Study on Influencing Parameters of Strength of Pervious Concrete

Radharapu Chinni Divya, P. Polu Raju, J. Leon Raj

Abstract: Pervious concrete is a special type of concrete with a mixture of cementatious material, the coarse aggregate of smaller size, admixtures, and water. Pervious concrete applications include road pavements, rainwater harvesting -and drainage in retaining walls due to its high porosity. The void content and water-cement ratio of pervious concrete are in the range of 15-30% and 0.27-0.36, respectively. The experimental data is collected from the literature cover and graphs are drawn for water to cement ratio, cement to aggregate ratio versus compressive strength. The maximum size of aggregate used in the mixture of pervious concrete is 20mm, thus, influences the porosity range from 11%-60%. In this paper, regression equation is predicted and validated for strength parameters like compressive strength, porosity, density of pervious concrete and the experimental results are obtained from the experiment done for the beams of size 500*100*100mm dimensions by using Master Glenium as the admixture in pervious concrete and the graphs are drawn for the predicted versus experimental results.

Index Terms: Master Glenium, pervious concrete, regression equation, water to cement ratio.

I. INTRODUCTION

Pervious concrete is environmentally friendly paving material and it consists of single sized coarse aggregate (6.5mm to 20mm), little to no fine aggregate, cementing materials, water, and admixtures. Pervious concrete is made with narrow aggregate graduation, but different surface textures that depend on aggregates size. Pervious concrete is typically designed for a void content in the range of 15-30% and is used for concrete flatwork application that allows water from precipitation and other sources to pass through it, thereby reducing the runoff from a site and recharging groundwater levels. Pervious concrete gives compressive strength not more than 20MPa. Pervious concrete has so many advantages to use mainly some of them are controlling runoff amount, recharge water table, purify water through filtration in the soil, eliminating HCL effects, reducing tire-pavement interaction noise, provide anti-skid resistance, etc. The focus of pervious concrete technology is to balance the permeability and mechanical properties as well as durability, if the mixture is too wet and easy to compact, the voids will be clogged, and the permeability will be compromised. However, if the mixture is too dry and hard for compaction, then the pervious concrete pavement will be weak and vulnerable to various types of distress [1]. Moreover, previous concrete is applied as a sound absorber in European countries and in river banks protection in Japan [2]. As an important factor, the pore structure also exerts a significant influence on permeability and the sound absorption capacity of porous pavement [3]. The ability to allow water penetrating through its pore structure makes it a very effective tool to control stormwater runoff. Although previous concrete has been used for over 30 years, the material is attracting renewed interests due to Federal Water Pollution Control Act [4]. Several researchers around the world have investigated the properties of pervious concrete for a few decades; some researchers have investigated the effects of aggregate type and aggregate grading on the properties of pervious concrete and evaluated the relationships among these properties [5-7]. This article reports influencing parameters affecting strength characteristics of pervious concrete and their importance.

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II. RESEARCH SIGNIFICANCE

In this study, the parameters influencing the compressive strength of pervious concrete was investigated and their influence was graphically represented. Also, this study aims to investigate the effects of aggregate size, porosity, permeability, density, water to cement ratio, admixture on compressive strength of pervious concrete.

III. STRENGTH INFLUENCING PARAMETERS

A. Effect of Aggregate Size on Compressive Strength

Aggregate properties have the strongest effect on the mechanical properties of porous concrete. The compressive strength for porous concrete is representative for 28 days [5]. The interfacial transition zone between the cement paste and aggregate is a critical factor that greatly affects the pervious concrete properties [9] aggregate size of 4.75-9.5 mm achieves the maximum compressive strength of 10.4 MPa corresponding to the lowest porosity[8].

B. Effect of Porosity on Compressive Strength

Figure 1 shows that the increase in porosity decreases the compressive strength. Porosity efficiency is more influenced by the aggregate size which ranges from 11% to 35% of the volume of concrete. With the density of pervious concrete between 1700 kg/m^3 and slightly higher than 1900 kg/m3, the range of porosity is from 0.20 to 0.40. The average porosity of pervious concrete is around 0.30. The compressive strength is reduced from 18MPa to 5MPa with a porosity increase by 0.1. An increase in porosity decreases the compressive strength [2]. The non-intrusive pores weaken the strength of concrete and due to its high porosity; pervious concrete generally has a significantly lower strength and durability properties than conventional concrete [10]. The large size pores in the pervious concrete results in passage of clogging material and small size pore material block the pores [11].

C. Effect of Density on Compressive Strength

Figure 2 shows that the compressive strength of the pervious concrete increased with an increase in density the compressive strength increased from 6MPa to 15MPa when density increased to 1900kg/m³. The increase in density of pervious concrete increases the compressive strength whereas porosity and permeability decreases [2].

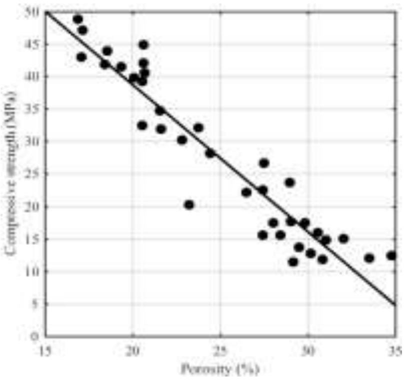

Figure 1: Porosity Vs Compressive strength

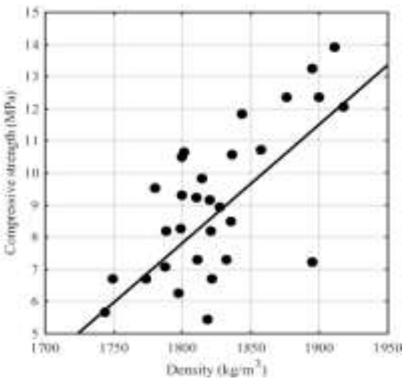

Figure 2: Density Vs Compressive strength

D. Effect of Water-Cement Ratio on Compressive Strength

From Figure 3, it is observed that the compressive strength increases with increase in water to cement ratio. Normal strength for the water-cement ratio of 0.55 (ASTM C230/C230M) compressive strength is 29MPa after 28 days. Reducing the water-cement ratio to 0.45 and adding a high range water reducer (HRWR) in the amount of 0.2% to the weight of the cement yielded and enhanced compressive strength of 61Mpa [4].

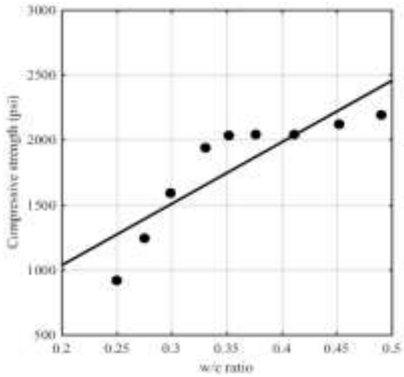

Figure 3: w/c ratio Vs Compressive strength

E. Effect of Admixture on Compressive Strength

The compressive strength can be decreased by 40% if a high percentage replacement of cement with fly ash (50%) is used and by mixing silica fume and silica powder the compressive strength can be increased [4]. The experiment with recycled aggregates gives the conclusion that the recycled aggregate compressive strength decreases with increases in crushing index when the index percentage was taken above 24% [7]. Using different types of aggregates for pervious concrete and finally concluded to use limestone and latex to increase compressive strength for pervious concrete [1]. The polymer modification improved the strength of pervious concrete [7].

F. Effect of Permeability on Compressive Strength

Figure 4 show that the increase in permeability decreases the compressive strength. Permeability is also influenced by the aggregate distribution and interconnectivity. The permeability coefficient of porous concrete decreases rapidly after adding sand and at the same time the resistivity increases [12]. The water permeability generally increased when the porosity increased [2]. The compressive strength of pervious concrete increases with the decrease in a/c ratio in the presence of more cement in the mixture, more cement in the mixture would fill void spaces once occupied by air, thereby reducing the permeability of the concrete. Generally, as the void content decreases the strength increases and permeability decreases in pervious concrete [13, 11].

RESULTS

Table I: Gradations and mix proportions for pervious concrete

Gradation Identifier	Aggregate size(mm)	Permeability (mm/s)	Compressive strength 28days(MPa)	porosity(%)	Density(kg/m3)	w/c ratio
	12	0.9	21.754	51	2420	0.35
M1	20	0.86	25.381	57	2222	0.35
	blinded	0.95	14.5	52	2630	0.35

	12	0.8	58.013	40	2215	0.35
M2	20	0.8	65.264	38	2218	0.35
	blinded	0.86	54.3872	41	2221	0.35
	12	0.8	65.2646	32	2222	0.35
M3	20	0.86	61.6388	39	2236	0.35
	blinded	0.9	58.013	33	2224	0.35

IV. MATERIALS AND METHODS

The materials used in the study mainly consisted of crushed aggregates, OPC 53 grade, and Master Glenium plasticizer. Three gradations were used as shown in Table I. M1 is without plasticizer and M2 and M3 are with plasticizers of 0.3% and 0.4% respectively. w/c ratio of the three gradations as same as 0.35 and the variation in the aggregate sizes are also mentioned.

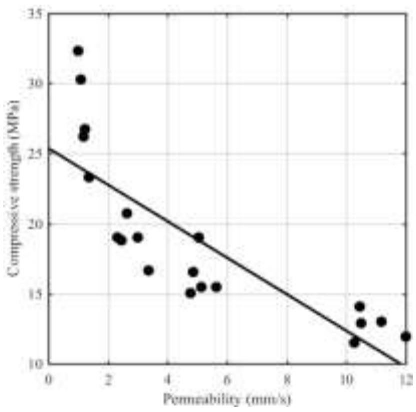

Figure 4: Permeability Vs Compressive strength

A. Specimen Preparation

Pervious concrete beam specimens of size 500mm length 100mm depth and breadth were compacted in two layers with 20 blows per layer using 2.5kg standard proctor hammer. The fresh samples were left undisturbed in the mold for 24 hours and cured in water for 7 days.

B. Hardened Density and Porosity

The hardened density of 7-days cured pervious concrete beams were dried for 1day at room temperature and then weighed. The porosity was calculated using the relation provided in ASTM C2012 procedure by determining the submerged weight in water after agitating the specimens for 10 minutes and subtracting it from the dried weight of the specimen.

C. Compressive Strength

Compressive strength (CS) was determined using a beam testing machine. The specimens were placed in the 2 point loading testing machine and adjusted the loading points to be placed on the beam at the exact points and then the displacement of the load was done.

D. Permeability

Permeability of the pervious concrete beams was determined by using the eq 1.

$$K = \frac{L}{t} * 2.303 * \ln\left(\frac{h1}{h2}\right) \quad (1)$$

Where K = permeability (cm/s), L = length of specimen (cm), t = time (s), h1 = initial head (cm), and h2 = final head (cm).

V. REGRESSION EQUATIONS AND VALIDATIONS

A. Fixing the Target Strength

In Pervious concrete, it is well known that a trade-off exists between strength and permeability. Pervious concrete with higher strength will have lower permeability, porosity and vice versa, which requires both properties are included in the same relationship in order to obtain rational values. In this study, the compressive strength of pervious concrete was in the range of, and density is in the range off. The target strength to be selected may be based on the application of PC as a pavement material.

B. Prediction of Hardened Density

The structural and functional properties of pervious concrete are largely dependent on the hardened density or porosity. In this study, a regression equation was developed that predicts the hardened density of pervious concrete chiefly to achieve target properties.

$$Density = 1721.609 + (12.09011 * CS) - (1.68682 * AS) \quad (2)$$

where CS= compressive strength (MPa), AS= aggregate size(mm)

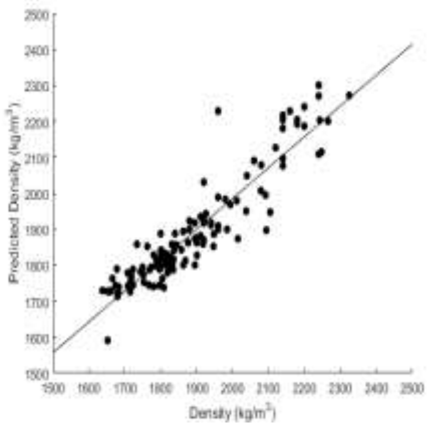

Figure 5.1: Observed versus predicted hardened density

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Table B-1: ANOVA Summary for hardened density model [Eq. 2]

Source	Sum of squares	Degree of freedom	Mean square	F- value	Significance F
Regression	2	3013985	1506993	359.7527	352E-51
Residual	119	498487.1	4188.968		
Total	121	3512472			

Table B-2: Parameter estimates for hardened density model [Eq. 2]

Variable	Coefficient	Standard Error	t-stat	p-value
Constant	1721.609	11.118	154.8488	4.3E-139
Compressive strength	12.0011	0.462884	26.11907	4.17E-51
Aggregate size	-1.68682	0.707162	-238534	0.018642

Eq. 2 has been obtained using various combinations of the mixture variables such as compressive strength and aggregate size. Tables B-1 and B-2 show the summaries of ANOVA and parameter estimates, respectively, for Eq. (2). All the variables considered in the equation had a positive relationship with hardened density and were statistically significant. Comparison of the observed and predicted values is shown in Figure 5.1.

C. Prediction of Compressive Strength

In this study, a regression equation was developed that predicts compressive strength of pervious concrete chiefly to achieve target properties. The regression equation to predict the required compressive strength based on the selected mixture variables such as aggregate size, porosity, water-cement ratio, density.

$$CS = -124.632 + (0.0753 * AS) + (0.18626 * P) - \left(22.961 * \frac{w}{c}\right) + (0.0743 * D) \quad (3)$$

Where CS=compressive strength, AS= aggregate size, P=porosity, w/c=water-cement ratio, D= density

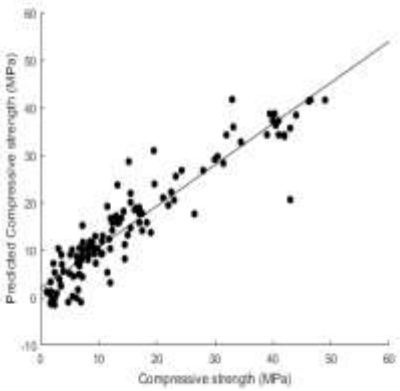

Figure 5.2: Observed versus predicted compressive strength

Table C-1: ANOVA Summary for compressive strength model [Eq. 3]

Source	Sum of squares	Degrees of Freedom	Mean square	F- value	Significance F
Regression	4	17308.33	4327.082	192.1833	193E-50
Residual	117	2634.301	22.5154		
Total	121	19942.63			

Table C-2: Parameter estimates for compressive strength model [Eq. 3]

Variable	Coefficient	Standard Error	t-stat	p-value
Constant	-124.632	16.21736	-7.68509	5.19E-12
Aggregate size	0.075303	0.052635	1.430661	0.155193
Porosity	0.18626	0.059943	3.107308	0.00237
w/c ratio	-22.961	45.40765	-0.50566	0.614044
Density	0.074398	0.002833	26.25979	7.09E-51

Eq. 3 has been obtained using various combinations of the mixture variables such as Aggregate size, Porosity, w/c ratio, Density. Tables C-1 and C-2 show the summaries of ANOVA and parameter estimates, respectively, for Eq. 3. All the variables considered in the equation had a positive relationship with compressive strength and were statistically significant. Comparison of the observed and predicted values is shown in Figure 5.2.

D. Prediction of Porosity

In this study, a regression equation was developed that predicts porosity of pervious concrete chiefly to achieve target properties. The regression equation to predict the required porosity based on the selected mixture variable such as density. The relationship between the porosity and the density are very flexible and the development of the equation used the previous data results to get the predicted equation.

$$Porosity = (-0.0785 * density) + 189 \quad (4)$$

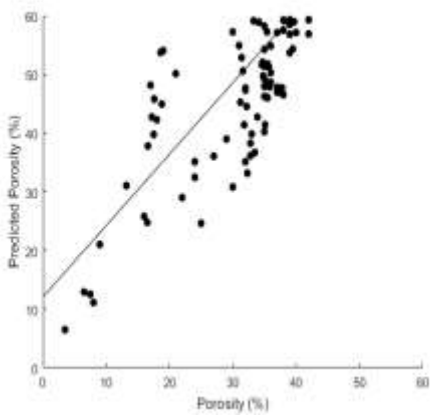

Figure 5.3: Observed versus predicted porosity

Table D-1: ANOVA Summary for porosity model [Eq. 4]

Source	Sum of squares	Degree of freedom	Mean square	F- value	Significance F
Regression	1807.30	1	1807.30	3777.52	0.0001
Residual	16.27	34	0.49		
Total	1823.56	35			

Table D-2: Parameter estimates for porosity model [Eq. 4]

Variable	Coefficient	Standard Error	t-stat	p-value
Constant	189.005	1.5021	79.895	0.001
Density	-0.0785	0.001	-61.428	0.001

Eq. 4 has been obtained using various mixtures such as Density. Tables D-1 and D-2 show the summaries of ANOVA and parameter estimates, respectively, for Eq. 4. All the variables considered in the equation had a positive relationship with porosity and were statistically significant. Comparison of the observed and predicted values is shown in Figure 5.3.

E. Validation

The above section showed that the regression equation developed has the best accuracy. The performance of the regression equation needs to be assessed by validating the specimens using a separate set of data which are not used in the development of equations. The comparison of laboratory measured values and predicted values of regression models are shown in Figures 5.4-5.6.

The Figures show that the models predicted the measured value of compressive strength and density of pervious concrete in the laboratory with good accuracy. This shows that equations for prediction can help in mix design optimization.

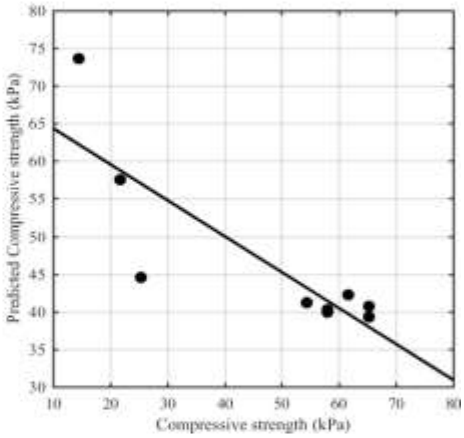

Figure 5.4: Compressive strength

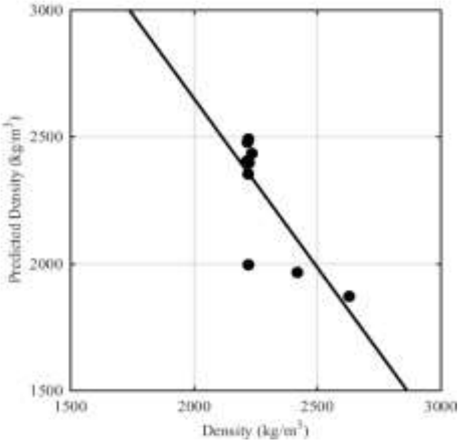

Figure 5.5: Density

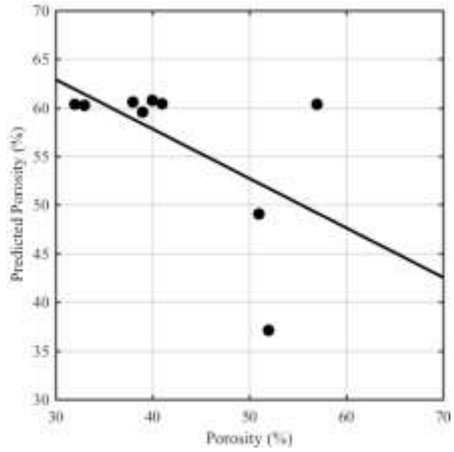

Figure 5.6: Porosity

VI. VI. CONCLUSION

The following conclusions were made upon detailed study on influencing properties of pervious concrete.

1. The study deals with the development of a series of regression equations, which are important in the selection of pervious concrete mixture and design.
2. These equations are found to be good in compressive strength prediction and hardened density prediction but not the porosity properties.
3. The compressive strength of pervious concrete increases with the cement-to-aggregate ratio, cement content and decreases with a water-cement ratio, aggregate size, and void content. Further, porosity increases with the size of the aggregate.
4. The equations can help in mixture optimization, which can decide the mixture variables to prepare the specimens and test them.

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