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Influence of Water Cement Ratio and The Size of Aggregate on The Properties Of Pervious Concrete

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Abstract: Pervious concrete is a tailored-property concrete with high water permeability which allow the passage of water to flow easily through the existing interconnected large pore structure which is obtained by eliminating the sand from the normal concrete mix. This study investigates the effect of water cement ratio and size of aggregate on the property of pervious concrete. Concrete mixes with five different water cement ratio (0.28, 0.30, 0.32, 0.33, 0.34) and two different single sized aggregate (10mm and 12.5mm) were prepared to find an optimum mix yielding the highest strength but the strength of no-fine concrete is lower that of normal concrete. It was found that the compressive strength increases with increase in water/cement ratio where the permeability decreases. Both the permeability and compressive strength increases as the size of aggregate increases.
Keywords: no – fine concrete, compressive strength, permeability, water cement ratio, single sized coarse aggregate.

I. INTRODUCTION

In recent times, major cities around the world have experienced frequent flooding and the socio-economic climate around the world is also changing due to increased urbanization, pervious surfaces and vegetation are replaced with impervious materials such as pavements and structures which lead to an increase in runoff and pollution. This increase directly affects the surrounding rivers and streams, with impacts such as increased stream bank erosion, decreased water quality, and decreased base flow as areas become less and less pervious. As a consequence, the drainage system gets overloaded and flash flooding becomes inevitable, thus causing disruption to the road transport and flooding of basement car parks and shopping centers. Engineers must consider not only the economics of a project, but the impact on the human and natural environment. Reducing the strain on our environment is essential to the overall health and wellbeing of our society. Sustainable construction designs have become extremely popular within the last few years. Many of these technologies for storm water management are emerging in the form of Best Management Practices (BMPs) and pervious concrete is considered to be one of the best methods by Environmental Protection Agency (EPA), American Public Works Association (APWA) and the Mid America Regional council (MARC). It has been gaining a lot of attention in recent years due to its various environmental benefits such as controlling storm water runoff, restoring groundwater supplies, reducing water and soil pollution specially used in primary pavements which are in: residential roads, alleys and driveways, low volume pavements, low water crossings, sidewalks and pathways, parking areas, tennis courts, slope stabilization, sub-base for conventional concrete pavements etc [Advanced Concrete Pavement Technology – ACPT; CIP 38 Pervious concrete].

Pervious concrete can be produced using conventional concrete-making materials, namely cement, supplementary cementitious materials, admixtures all types of coarse and fine aggregates, and water. They usually consist of single sized aggregate which is bonded together at its point of contact by a paste formed by the cement and water. The paste forms a thick coating around aggregate particles. Using enough paste to coat the particles maintain a system of interconnected voids which allow water and air to pass through. The lack of sand in pervious concrete results in a very harsh mix with a rough textured, and a honeycombed surface. To achieve the permeability, pervious concrete is typically designed with high void content (15%-30%).

Due to the high void content, pervious concrete has lower compressive strength and less unit weight of approximately 70% of conventional concrete [NRMCA 2004]. However, pervious concrete has a greater advantage in many regards. Nevertheless, it has its own limitations which must be put in effective consideration when planning its use. In general pervious concrete automatically acts as a drainage system, thereby putting water back where it belongs. The hydrological performance is always the “driving force” to permit pervious concrete construction. It also mitigates the urban heat island effect, quickly dissipating heat after sunset due to the large amount of surface area. In addition to decreasing the volume of runoff, pervious concrete has some general filtration properties, reducing the impurities caused by automobiles and other sources and enhancing the quality of storm water [Kevern et al, 2005]. Because the storm water is allowed to enter the groundwater and recharge the aquifer, pervious concrete reduces the overall impact that human development has on the existing ecosystem.

II. LITERATURE REVIEW

The standard type aggregate for use in pervious concrete is typically crushed stone or river gravel where the coarse aggregate grading is single-sized coarse aggregates or narrowly-graded. A narrow grading is an important characteristic and is the remarkable difference with conventional concrete. Typical sizes are from 9.52mm to 25.4mm (3/8 in. to 1 in.) [Tennis et al, 2004]. It has been shown that using smaller aggregates increases the compressive strength of pervious concrete by providing a tighter bond between coarse aggregate and cement. [Cosic et al, 2004]. Increasing the percent amount of larger aggregates will increase the void ratio in pervious concrete, but will decrease the compressive strength [Jain et al, 2007].

The size of the aggregate also has an important role in pervious concrete. While a 3/4 in. aggregate size allows for greater void space, a 3/8 in. aggregate improves the workability [Schaefer et al, 2007]. The use of 3/4 in. aggregate can decrease settling and workability. Recent studies have also found that pervious concrete with smaller aggregates had higher compressive strength [Jing Yang, 2002]. It was noted that the smaller aggregate sizes allowed for more cementitious material to bind around the aggregate and hence allowed for greater contact between the aggregate/binder. Use of coarser aggregates in the mixture increases skid resistance, void ratio, and permeability. Smaller aggregates produces higher mechanical strength but with trade off decreasing of permeability [Kevern 2014]. The increase of aggregates size would increase permeability and decrease the acoustic absorption property for the samples with similar total porosity [Neithalath et al, 2010; Bonicelli et al, 2004]. Good mixtures should achieve the balance between the hydraulic performance and mechanical properties.

In general Pervious concrete mixtures can develop compressive strengths from 2.8 MPa to 28 MPa (500 psi to 4000 psi). Meininger (1998) demonstrated the relationship between compressive strength and water-to-cement ratio. The optimal w/c ratio with the highest compressive strength was found to be between 0.30 and 0.35. Lower w/c ratios provide poor cohesion between the aggregates. Cement paste in permeable concrete is very thin layer which binds coarse aggregate. Porous concrete tends to fail at the binder interface between the aggregate and it results in the low compressive strength [Yang & Jiang, 2003; Zhuge & Lian, 2009]. Compressive strength decreased with increased porosity and with increased aggregate gradation coarseness [Stephen et al, 2006]. Degree of compaction and porosity are the two most important factors that influence the mechanical properties of pervious concrete. It has been found that the increase of fresh unit weight, increase of fine aggregates in mixtures, and the application of high compaction effort can increase the mechanical properties but also decrease the hydraulic performance [Schaefer et al, 2006]. Also aggregate-to-cement ratio is important to determine the mechanical properties of pervious concrete; lower the aggregate cement ratio higher could be the strength. The compaction energy also decides the compressive strength of pervious concrete i) Uncompacted, (Unc) ii) two layers compacted (2R), iii) three layers compacted with a standard proctor hammer.(PH) shows a high compressive strength for PH but reduced permeability [Torres et al, 2015]. To improve the strength of pervious concrete, three components must be improved: the strength of the paste, the paste thickness around the aggregate, and the interface between the aggregate and the paste. These goals can be achieved by altering the mixing process, using smaller size aggregate, and/or using admixtures [Suleiman et al, 2003].

Mixes used in Europe and Japan often incorporate aggregate smaller than that used in the United States, in addition to a small percentage of sand. These differences substantially increase strength values over domestic mixes. Some Belgian mix designs incorporating sand and a latex emulsion have produced a 28-day compressive strength of up to 31MPa (4,600 psi). However, the permeability of this mix was not reported [James et al, 2005]. Raveling of individual concrete pieces was observed at the entrance and exits of various sites leading to the recommendation of limiting pervious concrete installation where repetitive loading occurs. Higher aggregate to cement ratios decreased strength while higher water-to-cement ratios tended to decrease porosity. The recommendation was to limit pervious concrete to lower loading applications [Mohammed et al, 2007].

III. EXPERIMENTAL STUDY

A. Materials

Various engineering and physical properties of the aggregate sample such as flakiness index, los angel's abrasion value, water absorption, specific gravity, Bulk density, Impact value, Crushing value for both 10mm and 12.5mm aggregates has been determined. Details of material, mix proportion, sample preparation and test method used is as follows:

1) Cement

Ordinary Portland cement of 53 grade confirming to IS: 12269-1987 is used. Physical properties are determined as per IS: 4031-1988 and is given in Table 1.

Table 1: Properties of cement used in Experiments

Test	Value	Recommended as per IS:12269-1987
Specific gravity	3.14	-
Standard consistency (%)	28	-
Initial setting time(min)	185	30(min.)
Final setting time(min)	310	600(max.)

2) Coarse aggregate

Two different single graded Coarse aggregate of size passing through 12.5mm, retaining on 10mm and passing through 10mm retaining on 4.75mm were used for experimental work. The physical properties are determined as per IS: 2386-1963 as shown in table 2.

Table 2: physical properties of coarse aggregate

Physical properties	Natural aggregate	
	12.5mm	10mm
Specific gravity	2.738	2.729
Water absorption (%)	0.702	0.9
Bulk density (kg/m^3)	1334	1268
Flakiness index (%)	12	7.9
Elongation index (%)	12.3	10.6
Impact value (%)	20.61	
Crushing value (%)	23.13	
Abrasion value (%)	19.76	

3) Water

Potable water was used for preparation of mix and curing of concrete sample. As the scope of the study is limited to find out the effect of water cement ratio and size of aggregate used in pervious concrete, chemical admixtures is not used in the study.

B) Mix proportions

The specimens were casted with varying the water cement ratio as 0.28, 0.30, 0.32, 0.33, 0.34 for both single graded coarse aggregate of size 10mm and 12.5mm. The cement and the void content were kept constant as 400kg/m^3 and 15% respectively. Three specimens for each mix were prepared to determine the individual mechanical properties. Specimens of pervious concrete were cast with the compacting rod. All the specimens were extracted from the moulds 24 hours after the casting and placed in a water tank for 28 days at a temperature of 20$\pm$ 5 c. The mix proportion details have been shown in table 3.

Table 3: Mix proportion details

Materials	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5
Cement (kg/m^3)	400	400	400	400	400
Coarse aggregate (kg/m^3)	1667	1645	1624	1613	1602
Water (l/m^3)	112	120	128	132	136
W/C ratio	0.28	0.30	0.32	0.33	0.34
Void ratio (%)	15	15	15	15	15

IV. TEST RESULTS AND DISCUSSION

A) Compressive Strength

The compressive strength of no-fine concrete contains 12.5mm and 10mm singled graded aggregate was determined after 7, 14, and 28 days of water curing. Table 4 & 5 gives the compression strength of 12.5mm and 10mm aggregates of no-fine concrete with different water cement ratio respectively. Strength increases as the water cement ratio increases as 0.28, 0.30, 0.32, 0.33 but it reduces at the ratio of about 0.34. The maximum compressive strength is obtained with the water cement ratio of 0.33 of about 16.98MPa for 12.5mm aggregate and 15.09MPa for 10mm aggregate. The compressive strength of no fine concrete is lower then the compressive strength of normal concrete due to its porosity but appears to be sufficient enough for specialized use where compressive strength demand is not very high. However, its other advantages (as mentioned above) over conventional concrete may provide a mean for economic and sustainable concrete in construction works such as paver block, drainage material, pavements of low volume traffic, sidewalks, floor for green roof, etc.

Table 4: The compression strength of 12.5mm aggregates of no-fine concrete with different water cement ratio

w/c	Compressive strength (MPa)		
	7days	**14days**	**28days**
0.28	5.07	7.52	8.83
0.30	5.70	7.98	10.27
0.32	7.54	10.66	11.54
0.33	10.81	15.17	16.98
0.34	10.51	14.78	16.13

Table 5: The compression strength of 10mm aggregates of no-fine concrete with different water cement ratio

w/c	Compressive strength (MPa)		
	7days	**14days**	**28days**
0.28	3.87	6.27	7.07
0.30	4.11	8.31	8.87
0.32	6.56	8.79	10.23
0.33	9.5	14.42	15.09
0.34	7.13	12.49	14.34

B) Permeability

For each mix, three identical cylindrical specimens were tested under falling head method for water permeability using a specially made permeability test set-up as shown in fig 1. The specimens were wrapped with membrane to ensure that the water only flows through the cross – section without any leaks along its edges. The co-efficient of permeability is determined using the Eq. (1). Permeability decrease with increase in water cement ratio for both aggrading of aggregate. Table 4. Gives the co – efficient of permeability of various mixes.

$$k = \left(\frac{a \times L}{A \times T}\right) \ln\left(\frac{h_0}{h_1}\right) \qquad \text{………. (1)}$$

Where:

K= Coefficient of permeability, cm/sec
a= Cross-Sectional area of the pipe (cm²)
L= Length of the specimen (cm)
A=Cross-sectional area of the specimen (cm²)
T= Time taken for the head to fall from (h0) to (h1), by (sec)
h_0= Initial water head (cm)
h_1=Final water head (cm)

Table 4. Permeability of concrete

w/c ratio	Permeability (cm/s)	
Size of aggregate	**12.5mm**	**10mm**
0.28	2.72	1.96
0.30	2.50	1.89
0.32	2.265	1.78
0.33	2.049	1.745
0.34	1.962	1.716

Fig. 1. Permeability equipment

C) Influence of water cement ratio on the property of concrete.

Fig. 2 and 3 shows the variation in compressive strength of pervious concrete with various water cement ratio for 12.5mm and 10mm single graded aggregate respectively. A constant increase in compressive strength is seen when the water cement ratio increase from 0.28 to 0.33 and about 5% decrease in compressive strength is seen with W/C ratio of 0.34. The results shows that for a given size of aggregate, there is an optimum W/C ratio which could completely coat the surface of aggregates producing the higher compressive strength below which the mix is very dry i.e. not enough cement paste to coat the aggregate surface above which the water content increase thus reducing the strength. In this study an optimum W/C ratio of about 0.33 is obtained for both the size of aggregates. Permeability decreases with increase in W/C ratio. In case of low water cement ratio the mix is very dry leading to high porosity and permeability, but when the W/C ratio increases paste draw down effect is formed which fills the pores also causes paste draw down effect which reduces permeability.]

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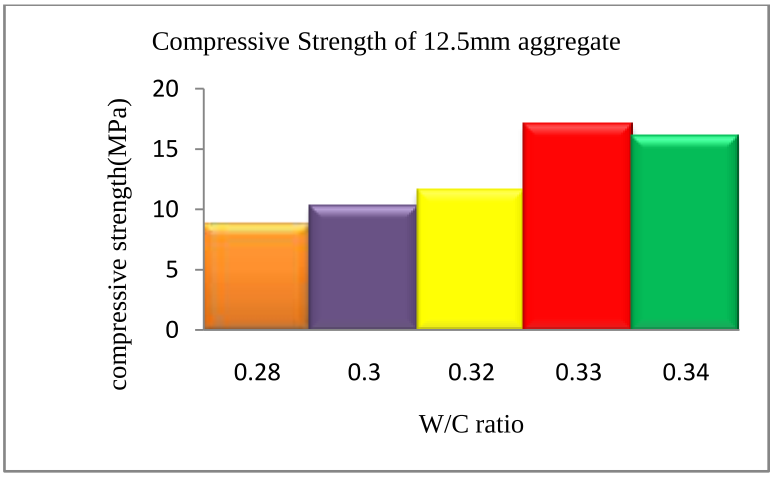

Fig.2. Compressive Strength of Pervious Concrete with Various Water Cement ratio for 12.5mm Aggregate.

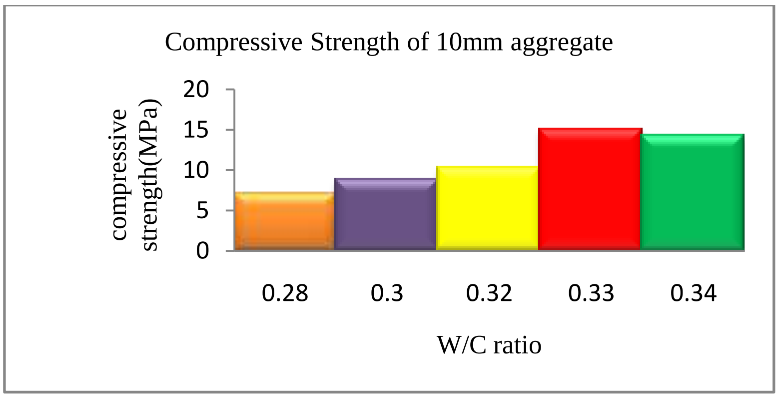

Fig.3. Compressive Strength of Pervious Concrete with Various Water Cement ratio for 10mm Aggregate.

D) Effect of aggregate size on the property of pervious concrete

The influence of size of the aggregate on the compressive strength of pervious concrete is shown in Fig.4. Pervious concrete mix produced using smaller size aggregate of about 10mm shows lesser compressive strength then the concrete produced with the aggregate of size 12.5mm. The highest compressive strength obtained in case of 12.5mm and 10mm is 16.98MPa and 15.09MPa respectively. This shows that the cement paste content with W/C ratio of 0.33 is enough to coat the surface of 12.5mm sized aggregates which is insufficient in case of 10mm aggregates. In case of permeability the mix prepared using larger sized aggregates produced pores larger in size, thus causing higher permeability then the concrete prepared using smaller size aggregate i.e. the concrete produced using 12.5mm aggregate produces permeability ranging from 2.72cm/s to 1.962 cm/s and for 10mm aggregate they produces 1.96 cm/s to 1.716cm/s for the increased water cement ratio.

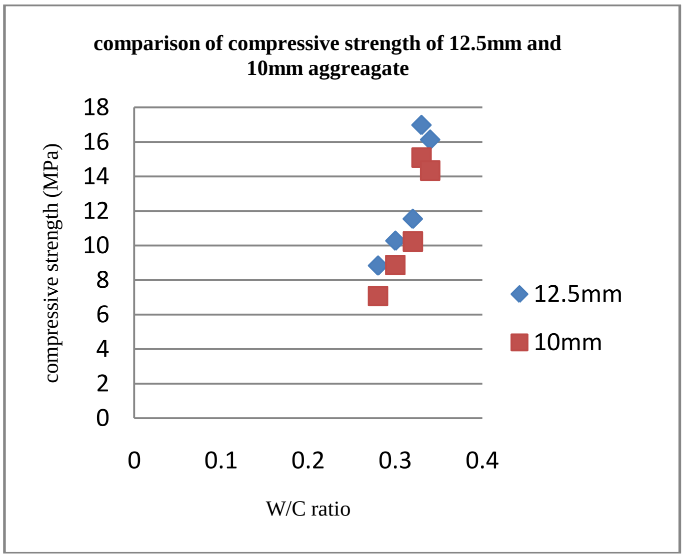

Fig. 4. The influence of size of the aggregate on the compressive strength of pervious concrete

E) Compressive strength Vs permeability of pervious concrete.

Fig.5 & 6 shows the relationship between compressive strength and permeability for 12.5mm and 10mm respectively. As compressive strength increases, the permeability decreases. In this study the highest compressive strength observed in mixes having 12.5mm aggregate at W/C ratio of 0.33 is 16.98MPa, but the highest permeability of about 2.72 cm/s is obtained with the W/C ratio of 0.28, thus when the W/C ratio increases the compressive strength increases which is contrary in case of permeability. Thus depending on the application of pervious concrete the compressive strength and the permeability should be decided.

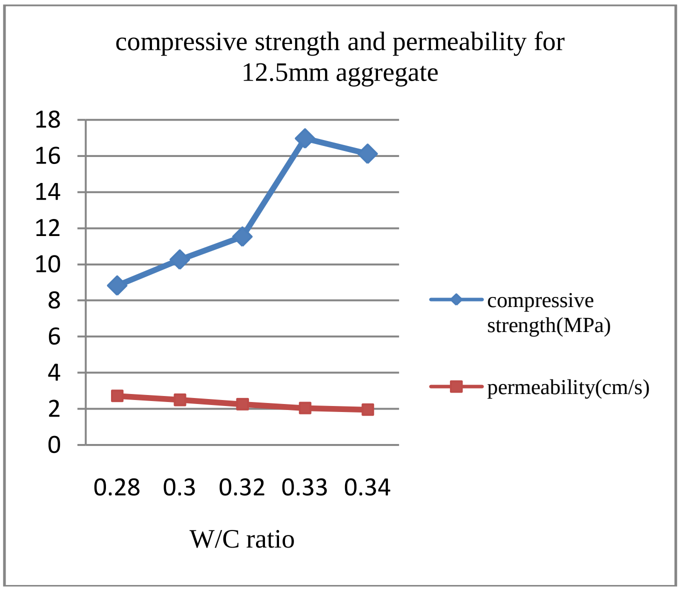

Fig.5. The relationship between compressive strength and permeability for 12.5mm aggregate.

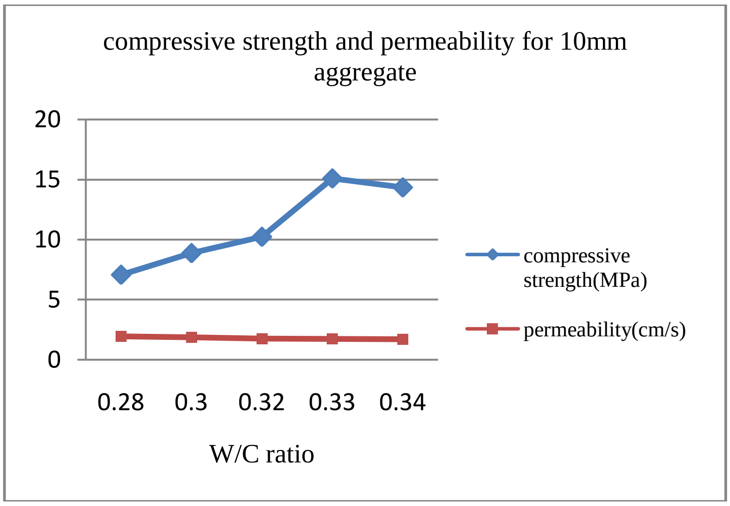

Fig.6. The relationship between compressive strength and permeability for 10mm aggregate

V. CONCLUSION

Properties of pervious concrete vary as a function of W/C ratio and size of aggregate.

1. For all W/C ratio, permeability of pervious concrete is recorded less for smaller size of aggregate and the rate of reduction in permeability occurs with increase in W/C ratio.

2. For a given size of aggregate, there is an optimum W/C ratio which produced balanced mix. Less than this optimum ratio have produce a mix having dull surface appearance leading to unsatisfactory performance of the pervious concrete, whereas more W/C ratio may cause the problem of paste draw down resulting to chocking of the pores at bottom leading to the functional failure of the pervious concrete.

3. For the fixed water cement content and the void content the 12.5mm aggregate shows a higher compressive strength and permeability of about 5% and 23% respectively when compared to 10mm aggregate.

Thus depending on the application of pervious concrete the factor such as w/c ratio, size and type of aggregate has to be selected.

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