STUDY OF THE CONCEPT OF POROUS CONCRETE FOR USE ON AIRPORT RUNWAYS

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ABSTRACT

Porous concrete or pervious concrete consists of no-fines, open-graded Portland concrete mixture usually with 15–25% voids, which enables water to be drained quickly. In the literature, porous concrete is cited as a material typically used in low-traffic areas such as residential streets, parking lots, sidewalks, recreation trails, plazas, and other paved areas.

However, it has been reported that a porous concrete layer over a conventional concrete base is an efficient means of reducing tyre spray and hydroplaning. The desirable properties are: significant noise reduction and drainage; acceptable strength and stiffness; adequate surface properties with respect to traffic safety such as skid resistance and sufficient service life; bonding with underlying dense concrete; and costs comparable to those of conventional pavements. Porous concrete had been reportedly used on airport runways.

The aim of this study was to verify the drainage properties of porous concrete for reducing hydroplaning as well as to verify its potential use on airport runways, in particular as a surface and thin layer over concrete pavement structures.

This study reports the selection and gradation of aggregates that are necessary for about 15–25% open porosity and just enough cement content required to bind the aggregates together; compressive and flexural strength behaviour; and finally, the related water permeation capacity or drainage properties. Porous concrete has the potential to serve as a wearing course even on airport runways, but further research is required to fully develop this.

1. INTRODUCTION

On 2nd August 2005, an Air France A-340 aircraft overran the runway in Toronto and was destroyed by fire. A month earlier, a Bangladeshi Biman DC-10 overran the runway at Chittagong and suffered extensive damage. On 30th July 2005, an Air India B747, which overran the runway at Mumbai, was lucky to escape with no damage. All these accidents occurred while the aircrafts were landing under heavy rain. Ranganathan (2005) asks whether they are aware of what is involved in a wet runway landing. The control of an aircraft during ground operations depends on adequate tyre contact and friction between tyre and pavement surface.

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The relationship necessary for good performance at an airport according to Jacobs et al. (2002) is based on the requirements for airport pavements and is defined in a pyramid of technical requirements on five different levels:

1. Users' requirements (availability, comfort, safety and sustainability of the surface of the pavement) which involve aspects such as accessibility, noise, ride (drivability/ smoothness), skid resistance, spray/splash and reflectivity.
2. Functional requirements such as chemical spill tolerance, cost, pavement life and reparability.
3. Structural requirements that involve the structural performance of the pavement, including cracking, debonding, delamination, faulting, pitting (tyre wear), polishing, ravelling, rutting and scaling.
4. The components of a material, e.g., the asphalt-concrete mix composition, aggregate size, distribution and form, density and percentage of air voids, etc.
5. Mix composition and component requirements that involve studies of the mix design to improve the performance of the pavement in each case.

At the top of the pyramid are the users' requirements. These are issues related to porous concrete, Portland cement and pervious concrete. Pervious concrete can simply be used because it is an open-graded friction course made of Portland cement, coarse aggregate and water. It allows the formation of a good macrotexture that improves surface drainage, reducing hydroplaning, splash and spray behind vehicles.

According to El-Desouky et al. (2003), the skid resistance of airfield runway pavement surfaces is essential to braking and deceleration and hence to safety. This behaviour is dependent on the surface microtexture and macrotexture. When the surface layer is very porous and permeable a decrease in accidents is observed. Excess water enters the pavement surface because of the high number of voids in the macrotexture and drainage is facilitated. Many agencies have been developing extensive programmes to obtain a surface that helps to reduce accidents.

2. BACKGROUND

Since 1990 there have been references in the literature to porous concrete in pavements. Porous concrete is also referred to as Portland cement pervious pavement or no-fines concrete, which is an open-graded material consisting of Portland cement, coarse aggregate and water.

This is a concrete mix with a high void content, and it is, thus, a skeleton of uniform aggregate size and a minimum of fines. Porous pavement, effectively, reduces road spray and hydroplaning, and 15 – 25% interconnected porosity has been recommended. Hoerner et al. (2003) explained that the principle of this technique is to create voids in the concrete (e.g. 20% by volume of concrete) so that water can quickly be drained from the surface. The same authors affirmed that the initial experience in Belgium with this surface type showed poor durability in freezing weather; however, the durability of these mixtures has been improved with the addition of polymers and the use of higher cement content.

The Georgia Stormwater Management Manual (2006) defines a porous concrete layer as an open-graded concrete mixture usually ranging from 50 to 100 mm in thickness, depending on the bearing strength and pavement design requirements. It is assumed to contain approximately 20% voids for design purposes. The porosity of the pavement is provided by the absence of fine aggregate. To provide a smooth riding surface and to enhance handling and placement, a coarse aggregate of 9,5 mm maximum size is recommended.

A higher void content associated with crushed stone facilitates the formation of a good macrotexture and consequently good frictional characteristics - the drainage of water occurs between the tyre and the pavement interface. Onstenk et al. (1993) give a list of the desirable properties: noise reduction, acceptable strength and stiffness, adequate surface properties with respect to traffic safety – skid resistance, evenness, sufficient service life - bonding to underlying dense concrete, costs comparable to those of conventional pavements.

The concept of porous concrete is represented in Figure 1, which shows a high-porosity concrete system. In terms of surface drainage, Figure 2 shows different behaviour under water conditions between normal concrete and porous concrete. Percolation rates of 100 to 750 litres are usual. In other words, it traps rainwater and recharges ground water, reducing storm water run-off.

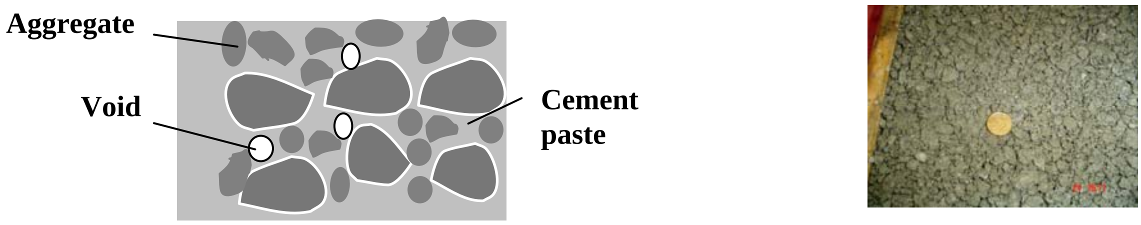


Figure 1. Schematic representation (left) and a porous concrete (right).

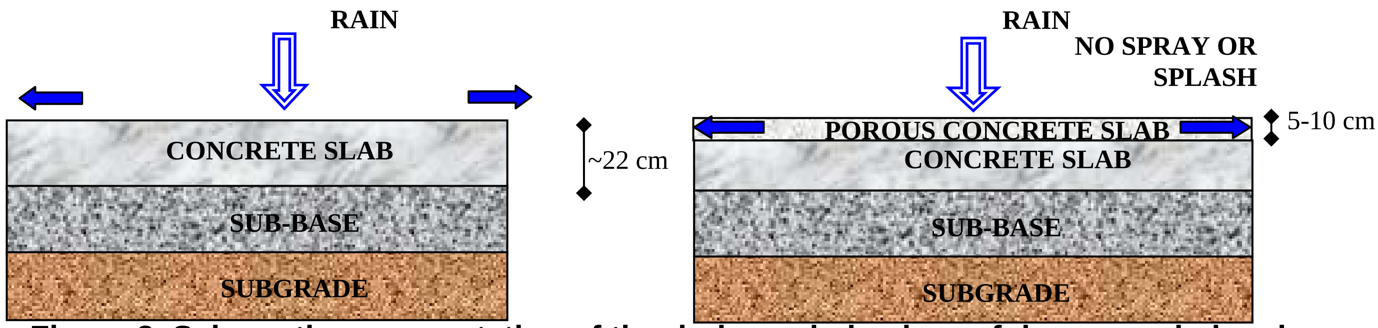


Figure 2. Schematic representation of the drainage behaviour of dense-graded and open-graded.

The technology of porous concrete has been utilised (Georgia Stormwater Management Manual, 2006) in low-traffic areas such as emergency vehicle and fire access lanes, golf cart and pedestrian paths, overflow parking areas, parking places in parking lots, pedestrian walkways, porous base layer for heavy duty use, recreation trails and residential street parking lanes.

The Georgia manual affirms that the use of pervious concrete is limited because of high maintenance requirements, a traditional high failure rate and short life span. Special attention to design and construction is needed; it should not be used in areas of soils with low permeability, wellhead protection zones or recharge areas of water supply aquifers, and there are restrictions on use by heavy vehicles. It is intended for low-volume automobile traffic areas or for overflow parking applications.

A typical cross-section of porous concrete pavement as shown in Figure 4 is recommended. Although the porous concrete layer is over a filter course, the present study proposes a different philosophy in which the porous layer is an overlay of an impermeable layer. The water should flow to the shoulder, as it occurs in the asphalt OGFC technology.

A filter layer is used under and over the stone reservoir layer. The top layer consists of 12,5 mm diameter crushed stone to about 50 mm thickness, and the surface of the subgrade should be a 150 mm (6") layer of sand or a 50 mm thick layer of 12,5 mm (0,5”) crushed stone.

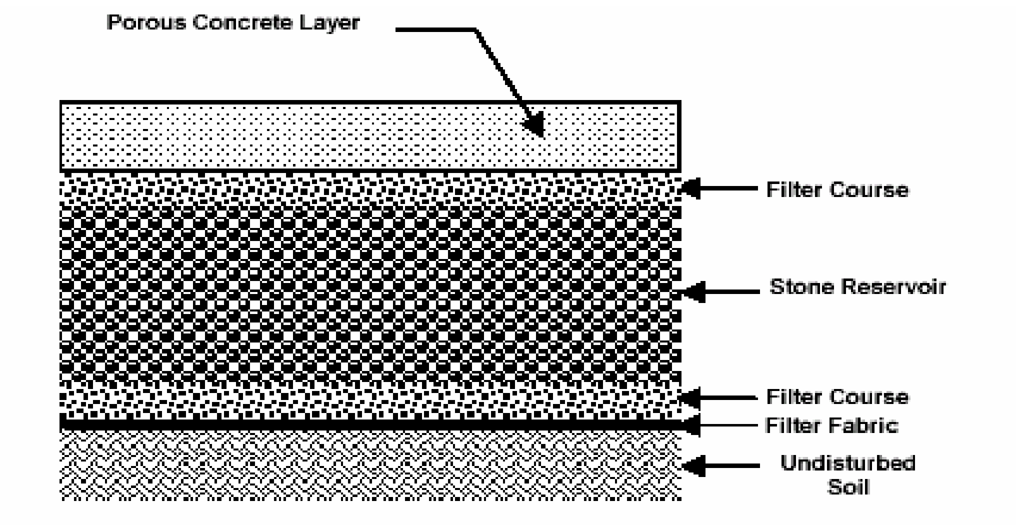


Figure 4. Porous concrete system section (modified from: LAC 2000) (Georgia Stormwater Management Manual, 2006).

Porous concrete has three advantages when compared to traditional concrete: it allows large amounts of water to pass quickly, and it reduces hydroplaning and noise. The manual recommends using it on airport runways, primarily for its better drainage properties.

In the authors' view, porous concrete material has the potential to be used as wearing course for upper the concrete layer in road (R), urban street (U) and airport (A) pavements for the following purposes:

i) Balance between stormwater run-off and the surrounding wetland ecosystem (urban area)
ii) Hydroplaning reduction (R and A)
iii) Noise reduction (U, R)
iv) Tyre spray reduction (R and U).

On the other hand, Kuennen (2003) affirms that porous concrete pavements are not appropriate for full-scale use on high-volume roadways, but for applications in low-volume roads - the technology improves road safety due to rapid drainage of rainwater.

3. SCOPE OF THE RESEARCH

This paper reports on ongoing research at Mackenzie Presbyterian University to investigate the friction course in airport runway pavements. The aim of the research is to find a concrete mix for pavement with good performance in terms of mechanical resistance and increase of surface frictional resistance. Data are presented on compressive and flexural strengths. Permeability values are analysed regarding aspects contributing to the development of new materials that could reduce the risk of hydroplaning.

Some preliminary studies were made using gradations similar to those recommended in open-graded mix asphalt projects. High porosity was sought, but low mechanical resistance was found. It is important to mention that the Stone Matrix Asphalt (SMA) concept was used in terms of stone-on-stone contact (Brown and Mallick, 1994; Brown and Haddock, 1997). Five gradations were selected: A, B, C, D and E. Mixes A, B and E had little variation of the cement content, mix C had a lower porosity than the others and mix D complied best with the OGFC concepts. Figure 5 shows the distribution of the five gradation curves studied compared to an open-graded friction course (OGFC) gradation used by Merighi and Fortes (2005).

Table 1 gives the details of the composition and some of the fresh concrete properties of the four concrete mixes used in the test programmes. The mixes are referred to as A, B, C, D and E.

Superplasticiser was used to obtain good workability due to the low water-to-cement ratios of the mixes. Crushed granite was used from a local quarry, with maximum aggregate sizes of 12,5 mm for coarse aggregate and 9.5 mm for small crushed aggregate. The Los Angeles Abrasion was 25.1%. River sand with a fineness modulus of 2.08 was used for the four mixes. Microsilica was used in mix C.

The Portland cement used in the present research was CP III 40 from Votoran according to the Brazilian Portland cement specification (NBR5732/1991). The main characteristics are given in Table 1.

The density of the mixes was low due to the higher porosity and pore size. The values are presented in Table 2.

Test specimens were used which were moulded in 100 x 200 mm concrete cylinders or drilled from concrete slabs as shown in Figure 6. The cylindrical specimens from representative samples of fresh concrete complied with the standard requirements for making, curing, protecting and transporting concrete test specimens. These specimens were cured in a moist room and kept at a minimum relative humidity of 80% and an average temperature of 20 ±2 ºC.

Table 1. Principal characteristics of Portland cement.

<table>
<tr><th>CHARACTERISTICS</th><th colspan="5">RESULTS</th></tr>
<tr><td>1. NORMAL CONSISTENCY</td><td colspan="5">24.2 %</td></tr>
<tr><td>2. MATERIAL PASSING # 200</td><td colspan="5">2.1 %</td></tr>
<tr><td rowspan="3">3. SETTING TIME</td><td colspan="3">BEGINNING</td><td colspan="2">3.25 HOURS</td></tr>
<tr><td colspan="3">ENDING</td><td colspan="2">6.15 HOURS</td></tr>
<tr><td colspan="3">COLD</td><td colspan="2">0.0 mm</td></tr>
<tr><td rowspan="2">4. LE CHATELIER EXPANSIBILITY</td><td colspan="2">HOT</td><td>0.5 mm</td><td>HOT</td><td>< 5 mm</td></tr>
<tr><td colspan="2">COLD</td><td>0.0 mm</td><td>COLD</td><td>< 5 mm</td></tr>
<tr><td>5. SPECIFIC AREA (BLAINE METHOD)</td><td colspan="5">4040 cm²/g</td></tr>
<tr><td rowspan="13">6. COMPRESSIVE STRENGTH</td><td>Age (days)</td><td>Value (MPa)</td><td>Average (MPa)</td><td colspan="2">STANDARD DEVIATION (%)</td></tr>
<tr><td rowspan="4">03</td><td>17.5</td><td rowspan="4">17.8</td><td colspan="2" rowspan="4">3.9</td></tr>
<tr><td>17.4</td></tr>
<tr><td>18.5</td></tr>
<tr><td>17.6</td></tr>
<tr><td rowspan="4">07</td><td>30.6</td><td rowspan="4">30.4</td><td colspan="2" rowspan="4">3.6</td></tr>
<tr><td>29.3</td></tr>
<tr><td>30.5</td></tr>
<tr><td>31.1</td></tr>
<tr><td rowspan="4">28</td><td>43.2</td><td rowspan="4">44.1</td><td colspan="2" rowspan="4">2.0</td></tr>
<tr><td>44.5</td></tr>
<tr><td>45.0</td></tr>
<tr><td>43.6</td></tr>
<tr><td>7. SPECIFIC GRAVITY</td><td colspan="5">3.02 g/cm³</td></tr>
</table>

Table 2. Composition and some properties of the concrete mixes.

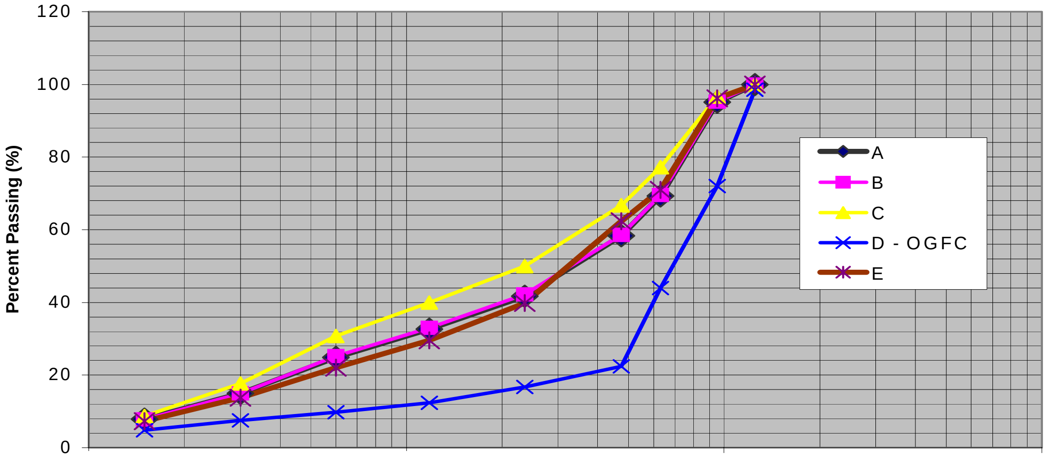
CHARACTERISTICS	MIXTURE				
	A	B	C	D	E
Cement (kN/m^3)	2.22	2.71	3.01	2.41	2.30
Sand	2.22	2.38	2.65	1.49	2.30
Micro silica	0	0	3.65	0	0
Small shower (kN/m^3)	1.33	1.35	3.65	1.12	2.21
Coarse aggregates (kg/m^3)	12.88	13.13	7.32	13.31	12.53
Total water (l/m^3)	0.65	0.70	0.87	0.62	0.67
Water-cement ratio	0.292	0.257	0.289	0.257	0.290
Superplasticiser (kN/m^3)	0.050	0.040	0.044	0.360	0.040
Slump (mm)	182	169	175	161	180
Air content (%)	17.3	14.6	10.1	19.8	17.0
Density (kN/m^3)	19.59	20.56	21.49	19.22	20.05

4. EXPERIMENTAL RESULTS

A test plan was developed which considered two processes of four specimen mixes, using cylindrical specimens and cores from slabs. The strength of porous concrete depends on the grain size distribution, accessible porosity and the type and amount of additive used.

The compressive and flexural strength of the concrete determined as recommended by NMBR5739/1994 and NBR12142/1991, respectively. The compressive strength was determined at 7, 14 and 28 days (Figure 7) and the flexural strength at 28 days.

Permeability testing was performed as recommended by Kandhal and Mallick (1997, 1998) using a constant-head permeameter. The hydrostatic head remains constant, with the quantity of water flowing through the concrete sample for any period of time measured by means of a graduated tube. The pervious samples were mounted on the cell pressure gauge and the space between the sample and the cells was filled with Bentonite clay (Figure 8(a)). A photograph of the apparatus is shown in Figure 8 (b).



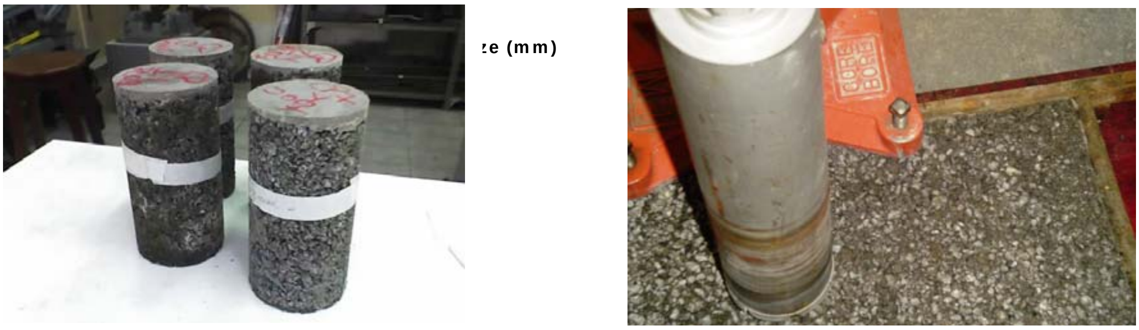


Figure 6. Specimens moulded in 100 x 200 mm concrete cylinders and cores from concrete slabs.

Figure 7. Compressive strength of concrete.

Figure 8 (a). The space between the sample and the cells was filled with Bentonite clay (b). permeameter used in the permeability determinations.

Table 3 presents the results of compressive and flexural strength and permeability.

Table 3. Results of compressive and flexural strength and permeability.

Concrete mix	Compressive strengths (MPa) - days			Permeability k (cm/s)	Flexural Strength (MPa)
	7	14	28		
A1	8.3	21.5	29.5	5.1×10^{-3}	2.5
A2	6.6	20.4	27.4	6.0×10^{-3}	2.3
B1	9.7	19.8	25.2	4.3×10^{-3}	2.2
B2	8.3	17.4	23.3	2.7×10^{-3}	2.4
C1	12.2	24.6	32.1	8.3×10^{-5}	3.1
C2	10.2	22.4	31.2	4.3×10^{-6}	2.9
D1	5.4	16.9	22.1	6.6×10^{-3}	1.8
D2	6.3	15.4	20.4	8.9×10^{-2}	1.7
E1	6.9	12.1	20.3	$7.8 X 10^{-2}$	1.6
E2	8.6	11.4	21.2	$6.4 X 10^{-2}$	1.7

5. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were drawn from the present study:

1) According to the literature review, porous concrete material is recommended for use in low-traffic pavement conditions, parking areas and urban areas, but also as a wearing course in the upper concrete layer of airport runway pavements. It is recommended for environmental considerations because it traps rainwater and recharges the soil.

2) Pervious concrete is more than a filter to permit water flow; it has good potential for use under high-traffic conditions if used as a surface layer because it promotes reduction of hydroplaning and minor tyre spray.

3) After many mixes were tested, it was possible to obtain a compressive strength at 28 days above 20 MPa associated with the coefficient of permeability of 10^{-3} cm/s.

4) Mixtures A and B had values of compressive strength of 28 and 25 MPa respectively, and porosity and permeability that was comparable with that found in OGFC layers. The flexural value was not high, but these two mixtures have the potential for increased resistance because the cement content was low, about 2.22 and 2.71 kN/m^3.

5) Mix C, which was denser, had the highest cement content (3.0 kN/m^3) and obviously the lowest porosity. As expected, the strength increased, but the decrease of permeability makes it unsuitable as a drainage layer.

6) Finally, mix D was in agreement with the OGFC and SMA concept considering the stone-on-stone contact. Its permeability performance was the best but it had the poorest strength values.

This research studied a range of gradations of porous concrete that was recommended in the literature to be used on airport runways because it promotes reduction of hydroplaning and tyre spray.

The authors intend to continue their research by doing more tests related to other gradations and also investigate the bond between the Portland cement concrete slab and a thin porous concrete overlay.

6. ACKNOWLEDGEMENTS

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