the oven, the specimen was cooled for 24± 0.5h and then weighed. The specimen was immersed in a water tank to a depth of 25± 5mm over the top for 30 ± 0.5 min. One specimen was then removed, shaken to remove excess water and surface-dried. The water absorption W_A was calculated as the increase in mass caused by immersion expressed as a percentage of the mass of the dry specimen [19, 20].

$$W_A = w_{sat} - w_{dry} / w_{dry} \times 100\% \qquad (2)$$

B.2. Vacuum Saturation Porosity

Vacuum saturation is a method which is used to access the total porosity of the material. Vacuum Saturation Apparatus was used to measure the porosity of aerated concrete after drying the specimens in an air oven at 100 °C ± 5 °C until the mass became stable [10]. The dried specimen was allowed to cool and then placed in a chamber which was connected to a vacuum pump. By pumping, the chamber was evacuated for a 20 min. and then back-filled with water to cover the specimen. The sample was left to soak for 20 min. after the chamber was returned to atmospheric pressure [10, 15]. The porosity was calculated from:

$$f = W_A \times P_{bulk} / P_{water} \qquad (3)$$

OR

$$f = w_{sat} - w_{dry} / w_{sat} - w_A \qquad (4)$$

P_{bulk} *: is the bulk density in kg/m^3*

C. Capillary suction tests

The capillary suction of the aerated concrete samples was measured by both sorptivity and coefficient of water absorption methods.

C.1. Sorptivity

A simple procedure to measure the sorptivity of mortar and bricks has been defined by Gummerson et al. and Hall and Tse [21, 22]. After drying the specimen to a constant mass at 70°C±5°C in an air oven [17] it was placed, supported by a small plastic spacers, in a shallow tray containing water to a depth of about 5mm. The specimen was removed at regular intervals, surface-dried then weighed. Each weighting was completed within 30 sec. The water level was kept constant in the tray throughout. The weight of water absorbed was obtained at ten different times (1, 4, 9, 16, 25, 36, 49, 64, 81and 100 minutes) and the absorbed volume of water per unit area of absorbing surface was calculated for each. The cumulative water absorption i is proportional during the initial absorption period to the square root of the elapsed time t [23].

$$i = S\sqrt{t} \qquad (5)$$

where i : is the cumulative volume of water absorbed per unit area; S, the sorptivity measured in mm^3 per mm^2 per min$^{1/2}$ and t, time in min.

The sorptivity was calculated from the slope of the linear part of the i versus $\sqrt{t}$ curve. The sorptivity is dependent on the initial water content and its homogeneity through the specimen under test. The point of origin in practice is neglected when the slope is determined on the graph. This is due to an increase in the mass of the specimen produced by filling of the open surface pores on the sides and inflow face of the specimen. To minimise these effects, it is essential to submerge the specimen in water; to a depth of between 2 and 5mm [16].

C.2. Coefficient of Water Absorption

The coefficient of water absorption was determined according to BS EN 772-11:2011. The specimens were dried in a ventilated oven at a temperature of 70 °C ± 5 °C until constant mass mdry,s was reached. They were then allowed to cool at room temperature at which point the dimensions of the faces to be immersed were measured and the gross area, As, calculated. As above the specimens were placed with their absorbing faces supported so that they were clear of the base of the tray and immersed in water to a depth of 5 mm ± 1 mm for 10, 30 and 90 minutes [24]. The water level was maintained constant throughout the test and to avoid evaporation from the wet specimens, the tank was covered. After each immersion time (t_{so}) the specimens were removed, the wet surfaces wiped and then weighed and the coefficient of water absorption calculated from [17].

$$C_{w,s} = m_{sat} - m_{dry} / A_s \sqrt{t}_{so} \tag{6}$$

$C_{w,s}$:Coefficient of water absorption due to capillary action for AC; m_{sat}: mass of saturated surface of the specimen and m_{dry}: mass of dry surface of the specimen.

IV. Results and Discussion

A. Bulk Density

The bulk density of the aerated concrete specimens varied with aluminium powder content. It decreased significantly from 2107.8 kg/m^3 at 0% to 1850.6 kg/m^3 at 0.75% and these results are shown in Fig1. With increasing aluminium powder content, the bulk density of the aerated concrete systematically decreases due to a high amount of pores formed [12]. In contract, Raj and John pointed out that an increase in aluminium powder causes an increase in density. In the work of Raj and John, different percentages of aluminium were used ranges 0.1% - 5% [12].

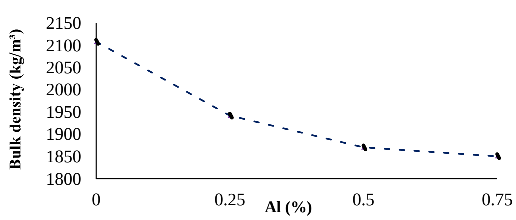


Fig 1: Bulk density of aerated concrete as a function of aluminium powder content.

B. Porosity

Porosity is the sum of the entrained air pores and voids within the paste. The porosity was increased as the aluminium powder content increased. The lowest porosities of 8.85% and 2.49% were obtained for the control (0% Al) by vacuum saturated and water soaking methods respectively as shown in Fig 2. On the contrary, Guglielmi et al., observed that the porosity of an autoclaved clayey cellular concrete decreased when the aluminium powder percentage was increased from 0.6 to 0.8 %. They reported that pore coalescence is caused by the high reactivity of aluminium powder and at higher concentrations it is possible that the number of bubbles is so high that it is more likely for them to coalesce into larger bubbles, which then escape, than to remain discrete. Ongoing microscopy by the author will indicate whether this is the case. They proposed that this problem could be reduced by minimizing the amount of superplasticizer in order to increase the viscosity of the cementitious paste so that the escape of the hydrogen bubbles would be reduced [11]. For the study reported here the maximum porosity was found to be 0.75% and the porosity of the specimens measured by vacuum saturated was significantly higher than that measured by the water soaking method. For the vacuum saturation method, the specimen was completely dried until a constant mass was obtained. Furthermore, the vacuum withdraws all the remaining moisture inside the pores. In contrast, the water soaking method indicated both incomplete drying (short drying period 72h) leading to residual water being left behind in the smaller pores in the pore system and also incomplete saturation since the water can only enter the material by capillary absorption at each face. Saturation is thus limited by the capillary transfer which can occur in 30 minutes.

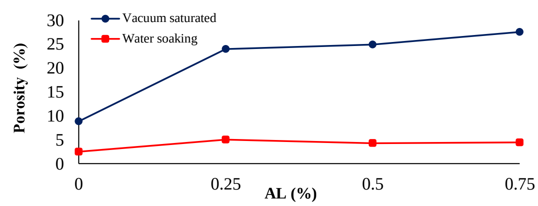
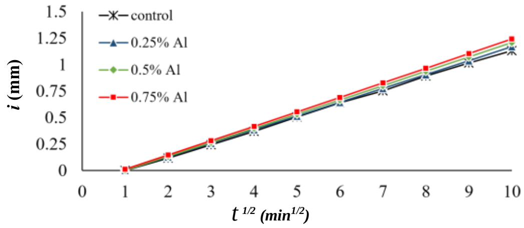


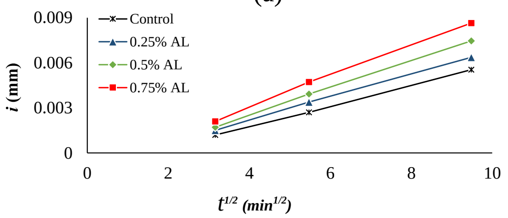
Fig 2: Porosity of the aerated concrete with different aluminium percentage.

C. Capillary Suction

The plots of cumulative volume of water absorbed per unit area of absorbed surface against square root of time for all specimens are shown in Figs 3 (a) and (b). The graphs are linear and the sorptivity is given by the slope of the straight line in each case. On the contrary, Hanzˇicˇ and Ilic et al., observed a non-linearity, they proposed that his phenomenon refers to the new hydration of cement which took place when the specimen was placed in water and causes an increase of effective grain size which tends to block the micropores. Accordingly, water movement through concrete is hindered [25]. Other trends of sorptivity were obtained by Jennings and Tennis, where the cumulative water absorption against square root of time was a curve. Since there is a reduced amount of low density C-S-H gel, it is predictable that there is minimal swelling and shrinkage [26]. It can be seen that the control mortar exhibits higher resistance to water absorption than those containing aluminium. The sorptivity of aerated concrete increases with increasing aluminium powder content and the highest sorptivity was found at 0.75% Al. The relationship between sorptivity and aluminium powder is shown in Fig 4 and the capillary suction measured by the coefficient of water absorption method was significantly lower than the sorptivity.



(a)



(b)

Fig 3: Cumulative water absorption per unit area of absorbing surface plotted against the square root of time for AC containing various percentages of Al: (a) sorptivity and (b) coefficient of water absorption.

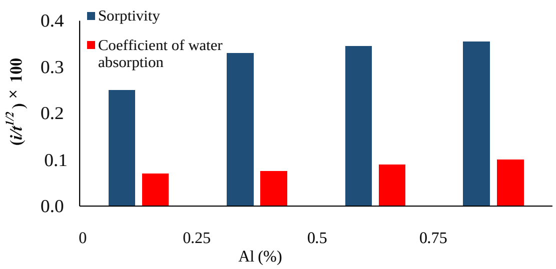


Fig 4: Dependence of sorptivity and coefficient of water absorption on different Al content.

V. Conclusion

This study aimed to investigate the influence of aluminium powder content on the bulk density, porosity and sorptivity of aerated concrete. Porosity and sorptivity of specimens with different aluminium powder were analysed and the results were compared to the control specimens containing no Al powder. The following may be concluded.

- By increasing the Al content, the density decreased due to the large porosity formed.
- Porosity obtained by vacuum saturation method was more accurate than water soaking and it allows the total pore volume to be measured.
- Capillary suction assessed by sorptivity was significantly higher than the coefficient of water absorption method. The reason for this has yet to be complained.

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