EFFECT OF FLY ASH PERFORMANCE OF PERVEROUS CONCRETE

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Systematic production of good quality pervious concrete is necessary to meet specification requirements for the infiltration of double concrete pervious pavements. This paper reports and discusses the results of an experimental investigation into the physical and engineering properties of pervious concrete having varying amounts of fly ash as the cement replacement material. The following properties were studied: porosity, density, compressive strength, weight loss on drying, loss on drying duration and water permeability. The results showed that porosity has significant effect on compressive strength and permeability of pervious concrete. Replacement of cement with fly ash up to 25% by mass of binder, had no significant effect on the water permeability and shrinkage of the pervious concrete, although marginal effect on strength was noticed.

Keywords: Drying shrinkage, Fly ash, Pervious concrete, Porosity, Strength, Water permeability

Introduction

The impervious nature of normal weight concrete used for pavement applications contributes to the increased stormwater runoff into drainage systems and causing excess flooding in low-lying urban areas. Pervious concrete, an open-graded material has significantly high porosity due to the presence of intergranular pores, ranging from 2 to 5 mm [1]. By capturing stormwater and allowing it to percolate into the ground, the pervious concrete is instrumental in reducing ground water and reducing stormwater runoff. In addition, pervious concrete is applied as a sound absorbing material for highway applications in Europe [2] and river banks in Japan [3].

The pervious concrete is produced by using conventional concrete making materials, with or without fine aggregate to have a porosity ranging from 15% to 35%. The intergranular large-sized pores in the concrete section lead to produce a high water permeability lightweight concrete compared to normal weight concrete. Typical water permeability coefficient for concrete is about 10-20 cm/s compared to 30-70 cm/s for normal weight concrete. Typical compressive strength for pervious concrete is ranging from 2 to 10 MPa, and used mainly for the construction of parking lots, footpaths, bus terminals and low traffic pathways.

World's cement production in 2006 reached 1.9 billion tonnes and the most populous countries, namely China and India, produced 41.5% and 3.2%, respectively, of the world's cement output [4]. Since 1 tonne of Portland cement production emission 0.64 tonne of carbon dioxide gas into the atmosphere, cement production contributes significantly to global warming and climate change. In Australia, 9 million tonnes of cement was produced in 2006 and due to the use of secondary materials, such as fly ash and slag, carbon dioxide emissions is reduced to 0.72 tonnes per tonne of cement produced [5].

Considering the environmental effects of using Portland cement, it is essential for the concrete industry to minimize the use of cement in the production of both structural and non-structural concrete. One way to reduce cement consumption is to use fly ash, a waste product from the combustion of coal for thermal power generation, as a cement replacement material because of the potential reactivity of fly ash. This paper reports the results of an experimental investigation into the production and properties of pervious concrete with various amount of Portland cement using high volume additions of fly ash.

Research significance

For the past few years, pioneering research on pervious concrete is being carried out at the University of Technology, Sydney, Australia. Preliminary results on the production and properties of pervious concrete were reported elsewhere [6]. The research is aimed to produce sustainable environmentally friendly pervious concrete, having significant water permeability with moderate strength of around 10-30 MPa. Portland cement replacements of up to 25% by mass with low-volatiles fly ash are investigated. The influence of cement replacement with fly ash on porosity, density, compressive strength, drying shrinkage and water permeability were determined. The significance of this research is to evaluate the feasibility of the production of environmentally friendly pervious concrete to meet the specification requirements for pavement applications.
EXPERIMENTAL PROGRAM

General purpose (GP) portland cement, conforming to AS3972 [9] and New South Wales low-calcium fly ash, conforming to AS3282 [10] were used as binder materials in the production of previous concrete mixtures. Typical chemical compositions for 100% fly ash indicate the lime, silicon and aluminium contents of 1.99%, 63.9% and 24.8%, respectively. Single size (10 mm) crushed river gravel (specific gravity of 2.70) was used for the coarse aggregate, crushed granite was not used for the previous concrete.

Three previous concrete mixtures were produced having three cement replacement levels of 0, 30% and 50% with fly ash by mass of binder. The aggregate-to-cementitious materials ratio for the investigated concrete was fixed at 4.4, by mass. The free water-to-cementitious materials ratio for these mixtures was maintained at 0.25 to maintain suitable workability assessed by test described elsewhere (8, 11).

Fresh previous concrete mixtures were produced in a pan-type mixer. For each mixture, a sufficient number of (50 mm diameter by 285 mm high cylinders and two 75 x 75 x 75 mm cubes) were cast in standard moulds. Fresh compression tests were used to test the test specimens. The concrete was removed from the moulds after 24 hours and stored in water at 20°C until the age of testing. The cylindrical specimens were used to determine the compressive strength and permeability of concrete, whereas the prismatic specimens were used for flexural strength testing. The shrinkage specimens were stored cured for 7 days followed by drying in an uncontrolled environment, having a mean temperature and relative humidity of 25°C and 65%, respectively, for 56 days. The compressive strength was carried out in accordance with the test procedures given in AS1012 [11]. At each age, identical three cylinders were tested, and the average of three results is reported. Permeability of previous concrete mixtures was calculated using Eq (1)

\[ P = \frac{L \times \ln \left( \frac{P_{in}}{P_{out}} \right)}{I} \times 100 \]  

where, \( P_{in} = \) porosity (\%), \( P_{out} = \) weight under water (g), \( P_{in} - \) oven dry weight (g), \( V_{f} = \) volume of sample (m³), and \( \rho_{w} = \) density of water (g/cm³).

The water permeability of previous concrete was determined using a procedure described below [4]. Figure 1 shows the experimental test setup for the determination of water permeability of previous concrete under constant head contact. Permeability of previous concrete was determined over a period of 39 minutes under a water head of 100 mm. The water permeability coefficient was calculated using Darcy's Law, as shown in Eq (2)

\[ Q = \frac{A \times H}{t} \]  

where, \( A = \) cross-sectional area of the cylinder (m²), \( Q = \) quantity of water drained (g over time t), \( H = \) density of water (1000 g/m³), \( k = \) water permeability coefficient (m/s), \( d = \) water head (mm), \( L = \) length of specimen (m), and \( I = \) height of specimen (m).

Free drying shrinkage of previous concrete was determined during 56 days of drying period over a 700 mm gauge length using a screw-on metallic strain gauge on two identical prismatic specimens. The reported results were the average of four readings taken on two opposite sides of each specimen. The shrinkage specimens were weighed, at the time of the shrinkage measurement.

RESULTS AND DISCUSSION

Details of previous concrete

Figure 2 shows the density of the hardened previous concrete in a flexural cement replacement with fly ash at 7 and 28 days. The mean density of the previous concrete mixture is about 1700 kg/m³, Mean 1 and 2 had approximately density of 1800 kg/m³ compared to 1700 kg/m³ for Mix 3. The density variations in previous concrete mixture are

The combined effects of varying degree of concreteness and presence of fly ash creates a difficult issue for Portland cement.

Permeability of previous concrete

Permeability of the three previous concrete mixtures is shown in Figure 3. This result shows that the porosity is not significantly affected by the partial replacement of cement by fly ash. These findings are consistent with the permeability of previous concrete is mainly affected by the grading of the aggregate. The mean porosity for the previous concrete mixture is 63%.

Water permeability of previous concrete

Figure 4 shows the water permeability coefficient of the previous concrete mixtures under the water head of 100 mm. The previous concrete had a water permeability coefficient of 13 to 16 m/s. The lower water permeability was observed for the previous concrete with 50% cement replacement with fly ash (Mix 2). The control previous concrete (Mix 1) and the mix with 30% fly ash (Mix 3) showed nearly the same water permeability coefficient of 16 m/s. Independence of the cement replacement with fly ash, the previous concrete showed high water permeability to be accepted for pavement pavement applications.

Relationship between porosity and permeability of previous concrete

Figure 5 shows the relationship between porosity and permeability for previous concrete, plotted with published data [12] and the results reported in this study. For previous concrete having the porosity between 15% and 20%, a linear relationship could be derived between porosity and permeability and given by Eq (3)

\[ k = 0.41 \times 10^{-} V - 0.51 \]  

where, \( k = \) permeability coefficient in m/s and \( V = \) porosity in percent.

Compressive strength of previous concrete

Figure 6 shows the compressive strength of the previous concrete mix at the age of 7 and 28 days. Each result showed the mean of three identical cylinders tested at the same age for each concrete mixture. Noticeable strength variations were noted among the three specimens due to the variations in the degree of compaction. As expected, the compressive strength of the previous concrete increased with the increase in age. This is due to the proper development and hydration of reactive fly ash and silica fume in the mixture. The control previous concrete mix with 100% concrete content (Mix 0) and the mix with 50% fly ash (Mix 1) showed 50% increase in the compressive strength from the age of 7 to 28 days. The previous concrete with 50% fly ash (Mix 3) showed an increase of 100% in strength during the same period.

At the age of 28 days, the highest compressive strength of about 20 MPa was recorded for the control previous concrete (Mix 1), and the lowest strength of about 6 MPa for Mix 3 (50% fly ash). Since there is no strength requirement in the specification for previous concrete, cement replacement with 50% fly ash will not affect the acceptance of previous concrete as a material for pavement application.

Relationship between porosity and compressive strength for previous concrete

Figure 7 shows the relationship between porosity and compressive strength at 28 days for previous concrete based on the published results [12], and the results of this investigation also plotted. With the porosity between 15% and 30%, the compressive strength dropped linearly with the increase in porosity as shown in Eq (4)

\[ f = -0.07 \times V + 28.6 \]  

where, \( f = \) compressive strength at 28 days in MPa and \( V = \) porosity in percent.
Drilling shrinkage of pervious concrete

Figure 8 shows the development of drying shrinkage with time for the pervious concrete. Figure 9 shows the relationship between drying shrinkage and dose loss for pervious concrete. Drying shrinkage for pervious concrete increased with time at a diminishing rate. The drying shrinkage of pervious concrete ranged from 400 to 500 microstrains. The pervious concrete having 50% cement and 20% fly ash (Mix 3) showed the lowest shrinkage of 150 microstrains compared to the control pervious concrete (Mix 1) of 400 microstrains. The results imply that fly ash increased the dimensional stability of pervious concrete.

The total mass loss for the pervious concrete mixtures after 36 days of drying to the unconfined laboratory environment was about 2.2%. Pervious concrete having 50% cement replacement with fly ash (Mix 3) showed the highest mass loss of about 5%, whereas the pervious concrete without cement replacement (Mix 1) showed the lowest mass loss of around 3%. For a given mass loss, the control pervious concrete showed maximum shrinkage compared to other pervious concrete mixtures having cement replacement with fly ash.

Relative effects of partial cement replacement with fly ash on properties of pervious concrete

Table 1 summarizes the engineering properties of pervious concrete mixtures using low-calcium fly ash relative to the control pervious concrete. In comparison to the properties of pervious concrete with cement replacement, the results showed that 30% of Portland cement with fly ash by mass, can reduce 28-day compressive strength of pervious concrete by 9%. However, water permeability was insignificantly reduced and the drying shrinkage after 36 days was reduced by 75%.

CONCLUSION

Three pervious concrete mixtures made with 0, 20%, and 50% fly ash substitutions to cement were investigated. The pervious concrete with high porosity showed low compressive strength and high water permeability. Based on the results presented, linear relationships between porosity and compressive strength, and porosity and water permeability are established for pervious concrete within the porosity range of 15% to 30%.

The results showed that the water permeability of pervious concrete was not significantly affected when 50% of the cement was replaced by fly ash. However, the dimensional stability due to drying shrinkage was increased significantly with fly ash use. It can be concluded that environmentally friendly pervious concrete could be produced with significantly reduced amount of Portland cement with fly ash.

REFERENCES

1. ACI Committee 522, "Pervious Concrete," Report No. 522R-96, American Concrete Institute, Detroit, USA, 2006, p. 25.

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Table 1: Effects of cement replacement with fly ash on the properties of pervious concrete mixtures

<table>
<thead>
<tr>
<th>Cement (%)</th>
<th>Fly Ash (%)</th>
<th>Porosity (%)</th>
<th>Strength (MPa)</th>
<th>Water Permeability (200h)</th>
<th>Drying Shrinkage (100d)</th>
<th>Mass Loss (%)</th>
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Figure 1: Water permeability test setup for pervious concrete

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Figure 2—Effect of age and fly ash content on density of pervious concrete

Figure 3—Effect of age and fly ash content on porosity of pervious concrete

Figure 4—Effect of fly ash on the permeability coefficient of pervious concrete

Figure 5—Relationship between porosity and permeability for pervious concrete
Figure 6: Effect of age and fly ash content on compressive strength of pervious concrete

Figure 7: Relationship between porosity and compressive strength for pervious concrete

Figure 8: Development of shrinkage with drying time for pervious concrete

Figure 9: Relationship between shrinkage and mass loss for pervious concrete
Front Cover Photo:
The Prophet Samuel in Infancy
Circa 1850

The first sculpture known to be made from Portland cement: the sculpting is attributed to both Joseph Aspdin, the inventor of Portland cement, and to his son James.

The statue, some two feet high, came into the possession of Professor and Mrs. Adam Neville who donated it to the Department of Civil Engineering, University of Leeds.

It had been outdoors in a garden for more than a century. It had "weathered" better than most granite monuments in the same environment at the same time.

Photo courtesy of:
Professor and Mrs. Adam Neville

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