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Experimental Investigation of Compressive Strength and Infiltration Rate of Pervious Concrete by Fully Reduction of Sand

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Abstract

The aim of the study is to investigate compressive strength of pervious concrete by reduction of fine aggregate from zero to 100%, additionally investigate infiltration rate of pervious concrete. Experimental study has conducted at Cecos Engineering University Peshawar. The pervious concrete samples were produced for 7 and 28 days. Compressive strength of pervious concrete indicated higher reduction of the sand reduces compressive strength and almost 50% compressive strength decreased by reduction of 100% sand from the design mix. On the other side, infiltration rate for 28 days shows direct relation above 40% reduction of sand and highest 273% of infiltration rate by reducing 100% sand from the design mix. The 90% reduction of sand from concrete give considerable compressive strength of 2150 psi and infiltration rate of 165.79 inch/hour, which can be recommended for pavements of parking and walking area.

Keywords: Pervious Concrete; Fine Aggregate Reduction; Compressive Strength; Infiltration Rate.

1. Introduction

The socio-economic climate around the world has changed drastically in the past few decades. The drastic effect of the socio economic has witnessed more visibly in the world has reshaped in the form of high rise buildings infrastructure, transportation infrastructure, dams, tunnels etc. These infrastructures has massively consumed and still highly depends on the natural resources among gravel, stones and sand are the most common material [1]. In the era sustainable development is needed for the environmental protection, energy saving and effective construction waste management. The concept of sustainable development has wide application so within the concept some researchers have reviewed impervious surface and waste of rainwater. A larger amount of rainwater ends up falling on impervious surfaces such as parking lots, driveways, sidewalks, and streets rather than soaking into the soil. This creates an imbalance in the natural ecosystem and leads to a host of problems including erosion, floods, ground water level depletion and pollution of rivers, lakes, and coastal waters as rainwater rushing across pavement surfaces picks up everything from oil and grease spills to de-icing Salts and chemical fertilizers [2-4]. Typically, parking lots, driveways, sidewalks and streets etc is constructed with Portland cement concrete. The impermeable nature of conventional cement concrete is help to increase the water runoff on the surface over-burdening the infrastructure and causing excessive flooding in built-up areas. Pervious concrete has less resistant and allow water to infiltrate into the ground surface also contribute to the rainwater harvesting. Recently, in the sustainable development and construction pervious concrete plays vital role due

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to its significant applications among to reduce wastage of rainwater [3]. Pervious concrete enhance the water quality through percolation and heat absorption also minimize the poles on the road surface [5]. In addition to the advantages of pervious concrete [6] postulated that pervious concrete is used in Europe to absorb the road/pavement sound and protect the river bank pervious concrete is use in Japan [7]. According to the [3] pervious concrete is produce from the traditional materials use for concrete making but without fine aggregate or very little quantity of fine aggregate added to obtain high porosity range from 0.14-0.35. Pervious concrete contains higher porosity of 11-35% than conventional concrete and it is less water resistant [8]. The permeability coefficient of the pervious concrete is ranges 2-6 mm/s [9] compared with 1×9-10 mm/s for normal weight concrete [7]. According to the American concrete institute [9] and [10] the pervious concrete has lower compressive strength of 5-10 MPa compare to conventional concrete due to its high porosity and the tensile strength is range between 1-3.8 MPa. The stability and durability of the pervious concrete is affected due to lower compressive strength. Pervious concrete has lower predisposition against frost and chemical action with pervious concrete is higher. These are limited application causes of pervious concrete in the heavy traffic road constructions.

The applications of pervious concrete are or can use for low volume pavements; residential roads and walkways; sidewalks and pathways; parking lots; tennis court; slop stabilization; floors for fish hatcheries and floors for zoos or children park etc. Pervious concrete is among one technology to allow rain or storm water to infiltrate into the ground rather than waste on the ground surface; mainly high compressive strength with high permeability in the previous concrete is the attention among researcher. This study is an attempt to reduce sand in the consecutive order proportion till 100% reduction of sand from the previous concrete to determine the compressive strength and infiltration rate; also find the optimum sand proportion to produce pervious concrete. The comparison of pervious concrete with standard concrete is shown in Figure 1[4] and the application of pervious concrete in sidewalks is shown in Figure 2[2].

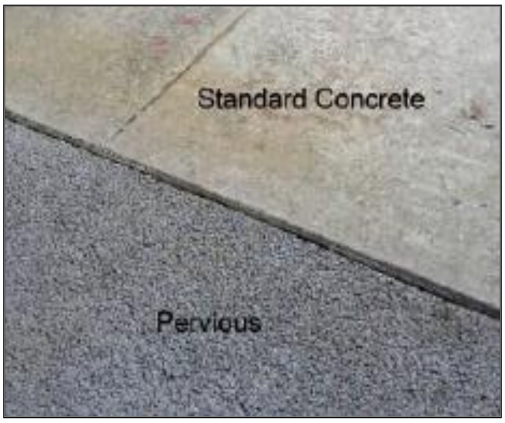

Figure 1. Comparison of pervious and conventional concrete [4]

Figure 2. Pervious concrete application in sidewalks [8]

2. Literature Review

In recent times, pervious concrete has been re-introduced for the development of world in an attempt to fulfil the concerning demands of environmental problems. It involves the applying of low slump, high consistence concrete mix that has received growing recognition as an answer to the issues arising from the excessive flow of storm water above the ground surface. Some general applications have mentioned above in the introduction. Bury [12] has quoted Environmental Protection Agency (EPA) and stated that pervious concrete among the best management practice for the storm water management as it has been used as storm water harvesting technique to control the contaminants. Early utilization of pervious concrete in the construction traced back to 1945 s post world war 2 when demolition of building infrastructures motive engineers to reuse the waste materials since many countries were lack of raw materials especially Germany, Japan and USA is practicing pervious material from 30 years [13-14]. An extensive research on the various aspects of pervious concrete has carried out. Meininger [15] found the optimum water cement ratio of pervious concrete to obtain the maximum permeability. Ghafoori [3] has obtained maximum compressive strength and various parameter relationships such as aggregate to cement ratio; water cement ratio and compaction energies. Author has concluded that compressive strength up to 3000 psi is achievable if the correct mix design proportion and maximum compaction energy is used, which was against the findings of the other researchers. Aoki [7] has conducted experimental study to replace partial cement 20-50% with fly ash and sand 7.5-10% to determine the density, the porosity, 7 and 28 days compressive strength. Study found the average density of pervious concrete is around 1800 kg/m^3, with a porosity of 0.33 and compressive strength is comparatively low (around 10 MPa) due to its high porosity. The compressive strength can decrease by 40% if a high-percentage replacement of cement with fly ash (i.e. 50%) is used. Netinger et al., [9] conducted experimental study to assess wearing characteristics of pervious concrete for light traffic in urban areas by addition of waste steel slag. The findings indicated that total porosity increased with increases in the share of coarse aggregate fractions; the density of pervious concrete mixtures decreased with increases in the total porosity. Steel slag as an aggregate ensured a higher total porosity in concrete specimens. Compressive and flexural strength decreased with the increases in the coarse fraction share.

Lian & Zhuge [16] investigated compressive strength and permeability of pervious concrete by addition of super plasticizer and mixture contain silica fume in the result strength and permeability properties found enhanced. Authors concluded that strength of the pervious concrete is inversely proportional to the permeability. Ajamu et al., [17] postulated that permeability and compressive strength of pervious concrete depend on the particle sizes and A/C ratio. A/C ratio of 6:1, 8:1 and 10:1 was investigated and A/C ratio of 6:1 gave the highest compressive strength compared the ratio of 8:1 and 10:1. Study concluded the small size of coarse aggregates produce a higher compressive strength and at the same time produces a lower permeability rate. A/C ratio 8:1 and 10:1 may use for the low compressive strength and high permeability rate required in pervious concrete pavement. Aforementioned environmental advantage of the pervious concrete is the highest permeability which allow storm water to infiltrate into the ground surface rather than waste also natural process of purification taken place when water infiltrate into the ground [18]. Panimayam et al., [21] added granite manufactured sand and determined the compressive strength and permeability. Pervious concrete is considered to be an advanced pavement material in terms of the environmental benefits arising from its basic feature-high water-permeability [22]. Most of the literature studies has either mixed the material or replaced partial sand so in this study authors have replaced sand/fine aggregate with consecutive order proportion from 10% up to 100% fully reduced to save the natural material also study the compressive strength and permeability.

3. Materials and Methods

The materials used in this is extensively and commonly used in the concrete development is listed. Experimental study conducted at the CECOS Engineering University Peshawar, Pakistan.

3.1. Cement

Ordinary Portland cement most commonly available in local market was used as the specification as given in Table 1. Specific gravity of cement is 3.15.

Table 1. Chemical compounds of a typical Ordinary Portland Cement

Name of chemical	Molecular Formula	Weight
Tricalcium silicate	Ca_3O_5Si	50%
Dicalcium silicate	Ca_2SiO_4	25%
Tricalcium aluminate	$Ca_3Al_2O_6$	10%
Tetracalcium aluminoferrite	$Ca_4Al_2Fe_2O_{10}$	10%
Gypsum	$CaSO_4{\cdot}2H_2O$	5%

3.2. Aggregate

Fine aggregates collected from Jailbal area city Sawabi and course aggregate from Pali area city Malakand district of Khyber Pakhtunkhwa (KPK), Pakistan. The properties of fine and course aggregates investigated experimentally and findings compare with ASTM standards is shown in Table 2.

Table 2. Properties of Aggregate

	Fine Aggregate	Course Aggregate
Fineness Modulus	2.26	2.69
Specific Gravity	2.62	2.72
Water absorption (%)	2.04	0.566
Density (kg/m^3)	1602.1	1597.6
Moisture contents (%)	1.64	0.536

3.3. Mix Design

The fine aggregate is reduced in various percentages from 0 to 100% in the design mixture for the compressive strength of 7 and 28 days. Table 3 shows the mix design of the cement, fine and course aggregate proportions. A constant W/C ratio of 0.69 was used for all mixes. The quantity of material taken for casting one cylinder is shown in Table 4.

Table 3. Cement, fine and course aggregate proportions in the mix design

Mix Type	Description	Ratio
M100	Control mix containing cement, sand and aggregate in the ratio	1:1.68:2.63
M90	Mix Containing 10% less sand than the control mix	1:1.512:2.63
M80	Mix Containing 20% less sand than the control mix	1:1.344:2.63
M70	Mix Containing 30% less sand than the control mix	1:1.176:2.63
M60	Mix Containing 40% less sand than the control mix	1:1.008:2.63
M50	Mix Containing 50% less sand than the control mix	1:0.84:2.63
M40	Mix Containing 60% less sand than the control mix	1:0.672:2.63
M30	Mix Containing 70% less sand than the control mix	1:0.504:2.63
M20	Mix Containing 80% less sand than the control mix	1:0.336:2.63
M10	Mix Containing 90% less sand than the control mix	1:0.168:2.63
M0	Mix Containing 100% less sand than the control mix	1:0:2.63

Table 4. Quantity of Cement, fine, course aggregate and water for one cubical cylinder

Mix Type	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (lit)
M_{100}	3.01	5.06	7.96	1.95
M_{90}	3.01	4.554	7.96	1.95
M_{80}	3.01	4.048	7.96	1.95
M_{70}	3.01	3.542	7.96	1.95
M_{60}	3.01	3.036	7.96	1.95
M_{50}	3.01	2.53	7.96	1.95
M_{40}	3.01	2.024	7.96	1.95
M_{30}	3.01	1.518	7.96	1.95
M_{20}	3.01	1.012	7.96	1.95
M_{10}	3.01	0.506	7.96	1.95
M_{0}	3.01	0	7.96	1.95

4. Finding and Discussion

The study has objectives to reduce the quantity of fine aggregates and determine the compressive strength of pervious concrete for 7 and 28 days. Fine aggregates were reduced in the mixture followed 0-100% reduction percentages and proportions are shown in the above tables. Table 1 shows the properties of ordinary Portland cement (OPC). The properties such as fine modules (2.26 and 2.69), density kg/m^3 (1602.1; 1597.6) , specific gravity (2.62; 2.72), water absorption (2.04; 0.566) and moisture content (1.64; 0.536) of fine aggregate and course aggregates properties is determined respectively and result is drafted in Table 2 above.

4.1. Compressive Strength of Pervious Concrete

Table 5 and trend line graph Figure 3 shows the average compressive strength result of pervious concrete for 7-days. The obtained result shows that by reducing fine aggregate/sand in the previous concrete reduce the compressive strength of the pervious concrete. The compressive strength of control mix is 1947.8 Psi; in the result of fine aggregate reduction 10% for each test sample till 100% reduction respectively shows that compressive strength of pervious concrete decrease as reduce the fine aggregate from the design mix. It shows by 100% reduction of fine aggregate 49.82% almost 50% compressive strength reduces. Study finding indicated that the higher reduction of sand from the concrete mix leads to the lower compressive strength which may limit the application of the pervious concrete.

Table 5. 7-Days cylinder compressive strength

Mix	7 Days Compressive Strength (psi)				% Decrease
	Sample 1	Sample 2	Sample 3	Average	
M100 (Control Concrete)	1958.0	1919.2	1966.4	1947.8	0
M90	1991.4	1674.1	1921.6	1862.4	-4.38
M80	1736.0	1769.0	1966.7	1823.9	-6.36
M70	1876.0	1815.0	1765.0	1818.7	-6.63
M60	1811.1	1687.8	1926.1	1808.3	-7.16
M50	1703.0	1868.4	1791.5	1787.6	-8.22
M40	1666.0	1538.2	1724.6	1642.9	-15.65
M30	1505.3	1453.7	1508.4	1489.1	-23.55
M20	1488.0	1312.5	1381.9	1394.1	-28.43
M10	1367.2	1459.4	1312.0	1379.5	-29.18
M00	986.0	990.2	956.0	977.4	-49.82

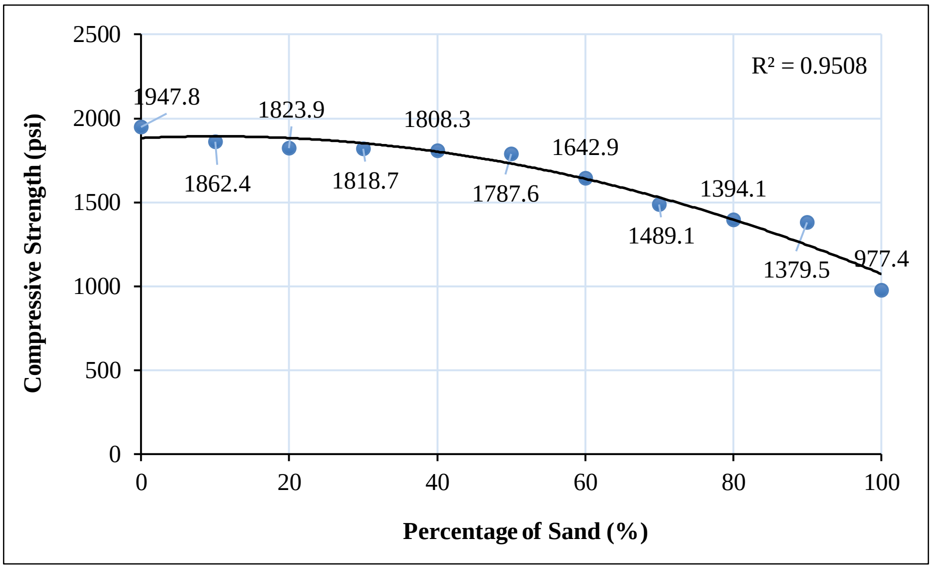

Figure 3. 7-Days cylinder compressive strength (Source: Experimental result/Primary data)

The obtained result for 28 days is shown in the Table 6 followed with graphically representation in Figure 4. The findings shows significant drop of compressive strength by reduction of fine aggregate. Maximum 46.25% compressive strength has decreased by the reduction of 100% fine aggregate form the design mix of pervious concrete.

Table 6. 28days cylinder compressive strength

Mix	28 Days Compressive Strength (psi)				% Decrease
	Sample 1	Sample 2	Sample 3	Average	
M100 (Control Concrete)	3165.35	2952.54	3025.22	3047.70	0
M90	3063.73	2575.61	2956.32	2865.22	-5.99
M80	3122.22	3223.11	3025.65	3123.66	2.49
M70	2826.62	2885.39	2652.36	2788.12	-8.52
M60	2786.24	2596.60	2963.25	2782.03	-8.72
M50	2755.42	2874.42	2756.16	2795.33	-8.28
M40	2563.11	2366.41	2653.21	2527.58	-17.06
M30	2315.84	2236.51	2320.58	2290.98	-24.83
M20	2289.24	2019.30	2125.95	2144.83	-29.62
M10	2103.38	2245.25	2103.87	2150.83	-29.42
M00	1765.2	1523.34	1625.96	1638.17	-46.25

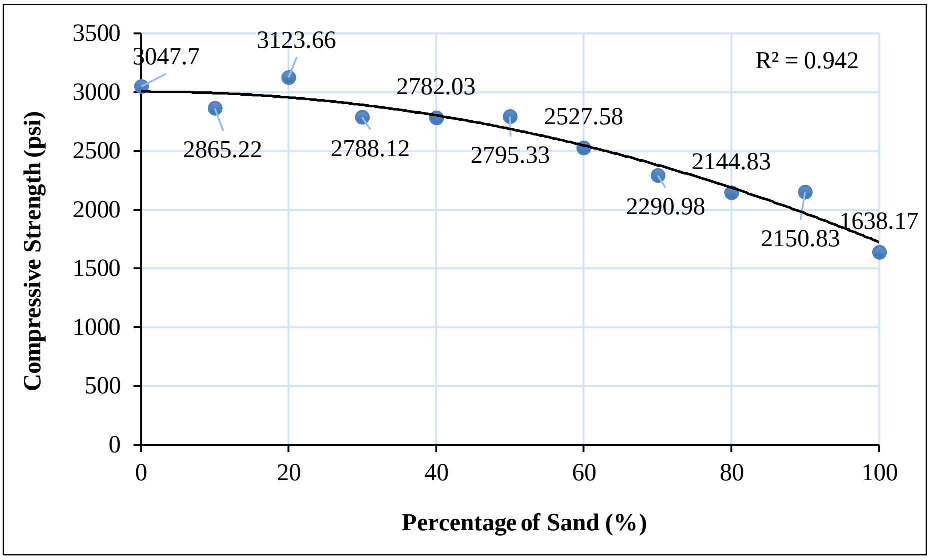

Figure 4. 28-Days cylinder compressive strength (Source: Experimental result/Primary data)

4.2. Infiltration Rate Test (ASTM C1701)

Infiltration test aim is to estimate the rate at which run off will pass through pervious concrete. The infiltration rate test was performed according to ASTM C 1701. Slabs size (2×2×0.5 ft) of pervious concrete pavement was casted and infiltration test was conducted on 28^{th} days. The obtain result in drawn in Table 7. The infiltration rate was estimated using given equation of ASTM D-1701-09 [19-21].

$$I = \frac{K\ M}{D^2\ T} \tag{1}$$

Where:

I= Surface Infiltration rate (mm/min) or In/hr

K = 126,780 in (inch-pound) units

M = Mass of Infiltrated Water (lb) = 40 lb

D = Inside Diameter of Infiltration Ring (in) = 12 inches

T = Time Required for Measured Amount of Water to Infiltrate through Concrete (sec)

The findings shown in Table 7 indicated that infiltration increase by reducing the fine aggregate in pervious concrete. Study found that 0-40% reduction of fine aggregate does not permit water runoff or zero percentage infiltration rate. By the reduction of 50% sand I=348.92 inch/hour further reduction of sand shows higher infiltration rate. The highest infiltration of 273.11% increase by the reduction of 100% fine aggregate from the previous concrete mix.

Table 7. Infiltration rate

Mix	T (sec)	M (lb)	D (in)	K	$I = \frac{KxM}{D^2xT}$ (in/hr)	% increase
M100 (Control Concrete)	-	40	12	126870	-	-
M90	-	40	12	126870	-	-
M80	-	40	12	126870	-	-
M70	-	40	12	126870	-	-
M60	-	40	12	126870	-	-
M50	101	40	12	126870	348.92	0
M40	78	40	12	126870	451.81	29.48
M30	64	40	12	126870	550.65	57.81
M20	43	40	12	126870	819.57	134.88
M10	38	40	12	126870	927.41	165.79
M00	27	40	12	126870	1301.87	273.11

4.3. Discussion

Compressive strength reduced by reduction of sand in pervious concrete [10, 14, 15, 16, 21]. The permeability or infiltration rate depends on the size of course aggregate since fine aggregate was completely reduced study found higher permeability. Permeability increased by reducing the fine aggregate because the void present in the concrete remain unfilled. Past study of Ajamu et al., [17] postulated that permeability and compressive strength of pervious concrete depend on the particle sizes and A/C ratio. Study concluded the small size of coarse aggregates produce a higher compressive strength and at the same time produces a lower permeability rate. Aforementioned environmental advantage of the pervious concrete is the highest permeability which allow storm water to infiltrate into the ground surface rather than waste also natural process of purification taken place when water infiltrate into the ground [18, 22].

The findings of the study drafted in the Tables 5-7 and Figure 3 and 4 shows the compressive strength determined on 7th days and 28 days of the pervious concrete curing period. Compressive strength of the pervious concrete reduced by reducing the fine aggregate/sand and in contrary infiltration rate or permeability increased by reducing the sand. Findings show that by 100% reduction of fine aggregate 49.82% almost 50% compressive strength reduces. Lower compressive strength may limit the applications of the pervious concrete but since high permeability is core purpose in the development of pervious concrete. It may applicable in the area where lower compressive strength required like pathways or sidewalks etc. The optimum sand reduction of 0-40% does not permit water infiltration but gives the highest compressive strength.

5. Conclusion

Study has investigated 7 and 28 days compressive strength of pervious concrete by reduction of fine aggregate from zero percentage to 100% in the design mix. It is concluded that by reduction of fine aggregate compressive strength of the pervious concrete decrease. Maximum 49.82% compressive strength of 7 days and 46.25% compressive strength decreased on 28 days by the reduction of 100% sand. Study found that compressive strength decrease by reducing fine aggregate from the previous concrete. Study concluded that infiltration increase by reducing the fine aggregate in pervious concrete. The findings indicated that 0-40% reduction of fine aggregate does not permit water runoff or zero percentage infiltration rate. The highest infiltration of 273.11% increase by the reduction of 100% fine aggregate from the previous concrete mix. The 90% reduction of sand from concrete give considerable compressive strength of 2150 psi and infiltration rate of 165.79 inch/hour, which can be recommended for pavements of parking and walking area. Lower compressive strength may limit the applications of the pervious concrete but since high permeability is core purpose in the development of pervious concrete. It may applicable in the area where lower compressive strength required like pathways or sidewalks etc.

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