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Uma Maguesvari Muthaiyan1* and Sundararajan Thirumalai1

Abstract: The aim of this study is to investigate the effect of variation of cement content, partial replacement of cement by 10 and 20% of fly ash, partial replacement of coarse aggregate by fine aggregates (ranging from 5 to 15%) with the addition of plasticizer on the characteristics of pervious concrete. Class C fly ash was used for the production of pervious concrete, adopting ACI method of mix proportioning. Coarse aggregates of size 19 to 9.5 mm and 9.5 to 4.75 mm blended in the ratio of 60:40 respectively, a constant water–binder ratio of 0.3, a plasticizer of 0.8% by weight of cement were adopted. Density, compressive strength, flexural strength, split tensile strength, total voids, permeable voids, permeability by falling head method, sand blasting abrasion and cantabro abrasion were determined. Replacement of cement by fly ash (up to 20%) has reduced the compressive strength marginally, whereas, addition of fine aggregates (5–15%) has increased the above strength ranging from “marginal” to “high”. Incorporation of fly ash has the effect of reduction in total voids in fly ash–cement pervious concretes. It is seen that reduction in total void reduces the sand blasting abrasion and cantabro loss in pervious cement concrete and fly ash cement concrete. All the mixes considered in this study with minimum cement content 250 kg/m³ and with 10 and 20% of replacement of cement by fly ash with fines content 10 and 15% can be considered for the application of DLC as a base coarse for rigid/flexible pavements.

ABOUT THE AUTHORS

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PUBLIC INTEREST STATEMENT

Pervious concrete is an open graded material in which voids are intentionally created to allow water to pass through it. It is a unique and effective means of addressing a number of environmental issues and supporting sustainable development. In this study, various characteristics of pervious concrete have been determined for various cement contents and also using class C fly ash as a partial replacement of cement, with and without fine aggregates and using plasticizer as an admixture. It is found that the above material can be used as a base/sub base layer in rigid/flexible pavements. Thus, the use of the above material can lead to sustainable construction and development, which is the need of the hour, globally.
1. Introduction

Pervious concrete is a unique and effective means of addressing a number of environmental issues and supporting sustainable development. Pervious concrete is a mixture of Portland cement, coarse aggregate, little or no fine aggregate, water and additives. The porous structure allows both water and air to percolate into underlying layers. Apart from the above, pervious concrete when used in a pavement system has structural, economic and road-user benefit (McCain & Dewoolkar, 2009; Nguyen, Sebaibi, Boutouil, Leleyter, & Baraud, 2014). Several studies have been conducted to evaluate the strength and permeability of pervious concrete, using various cement content, different type of aggregates and with different water cement ratios (Girish & Manjunath Rao, 2011; Kevern, Wang, & Schoafer, 2009; Lian & Zhuge, 2010; Ravi Shankar & Palankar, 2015). Cement has been partially replaced by rice husk ash (RHA) and various properties of pervious concrete have been evaluated (Hesami, Ahmadi, & Nematzadeh, 2014). Recycled aggregate (RA), sea shell, brick bats, rubber crumb and Municipal solid waste (MSW) incinerated bottom ash have also been used to partially replace coarse aggregate and studies have been carried out (Cheng, Hsu, Chao, & Lin, 2011; Gesoğlu, Güneyisi, Khoshnaw, & Ipek, 2014; Güneyisi, Gesoğlu, Kareem, & Ipek, 2016; Hussain, Salam, & Kader, 2012; Kuo, Liu, & Su, 2013; Nguyen, Boutouil, Sebaibi, Leleyter, & Baraud, 2013; Rafique, Bhutta, Tsuruta, & Mirza, 2013). In addition to the above, super plasticizer, polymer, fibers, silica fume and other admixtures have also been added to enhance the properties of pervious concretes (Huang, Wu, Shu, & Burdette, 2010; Lian & Zhuge, 2010; Ravi Shankar & Palankar, 2015; Rafique, Bhutta, Tsuruta, & Mirza, 2012). Image analysis has been used to study the interface and microstructure on pervious concretes (Deo & Neithalath, 2010; Neithalath, Sumanasooriya, & Deo, 2010). Studies have also been made to improve the fatigue strength and toughness of pervious concrete (Chen, Wang, Wang, & Zhou, 2013). Focus has also been on the use of geo polymer binder for making pervious material (Sata, Wongsa, & Chindaprasirt, 2013). There have been several studies on evaluating the abrasion resistance of pervious concrete. Standard surface abrasion test has been used to evaluate the abrasion resistance of pervious concrete using a rotary cutter device (ASTM C944) (Wu, Huang, Shu, & Dong, 2011). It has been shown that addition of fibers has the potential to reduce surface abrasion and increase tensile strength, while potentially increasing porosity and permeability. The Los Angeles abrasion machines which has been traditionally used for testing the abrasion resistance of coarse aggregate has been used for testing the abrasion resistance of pervious concretes. The loaded wheel test and Cantabro test have been used to evaluate the abrasion resistance of pervious concrete (Dong, Wu, Huang, Shu, & Wang, 2013).

Aoki, Ravindrarajah, and Khazzaz (2012) have considered seven mixes (3 control; 3 mixes with 20% class F fly ash; one mix with 50% class F fly ash) for evaluating the compressive strength, permeability and void content. The reported results were more focused towards the relationship between strength and permeability and strength and voids. However, the potential applications of the reported work have not been indicated. Hager, Durham, and Rens (2016) have used 20% of class C fly ash along with Portland cement admixtures etc. for the construction of the top layer of pavement for a parking lot test section in the Denver metropolitan region, Colorado, USA. The water quality of storm water after the construction of the parking lot with the above pervious concrete was used to highlight the hydrologic benefit of the system during storm events. In spite of the above types of studies carried out and reported, it can be seen that the use of supplementary cementitious materials (SCMs) in the production of pervious concrete and comprehensive studies thereof, including various application, especially for pavements, is still rare. However, such studies if carried out and reported, will contribute for sustainable development. Hence, the focus of this study is to evaluate the various characteristics of pervious concrete without and with fine aggregates, using various cement contents and also using class C fly ash at 10 and 20% as partial replacement of cement, and using plasticizer as an admixture for production of pervious concrete. The potential of the above
concrete has also been evaluated as a pavement material with reference to the existing relevant Indian codes, and reported. Further, compressive strength and other test results obtained in this study have been compared with the results obtained without the use of plasticizer, and reported by the authors elsewhere (Uma Maguesvari & Sundararajan, in press).

2. Experimental program

2.1. Materials and properties

Cement, fly ash, crushed gravel as coarse aggregates, river sand as fine aggregates, plasticizer and potable water were the constituent materials used in pervious concrete. Class C type fly ash obtained from the thermal power plant located nearby (Neyveli, Tamilnadu, India) was used in all the mixes. Specific gravity of coarse aggregate used was 2.71. Coarse aggregates of size 19–9.5 mm and 9.5–4.75 mm, as suggested in ACI 522 R-10 for pervious concrete was used in the present study in the ratio of 60:40 for the mix. Fine aggregates conforming to Zone II of IS:383-1978, with the specific gravity of 2.62 was used. Salient characteristics of the cement and fly ash determined as per various Indian standard code provisions (IS 4031: Part 3, 1988; IS 4031: Part 4, 1988; IS 4031: Part 5, 1988), are given in Table 1. Chemical composition of fly ash is given in Table 2. Particle size distribution of fly ash is shown in Figure 1.

![Figure 1. Particle size distribution of fly ash.](image-url)
The above fly ash is categorized as class C fly ash and hence it is expected to exhibit its cementitious property. Further, as the fly ash has substantial quantity of particles less than 450 microns, it is expected to contribute for the micro-filler effect in concrete.

Even though, several studies have been carried out and reported internationally, on pervious concrete using super plasticizer, in such studies, other admixture(s) like “air entraining agents” have been used, for “obvious reasons”, considering their local conditions and needs, that is “cold climatic conditions”. However, in a very recent work by Ravi Shankar and Palankar (2015), where, they have used only a super plasticizer (CONPLAST SP430) for a cement content 300 kg/m³ and for 15% fines content, the void content has been reported as 14.23%, which is less than requirements for pervious concrete (i.e. 15%) specified in ACI522-R-10. The above study is the only of its kind reported for pervious concrete, using only a super plasticizer and indicating the impact of the above admixture. Taking into consideration the above study, the authors have chosen a commercially available plasticizer over superplasticizer, for the present study. Accordingly, CONPLAST-P211, was selected and used for the experimental investigations.

2.2. Mix proportioning

Based on the previous study conducted by the authors, it was shown that pervious concrete with cement contents ranging from 200 to 300 kg/m³, and without using plasticizer has potential application in flexible/ rigid pavements, according to the relevant Indian standards (IRC58-2015, 2015; IRC74-1979, 1979; IRCSP49-2014, 2014; Uma Maguesvari & Sundararajan, in press). However, with a view to explicit the full potential of the above concrete, it was decided to use plasticizer and evaluate the various characteristics of pervious concrete. Therefore, the above range of cement content are retained for the present study. The above cement contents formed the basis for the mix proportioning of control mixes of pervious concrete, without “fines” (i.e. without fine aggregates), but using coarse aggregates. During preliminary studies, it was found that the compressive strength realized in pervious cement concrete, with cement content 200 kg/m³ was very low, and hence, it was decided not to consider it for further investigations. Accordingly, in each of the above control mixes, except for the cement content of 200 kg/m³, 10 and 20% (by weight) of cement was partially replaced by fly ash and coarse aggregates were partially replaced by fine aggregates by 5, 10 and 15% (by weight). About 60% of the total coarse aggregates content in the size range of 19-9.5 mm and 40% in the size range of 9.5-4.75 mm were used. Further, based on a set of trials conducted
separately, the desired dosage of plasticizer was arrived (i.e. 0.8% by weight of cement) and used in the mix proportioning of pervious concretes. A constant water-binder (w/b) ratio of 0.3 was maintained for all the mixes considered in the study. All the mixes were designed according to ACI 522 R-10 as there is no corresponding Indian code available as of now for pervious concrete. Altogether 7 control mixes without fines (i.e. 3 control mixes without fly ash content, 2 in each with 10 and 20% replacement of cement by fly ash); 9 mixes with fine aggregates content ranging from 5 to 15%; 12 fly ash based mixes (6 each for 10 and 20% replacement of cement by fly ash), were proportioned for casting various specimens for determining the strength, permeability, void characteristics, abrasion using sand blasting method and cantabro loss (Dong et al., 2013) (which is weight loss of specimens due to combined action of impact and abrasion) of pervious concrete. The designations of various mix series and the corresponding mixes in the series are given in Table 3. Further, detail of a typical mix (for cement content 250 kg/m³ and for two levels of replacement of cement by fly ash) are given in Table 4. However, complete details of all mixes are available as “supplementary material” to this paper.

### 2.3. Preparation and testing of specimens

#### 2.3.1. Compressive strength

Cubes of size 100 × 100 × 100 mm were cast for each mix and moist cured for 24 h before demoulding and curing in water continued at 24°C until testing at 7 and 28 days. Compressive strength was determined in accordance with the Indian standard IS:516-1959. As the largest nominal size of the coarse aggregate used in this study does not exceed 20, 100 mm cubes have been used, instead of the standard size of cube of 150 mm, as recommended in the above code. However, in order to assess the potential applications of pervious concretes investigated in the study, it becomes necessary to investigate the “size effect” on cube compressive strength of pervious concretes, as the strength requirements specified in the relevant IS codes correspond to the values based on tests conducted on 150 mm cube specimens. Accordingly, the size effect on compressive strength using plasticizer was carried out on a typical series of mixes and the average value of size effect for pervious concrete was determined as 0.92, which compares well with the size effect for conventional concretes as reported by Neville (2006). The above factor was used latter for assessing the suitability of pervious concrete for various types of pavement applications, based on the relevant IS codes.

| Mix designation | Cement content (kg/m³) | Fly ash (kg/m³) | Fine aggregate (kg/m³) | Coarse aggregate (kg/m³) |
|-----------------|------------------------|----------------|------------------------|-------------------------|
| PC2S1           | 250                    | 0              | 0                      | 1,640                   |
| PC2S2           | 250                    | 0              | 82                     | 1,590                   |
| PC2S3           | 250                    | 0              | 164                    | 1,540                   |
| PC2S4           | 250                    | 0              | 246                    | 1,474                   |
| PC2F1S1         | 225                    | 19.5           | 0                      | 1,640                   |
| PC2F1S2         | 225                    | 19.5           | 82                     | 1,590                   |
| PC2F1S3         | 225                    | 19.5           | 164                    | 1,540                   |
| PC2F1S4         | 225                    | 19.5           | 246                    | 1,474                   |
| PC2F2S1         | 200                    | 39             | 0                      | 1,640                   |
| PC2F2S2         | 200                    | 39             | 82                     | 1,590                   |
| PC2F2S3         | 200                    | 39             | 164                    | 1,540                   |
| PC2F2S4         | 200                    | 39             | 246                    | 1,474                   |

Notes: PC1, PC2, and PC3 are denote cement content 200, 250 and 300 kg/m³, in the mixes, with plasticizer; S1, S2, S3, S4 are denote the percentage of fine aggregates 0, 5, 10, 15%, respectively, used in the mix; F1 and F2 are 10 and 20% replacement of cement by fly ash in the mixes.
2.3.2. Flexural strength
Flexural strength of pervious concrete specimens was determined by three-point load test on beam specimens of size 100 × 100 × 500, and in accordance with the Indian standard IS:516-1959, after 28 days of normal curing. The above size of specimen is chosen, for the reasons stated above.

2.3.3. Split tensile strength
Split tensile strength was determined in accordance with the Indian standard IS:5816-1999, on cylindrical specimens of size 100 mm diameter and 200 mm height, after 28 days of normal curing. Even though, 150 mm diameter cylinder specimen is recommended in the above code, 100 mm diameter was chosen so as to limit the consumption of materials. Hence, all the reported results in this paper, are based on the above size of specimen only.

2.3.4. Permeability
Specimens of size 90 mm diameter and 150 mm height were cast and tested after 28 days of normal curing. An experimental set up (Figure 2) was exclusively fabricated for determining the permeability of pervious concrete specimens, based on the falling head permeability method, proposed and reported by Neithalath, Weiss, and Olek (2006), as there is no equivalent standard prescribed in India. The above procedure has also been prescribed as the standard procedure in ACI 522R-10 (2010).

2.3.5. Total and permeable voids
Specimens of size 90 mm diameter and 150 mm height were cast and tested after 28 days of normal curing, and the total voids were determined in accordance with ASTM C1754/C1754M-12 (2012). Permeable voids \( \phi_{pv} \) were calculated using the procedure in the above code and using Equation (1).

\[
\phi_{pv} = \left[ 1 - \frac{(w_2 - w_1)}{\rho V} \right] \times 100
\]  

where \( w_1 \) is the specimen weight under water, \( w_2 \) is the weight of the specimen with the SSD condition, \( \rho \) is the density of water and \( V \) is the volume of the specimen (Seo, 2006).
2.3.6. Cantabro abrasion test
The Cantabro test was conducted in accordance with the Indian standard IS:5816-1999, on cylindrical specimens of size 100 mm diameter and 200 mm height, after 28 days of normal curing.

2.3.7. Sand blasting abrasion
Cubes of size 100 × 100 × 100 mm were cast for each mix and moist cured for 24 h before demoulding, and curing in water continued at 24°C up to 28 days. Sand blasting abrasion was determined in accordance with the Indian standard IS:9284-1979.

3. Results and discussion
Results and discussion were based on the experimental investigations carried out on all the 28 mixes, as detailed in the section on mix proportioning. Further, the results of this work are compared with the salient results of an earlier work of the authors (without addition of plasticizer) (Uma Maguesvari & Sundararajan, in press), restricting the comparison only for the cement content of 250 kg/m³, and to the test results of: compressive strength, permeability and total voids, to highlight the role of plasticizer in pervious concrete.

3.1. Density
Considering all combination of mixes in this study, the density of pervious cement concrete and pervious fly ash–cement concrete ranges from 2,025 to 2,223 kg/m³ and 2,024 to 2,198 kg/m³, respectively (Figure 3). It is seen that the influence of fly ash content on the density of pervious concrete is negligible.

3.2. Compressive strength
Variation of compressive strength of pervious concretes for different cement contents, percentage of fine aggregates and for 10 and 20% replacement of cement by fly ash, are shown in Figure 4. It can be seen that the compressive strength of pervious concrete (i.e. zero fine and zero fly ash content), increases with increase in cement content and that the strength (at 28 days) ranges from...
5.8 to 9.83 MPa for the cement content ranging between 200 and 300 kg/m³ in PC series of mixes (Table 3). Incorporating the size effect, the estimated value of the above compressive strength ranges from 5.34 to 9.04 MPa (at 28 days). Replacement of cement by fly ash has marginally reduced the compressive strength of pervious fly ash–cement concrete. The percentage reduction in the above strength is about 8.6 for 10% replacement, and 12.5 for 20% replacement, when compared to pervious cement concrete. The above behaviour is found to be independent of the cement content used. The compressive strength of pervious fly ash–cement concrete, without fines, ranges from 6.54 to 8.86 MPa, (PCF1 and PCF2) and the above strength range falls within the typical compressive strength reported for pervious concretes (i.e. 2.8 to 20 MPa) in ACI 522 R-10.

Addition of fine aggregates has increased the compressive strength of pervious cement concrete, for all the range of fines-content considered. This is attributed to the improvement in interfacial bond, when compared to “no fines” pervious concrete. Further, there is continuous improvement in the compressive strength due to the addition of fines (Figure 5). Addition of fine aggregates has also increased the compressive strength of pervious fly ash–cement concretes for all the range of fines—content, and there is continuous improvement in compressive strength due to the addition of fines for both levels of replacement of cement (10 and 20%), by fly ash. The compressive strength of pervious fly ash–cement concretes varies from 8.11 to 12.56 MPa (Figures 6 and 7). The strength behaviour of pervious fly ash–cement concrete, with and without fines is similar.

The compressive strength range achieved by pervious cement concrete and fly ash–cement concretes fulfils the requirement for use as LCC in flexible pavement, as per the relevant Indian codes (Table 5) except, the pervious cement concrete and fly ash cement concrete with cement content 250 kg/m³ (no fine and 5% fines). In other words, pervious cement and fly ash cement concretes
with cement content 250 kg/m³, having 10 and 15% fines content and with 10 and 20% replacement of cement by fly ash, satisfy the requirements of DLC.

However, for the cement content of 300 kg/m³, for all fines content and fly ash replacement levels, the compressive strength attained satisfy the requirements of DLC. Hence, the compressive strength ranges of the mixes with cement content 250 kg/m³ reported in this study are compared with that of the strength range of the mixes with the same cement content, but without using plasticizer, and reported by the authors elsewhere (Uma Maguesvari & Sundararajan, in press). The above comparison is given in Table 6. It is seen that the influence of the plasticizer is to impart “marginal” to “slight” improvement in the compressive strength of pervious concretes, even for the cement content 250 kg/m³. On the other hand, the minimum cement/binder content for all pervious concretes, without the use of plasticizer, to be used in DLC of a rigid pavement is 300 kg/m³. Thus, there is substantial savings in the use of cement for pervious concrete, if plasticizer is used.

It is observed that the 7-days compressive strength behaviour of all pervious concretes considered in the study are similar to that of 28-days compressive strength (Figure 8).

| Binder type                  | Fines (%) | Compressive strength (MPa) | Remarks                      |
|------------------------------|-----------|-----------------------------|------------------------------|
|                              | Without plasticizer* | With plasticizer  |                     |
| Cement (100%)                |            |                             |                              |
| 5                            | 7.5        | 8.97                        | Overall improvement in strength 13.38% (marginal) |
| 10                           | 9.2        | 10.90                       |                              |
| 15                           | 10.8       | 11.70                       |                              |
| Fly ash and cement (20 and 80%) |            |                             |                              |
| 5                            | 6.19       | 8.11                        | Overall improvement in strength 17.48% (there is slight improvement) |
| 10                           | 7.40       | 9.34                        |                              |
| 15                           | 9.33       | 10.14                       |                              |

*The details of results are presented elsewhere (Uma Maguesvari & Sundararajan, in press).
3.3. Flexural and split tensile strength

Variation of flexural and split tensile strengths of pervious concrete for various cement contents, percentage of fines, and for two levels of replacement of cement by fly ash, are shown in Figures 9 and 10, respectively. Both the above strength behaviour is similar to that of the corresponding compressive strength behaviour with respect to no fines, range of fines and replacement levels of cement by fly ash, considered. The flexural strength attained is in the range of 1.44–1.88 MPa and 1.47–1.70 MPa, for no fines pervious cement concrete and fly ash–cement concrete, respectively. The flexural strength of pervious cement concretes and fly ash–cement concretes are in the range of 1.76–2.68 MPa, for all the ranges of fines considered (Figure 9). Similarly, split tensile strength attained is in the range of 1.53–2.06 MPa and 1.63–2.15 MPa for no fines pervious cement concretes and fly ash–cement concretes (Figure 10). The split tensile strength of pervious cement concrete and fly ash–cement concrete ranges from 1.59 to 2.65 MPa, for all ranges of fines considered. It is observed that replacement of cement by fly ash, up to 20%, has reduced marginally the flexural and split tensile strengths of pervious fly ash–cement concretes.

3.4. Total voids

The total voids content is in the range of 18.68–28.70% for pervious cement concrete, with and without fines. Addition of fines in pervious cement concrete reduces the total voids. In the case of pervious fly ash–cement concrete, with and without fines, the total voids content is in the range of 18.19–26.47% (for 10% replacement of cement by fly ash) and 16.82–23.55% (for 20% replacement...
of cement by fly ash) (Figure 11). It can be seen that replacement of cement by fly ash has resulted in the reduction of total voids, and this may be attributed to the micro-filler effect of fly ash and that of plasticizer, which has caused a cohesive action, thereby reducing the total voids in the above pervious concrete.

3.5. Permeability
Permeability of pervious cement concretes, without fines, decrease with increase in cement content, and it ranges from 1.650 to 0.889 cm/s. The same trend is exhibited by pervious fly ash–cement concretes for all replacement levels of cement by fly ash and fine aggregates content considered, and it ranges from 1.093 to 0.354 cm/s. The average reduction in permeability of pervious fly ash–cement concrete is about 13.28%, considering the effect of fines and no fines (Figure 12). Permeability of pervious cement concrete and fly ash–cement concrete (for 20% replacement of cement by fly ash) using plasticizer with fines, and for the binder content 250 kg/m³ are: 1.149 to 0.675 cm/s and 0.993 to 0.469 cm/s, respectively. However, for the corresponding mixes, without the use of plasticizer, it ranges between 1.248 and 0.973 cm/s and 1.068 and 0.615 cm/s, respectively. It can be seen that the use of plasticizer has caused a reduction in permeability of about 31.71% in pervious cement concrete, and 25.14% in pervious fly ash–cement pervious concrete.

3.6. Influence of total voids on compressive strength
The total voids content is in the range of 18.68–28.70%, for pervious cement concrete, with and without fines. The corresponding compressive strength of the above pervious concrete ranges from 5.8 to 13.80 MPa (Figure 13). In the case of pervious fly ash–cement concrete, with and without fines, the total void content is in the range of 18.19–26.47% (for 10% replacement of cement by fly ash) and 16.82–23.55% (for 20% replacement of cement by fly ash). The corresponding compressive strength of the above pervious concrete ranges from 6.87 to 12.70 MPa (10% replacement of cement by fly ash) and 6.54 to 11.90 MPa (20% replacement of cement by fly ash) (Figures 14 and 15). The above total voids content and the compressive strength ranges are within the typical void content and strength ranges of pervious concrete as reported in ACI 522 R-10. In general, replacement of cement by fly ash has resulted in reduction in total voids content, and this is primarily attributed to the micro-filler effect of fly ash, and addition of plasticizer which caused a cohesive action,
thereby reducing the total voids in the pervious concrete. In spite of the above effect, addition of fly ash still retains the beneficial effects from technical, economic and environmental considerations. The trends in variation of compressive strength with total voids are similar both for pervious cement concrete and pervious fly ash–cement concrete (Figures 13–15).

### 3.7 Influence of permeable voids on permeability

Increase in permeable voids increases the permeability and it is dependent of the binder content (cement/fly ash) in pervious concretes (Figures 16–18). Permeable voids in pervious cement concretes vary from 17.85 to 27.23% and its corresponding permeability is 0.488–1.650 cm/s. In the case of pervious fly ash–cement concrete, with and without fines, permeable voids are in the range of 16.42–24.79%, for 10% replacement of cement by fly ash and its corresponding permeability is
0.456–1.09 cm/s. It is 15.01–20.67%, for 20% replacement of cement by fly ash and its corresponding permeability is 0.354–0.993 cm/s.

3.8. Influence of total voids on abrasion

The weight-loss in percentage (sand blasting) ranges from 0.035 to 0.191%, whereas, Cantabro loss is in the range from 35.02 to 95.71% for pervious cement concrete, with and without fines (Figures 19 and 20). The above abrasion loss corresponds to the total voids content range of 18.68–28.70% in the above concrete. In the case of pervious fly ash–cement concrete, with and without fines, the total void contents are in the range of 18.18–26.47%. For 10% replacement of cement by fly ash in the above concrete, the percentage weight loss (sand blasting) is 0.046–0.159%, whereas, cantabro loss is 38.76–86.59% (Figures 21 and 23). When the replacement of cement by fly ash is 20% in the
above concrete, the total void content is in the range of 16.82–23.55%, and the corresponding percentage of weight loss (sand blasting) is 0.061–0.164% and the cantabro loss is 42.20–98.50% (Figures 22 and 24). From Figures 19–24, it can be seen that the trend in the increase of total voids results in the increase of the percentage of weight loss (sand blasting and cantabro loss), for both pervious cement and fly ash–cement concretes, and with/without fines.

According to IS:9284-1979 the maximum abrasion loss (sand blasting) is 0.16% for concrete pavements. It can be seen that the abrasion loss obtained for pervious cement concrete and pervious fly ash–cement concrete, are within the limit specified in the above IS code. According to ASTM C1747/C1747M-13 (2013) for the designed void contents of 18, 20 and 22%, the corresponding percent weight loss ranges between 19 and 95%. Cantabro loss evaluated in this study varies from 35.01 to 98.05% and its corresponding total voids is 18.68–23.55%, considering both pervious cement and fly ash–cement concretes, with and without fines. The above range of cantabro loss obtained in this study is closer to the weight loss reported for pervious concretes in ASTM C1747/C1747M-13 (2013).

4. Conclusions
The actual compressive strength of pervious cement concrete (at 28 days), with and without fines, ranges from 5.8 to 13.80 MPa for cement contents ranging from 200 to 300 kg/m³, and using a commercial plasticizer (0.8%—by weight of binder). The above strength range achieved in this study has the potential for use as a typical sub-base/base layer in a flexible pavement, and as a sub-base in a rigid pavement (as per Indian codes). 10 and 20% replacement of cement by fly ash (on weight basis)
has reduced the above compressive strength range only marginally, and therefore, it still has potential applications in flexible and rigid pavements, after improving the strength by various established methods. Addition of fine aggregates (ranging from 5 to 15%) has increased the compressive strength from “marginal” to “high” for both cement and fly ash–cement based pervious concretes, when compared to “no fines” pervious concretes. Strength behaviour of flexural and split tensile strength is similar to that of the corresponding compressive strength behaviour of pervious concrete, for all the parameters and their ranges, considered in this study. The total voids content of pervious cement concrete, with and without fines, is within the typical void content reported in ACI 522 R-10. However, replacement of cement by fly ash in pervious concrete has resulted in the reduction of total voids, which may be attributed to the micro-filler effect of fly ash. Consequently, there is a reduction of about 13.28% in permeability of pervious fly ash–cement concretes, considering all the effect of no fines and fines in the above two systems. The total void content increases the percentage of loss (sand blasting and Cantabro loss) in both the pervious cement concrete and pervious cement–fly ash concretes, considering with and without fines. There is substantial savings in the binder content due to the use of plasticizer. There is reduction in the permeability, total and permeable voids content, of pervious concretes, with/without fines due to the use of plasticizer. All the mixes considered in this study with a minimum cement content 250 kg/m³ and with 10 and 20% of replacement of the above cement content by fly ash, and with fines content 10 and 15%, can be considered for the application of DLC as a base course for rigid/flexible pavements, according to 15 codes.

Supplementary material
Supplementary material for this article can be accessed here http://dx.doi.org/10.1080/23311916.2017.1318802.

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