# EFFECT OF FLY ASH PERFORMANCE OF PERVIOUS CONCRETE

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Synopsis: Production of good quality pervious concrete is necessary to meet specification requirements for the construction of durable 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, free drying shrinkage 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 50%, 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



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## INTRODUCTION

Impervious nature of normal weight concrete used for pavement applications contributes to the increased stormwater water runoff into drainage systems and causing excessive flooding in built-up urban areas. Pervious concrete, an open-graded material has significantly high permeability due to the presence of interconnected pores, ranging from 2 to 8 mm [1]. By capturing stormwater and allowing it to seep into the ground, the pervious concrete is instrumental in recharging groundwater 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 connected large-sized pores in the concrete system lead to produce a high water permeability lightweight concrete compared to normal-weight concrete. Typical water permeability coefficient for pervious concrete is about 10 mm/s compared to $10^{-9}$ mm/s for normal-weight concrete. Typical compressive strength for pervious concrete is ranging from 5 to 10 MPa, and used mainly for the construction of parking lots, footpaths, bus terminals and low traffic pathways.

World's cement production in 2003 reached 1.9 billion tonnes and the most populous countries, namely China and India, produced 41.9% and 5.2%, respectively, of the world's cement output [4]. Since 1 tonne of portland cement production releases 0.94 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 emission is reduced to 0.72 tonne per tonne of cement produced [5].

Considering the environmental effects of using portland cement, it is essential for the concrete industry to minimise 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 pozzolanic reactivity of fly ash. This paper reports the results of an experimental investigation into the production and properties of pervious concrete with reduced 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 [6-8]. The research is aimed to produce sustainable environmentally friendly pervious concrete, having significant water permeability with moderate strength of around 10 MPa. Portland cement replacements of up to 50% by mass with low-calcium 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 application.

## EXPERIMENTAL PROGRAM

General purpose (GP) portland cement, conforming to AS3972 [9] and New South Wales low-calcium fly ash, conforming to AS3582 [10] were used as binder materials in the production of pervious concrete mixtures. Typical chemical compositions for NSW fly ash indicate the lime, silica and alumina contents of 1.59%, 65.9% and 24.0%, respectively. Single size (10 mm) crushed river gravel (specific gravity of 2.70) was used for the coarse aggregate. Fine aggregate was not used the pervious concrete.

Three pervious concrete mixtures were produced having three cement replacement levels of 0, 20% and 50% with fly ash, by mass of binder. The aggregate-to-cementitious materials ratio for the investigated mixtures was fixed at 4.0, by mass. The free water-to-cementitious materials ratio for these mixtures was maintained at 0.35 to maintain suitable workability assessed by test described elsewhere [6, 8].

Fresh pervious concrete mixtures were produced in a pan-type mixer. For each mixture, a sufficient number of 100 mm diameter by 200 mm high cylinders and two 75 × 75 × 285 mm prisms were cast in standard steel moulds. Minimum compaction effort was used to cast 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 free drying shrinkage testing. The shrinkage specimens were water-cured for 7 days followed by drying in an unsaturated uncontrolled laboratory environment, having a mean temperature and relative humidity of 20°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. Porosity of pervious concrete mixtures was calculated using Eq. (1)

$$V_r = \left[1 - \left(\frac{W_2 - W_1}{\rho_w Vol}\right)\right] 100(\%) \quad (1)$$

where, $V_r$ = porosity (%), $W_1$ = weight under water (g), $W_2$ = oven dry weight (g), $Vol$ = volume of sample (m$^3$), and $\rho_w$ = density of water (g/m$^3$).

The water permeability of pervious concrete was determined using a procedure described elsewhere [6]. Figure 1 shows the experimental test set-up for the determination of water permeability of pervious concrete under constant head. Permeability of pervious concrete was determined over a period of 30 seconds under a water head of 100 mm. The water permeability coefficient was calculated using Darcy's Law, as shown in Eq. (2)

$$\frac{Q}{At\rho_w} = k\frac{\Delta H}{L} \quad (2)$$

where, A = cross-sectional area of the cylinder (mm$^2$), Q = quantity of water collected (g) over time (t), $\rho_w$ = density of water ($1\times10^{-3}$ g/m$^3$), k = water permeability coefficient (mm/s), ΔH = water head (mm), and L = length of specimen (mm).

Free drying shrinkage of pervious concrete was determined during 56 days of drying period over a 200 mm gauge length using a demountable mechanical 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 measurements.

## RESULTS AND DISCUSSION

### Density of pervious concrete

Figure 2 shows the density of the hardened pervious concrete as a function cement replacement with fly ash at 7 and 28 days. The mean density of the pervious concrete mixtures is about 1770 kg/m$^3$. Mixes 1 and 2 had approximate density of 1800 kg/m$^3$ compared to 1750 kg/m$^3$ for Mix 3. The density variations in pervious concrete mixtures are



the combined effects of varying degree of compaction and presence of low density fly ash compared to portland cement.

### Porosity of pervious concrete

Porosity of the three pervious concrete mixtures is shown in Figure 3. The results show that the porosity is not significantly affected by the partial replacement of cement by fly ash. These finding are not surprising since the porosity of pervious concrete is mainly affected by the grading of the aggregate. The mean porosity for the pervious concrete mixtures is 0.33.

### Water permeability of pervious concrete

Figure 4 shows the water permeability coefficient of the pervious concrete mixtures under the water head of 100 mm. The pervious concrete had a water permeability coefficient of 12 to 16 mm/s. The lower water permeability was observed for the pervious concrete with 20% cement replacement with fly ash (Mix 2). The control pervious concrete (Mix 1) and the mix with 50% fly ash (Mix 3) showed nearly the same water permeability coefficient of 16 mm/s. Independent of the cement replacement with fly ash, the pervious concrete showed high water permeability to be accepted for pervious pavement applications.

### Relationship between porosity and permeability for pervious concrete

Figure 5 shows the relationship between porosity and permeability for pervious concrete, plotted with published data [12] and the results reported in this study. For pervious concrete having the porosity between 15% and 40%, a linear relationship could be derived between porosity and permeability and given by Eq. (3)

$$k = 0.41\ V + 0.51 \quad (3)$$

where, k = permeability coefficient in mm/s; and V = porosity in percent

### Compressive strength of pervious concrete

Figure 6 shows the compressive strength of the pervious concrete mix at the ages 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 variation in the degree of compaction. As expected, the compressive strength of the pervious concrete increased with the increase in age. This is due the progress of cement hydration and pozzolanic reaction of the fly ash with lime liberated from cement hydration. The control pervious concrete mix with 100% cement (Mix 1) and that mix with 20% fly ash (Mix 2) showed 30% increase in the compressive strength from the age of 7 to 28 days. The pervious concrete with 50% fly ash (Mix 3) showed an increase of 50% in strength during the same period.

At the age of 28 days, the highest compressive strength of about 10 MPa was recorded for the control pervious 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 pervious concrete, cement replacement with 50% fly ash will not affect the acceptance of pervious concrete as a material for pavement application.

### Relationship between porosity and compressive strength for pervious concrete

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

$$f = -0.71\ V + 26.6 \quad (4)$$

where, f = compressive strength at 28 days in MPa; and V = porosity in percent.

Drying 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 mass loss for pervious concrete. Drying shrinkage for pervious concrete increased with time at a decreasing rate. The 56-day drying shrinkage ranged from 480 to 600 microstrain. The pervious concrete having 50% cement and 50% fly ash (Mix 3), showed the lowest shrinkage of 480 microstrain compared to the control pervious concrete (Mix 1) of 600 microstrain. The results imply that the cement replacement with fly ash increased the dimensional stability of pervious concrete.

The mean mass loss for the pervious concrete mixtures after 56 days of drying in the uncontrolled laboratory environment was about 3.2%. Pervious concrete having 50% cement replacement with fly ash (Mix 3) showed the highest mass loss of about 3.5%, 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 summarises the engineering properties of pervious concrete mix made using low calcium fly ash relative to the control pervious concrete. In comparison with the properties of pervious concrete with no cement replacement, the results showed that 50% of Portland cement with fly ash, by mass, can reduce 28-day compressive strength of pervious concrete by 4%. However, water permeability was insignificantly reduced and the drying shrinkage after 56 days was reduced by 21%.

## 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 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 sustainable pervious concrete could be produced with significantly reduced amount of Portland cement with fly ash.

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

| Cement (%) | Fly Ash (%) | Porosity | Strength | Water permeability | Drying shrinkage | Mass loss |
|---|---|---|---|---|---|---|
| 100 | 0 | 100 | 100 | 100 | 100 | 100 |
| 80 | 20 | 92 | 87 | 81 | 92 | 110 |
| 50 | 50 | 89 | 56 | 107 | 79 | 109 |

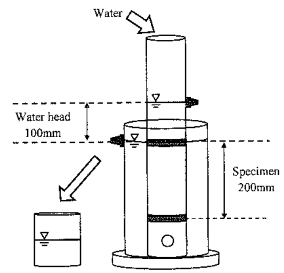


Figure 1– Water permeability test set-up for pervious concrete

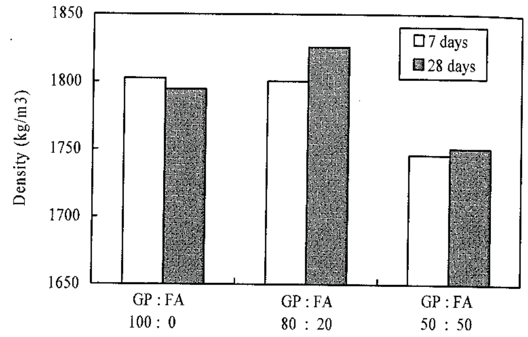


Figure 2-- Effect of age and fly ash content on density of pervious concrete

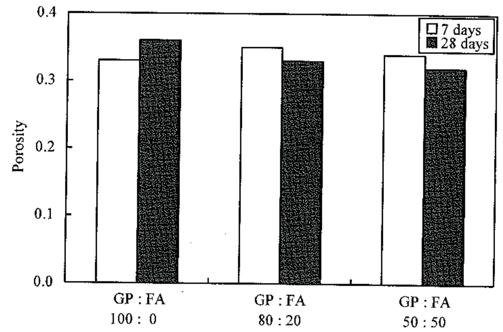


Figure 3-- Effect of age and fly ash content on porosity of pervious concrete



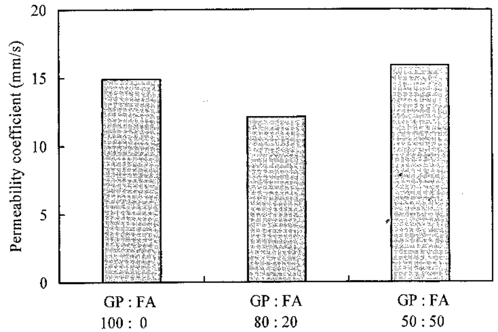


Figure 4-- Effect of fly ash on the permeability coefficient of pervious concrete

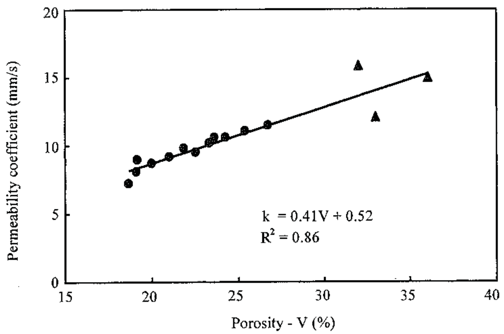


Figure 5-- Relationship between porosity and permeability for pervious concrete

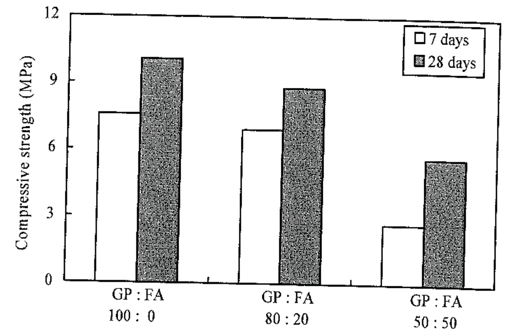


Figure 6-- Effect of age and fly ash content on compressive strength of pervious concrete

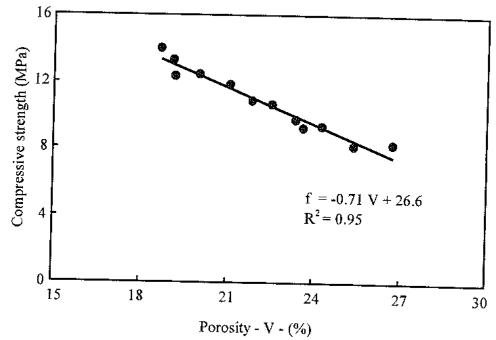


Figure 7-- Relationship between porosity and compressive strength for pervious concrete



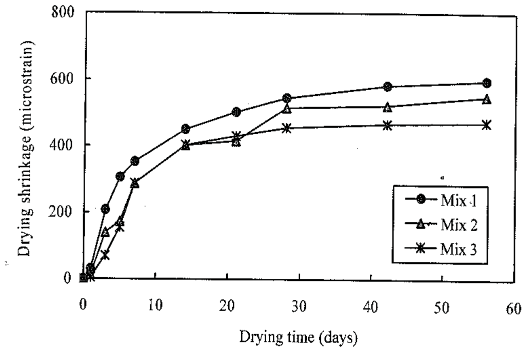


Figure 8-- Development of shrinkage with drying time for pervious concrete

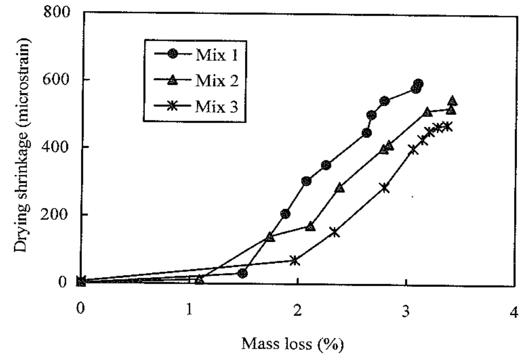


Figure 9-- Relationship between shrinkage and mass loss for pervious concrete

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**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 statuette, 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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