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Experimental Analysis on Engineering Properties of Pervious Concrete with GGBS as a Partial Replacement for Cement

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ABSTRACT: Porous Concrete has been developed as an emerging technology, since this is environmentally and hydrologically sustainable. The use of porous concrete is limited to parking lots, walkways, footpaths etc. But to use porous concrete on the road for vehicular movement is a challenge for any researcher. The current approach is to use porous concrete on the low volume road by improving the engineering properties. Using a variety of design criteria, this study prepares a number of test samples before examining the characteristics like strength and permeability of porous concrete mixes. Regarding characteristics such as flexural strength, permeability, compressive strength, tensile strength, and porosity the effects of cement-water ratio, aggregate gradation, and fine aggregate's percentage are estimated. Different samples of pervious concrete mixtures have been produced and experimentally tested employing aggregate sizes 20-16 mm, 16-12.5 mm, and 12.5-4.75 mm. In the study water-cement ratio is considered as 0.30 and 0.32. The presence of GGBS in the permeable concrete was evaluated using a systematic investigation through the compressive strength and permeability property. In this experimental initiative, it is suggested that GGBS may be utilized to partially replace cement. The percentages of replacement were considered as 25 percent, 30 percent, 35 percent and 40 percent. The combination started to lose its stability once we reached the maximum level of 40%. The split tensile strength, flexural strengths and, compressive strength were all improved with a 40% substitution. The GGBS has been raised, yet it has decreased permeability. The current study has improved the structural and hydrological properties of porous concrete by adding GGBS at some selected percentage, and this improved mix may be used for the preparation of porous concrete layer for low-volume roads construction.

Keywords: GGBS, Water cement ratio, Aggregate binder ratio, Strength, Permeability.
Abbreviations: GGBS, Ground Granulated Blast-furnace Slag; M, Mix; MPa, Mega Pascal; CC, Cement Concrete.

I. INTRODUCTION

Water, port land cement, and coarse aggregate are the components of permeable concrete. The pervious concrete is considered as a pavement because of having environmental friendly aspects like hydrological and mechanical properties [4, 10, 14]. The use of pervious concrete had been restricted to the construction of footpaths, walkways, parking lots etc. But gradually this concept has been implemented in the carriageway construction. The challenge faced in this concept is to sustain against the moving traffic load. Since pervious concrete is an open-graded pavement, it can allow water to percolate through it easily, but it must desperately withstand the traffic load. The lack of fine particles in the mix sets it apart from regular concrete. The aggregate is typically one size, and the point of contact is where a cement and water paste is used to bind the material together [8]. To make a paste, a specific amount of water and cementitious materials are combined. When mixed and applied, the paste creates a thick layer over the aggregate particles to prevent it from leaking off. Pervious concrete creates a harsh mix that is challenging to mix and put because it lacks fine aggregate [7]. As a result, the concrete has a significant number of interconnecting voids. Water may swiftly percolate through concrete when it is appropriately constructed [13, 15, 23]. Contrary to pervious concrete, which has a void ratio that can range from 15 to 40 percent, ordinary concrete has a void ratio of between 3 and 5 percent. Pervious concrete has a low weight (between 1600 and 2000 kg/m^3) because to its large void content [2-3]. Depending on the use, the void ratio of pervious concrete varies. A large degree of surface ravelling and honeycombing may be seen on the pervious concrete's surface. Many researches have been performed to improve the strength of pervious concrete layer. Aggregate having different size and shape have been used to improve the strength parameters of pervious concrete [6, 18]. To improve the strength and durability properties of pervious concrete different types of additives like polypropylene fibre, polyethylene fibres, fly ash have been used [19]. Over burnt brick aggregate also has been used as coarse aggregate to check the behaviour of pervious concrete [22]. Different mix designs have been done to check and compare the performance of pervious concrete in terms of hydrological and strength properties [16, 17, 21].

In earlier researches, it is observed that although pervious concrete is an open-graded pavement, if it has satisfactory bonding with the aggregates then it can resist traffic load as well as allow percolation of water. GGBS is a material which is having cementitious property to have good bonding in the mix [1]. In order to produce ground-granulated blast furnace slag, iron slag is quenched from the source of blast furnace molten in aqueous media to create a glassy, granular by-product which is further dried out and pulverized into fine powder. GGBS improves the workability, strength, and durability of concrete when added to it [9, 11, 12, 20]. In the current study, infiltration property has also been checked [5].The authors report that when up to 40% of the cement was substituted with slag, the flexural and compressive strengths of the concrete increased and also percolation of water is maintained.

II. MATERIALS AND METHODS

In this investigation, GGBS is used to replace the cement partially. Different tests have been initially performed to ascertain the physical characteristics of materials. Concrete mixes have been prepared with and without GGBS by replacing cement partially. Ten f mix variations were formed using water-cement ratios of 0.30 and 0.32. The aggregate-to-binder ratio adopted in the study was 1:4. M1, M2, M3, M4, M5, M6, M7, M8, M9 and M10 are the assigned mix combinations. Using the above-mentioned mix preparation, testing has been done to assess the behaviour of hardened concrete.

Materials

The materials used in this research are as follows:

• **Cement**: In this study, Portland Pozzolana Cement has been used.

• **Fine aggregate**: In this study, gaps have been filled and strength was increased by using readily accessible local sand. In comparison to the weight of coarse aggregate, 5% of fine aggregate has been utilised. The only mix combinations that contain fine aggregate are M2, M7, M8, M9, and M10.

• **Coarse aggregate**: As a coarse aggregate, locally available crushed aggregate has been used in the study. Granite stone is the aggregate employed in this study. Three aggregate sizes – 50% of 20 mm to 16 mm, 25% of 16 mm to 12.5 mm, and 25% of 12.5 mm to 4.75 mm have been utilised.

Table 1: Mix designations.

Mix designation	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Cement(%)	100	100	75	70	65	60	75	70	65	60
GGBS(%)	0	0	25	30	35	40	25	30	35	40
Fine aggregate(%)	0	5	0	0	0	0	5	5	5	5

Table 2: Cement properties.

% Of Fineness	Specific Gravity	Standard Consistency (%)	Setting Time (Initial) (In Min)	Setting Time (Final) (In Min)	Compressive Strength (MPa)
5.1	3.14	32	90	435 min	39

Table 3: Coarse Aggregate Properties.

Impact Value(%)	Crushing Value(%)	Los Angeles Abrasion Test(%)	Water Absorption (%)	Specific Gravity	Flakiness Index(%)	Elongation Index (%)
10.52	12.36	21.65	2.06	2.80	31.38	45.29

Table 4: Chemical compositions of cement and GGBS.

Chemical Constituent	CaO	Al_2O_3	SiO_2	MgO	Fe_2O_3	LOI	NaO	SO_3
GGBS	41.97	10.66	35.44	8.13	0.37	3.13	-	0.33
Cement	62.9	4.89	19.87	2.53	2.34	2.57	0.77	3.8

Ground granulated blast furnace slag (GGBS): Molten iron slag from blast furnaces is quenched in steam or water to produce GGBS, which is a by-product of the iron and steel industry. After drying, this glassy, granular substance is ground into a fine powder. When GGBS is added to concrete, it becomes stronger, more durable, and easier for the work. The blast furnace slag is composed of SiO_2, CaO, Al_2O_3, and MgO. The GGBS used in this study has been given by the Astra Chemicals facility in Chennai.

Water: Concrete is mixed with water, and water is also used to cure the concrete. Concrete should only be made using clean, contaminant-free water that is devoid of harmful substances like oil, alkali, acid, and other pollutants. The combination has been made using tap water from our campus.

Superplasticizer: Superplasticizers are the additives that are used to prepare the higher strength concrete. This is also called as water reducers of high range. These are the chemical ingredients that allow concrete to be made with 30% less water. The superplasticizer (AURAMIX 200) employed in this investigation is based on polycarboxylate ether. Depending on the weight of the cement, it is mixed with water at a rate between 0.7% and 0.8%.

Mix Proportioning: The mix proportioning technique is based on the absolute volume idea and adheres to specifications stated in ACI 522R-10 and IS 10262:2019. The required void volume is then evaluated. By deducting the volume of paste and the volume of voids from the unit volume of concrete, the total volume of aggregate is determined. The ratios of fine and coarse aggregate volumes are then selected. Based on field data found in the literature, an experimental setup has been established with water ranging from 132 Kg/m^3 to 141 Kg/m^3 and cement levels of 439 kg/m^3 as a practical range taken into account for ordinary concrete. The study has been done with two water-cement ratios of 0.30 and 0.32. The void of 15% has been selected and is considered for all the types of mix. To satisfy the dual essential criteria of acceptable strength and permeability, the fine aggregate composition of 5 Percentage has been employed.

Table 5: Mix proportions with water cement ratio 0.3 and super plasticizer 0.8%

Mix Designation	Cement	GGBS	Water	Fine Aggregate	Coarse Aggregate	Super Plasticizer
M1	439	0	98.775	0	1756	3.512
M2	329.25	109.75	98.775	0	1756	3.512
M3	307.3	131.7	98.775	0	1756	3.512
M4	285.35	153.65	98.775	0	1756	3.512
M5	263.4	175.6	98.775	0	1756	3.512
M6	439	0	98.775	87.8	1756	3.512
M7	329.25	109.75	98.775	87.8	1756	3.512
M8	307.3	131.7	98.775	87.8	1756	3.512
M9	285.35	153.65	98.775	87.8	1756	3.512
M10	263.4	175.6	98.775	87.8	1756	3.512

Table 6: Mix proportions with water cement ratio 0.32 and super plasticizer 0.7%

Mix Designation	Cement	GGBS	Water	Fine Aggregate	Coarse Aggregate	Super Plasticizer
M1	439	0	105.36	0	1756	3.073
M2	329.25	109.75	105.36	0	1756	3.073
M3	307.3	131.7	105.36	0	1756	3.073
M4	285.35	153.65	105.36	0	1756	3.073
M5	263.4	175.6	105.36	0	1756	3.073
M6	439	0	105.36	87.8	1756	3.073
M7	329.25	109.75	105.36	87.8	1756	3.073
M8	307.3	131.7	105.36	87.8	1756	3.073
M9	285.35	153.65	105.36	87.8	1756	3.073
M10	263.4	175.6	105.36	87.8	1756	3.073

All Proportions are in Kg/m^3

Sample Preparation

The samples have been prepared with a pan mixer. The dry mix constitutes namely cement, GGBS, fine aggregate, and coarse aggregate have been mixed for an additional two minutes, alongwith the addition of water and super plasticizer. The entire mixing process has been done at four (4) minutes for each attempt until the formation of homogeneous mixture. The mixes have been compacted by a regular tamping rod, and it has been ensured that the moulds have been filled in layers with proper number of blows. Each of the mixes has been prepared in the same manner. For curing, the samples have been submerged under water for 7 and 28 days.

Tests on concrete

Compressive Strength

Concrete has an important property like compressive strength. All of the other characteristics of concrete are inversely correlated with compressive strength. With the help of this test, it is possible to tell whether concrete pouring has been done correctly or not. Cubical mould of size 15 cm× 15 cm× 15 cm has been utilized. The cubes have been examined using a compression testing equipment after curing for the periods of 7 days and 28 days respectively.

Split tensile strength:

When designing structural lightweight concrete components, split tensile strength is applied to determine the development length of the reinforcement and analyze the concrete's shear resistance. Using this test method, a diametrical force is applied down the length of a concrete cylinder until failure occurs within the predetermined limit. The split tensile strength is computed by multiplying the maximum force that the specimen could withstand by the proper geometrical variables. The height and diameter of the cylindrical mould is 200 mm and 100 mm respectively.

Flexural strength:

The resistance of a concrete beam to breaking when bent is known as flexural strength. For testing, 50 cm-long concrete beams are loaded to assess their strength. This test is carried out using an experiment with four loading points. Forces are applied to the four different places during the four-point loading test. The beam is supported at two points below, 5 cm from the ends. The usual measurements are 15 x 15 x 70 cm. Instead, specimens 10 x 10 x 50 cm may be used, providing the aggregate nominal size does not exceed 19 mm.

Permeability:

In this work, the permeability property of porous concrete specimen has been assessed using the falling head permeability test apparatus. Permeability test set up is consistency of a graduated cylindrical tube to measure the hydraulic heads, valves to control water flow. The setup has a steel mould to retain the specimen, and an above tan k for continuous water delivery. The duct tape has been used to steal the concrete specimen in order to stop any lateral water movement. A commercially available water proof sealant substance has been used to cover the joint, where the specimen and the cylinder met. By alternately controlling the valves, the specimen has been given time to thoroughly soak with water prior to the test. This is done to make sure the specimen wouldn't contain any air voids.

$$k = \frac{2.3al}{At} \log\left(\frac{h_1}{h_2}\right)$$

Where, K = Permeability in cm/s, l = length of specimen in cm, a = sample's cross-sectional area in cm^2, A= surface area of stand pipe, h_1 = initial water head in mm, h_2 = ultimate water head in mm, t = time in sec.

Porosity:

The ASTM D 1754 water displacement technique has been used to assess the porosity by using the specimens of cylindrical shape with a diameter of 100 mm and height of 200 mm. By calculating the difference between the dry and submerged weights, the porosity has been estimated. After the proper curing of all the samples, their submerged height have been recorded. Then the samples have been kept for dry in the thermostatically controlled oven at 110° C for 24 hours. The formula listed below is used to calculate the porosity property.

$$\phi = \left[1 - \frac{(A-B)}{\rho_w \times D^2 \times L}\right] \times 100$$

Where, Ø = porosity of the mix; A = dry weight of the specimen; B = submerged weight of the specimen; ρw = density of water; D = average diameter of specimen; L = length of the specimen.

III. RESULTS AND DISCUSSIONS

Different tests like compressive strength, split tensile strength, flexural strength, porosity, and permeability have been conducted on porous concrete. All the tests demonstrate the effects of cement replacement with GGBS in varied percentages after the curing for the period of 7 and 28 days.

Tests were done on the samples after the 7 day's curing period considering the w/c ratios of 0.30 and 0.32 as shown in Table 7 & 8. From the results, it is observed that the mix (M10) containing 40% cement replacement by GGBS and 5% fine aggregate gave considerably higher strength in all three tests at water-cement ratio of 0.30.

Table 7: Results of permeable concrete with w/c ratio 0.30 after 7days curing period.

Designation of Mix	Strength (Compressive) (MPa)	Strength (Split Tensile) (MPa)	Strength (Flexural) (MPa)
M1	14.279	1.442	2.281
M2	11.289	1.398	2.275
M3	15.178	1.466	2.362
M4	17.252	1.429	2.438
M5	18.943	1.527	2.403
M6	17.740	1.396	2.471
M7	17.873	1.407	2.518
M8	19.686	1.462	2.661
M9	20.398	1.558	2.703
M10	20.483	1.711	2.794

Table 8: Results of permeable concrete with w/c ratio 0.32 after 7 days curing period.

Designation of Mix	Strength (Compressive) (MPa)	Strength (Split Tensile) (MPa)	Strength (Flexural) (MPa)
M1	13.478	1.223	2.127
M2	12.384	1.191	2.045
M3	15.600	1.424	2.442
M4	18.632	1.341	2.717
M5	13.498	1.318	1.312
M6	16.245	1.327	2.498
M7	16.158	1.336	2.512
M8	18.424	1.380	2.762
M9	19.421	1.506	2.787
M10	15.365	1.520	2.007

Table 9: Results of porous concrete samples with water-cement ratio 0.30 after 28 days curing period.

Designation of Mix	Strength (Compressive) (MPa)	Strength (Split Tensile) (MPa)	Strength (Flexural) (MPa)	Porosity (%)	Permeability (cm/s)
M1	20.605	1.825	2.521	24.89	2.24
M2	16.290	1.625	2.636	27.12	2.41
M3	21.902	1.842	2.629	24.51	2.19
M4	24.895	1.809	2.657	23.27	2.11
M5	27.335	1.898	3.075	20.75	1.86
M6	25.598	1.767	3.244	20.2	1.83
M7	25.790	1.781	3.358	19.37	1.75
M8	28.406	1.851	3.676	16.74	1.56
M9	29.435	1.876	3.841	13.21	1.33
M10	29.557	2.086	3.814	13.48	1.29

Table 10: Results of porous concrete samples with water-cement ratio 0.32 after 28 days curing period.

Designation of Mix	Strength (Compressive) (MPa)	Strength (Split Tensile) (MPa)	Strength (Flexural) (MPa)	Porosity (%)	Permeability(cm/s)
M1	18.851	1.487	2.351	26.53	2.38
M2	17.320	1.500	2.370	26.47	2.26
M3	21.819	1.720	2.595	24.22	2.14
M4	26.058	1.640	2.961	21.96	1.89
M5	18.879	2.019	1.679	19.89	1.76
M6	22.720	1.816	3.279	22.48	1.96
M7	22.598	1.780	3.350	23.71	2.02
M8	25.768	1.822	3.816	19.77	1.74
M9	27.162	2.020	3.960	17.62	1.61
M10	21.489	1.880	2.740	14.83	1.38

Samples were also tested after the curing period of 28 days considering the w/c ratios of 0.30 and 0.32 as shown Table 9 &10. From the results, it is observed that the mix (M10) containing 40% GGBS and 5% fine aggregate gave higher strength and considerable permeability.

Different properties of pervious concrete with respect to varying percentage of GGBS as partial replacement of cement have been presented graphically.

In the Fig. 1 & 2, it has been noticed that after 28 days the compressive strength is maximum at 5% fines and 40% cement replacement by GGBS with water cement ratio 0.30. And least compressive strength is obtained after 7 days curing with 0% fines and 25% cement replacement by GGBS at same water cement ratio.

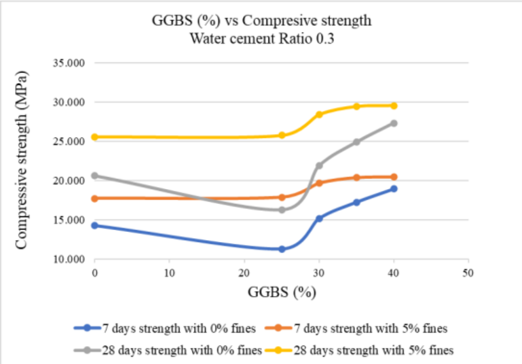

Fig. 1. GGBS(%) vs Compressive Strength.

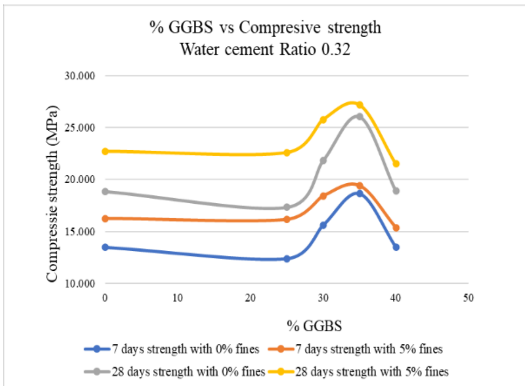

Fig. 2. GGBS(%) vs Compressive Strength.

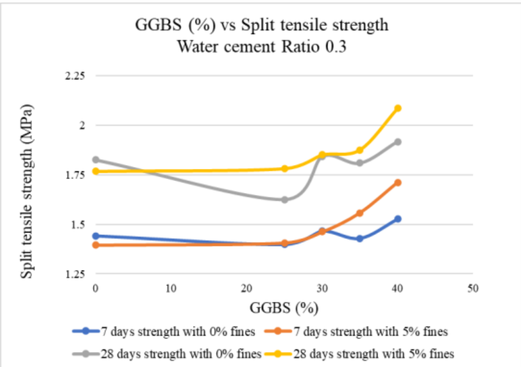

Fig. 3. GGBS (%)vs Split Tensile Strength.

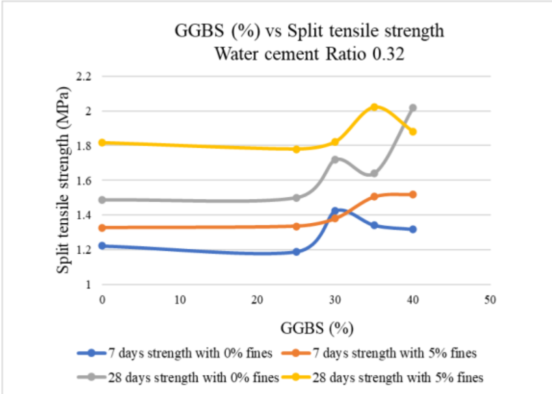

Fig. 4. GGBS (%) vs Split Tensile Strength.

From the Fig. 3 & 4, it has been observed that maximum split tensile strength is obtained after 28 days curing 5% fines and 40% cement replacement at water-cement ratio of 0.30.

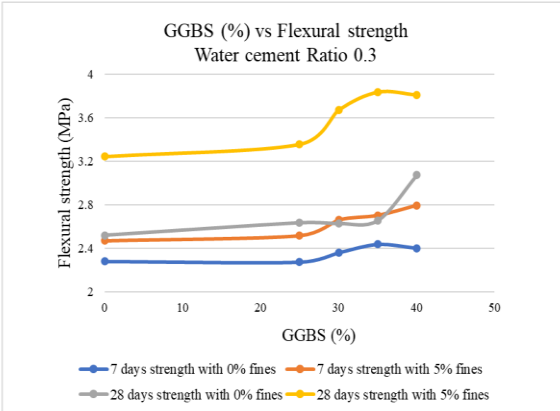

Fig. 5. GGBS (%) vs Flexural Strength.

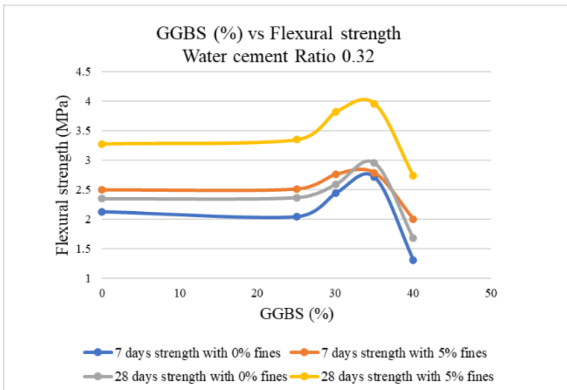

Fig. 6. GGBS(%) vs Flexural Strength.

From the Fig. 5 & 6, it has been noticed that after 28 days curing the flexural strength is maximum at 5% fines and 35% cement replacement. Although the maximum value has been attained for the water-cement ratio of 0.32, but substantial value has been attained for the same mix at water-cement ratio of 0.30.

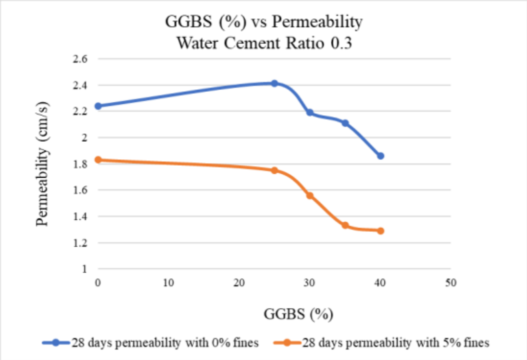

Fig. 7. GGBS(%) vs Permeability.

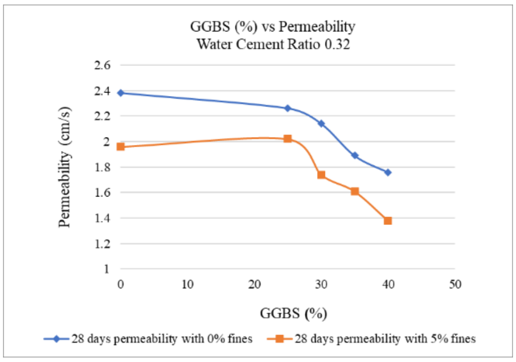

Fig. 8 GGBS(%) vs Permeability.

Permeability property of the mixes is checked after 28 days curing. From the figures 7 &8, it is observed that the mix with 0% fines shows maximum value with 25% cement replacement at water-cement ratio of 0.30.

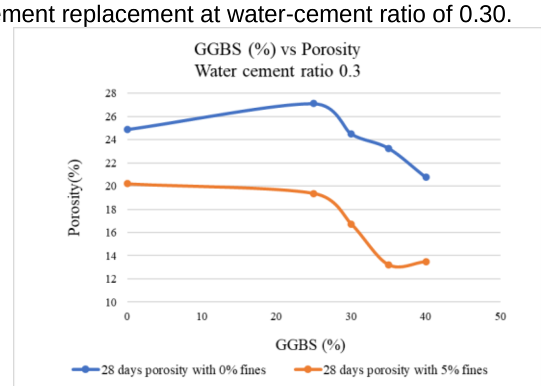

Fig. 9. GGBS (%)vs Porosity.

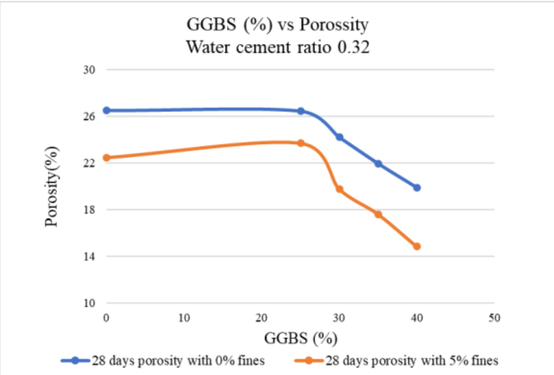

Fig. 10 GGBS (%) vs Porosity.

From Figs. 9, 10, it is observed that in terms of porosity, the mix with 0% fines and 25% cement replacement after 28days curing at water-cement ratio of 0.30 shows the maximum value and mix with 55 fines with 40% cement replacement at same water-cement ratio shows the least value.

IV. CONCLUSION

In this study, GGBS is added with the mixes at different percentages as cement replacement partially. Fine particles are also added to the mix. Mixes have been casted with two types of water-cement ratios viz 0.30 and 0.32. Various examinations, including flexural strength, compressive strength, permeability and split tensile strength, tests have been carried out on the mix samples. From the test results, it is observed that with strengths like compressive strength and split tensile strength, the maximum value is obtained when 40% cement of the mix is replaced by GGBS and 5% fine aggregates are added at w/c ratio of 0.30. It has been also noticed that the maximum value for flexural strength is found for the mix having 35% cement replacement and 5% fines at water-cement ratio of 0.32 after 28 days curing. In terms of permeability, mix having 0% fines with 25% cement replacement at water-cement ratio of 0.30 shows maximum value. So it may be concluded from the observations that the addition of GGBS in more percentage along with fine aggregates improves the mix in terms of different strength parameters, but permeability and porosity properties are decreased at the same time. So, based on the previous and current research, it may be stated that GGBS is one of the alternatives to use in pervious concrete mix as cementitious material, and it can improve the strength and hydrological property of the mix.

V. FUTURE SCOPE

Various opportunities related to this study can be summarized below:

- With the same amount of binder, GGBS concrete has a lower early age strength than CC. However, for concrete prepared with GGBS, the improvement in strength was greater after prolonging the curing time. This is due to the lengthy pozzolanic process, which produces calcium hydroxide slowly.
- By altering the aggregate sizes and creating the mix, the gradation may be changed. After analysis, several comparisons can be made depending on aggregate size.
- In addition to GGBS, some other modifying materials can be added to cement and it can be used to improve the strength characteristics of the mix. These materials can be used in various percentages and can be analyzed.
- A significant factor in the strength and permeability of concrete is the aggregate size. Therefore, different sizes of aggregate can be utilised in varied ratios in a single mix.
- The strength of the concrete is increased by altering the mix and thoroughly curing the concrete specimens because pozzolanic ingredients are present.

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