Research Article

EFFECT OF SHAPE OF AGGREGATE ON COMPRESSIVE STRENGTH AND PERMEABILITY PROPERTIES OF PERVIOUS CONCRETE

A.K. Jain[1]; Dr. J.S. Chouhan[2]

Address for Correspondence

Lecturer, Civil Engineering (Selection Grade), S.V. Polytechnic College, Bhopal M.P. 462-002, India;
Professor and Head, Civil Engineering Deptt, SATI (Engineering College) Vidisha, M.P. 464-001, India

ABSTRACT

Shape of aggregate used in manufacturing of pervious concrete have remarkable bearing on compressive strength and permeability of pervious concrete. The magnitude of this effect is determined by conducting laboratory experiments on mixes of pervious concrete prepared using aggregates of different shape with varying water cement ratio. Shape of the aggregate is measured in terms of its angularity number which is a laboratory method intended for comparing the properties of different aggregates for mix design purposes. Results indicate that strength and permeability of pervious concrete vary as a function of shape of the aggregate along with size of aggregate and water cement ratio in the mix which leads to the conclusion that shape of aggregate shall be considered as an important parameter in deciding the suitability of course aggregate to prepare pervious concrete.

KEYWORDS: Angularity number; pervious concrete; compressive strength.

INTRODUCTION:

In recent years, pervious concrete is widely gaining popularity as a viable paving material and a tool of sustainable development because of its environmental merits. Concern has been growing in recent years among public agencies, planners and developers, toward reducing the pollutants in water supplies and the environment (ACI 522R-06). Recharging of the ground water supplies, reducing the quantity of storm water generated from developed areas, improving the storm water quality, reducing discharge of pollutants in water supplies and minimizing the effect of development on watersheds have become the primary focus area while developing a natural land. Estimates of the impact that stormwater has on water resources in the United States indicate that up to 13% of impaired rivers, 18% of impaired lakes, and 32% of impaired estuaries are affected by stormwater runoff in urban or suburban areas (US EPA, 2005).

Pervious concrete pavement is one of the methods, recognized to reduce the impact of development by allowing the rain water to percolate in the soil below, recharging the ground water aquifers, reducing the volume of direct water runoff from pavement and enhance the quality of storm water (Water Environment Research Foundation, 2005).

Pervious concrete is an open-graded material consisting of Portland cement, coarse aggregate, little or no fine aggregate, admixtures, and water. Combination of these ingredients when placed, compacted and cured properly, produce a hardened material having sufficient permeability 81 to 730 L/min/m^2 along with moderate strength 2.8 to 28 MPa and durability. The drainage rate of pervious concrete pavement varies with aggregate size and density of the mixture (ACI 522R-06).

Its lower compressive strength than the normal Portland cement concrete, limited its use in low traffic density areas like parking lots, sidewalks, joggers tracks, pathways, low-volume roads etc., where it provide a rigid structural surface to serve the required structural function as well as allow all the water comes on it through rain or other sources to percolate through, to join ground water table. This way it effectively minimize runoff from paved areas thus helps in ground water recharging and storm water management. (ACI 522R-06).

Permeability and compressive strength are basic properties of pervious concrete. Many researchers have worked to optimize these properties of pervious concrete and came out with various conclusions. Crouch et al. (2006) found that for a constant paste amount and character, compressive strength of pervious concrete appears to be a function of effective air void content and gradation fineness modulus. In an another study he concluded that, for a constant paste amount and character, permeability of pervious concrete appears to be a function of effective air void content, effective void size, and drain down. Study suggest that the combination of low cementitious content, uniform aggregate gradation and high compactive effort in the field appears to be capable of producing pervious concrete with high permeability (greater than 3600 mm/hr.) and high compressive strength (greater than 21 MPa). Tennish et al. (2004) and Schaefer et.al. (2006) reported that compressive strength decreases with increasing effective void content and increasing aggregate fineness modulus.

As the applications of pervious pavement include low traffic density areas, the required strength of pervious pavements will, therefore, be less than as required for normal road work. For parking lots a design compressive strength of 13.8 MPa is desired, and even lower strengths may be acceptable when the concrete receive light vehicular loads (Crouch et al. 2006).

Schaefer et.al. (2006) concluded that a minimum air void content of 15 percent is needed for the pervious concrete to serve as a permeable pavement and allow the water to pass through. However Crouch et al. (2006) reported that with a high water-cement ratio or too much compaction, even pavements with a void content above 15 percent may experience reduced water infiltration due to either drain down of the paste that clogs the lower levels of the concrete or clogging of the surface.

Neithalath et al. (2005) experimented to analyses the pore structure of pervious concrete and found that permeability is not a function of the porosity and the pore sizes alone, rather the pore connectivity shall also be taken in to consideration to gain a fundamental understanding of the permeability of the system.]

Presently almost all the countries are experiencing the natural consequences of urbanization and unprecedented developmental activities like increased and more polluted storm water, sinking groundwater table, frequent flooding, reducing dry weather flow in rivers etc. but are slow to adopt the technology of installations of pervious pavements, as has been embarrassed by United States, Canada and some European countries. Major reasons includes little data available on properties of pervious concrete manufactured using locally available materials along with a lack of experience base in implementing porous pavements.

In order to make pervious concrete a material of preferred choice for pavement and other locations having low density and light vehicle traffic, structured study is required to understand the effect of property and proportions of ingredients on different properties of pervious concrete. As the shape of crushed aggregate depends on the properties of parent rock, crushing machine used, reduction ratio of the crusher etc., a wide range of variation has been observed in the shape of aggregate found at different places in India. Therefore the evaluation of properties of coarse aggregate and their influence on properties of pervious concrete will help the stakeholders to develop better understanding of the material which ultimately, will lead to its production and purposeful placement.

2. Laboratory experiment

The testing plan was devised to determine the effects of shape of aggregate, measured as their angularity number; size of aggregate and W/C ratio on compressive strength and permeability properties of pervious concrete. Details of the materials and methods used in the study are given below:

2.1. Materials

Cement: Portland pozzolana cement (Fly Ash based) complying with IS:1489-1991(Part I) requirements, procured from local suppliers was used in the experiments. Specific Gravity of the cement procured from time to time was found between 2.89 to 2.9.

Aggregates: Three types of course aggregate were used. Based on their shape characteristics, the aggregates were classified as flaky, angular and irregular as per the classification given in IS: 2386 (Part I)-1963 . The test samples collected were sieved to separate then into single size fractions. Details of the pair of IS sieves used, designation of the aggregate retained between pair of sieves (square mesh) and their properties are given in Table 1 and 2.

Water: For preparation of mix and curing of concrete samples, potable water supplied from a tube well located in the campus was used.

Table 1: Engineering Properties of Aggregate Used in the Study

S. No	Shape Characteristics of the Aggregate IS: 2386 (Part I) – 1963	Flakiness Index	Aggregate Designation	Los Angels Abrasion Value (%)	Mean Water Absorption (%)	Specific Gravity
1	Material having small thickness relative to the other two dimensions	40%	F (Flaky)	22	0.81	2.76
2	Possessing well defined edges formed at the intersection of roughly planner faces	11%	A (Angular)	17	0.78	2.77
3	Partly shaped by attrition and having rounded edges	6 %	I (Irregular)	11	0.62	2.77

Table 2: Properties of Aggregate used in Experimental Study

Aggregate Type	Aggregate as Retained Between the Pair of Sieves	Aggregate Identification	Compacted Unit Weight (kg/m^3)	Voids (%)	Average Angularity Number
F (Flaky)	16 mm and 12.5 mm	F-12.5	1463	46.99	13
	12.5 mm and 10 mm	F-10	1454	47.32	
	10 mm and 6.3 mm	F-6.3	1439	47.86	
A (Angular)	16 mm and 12.5 mm	A-12.5	1582	42.89	10
	12.5 mm and 10 mm	A-10	1569	43.36	
	10 mm and 6.3 mm	A-6.3	1563	43.57	
I (Irregular)	16 mm and 12.5 mm	I-12.5	1672	39.69	7
	12.5 mm and 10 mm	I-10	1663	39.96	
	10 mm and 6.3 mm	I-6.3	1658	40.14	

2.2 Mix proportions

Three types and three sizes of aggregates were used to conduct the study. A distinct identification number were assigned to different mixes in which the first letter indicates the type of aggregate like Flaky, Angular or Irregular (F/A/I), second figure indicates the size of the aggregate (12.5 mm, 10 mm, and 6.3 mm), third and fourth figure indicates Aggregate-Cement (A/C) ratio and Water-Cement (W/C) ratio respectively. Mixes with 0.30 to 0.45 W/C ratio were prepared keeping A/C ratio 4.0 for this set of study. Proportion of ingredients to prepare pervious concrete mixes using different aggregate types, size and W/C ratio is given in column 1, 2, 3 and 4 of Table 3(a), 3(b) and 3(c).

2.3. Test methods

Various physical and engineering properties of the aggregate samples used in the study were determined following the method as explained in the relevant IS code. IS: 2386 (Part I)- 1963, was followed to find out flakiness index and angularity number, IS: 2386 (Part III)- 1963 was referred to determine specific gravity, water absorption; bulk density and void contents. Los Angels Abrasion Value of the aggregate samples was determined following the procedure explained in IS: 2386 (Part IV)- 1963.

The test mixes were prepared using a laboratory machine mixer. Each mix preparation was started following an initial butter batch in the mixer having the same w/c ratio as is in the desired mix. To determine the compressive strength of pervious concrete mixes, cube of 150 mm size were casted, cured and tested after seven days following the process as explained in "IS 516 : 1959, Method of test for strength of concrete". To determine permeability of the pervious concrete mixes, cylinders of 100 mm diameter and 150 mm long were casted using PVC pipe as mold and same compaction method as was used in the compaction of cube specimen. Cylinders were tested after seven days of curing. Permeability of the mixes was determined using constant head permeameter assembled in the laboratory for this purpose. The inlet of the permeameter was so designed that a constant water head of 50 mm is maintained above the top of sample. Quantity of water percolated through the sample within known time interval were recorded and rate of flow of water through the sample cross section is calculated in mm/hour. Based on the results obtained, effect of angularity number of aggregate, size of aggregate and W/C ratio on compressive strength and permeability of the pervious concrete mixes were evaluated and presented in form of tables and graphs. A schematic diagramme of the constant head permeameter used in the research is given in Figure 1.

3. TEST RESULTS AND DISCUSSION

Results of the study performed and associated remark is presented in col 5, 6 and 7 of Table 3(a), 3(b) and 3(c).

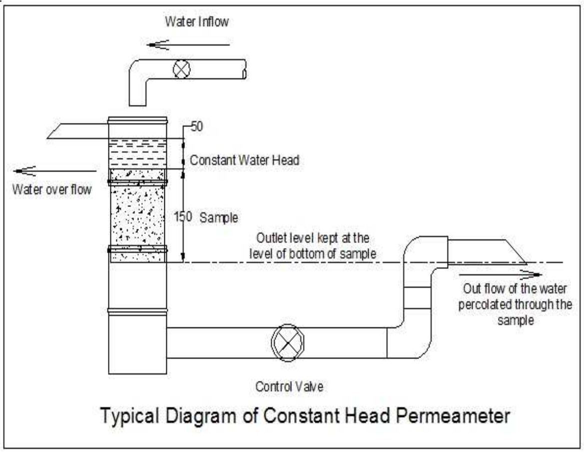

Figure 1: Typical diagram of constant head permeameter used to determine Permeability of pervious concrete specimens.

Table 3(a): Details of the mix proportion of pervious concrete and laboratory results of compressive strength and permeability of mixes, aggregate size 6.3 mm.

Aggregate Size 6.3 mm						
Mix details				Results		
1	2	3	4	5	6	7
Mix	Course Aggregate (kg)	Cement (kg)	Water (liters)	Com. St (MPa)	Permeability (mm/hr.)	Surface Appearance
I- 6.3- 4.0- 0.30	45	11.25	3.375	7.64	1366	DSA
I- 6.3- 4.0- 0.33	45	11.25	3.713	10.37	918	MSA
I- 6.3- 4.0- 0.36	45	11.25	4.050	11.38	468	MSA
I- 6.3- 4.0- 0.39	45	11.25	4.388	12.18	122	MSA
I- 6.3- 4.0- 0.42	45	11.25	4.725	11.67	118	MSA
I- 6.3- 4.0- 0.45	45	11.25	5.063	11.35	84	PDD
A- 6.3- 4.0- 0.30	42	10.5	3.150	5.51	3464	VD
A- 6.3- 4.0- 0.33	42	10.5	3.465	6.25	2872	VD
A- 6.3- 4.0- 0.36	42	10.5	3.780	8.27	2578	DSA
A- 6.3- 4.0- 0.39	42	10.5	4.095	10.84	1952	MSA
A- 6.3- 4.0- 0.42	42	10.5	4.410	11.47	1464	MSA
A- 6.3- 4.0- 0.45	42	10.5	4.725	10.99	194	MSA
F- 6.3- 4.0- 0.30	40	10	3.00	2.79	7600	VD
F- 6.3-4.0-0.33	40	10	3.300	3.26	6416	VD
F- 6.3- 4.0- 0.36	40	10	3.600	4.06	5328	VD
F- 6.3- 4.0- 0.39	40	10	3.900	5.93	4324	DSA
F- 6.3- 4.0- 0.42	40	10	4.200	5.78	2536	MSA
F- 6.3- 4.0- 0.45	40	10	4.500	5.42	2134	MSA

Table 3(b): Details of the mix proportion of pervious concrete and laboratory results of compressive strength and permeability of mixes, aggregate size 10 mm.

Aggregate Size 10 mm						
Mix details				Results		
1	2	3	4	5	6	7
Mix	Course Aggregate (kg)	Cement (kg)	Water (liters)	Com. St (MPa)	Permeability (mm/hr.)	Surface Appearance
I- 10- 4.0- 0.30	45	11.25	3.375	7.20	1568	DSA
I- 10-4.0- 0.33	45	11.25	3.713	9.27	756	MSA
I- 10- 4.0- 0.36	45	11.25	4.050	10.52	684	MSA
I- 10- 4.0- 0.39	45	11.25	4.388	11.23	152	MSA
I- 10- 4.0- 0.42	45	11.25	4.725	10.84	104	PDD
I- 10- 4.0- 0.45	45	11.25	5.063	10.67	76	PDD
A- 10- 4.0- 0.30	42	10.5	3.150	4.27	3970	VD
A- 10-4.0- 0.33	42	10.5	3.465	6.22	3356	DSA
A- 10- 4.0- 0.36	42	10.5	3.780	7.47	2936	MSA
A- 10- 4.0- 0.39	42	10.5	4.095	9.75	2314	MSA
A- 10- 4.0- 0.42	42	10.5	4.410	10.67	1572	MSA
A- 10- 4.0- 0.45	42	10.5	4.725	9.78	236	PDD
F- 10- 4.0- 0.30	40	10	3.000	2.99	7950	VD
F- 10-4.0- 0.33	40	10	3.300	3.76	6552	VD
F- 10- 4.0- 0.36	40	10	3.600	3.85	5530	DSA
F-10- 4.0- 0.39	40	10	3.900	5.72	4608	MSA
F- 10- 4.0- 0.42	40	10	4.200	5.66	2470	MSA
F- 10- 4.0- 0.45	40	10	4.500	5.54	2442	MSA

Table 3 (c): Details of the mix proportion of pervious concrete and laboratory results of compressive strength and permeability of mixes, aggregate size 12.5 mm.

Aggregate Size 12.5 mm						
Mix details				Results		
1	2	3	4	5	6	7
Mix	Course Aggregate (kg)	Cement (kg)	Water (liters)	Com. St (MPa)	Permeability (mm/hr)	Surface Appearance
I- 12.5- 4.0- 0.30	45	11.25	3.375	6.73	2144	DSA
I- 12.5- 4.0- 0.33	45	11.25	3.713	8.74	1308	MSA
I- 12.5- 4.0- 0.36	45	11.25	4.050	8.95	938	MSA
I- 12.5- 4.0- 0.39	45	11.25	4.388	9.60	176	PDD
I- 12.5- 4.0- 0.42	45	11.25	4.725	9.19	68	PDD
I- 12.5- 4.0- 0.45	45	11.25	5.063	8.62	46	PDD
A- 12.5- 4.0- 0.30	42	10.5	3.150	4.36	4290	VD
A- 12.5- 4.0- 0.33	42	10.5	3.465	4.53	3780	DSA
A- 12.5- 4.0- 0.36	42	10.5	3.780	6.87	3358	MSA
A- 12.5- 4.0- 0.39	42	10.5	4.095	8.95	2714	MSA
A- 12.5- 4.0- 0.42	42	10.5	4.410	8.77	1956	PDD
A- 12.5- 4.0- 0.45	42	10.5	4.725	8.71	388	PDD
F- 12.5- 4.0- 0.30	40	10	3.000	2.96	9078	VD
F- 12.5- 4.0- 0.33	40	10	3.300	3.44	7190	DSA
F- 12.5- 4.0- 0.36	40	10	3.600	4.24	5784	MSA
F-12.5- 4.0- 0.39	40	10	3.900	5.24	5096	MSA
F- 12.5- 4.0- 0.42	40	10	4.200	5.39	3076	MSA
F- 12.5- 4.0- 0.45	40	10	4.500	5.16	2712	MSA

Remark*: VD- Very dry mix with dull surface appearance. (Highly unsatisfactory mix)
DSA- Dry surface appearance (Unsatisfactory mix)
MSA- Metallic sheen appeared throughout the mix. (Satisfactory mix)
PDD- Paste drain down (Dripping of paste at the bottom of the cube leading to clogging of the pores)

3.1 Effect of Angularity Number, Size of Aggregate and W/C Ratio on Compressive Strength of Pervious Concrete.

Relationship between W/C ratio and compressive strength for various aggregate size and angularity number is given as Figure 2 (a), 2 (b) and 2(c). Figures 2 (a), 2(b) and 2 (c) demonstrates that for all sizes of aggregates, compressive strength of pervious concrete mixes vary inversely with the angularity number of the aggregate used. Mixes prepared using irregular aggregates demonstrated highest strength followed by mixes prepared using angular aggregate and flaky aggregate for a given size of aggregate and W/C ratio. It is also well demonstrated from the figures that for all types and all sizes of aggregate, compressive strength of concrete mixes increases with increase in W/C ratio up to a certain value, thereafter compressive strength tends to reduce.

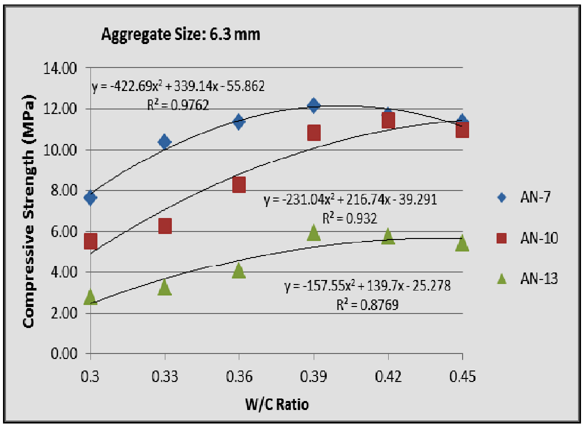

Figure 2 (a)

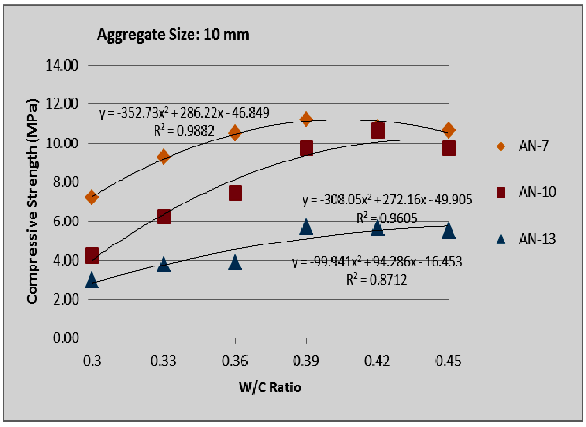

Figure 2 (b)

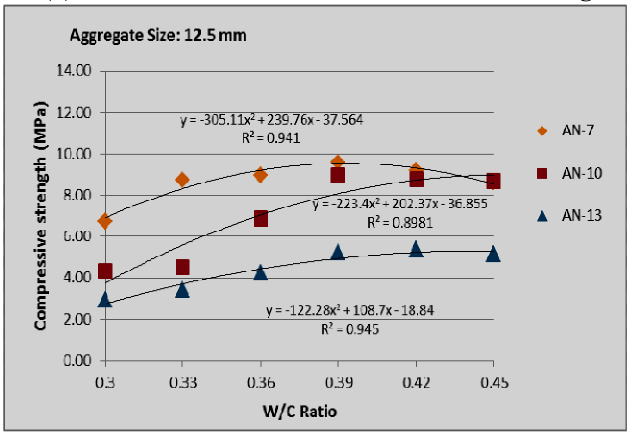

Figure 2(c)

Figure 2: Relationship between W/C ratio and compressive strength of pervious concrete for aggregate of different angularity number and size.

This trend of reduction in strength is more noticeable in mixes having aggregate of smaller angularity number. It is also observed that the W/C ratio for which maximum strength is recorded was one, which imparts wet metallic sheen to the mix without paste draw down. At lower W/C ratio than the optimum value, the mix gave a dull surface appearance which indicates insufficient availability of water to give the cement water paste required fluidity and to allow complete hydration of cement available in the mix. This is the important reason for reduced compressive strength of the mix at lower W/C Ratio. W/C ratio more than the optimum values leads to paste draw down, leads to accumulation of paste at the bottom of the sample. This may impart non-homogeneity in to the mix with reduced availability of cement paste at the top portion of the sample. These mixes (I- 6.3-4.0- 0.45, I- 10- 4.0- 0.42, I- 10- 4.0- 0.45, A- 10-4.0- 0.45, I- 12.5- 4.0- 0.39, I- 12.5- 4.0- 0.42, I-12.5- 4.0- 0.45, A- 12.5- 4.0- 0.42, A- 12.5- 4.0-0.45) demonstrated lesser compressive strength. The phenomenon of paste draw down also leads to choking of pores at bottom of the sample. Photographs of the sample casted in the laboratory, for determination of permeability, for mix A-12.5-4.0-0.39 are shown in Figure 3(a) and 3 (b). Partial accumulation of cement paste at bottom of sample is clearly visible in figure 3(b). This phenomena also affect the permeability values of the mix which otherwise would be higher.

Figure 3a and 3b: Sample of Pervious concrete prepared for determination of permeability of concrete. Sample 1b (Mix: A-12.5-4.0-0.39), accumulation of paste at bottom of the specimen is visible which affect the permeability values of the mix.

Another reason for lesser compressive strength at higher W/C ratio may be explained that more water content in cement paste makes it more porous, leads to weaker cement aggregate joints and lesser compressive strength. Relationship of permeability and compressive strength for different pervious concrete mixes evaluated is shown in Figure 4.

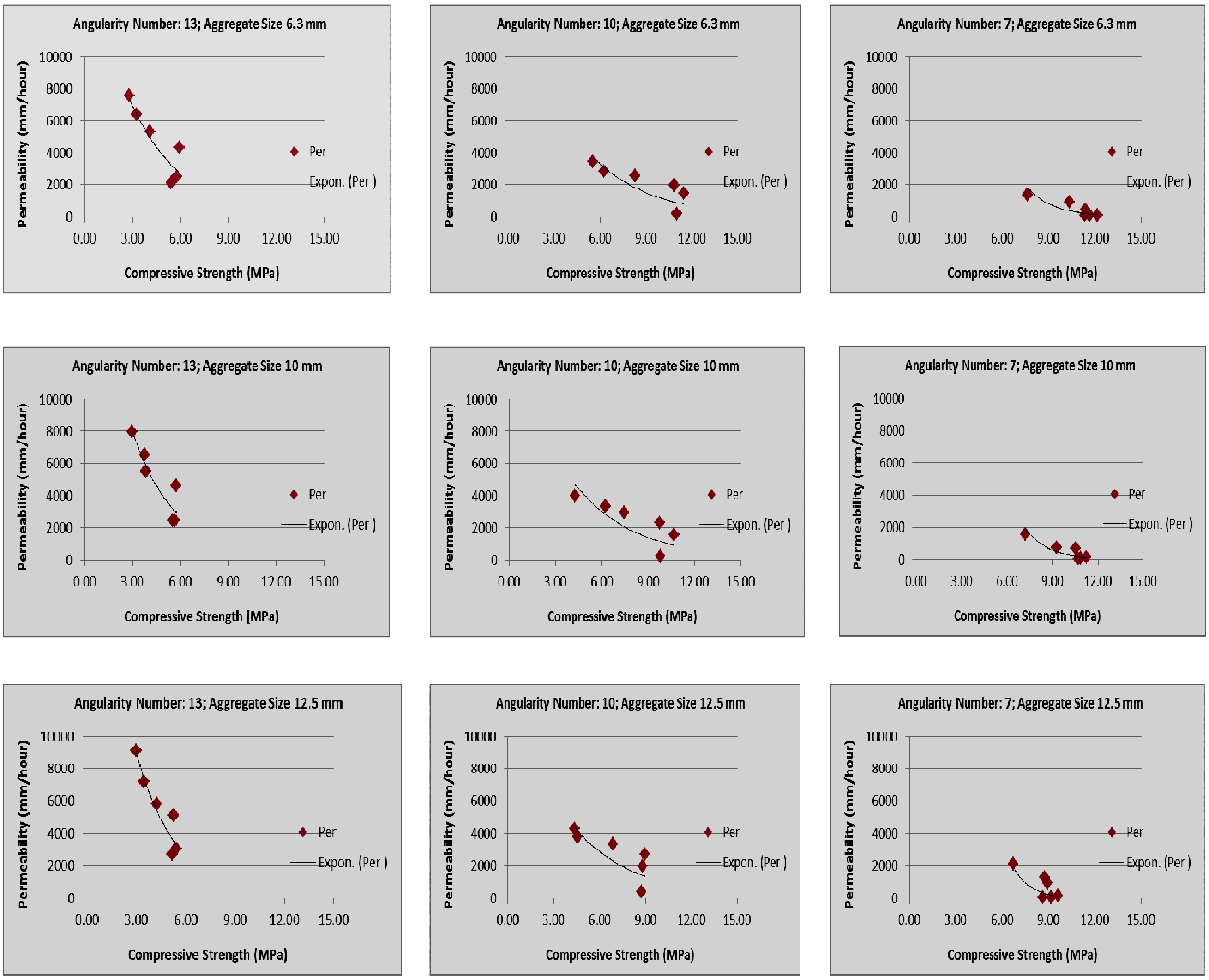

Figure-4: Relationship of permeability and compressive strength for different pervious concrete mixes prepared using aggregate of different angularity number and aggregate size

It is clearly demonstrated in the figure that with the reduction in angularity number of aggregate, compressive strength of mixes increases and permeability reduces. This is being demonstrated by gradual shifting of curve between compressive strength and permeability towards bottom and right side of the graph. This result is in agreement with the results obtained through various previous studies as referred in this paper.

4. CONCLUSION

From the analysis of results obtained and above mentioned discussion, it may be concluded that for all sizes of aggregates, compressive strength of pervious concrete vary inversely with the angularity number of the aggregate. Similarly, for all types of aggregates, pervious concrete mix prepared using smaller size of aggregates demonstrated higher compressive strength. Also a mix with wet metallic sheen which do not suffer with paste draw down, produce optimum compressive strength. For all the lower as well as higher value of water cement ratio than this optimum value, the compressive strength of the mix is typically lower.

It may also be concluded that permeability of pervious concrete varies as a function of water cement ratio, shape and size of aggregate. For all sizes of aggregates, permeability of pervious concrete mixes prepared using aggregates with smaller value of angularity number demonstrated less permeability but higher compressive strength.

Based on the aforesaid conclusions, it is recommended that shape characteristics of course aggregate must be taken in to consideration to manufacture pervious concrete in order to optimize its compressive strength and permeability. Aggregate of minimum possible angularity number and size, practically and economically available, shall be used to manufacture pervious concrete. Aggregate of desired angularity number may be manufactured to prepare pervious concrete, although further investigation will be required to study the extra cost involved in producing aggregate with lower angularity number and cost effectiveness achieved in terms of increased strength.

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