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Assessment of Strength and Permeability Variation in Pervious Concrete by using Industrial Waste as a Partial Replacement for Cement

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Abstract— In this study, two issues related to the pervious concrete are addressed, and a proper solution is drawn. The first issue is related to strength and the second one is related to permeability. We have used some of the available industrial waste like fly ash, silica fume, and furnace slag in replacement of cement at 20%, 35%, and 50%. The study is conducted to check whether this waste materials replacement can increase the strength and permeability of pervious concrete. Results revealed that fly ash replacement at 35% gave the best result than no cement replacement in both strength and permeability.

Index Terms—Compressive strength, Permeability, Pervious concrete, Waste materials.

I. INTRODUCTION

Due to rapid urbanization, the earth's surface is made impervious by constructing buildings and pavements, which does not allow the stormwater to percolate through the intergranular surface pores. Hence, there is a reduction in groundwater recharge drastically. Pervious concrete is a particular type of concrete, which intentionally allows water to pass through it; when such concrete is used in pavement construction, it absorbs the stormwater and sends it to the surrounding soil. This process increases the groundwater recharge condition. Doing so also keeps the massive quantity of rainwater from running off to the downstream areas and getting eroded. This technique is identified as one of the best management practices to store stormwater by collecting it through pipes [1]. Another identified problem is a huge quantity of natural resources are exploited and used as raw materials for constructing pavements, buildings, and other civil structures. The use of industrial waste or agricultural waste in manufacturing concrete is one of the best solutions to reduce the negative environmental impact. This solution makes construction activities sustainable by reducing the exploitation of natural resources [2]. The pervious concrete also adds some more benefits to the environment by reducing the tire-pavement interaction noise, which is identified as the primary source for the road transport sector [3]. This work addresses both the issues by utilizing industrial waste like fly ash, silica fume, and furnace slag in replacement of cement and by testing the concrete for permeability and strength.

A block of conventional concrete has a coefficient of permeability value of 10^{-12} m/s, whereas the pervious concrete has 10^{-3} to 10^{-4} m/s [4]. The actual porosity of traditional concrete is 9% to 10%, but for the previous concrete, the value ranges from 15% to 25% [5]. These additional pores allow the running water to percolate through it and transfer to the surrounding soil. Along with water, some of the debris particles pass through these pores and clog them. This debris reduces the percolating capability of the pavements. So, proper maintenance has to be done to avoid such circumstances. Vacuuming the surface of the pavement once or twice a year will prevent the accumulation of debris particles in the pores [6].

A pervious concrete mixture consists of coarse aggregate, little or no sand, cement, water, and admixtures. Due to the absence of fine aggregate, it is also called "*no-fines concrete*" or "*zero fines concrete*." This type of concrete has relatively lesser strength when compared to conventional concrete with a sufficient amount of fine aggregate present in it [7]. The less strength is due to the weak bond between the coarse aggregate and binder. Due to the absence of fine aggregate, there exists a more fragile bond between coarse aggregate and cement. Due to its less strength, it is not recommended to be used for heavy traffic highways. So, a lot of research is being done to identify the major factors affecting the strength and to improve the structural characteristics without affecting the permeability of the concrete [8].

A. Fly ash

Several research identified the usage of fly ash as a replacement for cement in a proportion ranging from 15% to 25% based on its practical application and its chemical properties [9]. To control the temperature in massive structures like foundations and dams, the proportion of fly ash is increased from 30% to 50%. The fineness of fly ash varies from 400 to 700 m^2/kg [10]. The question for what is the exact proportion of fly ash that can be replaced with cement when it comes to pervious concrete is answered in this research paper. Keeping in mind the economic benefits and technical usage (i.e. structural and functional characteristics), the optimum percentage replacement can be obtained without affecting the rate of construction and durability of the structure. The present study uses fly ash with

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a specific gravity of 2.51, and it is of Class- C. Table I shows the classification of several proportions of fly ash replaced with cement.

TABLE I: PARTIAL REPLACEMENT OF FLY ASH WITH CEMENT

The proportion of Fly ash replacement (%)	Classification
0-20	Low
20-30	Medium
30-50	High
Greater than 50	Very high

B. *Silica fume*

When raw materials of coal are heated to a very high temperature of 2000 °C the silica fume is obtained as a by-product [11]. The fineness of silica fume varies from 13,000 to 30,000 m^2/kg. Literature states that a partial replacement of cement by silica fume (15%) of total weight increases the strength of concrete [12]. The optimum strength is achieved when replaced by 10%. After reaching the maximum strength at 10% replacement, the value started to reduce when 4 KN load is applied uniformly. Another study revealed that the usage of silica fume by replacing it with cement by (5 to 15%) increased the compressive strength by 20%, flexural strength by 30%, and split tensile strength by 10% [13]. So, there is a need to test the optimal percentage replacement of silica fume with cement when applied to pervious concrete. The specific gravity of silica fume used in our study is 2.25.

C. *Furnace slag*

Slag is obtained as a by-product during the iron and steel manufacturing process. A study conducted on the replacement of cement with furnace slag revealed that 15% replacement increases the efficiency by 65% after curing for 90 days. After increasing the percentage of slag, it started decreasing the efficiency similar to 50% replacement [14]. Another study was conducted to know the optimum replacement of slag with cement at three different proportions, i.e., 30%, 40%, and 50%. The samples are placed in a water bath for 7-days and 28-days for curing, and the cubes and cylinders are tested for strength [15]. The water-cement ratio adopted in this test is 0.45, and the grade of concrete is M35. Results revealed that 30% replacement gave the best results among all the three proportions [16]. The specific gravity of the furnace slag used in our study is 2.85.

This work aims to compare the usage of industrial waste like fly ash, silica fume, and furnace slag with the replacement of cement in the percentages of 20%, 35%, and 50%. After making the specimen and testing it for 7-days and 28-day the compression test. Permeability is also tested it using a special apparatus by constant head permeability test. By conducting these two major tests, the conclusion is drawn for an optimal percentage of waste material replacement and type of waste material, i.e., fly ash, silica fume, and furnace slag.

II. PROPERTIES OF CONSTITUENTS

A. *Cement*

The commonly used cement in most construction activities is the Ordinary Portland cement (OPC). In this study, OPC of 43 grade is used, and the tests were conducted as per IS 4032-1988 [17]. Proper care was taken to collect the cement from a single batching plant into an airtight container to avoid moisture entry into the cement. The physical properties of cement are listed in Table II.

TABLE II: PHYSICAL PROPERTIES OF CEMENT

Properties	Obtained value	IS: 8112-1989
Fineness (%)	4.4	Not more than 10
Normal Consistency (%)	28	----
Initial setting time (minutes)	60	Minimum 30
Final setting time (minutes)	258	Maximum 600
Compressive strength (MPa)		
3 days	24.3	Greater than 23
7 days	34.8	Greater than 33
Specific gravity	3.13	----

B. *Fine aggregate*

The locally available river sand is used as a fine aggregate in our study. Before mixing it with other components, it is screened to avoid deleterious materials and tested as per IS: 2386-1963 [18]. It is a naturally available granular material that mainly consists of mineral particles and rocky substances. The physical properties like gradation, fineness modulus and a specific gravity of the material are mentioned in Table III.

TABLE III: PHYSICAL PROPERTIES OF FINE AGGREGATE

Sieve size (mm)	% of mass retained	Cumulative % retained
4.75	0.12	0.12
2.36	0.54	0.66
1.18	11.62	12.28
0.60	28.40	40.68
0.30	46.58	87.26
0.15	12.62	99.88
Pan	0.12	100
Fineness modulus		2.48
Specific gravity		2.6
Water absorption		0.70

C. *Coarse aggregate*

Coarse aggregate should have sufficient strength, be free from weak surfaces, and clean surface without any coatings. These constitutes are mainly responsible for gaining strength. To increase the workability of concrete round-shaped aggregates are used. The physical properties of coarse aggregate like specific gravity gradation, water absorption, and fineness modulus are tested as per IS: 2386-1963[19]. Table IV below shows these physical properties.

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TABLE IV: PHYSICAL PROPERTIES OF COARSE AGGREGATE

Sieve size (mm)	% of mass retained	Cumulative % retained
80	0	0
63	0	0
50	0	0
25	21.64	21.64
20	72.00	93.64
5.6	6.36	100
2.36	0	100
1.18	0	100
Pan	0	100
Fineness modulus		6.15
Specific gravity		2.6
Water absorption		0.70

The water is also tested as per the standards of IS: 456-2000 [20]. The water-cement ratio, which is observed as the main driving unit, is taken as 0.40 from the previous work experience. After testing the physical properties of all the constituents, mixing is done using a pan mixer, and mixing constituents were taken, considering that 25% of the loss of concrete will occur while the mixing process. After mixing, the concrete is cast in steel molds, and it is consolidated using a table vibrator. After 24 hours, the specimens are demolded and placed in the water bath for several curing periods. The grade of concrete manufactured is M30, and the process is done as per ACI 522R-10. The mix proportions are shown in Table V. The amount of water considered in all the cases is 186 kg.

TABLE V: MIX PROPORTIONS

Waste material	Coarse aggregate (kg)	Fine aggregate (kg)	Cement (kg)	Replaced material (kg)
Fly ash -20%	947	67	396	99
Fly ash -35%	795	56	321	173
Fly ash -50%	695	48	247	247
Silica Fume 20%	1040	72	396	99
Silica Fume 35%	985	69	321	173
Silica Fume 50%	928	65	247	247
Furnace Slag 20%	1057	74	396	99
Furnace Slag 35%	1012	71	321	173
Furnace Slag 50%	967	67	247	247

III. TEST PROCEDURE

A. Compressive strength test

The strength and durability of this concrete are low when compared to conventional concrete due to the open structure with large gaps in between. Several studies indicated that this is used in low-volume highways like parking lots, sidewalks, and driveways. Compressive strength was conducted as per ASTM C 39[21]. The specimen was prepared using M30 concrete with different waste materials replaced at various percentages. The total number of cubes cast for testing 7 and 28-day strength is 42. The size of the specimen for 7 and 28-day strength is 150*150*150 mm. A compression testing machine as per IS: 516-1975 was used [22]. All the specimens tested have attained minimum target strength for the M30 concrete, i.e., 38.25 MPa. The casting and testing procedure is shown in Fig. 1, 2, and 3.
Compressive strength = (Applied Load /Area).

B. Porosity test

This is one of the important parameters to increase or decrease the permeability of the pervious concrete. The important source for porosity is the water-cement ratio of the concrete. The porosity is calculated using the formula given below in Equation 1.

$$\tilde{\eta} = 1 - \frac{(W2 - W1)}{\gamma V} \quad (1)$$

Where $\tilde{\eta}$ = porosity (%)
W1 =Sample weight taken in water (gm)
W2 = Sample weight when oven dried (gm)
γ = Water density (gm/cc)
V = volume of sample (cm^3)

C. Permeability test

The constant head permeability test is used to calculate the coefficient of permeability values. A different test procedure is used in casting the pervious concrete. The concrete is mixed with different waste materials as per the procedure explained above. PVC pipes are used as a mold to give the cylindrical shape to the concrete specimen. The inner surface of the pipe is lubricated to easily remove the concrete while demolding. The two open ends are closed with PVC caps to give a closed structure. The caps are pierced, and valves are introduced into the hole so that the discharged water can be collected through the valves. The detailed procedure is shown in Fig. 1, 2, and 3. The coefficient of permeability (*k*) is calculated using the formula shown in Equation 2.

$$K = \frac{Q * L}{A * h * t}$$

Where K = Coefficient of Permeability (cm/sec)
Q= Amount of water discharge (cm^3)
L= Length of concrete specimen (cm)
A= Area of concrete specimen (cm^2)
h= Height of water (cm)
t= Time (sec)

Fig. 1. Casting pervious concrete in PVC pipes

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Fig. 2. Closing both sides with PVC caps

Fig. 3. Collecting discharge into the measuring jar

IV. RESULTS AND DISCUSSIONS

The compressive strength test results for 7-days and 28-days when cement is replaced with 20%, 35%, and 50% of Fly ash, Silica Fume and Furnace slag are listed below in Tables VI and VII. The compressive strength obtained for a concrete cube with 100% cement (No replacement with waste material) is 22.2 MPa for 7-days and 34.2 MPa for 28-days. When fly ash is replaced at three different proportions, the strength obtained is greater than no replacement concrete. This clearly shows that the replacement of fly ash with cement is giving better strength. In the case of Silica fume, the 7-day strength is less when compared to no replacement concrete. But for 28 days, the silica fume gave higher strength. This shows that silica fume replacement with cement requires more time to gain strength. In the case of Furnace slag, the compressive strength test conducted for 7-days and 28-days curing is greater than no cement replacement concrete.

From all the results, the maximum compressive strength for 7-days and 28-day curing has occurred for 35% replacement of cement with Fly ash. These results suggest that Fly ash has more affinity with cement at a given percentage of 35% when compared with other waste materials. The compressive strength values for 7-days and 28-day curing are shown in Table VI and VII. The strength variation through pictorial representation is shown in Fig. 4 and 5.

TABLE VI: COMPRESSIVE STRENGTH FOR 7-DAYS

Materials	Ultimate load (KN)	Compressive strength (MPa)
No replacement	500	22.2
Fly ash -20%	560	24.9
Fly ash -35%	571	25.3
Fly ash -50%	506	22.5
Silica Fume-20%	481	21.4
Silica Fume-35%	490	21.7
Silica Fume-50%	501	22.0
Furnace Slag-20%	531	23.6
Furnace Slag-35%	540	24.0
Furnace Slag-50%	551	24.2

TABLE VII: COMPRESSIVE STRENGTH FOR 28-DAYS

Materials	Ultimate load (KN)	Compressive strength (MPa)
No replacement	769	34.2
Fly ash -20%	801	35.6
Fly ash -35%	828	36.8
Fly ash -50%	807	35.9
Silica Fume-20%	771	34.3
Silica Fume-35%	789	35.1
Silica Fume-50%	810	36.0
Furnace Slag-20%	807	35.9
Furnace Slag-35%	811	36.1
Furnace Slag-50%	816	36.3

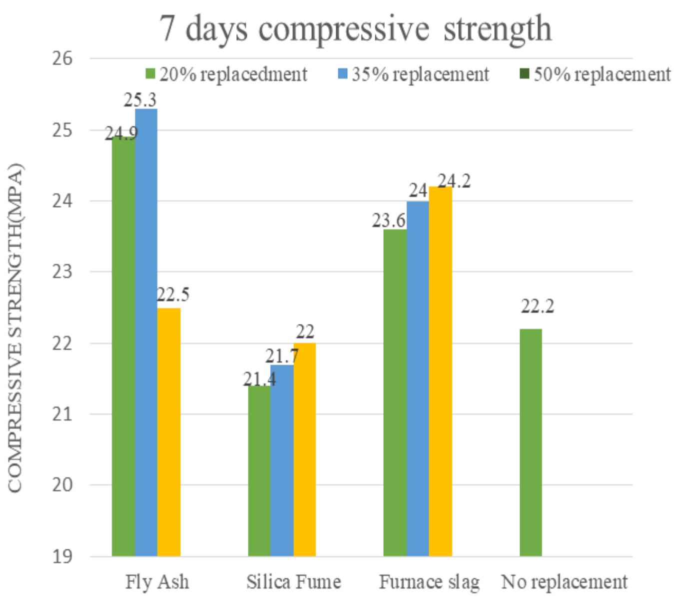

Fig. 4. Variation of 7-day compressive strength

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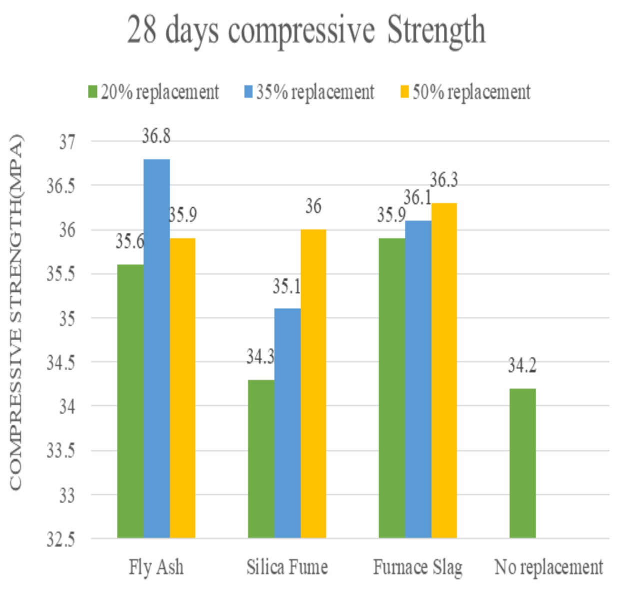

Fig. 5. Variation of 28-day compressive strength

To test the permeability of the concrete with different proportions of waste materials replaced with cement, concrete cylinders of size 100mm in diameter and 150mm in height cured for 28 days are used. The test results are shown in Table VIII. From the results, the coefficient of permeability for no replacement concrete is 1.17 cm/s. In the case of fly ash replacement at 20% and 35% gave higher permeability than no replacement concrete. In any other case, there is no higher value than conventional pervious concrete. The coefficient of permeability value is entirely dependent on the porosity value. If the porosity is high, the discharge from the pervious concrete is increased. These results show that fly ash acts as a suitable replacement for cement in both strength and permeability. The permeability results are shown in Table VIII and variation is shown in Fig. 6. Table IX compares strength and permeability.

TABLE VIII: PERMEABILITY TEST RESULTS

Material	Discharge (cm^3)	Coefficient of permeability (cm/s)	Porosity (%)
No replacement	460	1.12	31.49
Fly ash -20%	520	1.25	32.34
Fly ash -20%	490	1.17	31.59
Fly ash -20%	350	0.85	28.36
Silica Fume-20%	460	1.12	31.46
Silica Fume-20%	390	0.95	29.65
Silica Fume-20%	310	0.75	26.30
Furnace Slag-20%	430	1.03	30.71
Furnace Slag-20%	330	0.80	27.90
Furnace Slag-20%	300	0.72	25.89

From table IX, the strength and permeability values are shown to draw an optimal result. Fly ash replacement at 35% gave the best result than no replacement concrete in both strength and permeability. But at 20% replacement, it gave better results only in the case of permeability. So, we can say that out of all the waste materials replaced at different percentages, fly ash at 35% is an optimal replacement for cement. Fly ash particles are generally made up of oxides of silicon, aluminum, and iron with particle sizes ranging between 2 to 10 micrometers. When fly ash is mixed with the cement during the hydration process, calcium hydroxide is released to form calcium-silicate and calcium-aluminate hydrates. These bonds may be responsible for higher strength and permeability when replaced with cement in the case of pervious concrete.

TABLE IX: COMPARISON OF STRENGTH AND PERMEABILITY

Materials	Permeability (cm/s)	Compressive strength (MPa)
No replacement	1.17	34.2
Fly ash -20%	1.25	35.6
Fly ash -35%	1.01	36.8
Fly ash -50%	0.85	35.9
Silica Fume-20%	1.12	34.3
Silica Fume-35%	0.95	35.1
Silica Fume-50%	0.75	36.0
Furnace Slag-20%	1.03	35.9
Furnace Slag-35%	0.80	36.1
Furnace Slag-50%	0.72	36.3

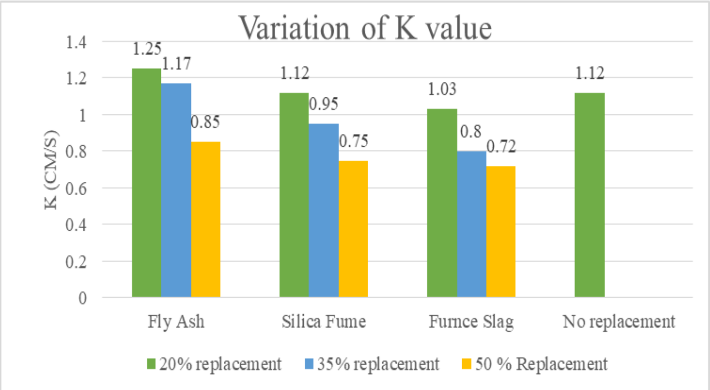

Fig. 6. Variation of coefficient of permeability

V. CONCLUSIONS

Compressive strength is identified as the major concern for pervious concrete. Several research conducted to find a solution to increase the strength without compromising its permeability. Literature has shown that the usage of some waste materials in replacement of cement at a certain percentage increases the strength. Using these waste materials in concrete production reduces environmental pollution. In the present study, usage of three waste materials, i.e., fly ash, silica fume, and furnace slag in replacement of cement to test the compressive strength and permeability. Proper care is taken in maintaining the properties of cement, aggregate, and waste materials suitable for pervious concrete production. Results revealed that fly ash replacement at 35% gave the best result than no replacement concrete in both strength and permeability. But at 20% replacement, it gave better results only in the case of permeability. So, we can say that out of all the waste materials replaced at different percentages, fly ash at 35% is an optimal replacement for

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cement. The reason for this may be the molecular structure of fly ash and hydrates (calcium-silicate and calcium-aluminate hydrates) formed during the hydration process. There is a future scope in finding better strength and permeability from the pervious concrete by changing the aggregate size and gradation. Several strength tests like split tensile and triaxle tests can also be performed.

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CONFLICT OF INTEREST

"The author declare no conflict of interest".

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