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Correlation among Properties of No Fines Concrete – A Review

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Abstract —*In the current century, the construction industries have shown an increasing interest in no fines (pervious concrete), an environmentally friendly material. No fines concrete (pervious concrete is a composite material consisting of course aggregate, cement, water and admixtures with the elimination of fine aggregate. Recently an emphasis has been placed on the relationship between the strength, density, porosity and permeability. Researchers have been carrying out investigations to characterize the relationship between the properties of no fines concrete. The objective of this paper is to highlight the important relationship between the properties of no fines concrete. This overview presents the correlation among the properties of no fines concrete including strength, permeability, porosity and void ratio. Based on the results of previous research works on no fines concrete (pervious concrete), it was found that there is a correlation between the properties of no fines concrete and by determining the correlation between the properties of no fines concrete, it could possible to obtain proper no fines concrete used for various construction applications.*

Keywords:*Pervious concrete, no fines concrete, properties, density, strength, permeability, porosity, void ratio.*

I. INTRODUCTION

No fine concrete is a conventional concrete used for draining of storm water and increasing the ground water level [1]. It is prepared of course aggregate, cement and water with the elimination of fine aggregate. Sometime chemical admixtures are added to ease the mixing and placement of no fines concrete. It is also known as pervious, open graded concrete or porous concrete. In normal concrete, the fine aggregates typically fill in the voids between coarse aggregates. But in pervious concrete fine aggregate is non-existent or present in very small amounts. Typically no fines concrete has water to cementitious materials ratio (W/C) of 0.28 to 0.40 [2]. Comparing to conventional concrete which has a void ratio of about 3-5%, no fines possesses void ratio as high as 15-40% depending on its application. The high percentage of void ratio results in low unit weight of about 70% of that of conventional concrete [3]. It has been used in many countries and it continues to gain the popularity as environmentally friendly materials.

II. COMPONENTS OF PERVIOUS CONCRETE

The main components of no fines concrete (pervious concrete) are coarse aggregate, cement, and water. In case higher compressive strength is required, little amount of fine aggregate may be added. Other admixtures such as High/Middle Range Water Reducer (HRWR, MRWR), water retarder, viscosity modifying admixtures, and fibers are usually used. In some cases, cementitious materials are used as a substitute for Portland cement to enhance the environmental friendliness of permeable concrete [2, 4, 5, 6, 7].

III. MIX PROPORTIONS:

There are no specific codal provisions relevant to the mix design of no fines concrete (pervious concrete) in any standard. ACI 211.3 has provided a procedure for proportioning pervious concrete mixtures. Typical mix designs of pervious concrete also had been recommended by different agencies such as National Ready Mixed Concrete Association (NRMCA), and the Southern California Ready Mix Concrete Association (SCRMCA) [7, 8, 9, 10].

Table 1 provides typical ranges of materials proportions in no fines concrete (pervious concrete). Often, local concrete producers will be able to best determine the mix proportions for locally available materials based on trial batching and experience. Sometimes chemical admixtures/retarders are used to ease the placement of no fines concrete (pervious concrete) and reduce the W/C ratio. Little fine aggregate may also added resulting in decrease of the void content and increase of the strength.

TABLE 1
A TYPICAL MIX PROPORTION OF NO FINES CONCRETE

Sr. No	**Materials**	**Amount Per m^3 of Concrete**		
		ACI211.3	**NRMCA**	**SCMCA**
1	Cement (OPC or blended) Kg	270 to 415	224 – 388	286-316
2	Aggregate Kg	1190 to 1480	1431-1670	1027
3	Water: cement ratio (by mass)	0.17 to 0.36	0.27 to 0.38	0.29 – 0.36
4	Fine: course aggregate ratio (by mass)	0 to 1:1	NA	NA
5	Achieved strength at 28 Days (MPa)	20	NA	NA

VI. PERMEABILITY, POROSITY AND DENSITY

Ahmed I. et al (2014) analysed the correlation between the permeability, density and porosity by performing linear regression. He observed that the water permeability generally increases when the porosity increases. The highest permeability of around 0.0282 m/s was obtained when the porosity is higher than 39%. A better correlation was noted, whenthe effective porosity was used. The results indicated a satisfactory trend as the porosity decreased with an increase in density. For the range of densities studied, the linear regression revealed a significant ($p<0.5$) inverse relationship between the density and porosity of the specimens [11].

Ravindrarajah et al. (2014) found that the silica fume plays an important role in strengthening the quality of binding paste and reducing the permeability of pervious concrete, even though the total porosity of pervious concrete has not changed significantly. It was observed that the porosity of pervious concrete marginally reduced when the cement was partially replaced with supplementary cementitious materials. Variation in the wet density was seen due to the combination of the difference in the porosity as well as the use of lower density supplementary cementitious materials compared to cement [12].

It was noticed that for pervious concrete having the porosity between 15% and 40%, a linear relationship could be derived between porosity and permeability and given by the following equation:

$$k = 0.41\ V + 0.51 \qquad (1)$$

Where, k = permeability coefficient inmm/s; and V = porosity in percent [12].

Erhan G. et al. (2014) observed that the high cement content decreased both the permeability and void content of the pervious concrete due to filling the porosity and increasing the cement past thickness. The R-square value of 0.793 indicates a good correlation between permeability and void content. The water permeability generally increases when the void content increases. The high permeability of 12.8 mm/s was obtained when the void content was 25.3 %. The use of a single aggregate gradation was also related to the pore size distribution, pore roughness, and pore connectivity that affect the permeability of the pervious concrete in addition to the void content. However, increasing the permeability implies a higher void content and this decreases the load bearing capacity of the porous concrete [13].

Maguesvari M. U. et al. (2013) found that the void content increase the permeability of the pervious concrete and also it increases regardless of aggregate size and the amount of fine aggregate. The coefficient of permeability increases exponentially with void ratio. The results signify the importance of void content present in aggregate and percentage of fine aggregate regardless of the size of aggregate and cement content [14].

Kuo W. T. et al. (2013) noticed that for the same w/c ratio, it was found that both connected porosity and the permeability coefficient decreased as the pore filling paste ratio increased. The relationship between the connected porosity and the permeability coefficient is approximately linear [15].

Tawatchai et al. (2012) also found that there was a definite trend that the water permeability increased with increase in the void content. However, goodness of fit of the relationship between void content and water permeability was not high due mainly to the narrow void content range (28.7-34.4%) resulted from the use of a single aggregate gradation. This was also related to the pore size distribution, pore roughness, and pore connectivity that affect the permeability of pervious concrete in addition to the void content [16].

Luck J. D. et al. (2006) observed that the regression model for specimen density and permeability suggests that if the density of the concrete mixture were to increase, the permeability would be greatly reduced. The loss of permeability would be attributed to the lack of interconnected voids in the mixture at high densities. The following equation was used to determine the relationship between the permeability and density [17]:

Permeability = 0.064 (Density) + 132.04 (2)
R^2 = 0.72
In this study, linear regression was used to analyse the relationship between the specimen porosity and permeability. As the porosity is reduced, the interconnected voids are eliminated, greatly reducing the permeability of the pervious concrete. Therefore, at a low value of porosity, the pervious concrete would be ineffective at allowing water to infiltrate rapidly through the matrix. The loss of permeability would be attributed to the lack of interconnected voids in the mixture at high densities. The following equation was used to determine the relationship between permeability and porosity [17]:

Permeability = 1.31 (porosity) – 2044 (3)
R^2 = 0.81
The porosity of the specimens was found to follow a consistent trend with respect to the measured density. The relationship between the specimen density and porosity was analysed by performing linear regression. For the range of densities studied, the linear regression revealed a significant ($p < 0.05$) inverse relationship between the density and porosity of the specimens. The following equation was used to determine the relationship between porosity and density [17]:
Porosity =−0.049 (Density) + 116.97 (4)
R^2 = 0.9

VII. PERMEABILITY, VOID RATIO STRENGTH AND DENSITY

Zhong R. et al. (2016) found that there is a decrease in total porosity and an increase in the matrix strength increases the compressive strength of pervious concrete. A linear correlation was used to represent the relationship between the porosity and strength. It was observed that for the different matrices at the same A/B ratios, different strength were observed, this implies that aggregate size influences the strength of concrete in addition to total porosity and matrix strength [18].
Kim W. H. et al. (2016) demonstrated that based on the relationship between void ratio and residual compressive strength, the mixtures which satisfied the target void ratio of 25% and the target residual compressive strength of over 80% after 100 freeze/thaw cycles were the control mixtures, the mixtures containing natural jute fiber—replacement rates of 20% and 40% for blast-furnace slag aggregates—and the mixtures containing latex at replacement rates more than 40% [19].
Erhan G. et al. (2014) observed that while increasing the thickness of cement layer leads to higher compressive strength, however, it decreases the void content and permeability of pervious concrete [13].
Alireza J. et al. (2014) also observed that the pervious concrete mixtures that were expected to have highest permeability rates were those constructed from single sized aggregates. As with the effective porosity, the trends were opposite those of the concrete strength. The relationships among porosity, strength and permeability for pervious concrete were shown. It used to estimate the void content needed for mixtures to satisfy the specification requirement for permeability and strength of concrete. By determining the void ratio, it could possible to obtain proper permeability and compressive [20].
Ahmed I. et al. (2014) also demonstrated that W/C ratio and the pore filling paste ratio have an effect on the permeability and compressive strength of concrete. It was observed that when the w/c ratio of pervious concrete is fixed, an increase in

the pore-filling paste ratio causes a decrease in the permeability coefficient and an increase in the compressive strength. It was also seem that the compressive strength increases linearly with the density [11].

Sonebi M. et al. (2013) also found that surplus paste clogged the open pore structure of Portland cement pervious concrete (PCPC), thus reducing the void ratio and increasing the compressive strength [4].

Maguesvari M. U. et al. (2013) noticed that as void content increases compressive strength decreases. With the addition of percentage fine aggregate in the mix increases Compressive strength. Compressive strength varies from 9.6 $N/mm^2$to 26.2 N/mm^2 irrespective of the size of aggregate and the influence of fine aggregate addition. Total void present in aggregate varies from 28.13% to 40.91%. It follows the general trend. There is a definite correlation between total void and compressive strength [14].

Tawatchai T. et al. (2012) also noticed that the density decreased linearly with an increase in the void content for all pervious geopolymer concretes (PCGs). Similar trend of relationship was observed for the normal Portland cement pervious concrete. A linear relationship with high $R^2$of o.98 was derived as given in Eq. [16].

D= 2481 – 23.2 (V_T) (5)

Where D = density kg/m3 and V_T = void content (%)

It was noticed that the compressive strength of concrete is improved when the density is increased. A linear relationship between compressive strength and density of PGC is shown in the following Eq. [16].

f_C' = 0.035 (D) – 53.6 (6)

Where f_C' = compressive strength in MPa and D is the density of PGC (%)

Similar to the empirical formula of PCPC which were previously reported, the following equation is used to determine the relationship between the compressive strength and void content [16]:

f_C' = 237.77 $e^{-0.107\,(V^T)}$ (7)

Where f_C' is the compressive strength of PGC (MPa) and V^T is the void content of PGC (%)

Karthik H et al. (2007) concluded that for a given mixture proportion strength and permeability of pervious concrete are a function of the concrete density. Greater the amount of consolidation higher the strength, and lower the permeability. The relationship between the w/cm and compressive strength of conventional concrete is not significant. A high w/cm can result in the paste flowing from the aggregate and filling the void structure. A low w/cm can result in reduced adhesion between aggregate particles and placement problems [5].

VIII. POROSITY AND STRENGTH

Ahmed I. et al. (2014) observed that Overall, when compressive strength decreased from 8.96 MPa to 1.06 MPa with increase in porosity (from 30% to 40%) [11].

Alireza J. et al. (2014) found that with the increase in the porosity, the strength of pervious concrete is reduced.. The results confirm that the compressive strength of pervious concrete reduces with an increase in void ratio. The equation relating strength and void ratio is applicable [20].

C = 11.568$e^{-0.022\,P}$ (Mpa) (8)

R^2 = 0.8205

Where, C = the 28-day compressive strength for pervious concreteand P = the porosity of the pervious concrete mix [20].

Ravindrarajah et al (2010) found that the relationship between compressive strength at 28 days and porosity for pervious concrete was linear. Within the porosity between 15% and 30%, the compressive strength dropped linearly with the increase in porosity: f = - 0.71 V + 26.6 where, f = compressive strength at 28 days in MPa; and V = porosity in percent [21].

IX. CONCLUSION

This paper presents an overview of the correlation between strength, density, permeability, porosity and void ratio. Based on previous research works, It was found that the water permeability generally increases when the density of no fine concrete increase. The coefficient of permeability increases exponentially with void content. The regression model for specimen density and permeability suggests that if the density of the concrete mixture were to increase, the permeability would be greatly reduced. The loss of permeability would be attributed to the lack of interconnected voids in the mixture at high densities. It was also observed that when there is a decrease in total porosity and an increase in the matrix strength, compressive strength of no fine concrete (pervious concrete) increases. Strength is reversely related to the permeability and void content of pervious concrete. This implies that when the strength of no fines concrete (pervious concrete) is increased, there will be a reduction in the void content and permeability of no fines concrete. It is concluded that by determining the correlation between the properties of no fines concrete, it could possible to obtain proper no fines concrete used for various construction applications.

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