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Reinforced Foamed Concrete – Can it be Durable?

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ABSTRACT:

Foamed concrete is produced by mixing a stable foam, formed using an aerated foaming agent, into a cement-based mortar. The foam creates innumerable small voids in the foamed concrete, which could, if the voids are inter-linked, form paths for water or gas to reach steel reinforcement, resulting in corrosion, and thus low durability. The durability of the foamed concrete is currently being investigated at the University of Pretoria and this article contains some of the initial results of this investigation.

No historical durability information on foamed concrete is available, therefore accelerated corrosion tests were conducted to compare the accelerated rate of reinforcement corrosion in foamed concrete with that in normal-weight 25 MPa portland cement concrete. The oxygen permeability of concrete can be used as an indication of its likely durability and, for this reason, relative oxygen permeability was determined. The results obtained from the corrosion and permeability tests are discussed in this article.

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TECHNICAL PAPER

REINFORCED FOAMED CONCRETE – CAN IT BE DURABLE?

by E.P. Kearsley (Pr Eng. M Eng.) and P.J. Booysens (B Eng.)

Elsabé Kearsley graduated from the University of Pretoria with a BEng (Civil) degree in 1984. After working in the design office and on construction sites for consultants in both South Africa and the UK, she joined the staff of the University of Pretoria in 1990 where she is currently employed as senior lecturer in Civil Engineering. She holds a Masters degree in Civil Engineering and has been involved in foamed concrete for the past seven years.

Pieter Booysens obtained his BEng (Civil) degree from the University of Pretoria in 1997. It was during his final year studies at the University of Pretoria that he became involved with research in foamed concrete. His final year project report was written on "The durability of steel reinforcement in foamed concrete", and this paper is based on the results obtained from his final project. He was working at VKE Consulting Engineers when sadly, he was killed in July 1998 in the Bushbuckridge bridge disaster.

SYNOPSIS

Foamed concrete is produced by mixing a stable foam, formed using an aerated foaming agent, into a cement based mortar. The foam creates innumerable small voids in the foamed concrete, which could, if the voids are inter-linked, form paths for water or gas to reach steel reinforcement, resulting in corrosion, and thus low durability. The durability of foamed concrete is currently being investigated at the University of Pretoria and this article contains some of the initial results of this investigation.

No historical durability information on foamed concrete is available, therefore accelerated corrosion tests were conducted to compare the accelerated rate of reinforcement corrosion in foamed concrete with that in normal-weight 25 MPa Portland Cement concrete. The oxygen permeability of concrete can be used as an indication of its likely durability and for this reason relative oxygen permeability was determined. The results obtained from the corrosion and permeability tests are discussed in this article.

1. INTRODUCTION

Cellular or aerated concrete is produced by introducing voids into a cement based mortar. These voids can be produced by gas generated during a chemical reaction, normally caused by the addition of aluminium powder (gas concrete), or air. If air is introduced to a cement based mortar by the addition of a foaming agent, the material produced is called foamed concrete. Foamed concrete normally has a density of between 300 and 1800 kg/m^3. The compressive strength generally increasing with density. The density of foamed concrete is a function of the volume of foam added to the mix, while the compressive strength is an exponential function of the density as indicated in Figure 1[1].

Although the compressive strength of foamed concrete is much lower than that obtainable from normal concrete it is possible to manufacture foamed concrete with dry densities as low as 1 250 kg/m^3 and compressive strengths in excess of 24 MPa. It is, therefore, possible to significantly reduce the dead load of reinforced concrete structures by using foamed concrete, on condition that the foamed concrete has suitable long term properties (such as creep and durability).

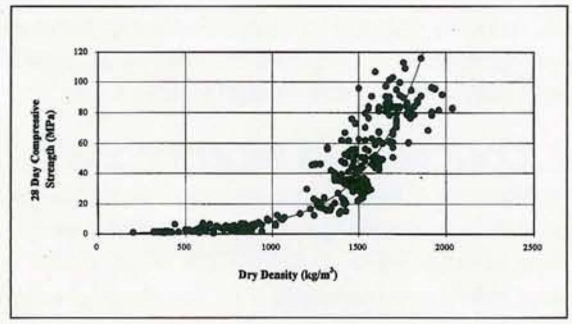

Figure 1: Relationship between Compressive Strength and Dry Density of Foamed Concrete.

Foamed concrete is self-compacting, free flowing and pumpable and therefore easy to place in inaccessible positions[2]. Over the last fifty years, the use of foamed concrete in the construction industry has been almost exclusively limited to non-structural applications such as void filling, thermal insulation, acoustic damping, trench filling for reinstating of roads and building blocks. In the Netherlands, foamed concrete has been used as a fill material, where ground subsidence has taken place and as a founding layer for roadworks on very weak soils[3]. In South Africa, foamed concrete was first used in bulk in 1989 as lightweight backfill behind two berths at Richards Bay Harbour[4]. In the UK, foamed concrete has recently been used as lightweight backfill to bridge abutments[5].

Although foamed concrete has been widely used throughout the world, it is perceived to be weak and non-durable. A durable structure will maintain its required strength and serviceability during its service life, and the durability of concrete depends largely on the penetrability of concrete. Authors such as Short and Kinniburgh[6] state that for aerated concrete "it is obvious that because of its overall macro-porosity and cell-like structure and also because of the possible porosity of the cell walls the cellular material is inherently less resistant to the penetration of moisture and vapour than dense, compacted concrete". Neville[7] has stated that untreated aerated concrete should not be exposed to an aggressive atmosphere and that unprotected reinforcement in aerated concrete would be vulnerable to corrosion, even when the external attack is not very severe. From available literature [6,7] it could be concluded that reinforced foamed concrete is likely to provide low levels of durability, as the reinforcement will be prone to corrosion. This conclusion has to be proven, however, before preventative measures can be evaluated.

Against this background, preliminary tests have been conducted at the University of Pretoria to compare the accelerated rate of reinforcement corrosion in foamed concrete with that in normal-weight, Portland Cement (PC) concrete. Foamed concrete with different densities were considered to determine the effect of increased void content on the reinforcement corrosion rate.

2. CONCRETE MIX PROPORTIONS

As the density of foamed concrete has a major influence on its compressive strength, it was not possible to design mixes based on equal 28 day strength. Mix proportions were initially selected to give a 28 day standard cube strength of 25 MPa for a normal-weight control PC mix and a foamed concrete mix with a casting density of 1 500 kg/m^3. Foamed concrete mixes with design casting densities of 1 000 and 1 250 kg/m^3 were chosen to have the same mix proportions as the 1 500 kg/m^3 mix. Densities recorded for the experimental mixes are given in Table 1[8]. The casting densities were obtained by weighing samples during casting, while the dry densities were determined form cubes that were cured for 28 days and then placed in a drying oven at 100 +5°C until constant mass was reached.

3. EXPERIMENTAL TEST PROCEDURES

3.1 Strength Development

Two different curing regimes were applied, where the first and preferred method of curing for foamed concrete involved wrapping the samples in polythene, before curing them in air at 40°C, while the second method is the normal method of curing concrete in water at 22°C[9]. The 28 day compressive strengths are the mean values obtained from crushing three 100 mm cubes. The cubes were tested within 30 minutes after removal from either the water bath or the curing room and although the samples taken from the curing room were not saturated, they were tested before drying out could take place.

3.2 Accelerated corrosion test

The corrosion of steel in concrete structures is essentially a long term process but for rapid initial evaluation of the durability of reinforced foamed concrete, accelerated laboratory tests using a galvanostatic setup were conducted. In the accelerated galvanostatic method used, the reinforcement was corroded by the application of eternal electric current[10,11]. The potential difference over the sample was kept constant and as the steel corrosion progressed, the value of the measured current became larger. When a graph is drawn of the measured current as a function of time the area under the current-time graph is, according to Faraday's Law, directly related to the total amount of steel corrosion[12]. The results obtained form these tests were for comparative purposes only and long term exposure tests will need to be conducted to confirm these results.

Table 1: Mix Proportions and Properties.

Mix	Casting Density (kg/m^3)	Dry Density (kg/m^3)	Water/ Cement Ratio
25 MPa PC Concrete (Control mix)	2 385	2 170	0.8
1 500 kg/m^3 Foamed Concrete	1 472	1 246	0.6
1 250 kg/m^3 Foamed Concrete	1 274	1 055	0.6
1 000 kg/m^3 Foamed Concrete	985	770	0.6

The electrochemical system used is shown schematically in Figure 2. Three cylindrical specimens (80 mm diameter; 300 mm long) were cast from each of the four concrete mixes with each sample consisting of a reinforcing bar (20 mm diameter) cast into the centre of the mould, providing 30 mm cover the reinforcement. The concrete mix proportions and depth of cover to steel used in this study were not chosen to meet the durability requirements for severe conditions of exposure given in SABS 0100[13], but to provide concretes which would undergo a measurable amount of deterioration in a relatively short period of time. The normal-weight PC concrete mix proportions and cover depth used are however typical values often used on construction sites and therefore the results obtained from this mixture was used as a control.

Each reinforcing bar was cleaned and weighed before samples were cast. The samples were demoulded after 24 hours, wrapped in polythene and cured in the curing room at 40°C for 28 days. After curing the samples were placed in an electrolyte (2.5% NaCl per weight) for 24 hours. A potential difference of 12 V DC was then applied over each sample in such a way that the reinforcing steel acted as an anode and the copper plate as a cathode. The current through each sample was measured at 24 hour intervals. Large increases in current would indicate the formation of cracks, reducing the resistance of the sample, caused by the concrete cover.

After 21 days one specimen from each concrete mix was removed and the rate of reinforcement corrosion estimated by measuring weight loss. The remaining samples were removed after 28 days and the weight loss of the reinforcement was again determined by removing the reinforcing bars.

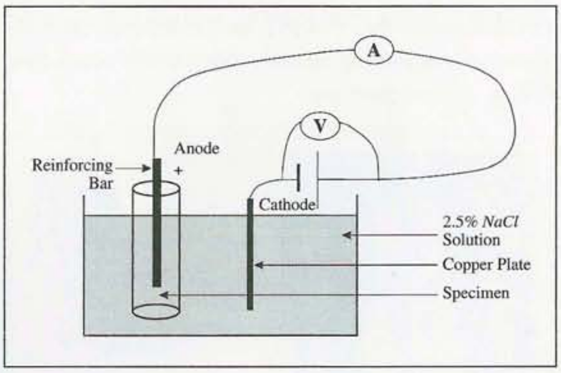

Figure 2: Galvanostatic Setup.

3.3 Oxygen Permeability Test

In order to relate the results obtained from the accelerated corrosion test to penetration resistance, an additional series of oxygen permeability tests were undertaken using a falling head permeameter[14]. The samples tested were 68 mm diameter cores drilled from the centre of 150 mm cubes and sliced into 15 mm thick disks. Each disk was placed in a silicone rubber collar and the pressure on the one side of the disk was increased to approximately 100 kPa, whereafter the decline in pressure was recorded as a function of time.

4. EXPERIMENTAL RESULTS

4.1 Strength Development

The 28 day compressive strength results given in Table 2 are the mean values obtained from crushing tree cubes. The 28 day compressive strengths of individual cubes crushed have been plotted as a function of testing density in Figure 3. As expected, the compressive strength of the foamed concrete was a function of density, with the strength results recorded increasing with the testing density of the concrete. It can also be seen from Figure 3 that the foamed concrete cured in humid air at 40°C developed significantly higher compressive strength than those standard cured in water.

It is interesting to note that this trend does not exist for the normal 25 MPa control concrete. The increase in density between casting and testing of samples cured under water (as can be seen in Figure 3) indicate that the water is absorbed and this could affect the compressive strengths. As this volume of water varies, and cannot be controlled, it was decided to prevent water absorption by wrapping all samples in polythene.

Table 2: 28 Day Compressive Strengths

Mix	28 Days 40°C Air (MPa)	28 Days 22°C Water (MPa)
25 MPa PC Concrete (Control mix)	27.4	26.7
1 500 kg/m^3 Foamed Concrete	29.3	19.9
1 250 kg/m^3 Foamed Concrete	17.6	11.7
1 000 kg/m^3 Foamed Concrete	5.0	2.8

4.2 Accelerated corrosion test

The current passing through each of the samples in the accelerated potentiometer test was measured daily and the cumulative current (area under the time-current diagram) measured, as shown in Figure 4 (i to iv). The graphs are arranged in decreasing density order and on each graph the results obtained for three separate samples are plotted. A sudden increase in current indicates the formation of a crack, which is indicated on these by an increase in the grade or slope of the cumulative current. From the results in Figure 4(i) it can be seen that one normal concrete sample cracked after about four days, whilst the foamed concretes (Figure 4(ii to iv)) did not show any signs of increased current for the first five to ten days. This seems to indicate that the voids in the foamed concrete might prevent the formationof cracks by absorbing the stresses exerted by the products of corrosion[11].

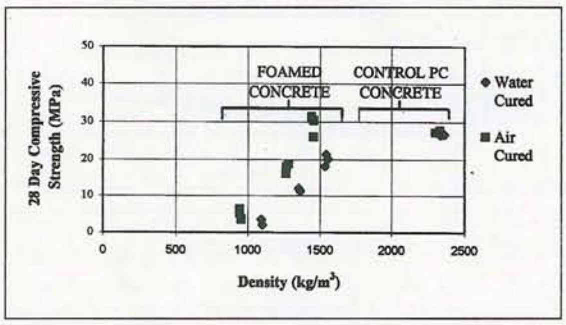

Figure 3: Effect of Curing on Compressive Strength.

If the area under the current-time diagram is related to the total amount of steel corrosion[12], Figure 4 indicates that the degree of corrosion of reinforcement in foamed concrete decreases with decreasing density. The rate of corrosion in all the foamed concrete samples were lower than that of the normal concrete. The variation between the samples seems to decrease with decreasing density. The accelerated potentio-meter tests seem to indicate, therefore, that foamed concrete is no less durable than normal concrete. The fact that samples with more voids allow less current flow, indicates that the voids act as a buffer, preventing the flow of ions through the sample. The cell-like structure of foamed concrete and the possible porosity of the cell walls do therefore not necessarily make the foamed concrete less resistant to penetration of moisture than dense, compacted concrete. The ability of the voids in foamed concrete to prevent the penetration of water can best be shown by the photo in Figure 5. This photo of 1 000 kg/m³ foamed concrete was taken when the sample was split open just after being removed from 21 days in the accelerated corrosion setup.

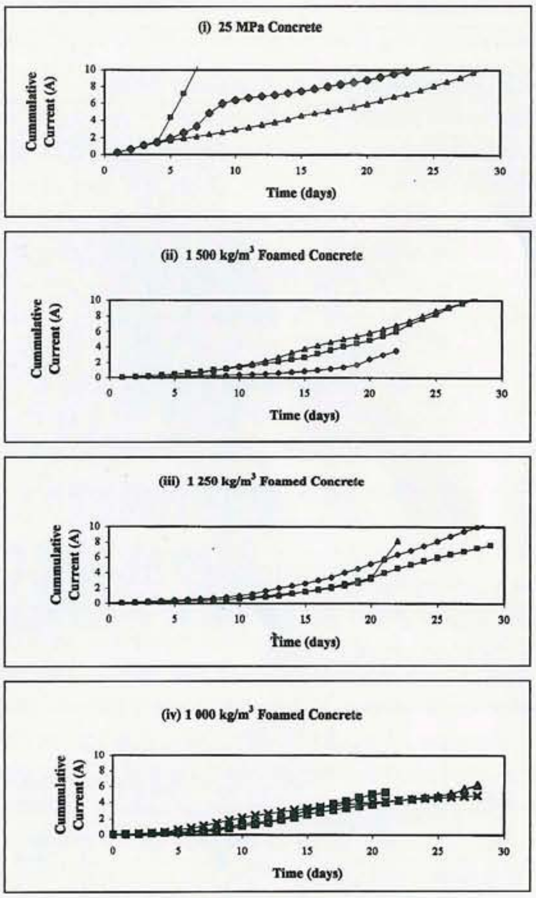

Figure 4: Cumulative Current through Samples.

From Figure 5 it can be seen that (after being submerged for more than 21 days) large areas in the centre of the foamed concrete sample is dry, whereas the outer region of the sample, (approximately 10 mm thick), is saturated. The air in the voids seems to prevent the moisture from reaching the steel.

A question that still remains unanswered is whether the cumulative current measured is a function of the corrosion of the reinforcement. To answer this question the relationship between loss in weight of the reinforcing bars and cumulative current measured was considered, as shown in Figure 6. From this graph, it can be concluded that for foamed concrete samples there is a trend between the cumulative current measured and the percentage weight loss of the reinforcing bars. However, this relation does not exist for the normal concrete specimens. It can, however, again be concluded that the reinforcement in foamed concrete does not necessarily corrode significantly more than that in normal concrete.

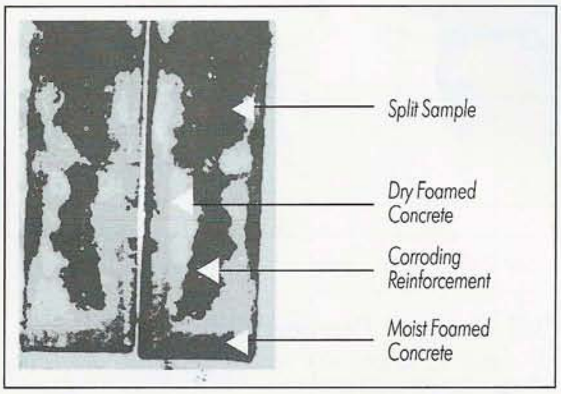

Figure 5: Foamed Concrete Submerged for 21 Days.

4.3 Oxygen Permeability Test

The permeability of concrete can be used as an indication of its likely durability[7]. For this reason the relative oxygen permeability of each mix was determined as shown in Figure 7. In this graph, time is plotted as a function of the log for the ration of pressure at the beginning of the test (P_0) to the pressure at the end of the test (P). From these results it can be seen that pressure decline is, as expected, a function of the density for the foamed concrete, with the higher density mixes exhibiting slower rates of decline. Indeed determining the permeability of the 1 000 kg/m³ foamed concrete was virtually impossible due to the rapid decline in pressure.

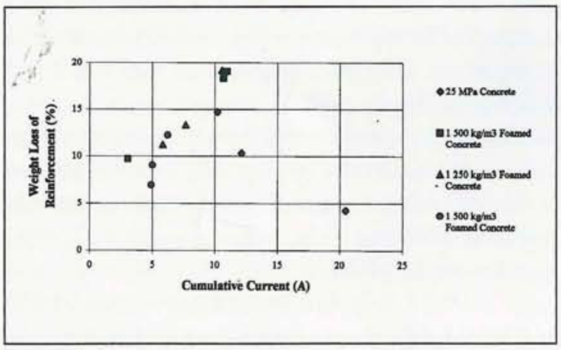

Figure 6: Loss in Weight of Reinforcement.

Repeating the test on the low density samples resulted in a higher rate of decline, indicating that the pressure may have damaged the porous structure of these samples. For this reason the falling head permeameter may not be suitable for determining the permeability of low density foamed concretes.

It is worth noting that the 1 500 kg/m^3 foamed concrete was less permeable than the normal 25 MPa concrete. If oxygen permeability is taken as an indication of concrete durability, it does, therefore, seem possible that foamed concrete with relatively high densities could be used as a durable alternative to normal concrete.

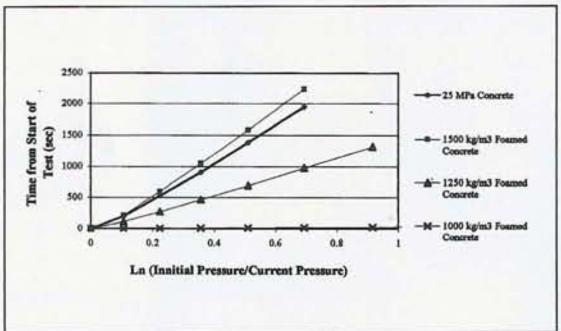

Figure 7: Relative Oxygen Permeability of Experimental Mixes.

5. CONCLUSION AND RECOMMENDATION

The compressive strength of foamed concrete is a function of its density. Foamed concrete samples that were cured in air at 40°C have significantly higher 28 day compressive strengths than those cured in water.

The cell-like structure of foamed concrete and the possible porosity of the cell walls do not necessarily make the foamed concrete less resistant to penetration of moisture than dense, compacted concrete. The air voids seem to act as a buffer, preventing rapid penetration.

The results of the accelerated corrosion tests indicate that foamed concrete can be just as durable as normal 25 MPa concrete. These comparisons were made only of corrosion propagation using an impressed current and further testing is still required to determine and compare the time to corrosion activation. Furthermore the results of this investigation still need to be correlated with full scale, long term durability tests.

Foamed concrete with a density of 1 500 kg/m^3 is less permeable than the normal 25 MPa concrete. If oxygen permeability is taken as an indicator of the durability of concrete, it does, therefore, seem possible that foamed concrete with relatively high densities could be used as a durable alternative to normal concrete.

At this stage it can be concluded that the use of foamed concrete for low rise buildings will not necessarily lead to a reduction in durability. If due care is taken a structure containing foamed concrete can be less permeable and more durable than that if normal low strength concrete was sued.

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