Experimental Studies on Pervious Concrete Utilizing GGBFS and Silica Fume as a Partial Replacement of Cement

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ABSTRACT

In order to develop material specification for pervious concrete, it is necessary to conduct tests to evaluate the performance of this new type of high-performance concrete made by conventional cementitious materials, aggregates and water. Main focus of this investigation is 1) To evaluate optimum sand content (%) for ordinary pervious concrete (OPC) by ratio of sand used in three phases (5%, 7.5%, 10%). 2) To prepare pervious concrete replacing cement with silica fume (5%,10%,15%) and Ground Granulated Blast Furnace Slag (GGBFS) (10%,20%,30%) and evaluate its mechanical properties such as density, void content, compressive strength, flexural strength, abrasion resistance, split tensile strength, water permeability, porosity and optimum percentages.

Keyword: - *Pervious concrete, GGBFS, Silica Fume, Sand Content, Mechanical Properties of Pervious concrete.*

1. INTRODUCTION

Portland Cement Pervious Concrete (PCPC) has been used in construction for past several years with first documented usage in Europe. World over, Pervious Concrete has becoming popular due to its great environmental benefits in storm water management and futuristic pavement construction. More than just the drainage of surface water runoff, its advantages include pollution treatment of runoff water, reducing traffic noise, recharging of aquifers, increasing skid resistance, and minimizing the heat island effect in large cities. Pervious concrete has been used in the United State for over 3 decade. Pervious concrete is special type of high porosity concrete which allows water and other water soluble particles to percolate through it and reducing the water flow on ground and increases the ground water level.

According to National Ready Mixed Concrete Association (NRMCA) "pervious concrete is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass-through it, thereby reducing the runoff from a site and recharging ground water-levels." It is also known as **"no-fines concrete"** and composed of Portland cement, coarse aggregate, water, admixtures, and little or no sand.

Generally for construction of pavements Conventional normal weight Portland cement concrete is used. The impervious nature of the concrete pavements contributes to the increased water runoff into the drainage system, and by that, over-burdening the infrastructure and causing excessive flooding in built-up areas. So in this era of urbanization, pervious concrete would be a boon. Pervious concrete is a type of concrete with significantly high water permeability compared to normal weight concrete. It has been mainly developed for draining water from the ground surface, so that storm water runoff is reduced and the groundwater is recharged.

Pervious concrete, however, has deficiencies which limit its application as pavements. These limitations include low compressive strength and flexural strength, clogging and other durability issues. This issue can be addressed efficiently by researching the optimum material and process of making the pavement by pervious concrete.

2. MATERIAL SELECTION OF PROJECT

2.1 Cement

Ordinary Portland cement of 53-grade will be used in this study conforming to IS: 8112-1989 having specific gravity of 3.15.

2.2 Aggregates

The coarse aggregate passing through 20 mm and retained on 10 mm sieve was used in research. Aggregates of size 10 mm and 20 mm used in the project will be local angular aggregates available with distributer.

2.3 Ground Granulated Blast Furnace Slag (GGBFS)

The GGBS used in research was obtained from Steel Plant. The specific gravity of about GGBFS is 2.88.

2.4 Silica Fume

Silica Fume required for the project was obtained from local Silica Fume manufacturer having its source from Rajkot Plant having a specific gravity of 2.23.

2.5 Water

Water quality used in pervious concrete should be the same as that used in conventional concrete: potable water, recycled water from the concrete industry, or tap water. Due to the sensitivity of pervious concrete, water quality control is very important.

Figure 1. GGBFS

Figure 2. Silica Fume

Table 1. Chemical properties of GGBFS & silica fume

Sr. No.	Characteristic	GGBFS	Silica Fume
1	SiO_2	35.47	93.00
2	CaO	35.89	0.10
3	MgO	8.06	1.50
4	Fe_2O_3	2.41	1.00
5	Al_2O_3	14.27	1.40

6	Loss on Ignition	0.70	-
7	Insoluble Residue	0.52	-
8	MnO	0.34	-
9	Alkalis	0.20	2.50
10	Sulphide Sulphur as SO_3	1.58	0.50
11	Fineness	3820	2250
12	Specific Gravity	2.8	2.23

3. EXPERIMENTAL PROGRAMME

As part of project, 9 samples of pervious concrete were prepared. Practical preparation of concrete mixes for various concrete/ aggregate mix proportions.

Proportion 1- Use of only 10 mm aggregate of 60% or 20 mm of aggregate of 40% as OPC.
Proportion 2- Use of only 10 mm aggregate of 60% or 20 mm of aggregate of 40% as OPC1, addition of sand 5% to 10mm aggregate.
Proportion 3- Use of only 10 mm aggregate of 60% or 20 mm of aggregate of 40% as OPC2, addition of sand 7.5% to 10mm aggregate.
Proportion 4- Use of only 10 mm aggregate of 60% or 20 mm of aggregate of 40% as OPC3, addition of sand 10% to 10mm aggregate.
Proportion 5- Higher strength mix (From above OPC1-3) + Silica Fume Replacement of Cement (5%) as SPC1
Proportion 6- Higher strength mix (From above OPC1-3) + Silica Fume Replacement of Cement (10%) as SPC2
Proportion 7- Higher strength mix (From above OPC1-3) + Silica Fume Replacement of Cement (15%) as SPC3
Proportion 8-Higher strength mix (From above OPC1-3) + GGBFS Replacement of Cement (10%) as GPC1
Proportion 9- Higher strength mix (From above OPC1-3) + GGBFS Replacement of Cement (20%) as GPC2
Proportion 10- Higher strength mix (From above OPC1-3) + GGBFS Replacement of Cement (30%) as GPC3

Table 2. Necessary specimen casted for various test

OPC, OPC 5-7.5-10, SPC 5-10-15, GPC 10-20-30	**6 x 3**	**150 X 150 X 150**	**Compressive strength at 7 & 28 days**
	6 x 3	150 X 300	Permeability test at 28 days
	3 x 3	70 X 70 X 70	Abrasion test at 28 days
	3 x 3	150 X 300	Split Tensile test 28 days
	6 x 3	150X 150 X 700	Flexural strength at 28 days

OPC= Ordinary pervious concrete SPC= Silica fume pervious concrete

GPC= GGBFS pervious concrete

4. EXPERIMENTAL RESULTS AND DISCUSSION

Table shows all the test of pervious concrete with different proportion of Sand, Silica fume and GGBFS.

Table 3. Results of all tests

Identification Mark	Compressive Strength (N/mm^2)		Density	Porosity (%)	Permeability (cm/second)	Cantabro Test (%)	Flexural Strength (N/mm^2)	Split Tensile Strength (N/mm^2)
	7 days	28 days	28 days	28 days	28 days	28 days	28 days	28 days
OPC	1.84	2.96	1696	32.15	1.92	72.16	0.35	0.45
OPC = Ordinary Pervious Concrete								
OPC 1	2.82	4.41	1832	26.71	1.69	64.18	0.95	0.73
OPC 2	5.17	7.42	1883	24.66	1.51	48.99	1.18	0.95
OPC 3	6.78	9.23	2038	18.44	1.26	40.02	1.40	1.13
OPC 1 = 5% sand, OPC 2 = 7.5% sand, OPC 3 = 10% sand								
SPC 1	9.27	14.09	1954	21.84	1.64	28.32	1.38	1.00
SPC 2	10.16	15.83	1991	20.36	1.42	26.52	1.81	1.17
SPC 3	10.88	18.81	2027	18.92	1.29	22.85	2.42	1.406
SPC1=5% Silica fume, SPC2=10% Silica fume, SPC3=15% Silica fume								
GPC 1	9.80	14.42	1986	20.56	1.34	26.12	1.70	1.19
GPC 2	11.23	17.23	2041	18.6	1.18	23.2	2.43	1.55
GPC 3	13.56	23.49	2070	16.90	0.99	18.42	2.96	1.95
GPC=10% GGBFS, GPC=20% GGBFS, GPC=30% GGBFS								

4.1 Compressive Strength

The compressive strength of ordinary pervious concrete (OPC) at 28 days ranges from 4.41 N/mm^2 to 9.23 N/mm^2. That shows when we increase in sand content, compressive strength also increases. But we need a desired 20% porosity which we get in 7.5% sand content. So, by using 7.5% sand content in SPC & GPC proportions, Compressive strength ranges from 14.09 N/mm^2 to 18.81 N/mm^2 in SPC and 14.42 N/mm^2 to 23.49 N/mm^2 in GPC. Variation in Compressive strength shows in figure.

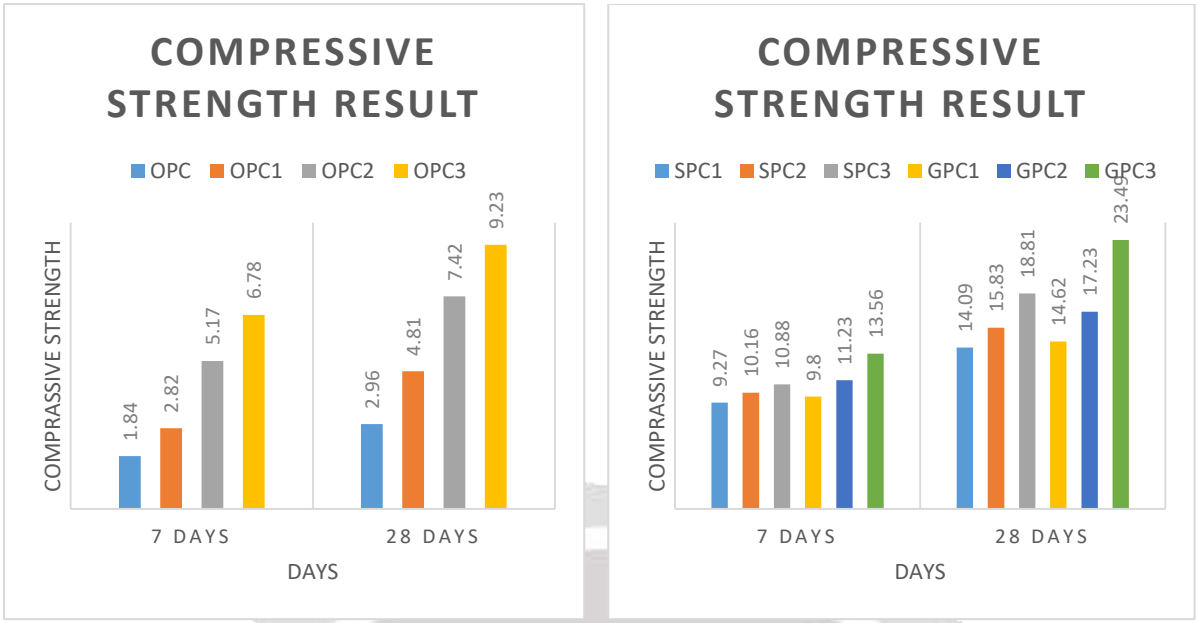

Chart 1. Compressive strength

4.2 Porosity

Porosity for OPC is around 32.15%, but after adding sand content in pervious concrete, Porosity of OPC1, OPC2, OPC3 is around 21.84%, 20.36% & 18.92% respectively. By adding cementitious materials of Silica fume as partial replacement of cement, porosity ranges for SPC1-SPC3 from around 21.84%, 20.36% & 19.92% respectively. By adding cementitious materials of GGBFS as partial replacement of cement, porosity ranges for GPC1-GPC3 from around 20.56%, 18.60% & 16.90% respectively. Variation in Porosity shows in figure.

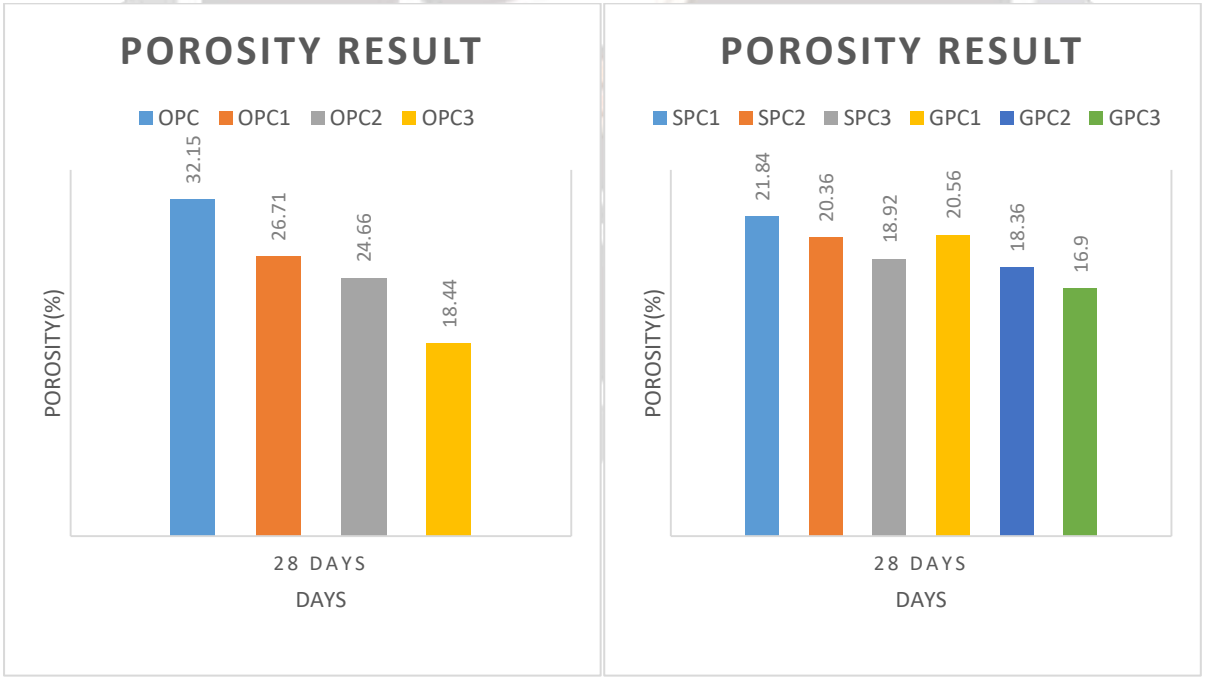

Chart 2. Porosity

4.3 Permeability

Permeability values for all mixes are listed in figure. Permeability for OPC is around 1.92 cm/sec. after adding sand content permeability continuously decreases. After adding silica fume and GGBFS in Pervious concrete, permeability ranges 1.64 cm/sec to 1.29 cm/sec for SPC and 1.34 cm/sec to 0.99 cm/sec for GGBFS. The

pervious concrete mix with small aggregates showed a lower permeability when compared to the mix with large-size aggregates.

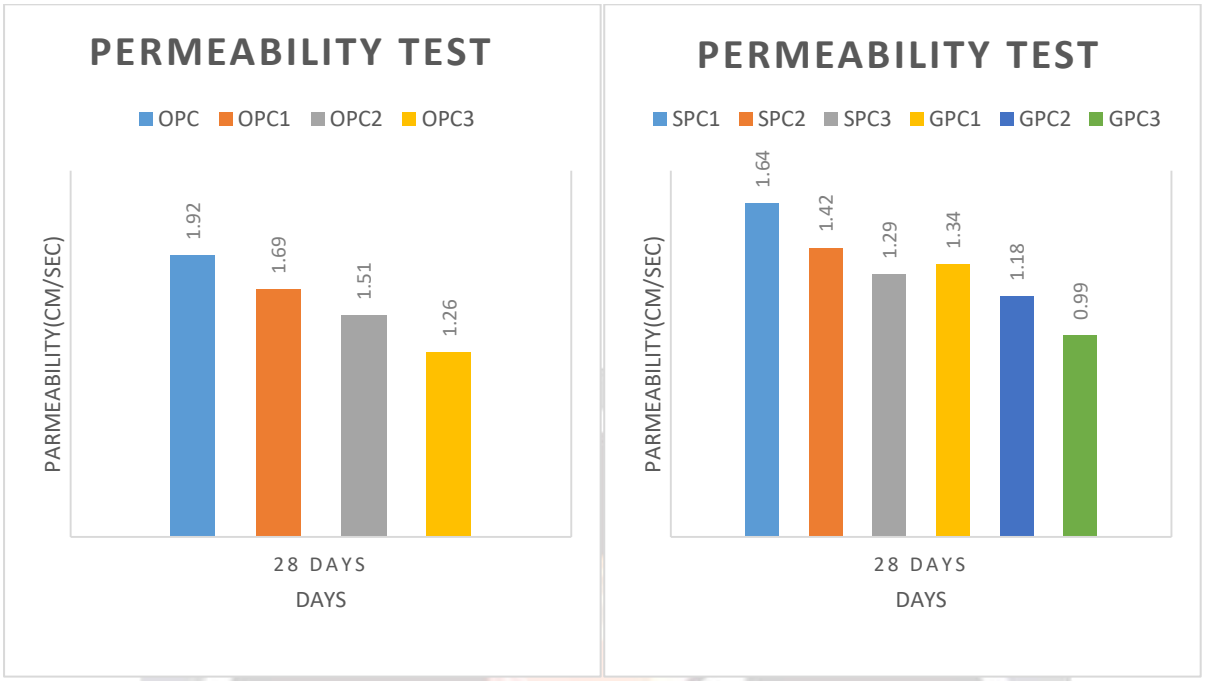

Chart 3. Permeability

4.4 Cantabro Test

The Cantabro loss of ordinary pervious concrete (OPC) is around 72.16%. Which ranges between 64.18%, 48.99% & 40.02% for OPC1-OPC3 mixes. In Silica fume Pervious Concrete (SPC) mixes, Cantabro loss ranges from 28.32%, 26.52% & 22.85%. In GGBFS Pervious Concrete (GPC) mixes, Cantabro loss ranges from 26.12%, 23.20% & 18.42%.Variation in Cantabro loss shows in figure.

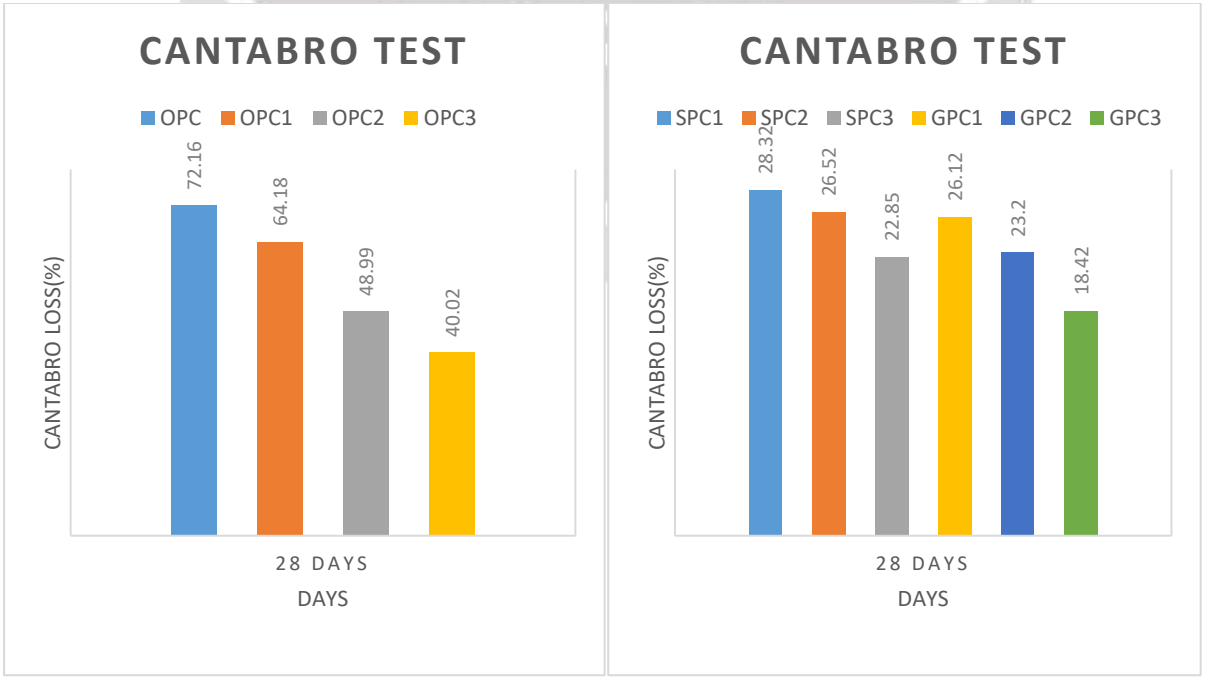

Chart 4. Cantabro test

4.5 Flexural Strength

The Flexural Strength of ordinary pervious concrete (OPC) is around 0.35 N/mm^2. But for OPC1 to OPC3 mixes, it increases from 0.95 to 1.40 N/mm^2.In Silica fume Pervious Concrete (SPC), with silica fume mixes of 5%, 10% & 15%, Flexural Strength ranges from 1.38 N/mm^2, 1.81 N/mm^2 & 2.42 N/mm^2. For GGBFS Pervious Concrete (GPC) mixes of 10%, 20% & 30%, Flexural strength ranges from 1.70 N/mm^2, 2.43 N/mm^2 & 2.96 N/mm^2 respectively. Variation in Flexural strength shows in figure.

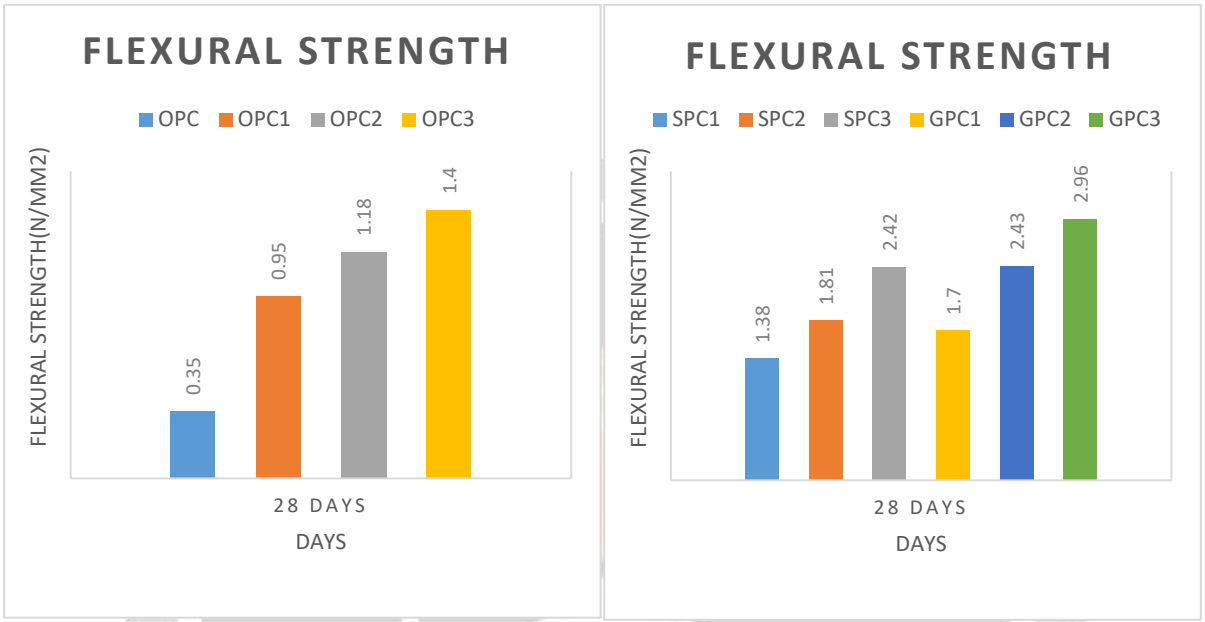

Chart 5. Flexural strength

4.5 Split Tensile Strength

The Split Tensile Strength of ordinary pervious concrete (OPC) is around 0.45 N/mm^2. But for OPC1 to OPC3 mixes, it increases from 0.73 N/mm^2 to 1.138 N/mm^2.In Silica fume Pervious Concrete (SPC), with silica fume mixes of 5%, 10% & 15%, Split Tensile Strength ranges from 1.0 N/mm^2, 1.17 N/mm^2 & 1.40 N/mm^2. For GGBFS Pervious Concrete (GPC) mixes of 10%, 20% & 30%, Split Tensile Strength ranges from 1.19 N/mm^2, 1.55 N/mm^2 & 1.98 N/mm^2 respectively. Variation in Split Tensile Strength shows in figure.

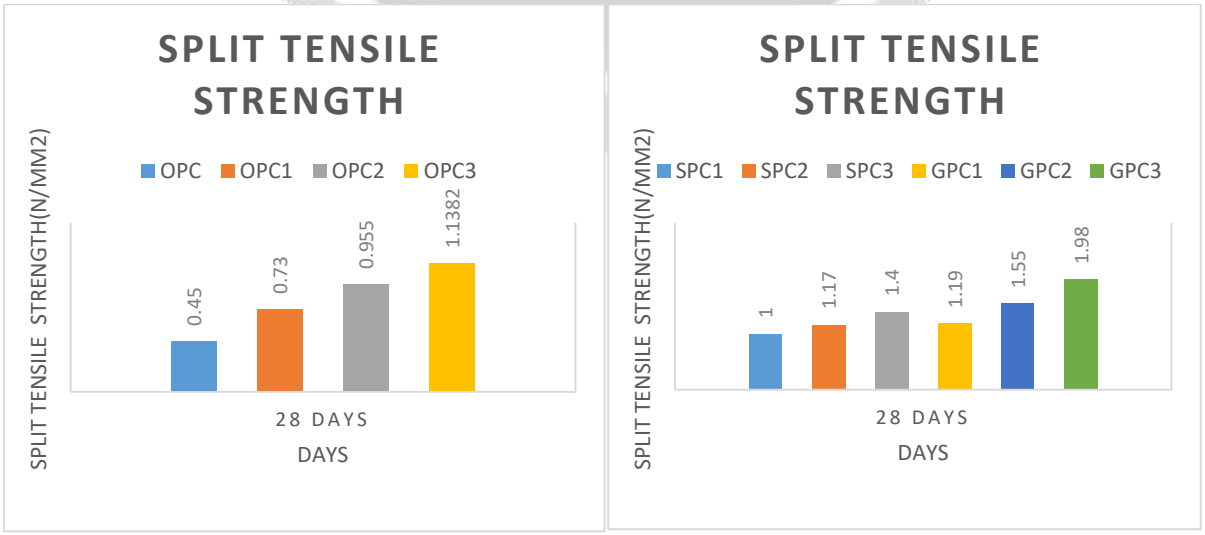

Chart 6. Split tensile strength

5. CONCLUSION

I. For Ordinary Pervious Concrete, finding the optimum quantity of sand by concluding the results given above following interpretations can be made,

- The Compressive strength of ordinary pervious concrete increases by increasing sand content. 0% sand OPC has compressive strength of 1.84 N\mm$^{2.}$ By adding sand content of 5-7.5-10% of the OPC, Compressive strength increases by 1.62, 2.5 and 3.11 times respectively.
- The porosity of ordinary pervious concrete decreases by increasing sand content. 0% sand OPC has porosity of 32.15% .By adding sand content of 5-7.5-10% of the OPC, porosity decreases by 17%, 23.5% and 43%.
- The Flexural strength of ordinary pervious concrete increases by increasing sand content. 0% sand OPC has Flexural strength of 0.35 N\mm$^{2.}$ By adding sand content of 5-7.5-10% of the OPC, Compressive strength increases by 2.71, 3.37 and 4.0 times respectively.
- Permeability of OPC is around 1.92 to 2.00 cm/sec. But Permeability decreased when sand content increased from 5 to 10% around 1.69- 1.51- 126 cm/sec.
- The Split tensile strength of ordinary pervious concrete increases by increasing sand content. 0% sand OPC has Split tensile strength of 0.45 N\mm$^{2.}$ By adding sand content of 5-7.5-10% of the OPC, Split tensile strength increases by 1.62, 2.11 and 2.51 times respectively.

As the above interpretations of various results of laboratory investigations on different proportions of sand and its effect on the desired property of pervious concrete, we can conclude that, as the sand content increases in percentage compressive strength, flexural strength, tensile strength and abrasion resistance increases, which is good for any concrete but we got decreased porosity at increasing the sand percentage, which is an essential property for pervious concrete. That's why, in phase 2 we will take mid 7.5% sand as standard for testing the SPC & GPC as partial replacement of cement.

II. In Phase 2, following conclusions can be made.

1. For silica fume pervious concrete (SPC),

- The Compressive strength of SPC increases by increasing silica fume content. Normal Pervious Concrete has compressive strength of 2.96 N\mm^2 at 28th day. By adding silica fume content of 5%, 10% & 15% of the SPC, Compressive strength increases by 4.76, 5.34 and 6.35 times respectively.
- The porosity of ordinary pervious concrete decreases by increasing silica fume content. Ordinary Pervious Concrete has porosity of 32.15% .By adding silica fume content of 5%, 10% & 15% of the OPC, porosity decreases by 32.06%, 36.67% and 41.15%.
- Permeability of OPC mixes is around 1.92 cm/sec to 2.00 cm/sec. But Permeability decreased around 1.64 cm/sec-1.29 cm/sec, when silica fume content increased from 5 to 15%
- The Split tensile strength of ordinary pervious concrete increases by increasing silica fume content. Ordinary Pervious Concrete has Split tensile strength of 0.45 N\mm^2. By adding silica fume content of 5%, 10% & 15% of the OPC, Split tensile strength increases by 2.24, 2.60 and 3.12 times respectively.
- The Flexural strength of ordinary pervious concrete increases by increasing silica fume content. Ordinary Pervious Concrete has Flexural strength of 0.35 N\mm$^{2.}$ By adding more silica fume content of 5%, 10% & 15% of the OPC, strength increases by 3.94,5.17 & 6.91 times respectively.

2. For GGBFS pervious concrete (GPC),

- The Compressive strength of GPC increases by increasing GGBFS content. Normal Pervious Concrete has compressive strength of 2.96 N\mm^2 at 28th day. By adding GGBFS content of 10%, 20% & 30% of the OPC, Compressive strength increases by 4.93, 5.82 and 7.93 times respectively.
- The porosity of ordinary pervious concrete decreases by increasing GGBFS content. Normal Pervious Concrete has porosity of 32.15% .By adding GGBFS content of 10%, 20% & 30% of the OPC, porosity decreases by 36.04%, 42.89% & 47.43%.
- Permeability of OPC is around 1.92 to 2.00 cm/sec. But Permeability decreased around 1.340 cm/sec-0.99 cm/sec, when GGBFS content increased from 10% to 30%

- Ordinary Pervious Concrete has Split tensile strength of 0.45 N\mm$^{2.}$ By adding GGBFS content of 10%, 20% & 30% of the OPC, Split tensile strength increases by 2.64, 3.44 and 4.40 times respectively.
- The Flexural strength of ordinary pervious concrete increases by increasing GGBFS content. Normal Pervious Concrete has Flexural strength of 0.35 N\mm$^{2.}$ By adding more GGBFS content of 10%, 20% & 30% of the OPC, flexural strength increases by 4.85, 6.94 & 8.45 times respectively.

So, for the desired optimum mechanical properties of the pervious concrete, optimum percentage of GGBFS and silica fume as partial replacement of cement is 10% for each material. At the 10% level of replacement GGBFS in GPC and 10% level of replacement of silica fume in SPC, we get the required void content, permeability and overall optimum mechanical properties.

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