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EXPERIMENTAL INVESTIGATION OF EFFECT OF PERVIOUS CONCRETE ON RIGID PAVEMENT IN PAKISTAN

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ABSTRACT

Pakistan is facing adverse environmental issues peculiarly in major cities. The condition gets worst during monsoon period when the whole city faces the urban flooding due to stagnation of storm water on all major streets and areas. The main reason is the lack of infrastructure to mitigate the crisis which is faced by the country during whole rainfall season. The introduction of Pervious Concrete in major pavement infrastructure can easily limit the problems of sump of rain water. As a part of road infrastructure, the upper layer of pavement can be pervious, making runoff water to move to sub-base. This paper offers the exploratory research to ascertain the compressive strengths and infiltration rate of different samples of Porous Concrete following the American Concrete Institute guidelines. The experiments were done with varying the properties of Pervious Concrete. The effects which were considered are curing time, mix proportion, percentage quantity of fine aggregate, ratio of water to cement and varying coarse aggregate size. The mix design ratio considered were 1:4, 1:5 and 1:6. For further experiment of infiltration rate, the custom slab was formed with dimensions 2’x1’x4” and was tested for all the desired ratios. For the purpose of cost comparison, a fixed size on land is kept as standard. The cost is compared for construction on the land, using three different materials: Pervious concrete, Traditional concrete and Asphalt premix. It was showed that the Traditional concrete is cheaper than the Pervious and Asphalt layer but Pervious concrete is also economical than Asphalt layer.

KEYWORDS

Infrastructure, Pervious concrete, Compressive strength, Infiltration rate, Mix design, Asphalt premix, Traditional concrete

INTRODUCTION

One of the main engineering systems for the transportation and drainage of urban sewage and rainwater is the drainage system of every given city. The primary system for defending the city against flood damage and water logging, which can result in unanticipated loss and hardship. In the US, the use of Portland cement pervious concrete is rising in parking lots and sidewalks due to the fact that it provides benefits in reducing rainwater runoff and improve water quality [1]. “Porous Concrete is made of cement, water, coarse aggregate, and little to no fine aggregate is known as "pervious concrete." Because of its special benefits like a road drainage system, a reduction in tyre and pavement noise, skid resistance, recharging of underground water, reducing storm water runoff, and limiting the pollutants to enter the groundwater, pervious concrete pavement has been used extensively throughout the world. All of these benefits are made possible by its open pore structure, which is primarily the connected porosity and larger size of pores [2, 3]. It depends on the design that the concrete pavement that drains and its sub base material may have ample storage capacity for water so that a swale is not needed. During rainy days the pavement is free from splash on surface and slipping, hence improving the safety. [4, 5]. The durability and permeability characteristics of permeable concrete is of prime importance. Due to unique features, pervious concrete may require special testing procedures also like compaction and consolidation. It is investigated compressive strength of pervious concrete with the relationship of different properties like water cement ration, aggregate cement ratio, aggregate size, quantity of admixture and compaction. The correlation was obtained to determine the porosity of pervious concrete so as to design the PC mixtures [6-9]. PC generally own high permeability and low compressive strength which can be enhanced by the addition of several cementitious materials and/or admixtures. The ordinary Portland cement acts as main binder and cementitious materials like fly ash, blast furnace slag and silica fume and water reducing admixtures can be used with Portland cement. Study [10] showed that the compressive strength can be improved 9-15% with use of super-plasticizer as to reduce w/c ratio. 6:1, 8:1, and 10:1 aggregate to cement ratios were employed in batches with aggregate sizes of 18.75mm and 9.375mm. The 6:1 ratio gave high compressive strength whereas 10:1 gave high permeability as a result [10-13]. Another studies [14-16] carried three methods of compaction (self-consolidating, half rodded, and standard proctor hammer). The most compressive strength was obtained using the traditional proctor hammer method whereas the samples of self-consolidating method gave the high infiltration rate thus found more pervious [14-16]. Studies [18] illustrates that the angularity number, Latex and fibre additions have an impact on the qualities as well and behaviour of pervious concrete in the way that Compressive strength, flexural strength, and split tensile strength all rise as fine aggregate volume decreases, which is caused by an increase in fine aggregate. However, PC's split tensile strength was the only thing that latex and fibre enhanced [17-20]. The aim of the research is to introduce the pervious concrete in urban infrastructure of Pakistan where there is severe urban flooding during the whole rainy season hence rain water remains on surface of pavement for many days. In this regard the objective of the study is to make possible provision of pervious concrete through sewage drain slabs, on sides of main highways and roads, walkways, parking lots and as a part of pavement. Moreover, the study is limited to compressive strength and infiltration rate tests of the pervious concrete without addition of any admixtures.

METHODS

Materials

The materials used for Pervious Concrete was Ordinary Portland Cement (locally available OPC 53 Grade cement with more compressive strength), Coarse aggregate (passing #4 sieve) which were available locally. The size of aggregate used for casting was limited to 20mm, not larger than 20mm and not smaller than 10mm. Mix design ratios were calculated for each trial batch. It included the required amount of Coarse aggregate, Cement and water for each sample of pervious concrete prepared in lab. Trial batches were conducted following the American Concrete Institute (ACI) guidelines ACI 522R-10 [10].

Preparation of testing samples:

For sample preparation the cylinder taken was 6-inch diameter with 12-inch height. The density of pervious concrete was considered as 125 lb/cu.ft. Hence for total volume of 0.196 cu.ft, the total mass of concrete including 15% wastage was found to be 12.783 kg. Therefore, the mix proportion for all mix ratios is shown in Table 1.

MIX RATIO	CEMENT (kg)	COARSE AGGREGATE (kg)
1:4	2.55	10.22
1:5	2.13	10.65
1:6	1.82	10.95

The five trial batches were prepared with varying curing period, mix design ratio, water to cement ratio, percentage of fine aggregate content and the size of coarse aggregate to investigate the compressive strength as shown in Figure 1. The trial batch made with varying mix design was prepared with ratios 1:4, 1:5, and 1:6. On the other hand, all the other trial batches were composed with design ratio of 1:4. The first trial batch was comprised of three cylinder samples with by varying only the curing period for which casted cylinders were kept submerged for the purpose of attaining prospective compressive strength as shown in Figure 2. To have uniformity in each trial, three cylinders were casted, each having the same constituents as the rest. This pertains to have uniform W/C ratio for all, same cement, aggregate size and shape. The primary difference to be maintained was of curing i.e. 7, 14 and 28 days. The second trial batch was comprised of samples with varying concrete mix design ratios i.e. 1:4, 1:5 and 1:6.

Third round of trial batches were conducted by varying the water to cement ratio with w/c ratios 0.25, 0.35 and 0.45 respectively with 28 days curing. The small percentage of the fine aggregate was added for the fourth trial batch. Three cylinders with 4%, 8% and 12% of fine aggregate were casted. The fifth and last trial batch was done with varying size of coarse aggregate while keeping the other factors constant i.e. mix design ratio as 1:4, w/c ratio was 0.4 and curing period of 28 days. The coarse aggregate size range selected were 19.5mm - 12.5mm and 12.5mm-9.55mm. For the size range 19.5mm-12.5mm, material passing through the sieve of ¾” and retaining on sieve of ½” was selected, whereas for size range 12.5mm-9.55mm, the material passing through the sieve ½” and retaining on the sieve 3/8” was selected.

Fig. 1 – Preparation of Trial Batch

Fig. 2 – Cylinder Samples for Testing

After conduction of trial batches of cylinders were completed, the slabs were constructed in order to experiment for Infiltration Rate. The design ratios on which slab was to be constructed were 1:4, 1:5 and 1:6 with 28 days curing period. For slab, a custom mould was made having dimensions 2' x 1' x 4" as shown in Figure 3. The size was selected by keeping in view the easiness of work with and at the same time if fulfilled the purpose to test the infiltration rate. Curing of slab was done by using jute bags. Wet jute bags were placed on slab samples making sure to dip the jute bag in water and place on slab again as shown in Figure 4.

Fig. 3 – Slab placed in its Custom Wooden Mould

Fig. 4 – Curing of Slab using Jute bags

Compressive strength and infiltration rate tests:

The cylinders were tested for compressive strength so that an idea for the compressive strength of Pervious Concrete could be established. The testing was conducted on Compression Testing Machine.

The casted slab samples were tested for infiltration rate keeping water to cement ratio constant with varying Concrete mix design. The slab samples had mix design ratio of 1:4, 1:5 and 1:6 for which the Infiltration rate was calculated. The ASTM C1701 standard test method for determining the infiltration rate of pervious concrete was used to measure the infiltration rate. The experimental setup requires an infiltration ring, a five-litre container of water, plumber's putty, water and a stop watch. Two lines should be marked on the inner surface of the infiltration ring at intervals of 4 inches and 6 inches respectively as shown in Figure 5. The infiltration ring should be placed at a clean pervious concrete pavement, after placing the ring on the pavement/slab plumbers' putty was placed so that the ring gets fixed and a water tight seal is created. Start pouring water at a steady rate so that the water level does not rise above the lines marked on the inner surface of the ring and start timing. After following these steps, we can calculate the infiltration rate easily by using the equation 1.

$$I = K\,M / D2\,t \qquad (1)$$

I = Infiltration rate (in/min)

M = Mass of water absorbed/infiltrated (lbs)

D2 = Square of Inner diameter of infiltration ring (inch)

t = Time the amount of water to infiltrate the pervious concrete (sec)

K = 126870 (in3. s/ kg.min)

Fig. 5- Infiltration Rate Setup

Fig. 6 – Pervious Concrete Slab

Cost Comparison of traditional and Pervious concrete shown in Figure 6, was done. For the purpose of comparison, a fixed size on land is kept as standard. The cost is compared for construction on this land, using three different materials:

- Pervious concrete
- Traditional concrete
- Asphalt premix

A size of land measuring 100 feet long and 3 feet wide is selected for cost comparison. The cost will be calculated only for the top surface of construction. Whether the road or construction employs pervious concrete, normal concrete or asphalt premix, each of these have a sub-base layer beneath them. However, the cost of this sub-base is not calculated. The current rates of that time were considered for cost comparison of materials. The revealed comparison that conventional concrete is less expensive than that of pervious and asphalt layer but pervious concrete is also more cost effective than asphalt layer. In general, initial costs for pervious concrete pavements are more than that for traditional concrete or asphalt paving. But the complete costs can be substantially lower.

RESULTS AND DISCUSSIONS

Results:

Compressive strength values for all the five trials batches with different properties is summarized below in Table 2. Each batch consist of three samples making it total of fourteen samples for compressive strengths and total three slab samples for infiltration test. However poorly casted or samples with defects were discarded and did not consider for results.

Tab. 2 - Summary of Trial batches with corresponding Compressive Strengths

Batch	Concrete Mix Design	W/C Ratio	Fine Aggregate (%)	Curing period	Compressive Strength (psi)
Batch 1: Varying curing period					
1	1:4	0.4	0%	7	1415
1	1:4	0.4	0%	14	1503
1	1:4	0.4	0%	28	1627
Batch 2: Varying mix design ratio					
2	1:4	0.4	0%	28	1556
2	1:5	0.4	0%	28	1149
2	1:6	0.4	0%	28	884
Batch 3: Varying W/c ratio					
3	1:4	0.25	0%	28	1644
3	1:4	0.35	0%	28	1591
3	1:4	0.45	0%	28	1538
Batch 4: Varying amount of fine aggregate					
4	1:4	0.4	4%	28	1574
4	1:4	0.4	8%	28	1645
4	1:4	0.4	12%	28	1698
Batch 5: Varying size of coarse aggregate					
5	1:4 (20-12.5mm)	0.4	0%	28	1556
5	1:4 (12.5-9.5mm)	0.4	0%	28	1715

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The graphical representations of relationship of each parameter and compressive strength is shown below.

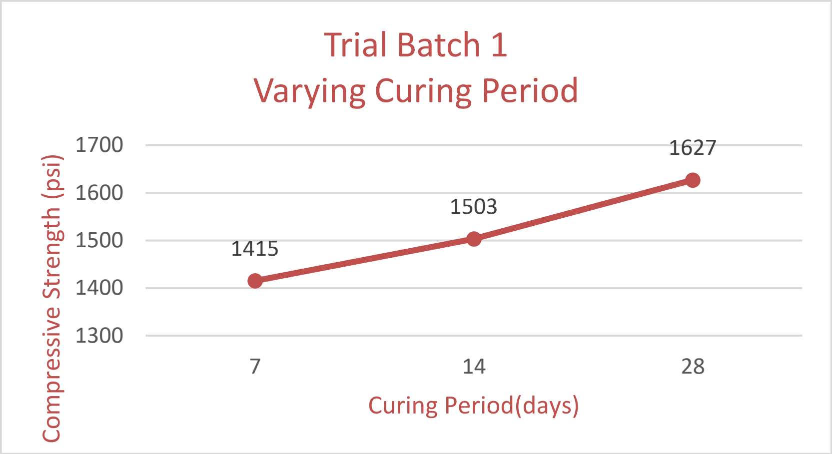

Fig. 7 – Graph between Curing Period and Compressive Strength

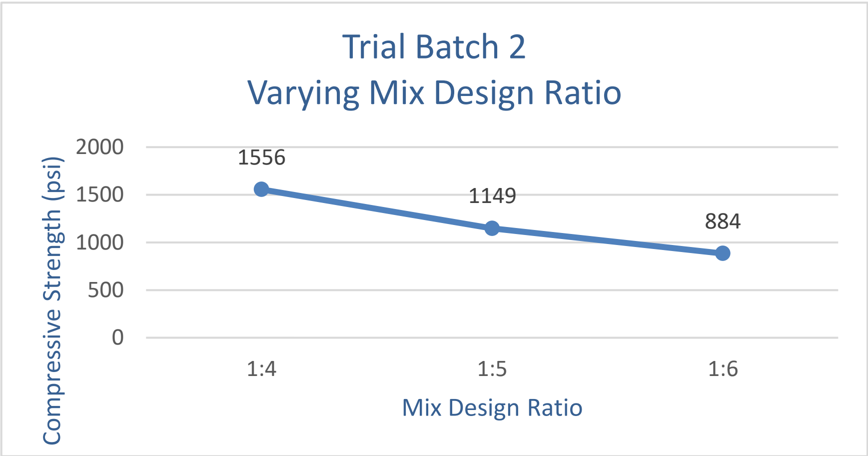

Fig. 8 – Compressive Strength and Mix Design Ratio

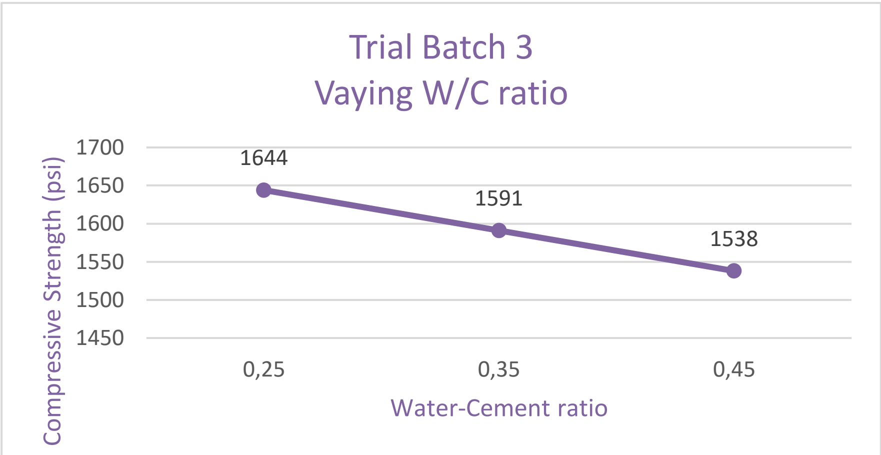

Fig. 9 – Compressive Strength and water-cement ratio

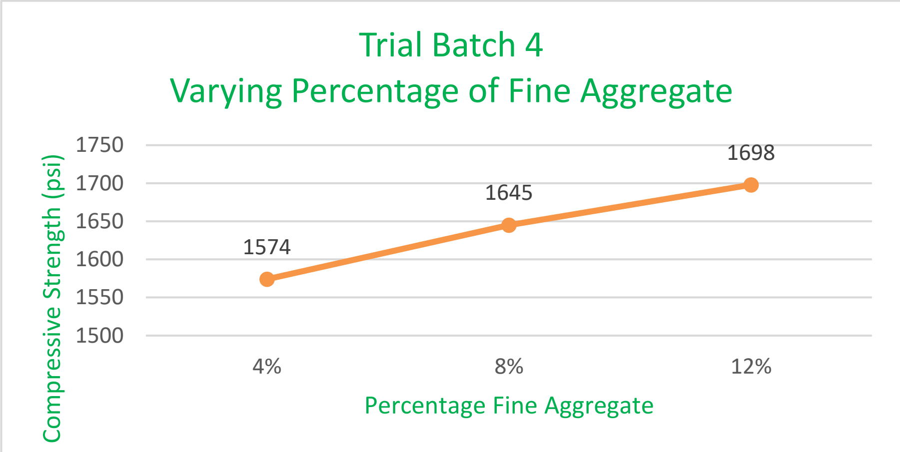

Fig. 10 – Compressive Strength and Percentage Fine Aggregate

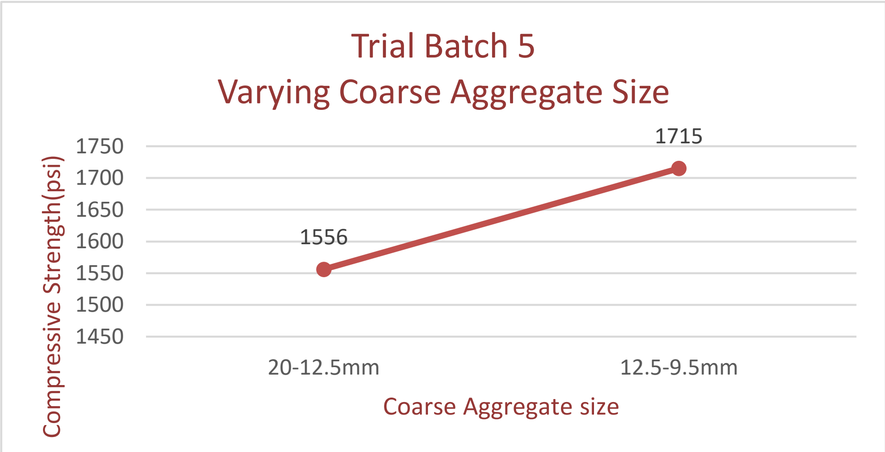

Fig. 11 – Compressive Strength and Coarse Aggregate Size

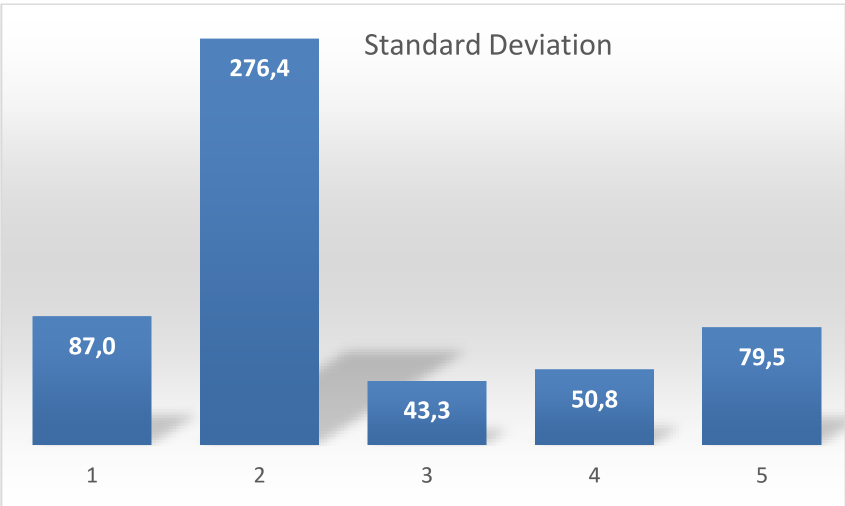

Fig. 12 - Standard deviation of Compressive strengths of each batch

Tab. 3 - Infiltration Rate with corresponding Concrete Mix Design

S #	Concrete Mix	w/c Ratio	Infiltration Rate
			(inch/min)
1.	1:4	0.45	198
2.	1:5	0.45	282
3.	1:6	0.45	335

Discussion:

Figure 7 shows the increment of compressive strength with the rise in curing days of the sample.

Figure 8 and Figure 9 represents the trial batch 2 and 3 respectively. These shows the decrease in Compressive Strength of Pervious Concrete with the increase in Mix Design ratio and water to cement ratio.

Figure 10 and Figure 11 shows the results of trial batches 4 and 5 respectively. These shows the increase in Compressive Strength of Pervious Concrete with the increase in Fine Aggregate percentage but decrease in size of Coarse Aggregate.

The infiltration rate results for three samples of slabs are shown in Table 3 having varying concrete mix design ratios and constant water-cement ratio. The results showed the increment in Infiltration rate of Pervious concrete slab with the increase in Concrete Mix Design ratio.

CONCLUSION

There is lot of research work going on in the field of pervious concrete. Due to its porosity and presence of voids it has lesser compressive strength. Hence the usage of pervious concrete is very limited in Pakistan. With the improved compressive strength and infiltration rate, it can have greater number of applications like in medium to heavy traffic rigid pavements. Therefore, it can also eliminate surface runoff of storm water, facilitates ground water recharge and make the effective use of land

Results showed that mix design ratio with higher cement to aggregate content like 1:6 is considered suitable for pavements requiring less compressive strength but higher infiltration rate. Whereas the lower cement to aggregate ratio like 1:4 showed higher compressive strength and lower infiltration rate.

The reduced water-cement ratio increases compressive strength with less workability, and makes it difficult to work with permeable concrete. The higher the water-cement ratio, decreases the compressive strength, but gives a more workable and permeable concrete. Introducing small percentage of fine aggregate to the pervious concrete although increased the strength but closed some of the pores and hence slow down the infiltration of water through the pavement.

The smaller size coarse aggregate showed greater compressive strength as well as produced more infiltration rate in contrast to large size aggregate.

It is recommended that by the addition of suitable admixture, retarders, super plasticizers and/or any supplementary cementitious materials, the pervious concrete can have more workability and compressive strength so as to achieve the desired design results.

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