International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 1, January-2019

Mechanical and Hydrological Properties of Pervious concrete made with blended mineral admixtures

Rekha Singh[1], Sanjay Goel[2]

[1]Department of civil engineering, I.K.G Punjab Technical University, Jalandhar, India, rekhasingh14@gmail.com
[2]Department of civil engineering DAV Institute of Engineering and Technology, Jalandhar, India, goelsanjay100@yahoo.com

Abstract*— The purpose of this experimental research work was to examine porosity, permeability, compressive strength, split tensile and flexural strength of cement based blends of pervious concrete. Seven different mixtures of pervious concrete were prepared with two different aggregate fractions (passing 9.5mm retained on 6.3mm and passing 6.3mm retained on 4.75mm) in the ratio 60:40. The obtained cement blends (binary and ternary blends of mineral admixture) of pervious concrete exhibit sufficient permeability in the realm 7.7-13.3 mm/s for draining storm water with respect to typical application of pervious concrete for low volume roads. Ternary blends (PFS & PLS) demonstrated higher compressive, split tensile and flexural strength than binary (PF & PL) and control mixtures with acceptable porosity and permeability at all curing periods. The Ternary blended pervious concrete (PLM) could achieve 30% increased compressive strength and permeability of 7.7 mm/s at 90 days curing. The result thus obtained encourages the use of blended mineral admixtures in pervious concrete.

***Keywords*— Cement paste; cementitious material; Permeability; Porosity; Compressive strength; Split tensile strength; Flexure strength**

I. INTRODUCTION

Pervious concrete has been categorized as composite material comprising of coarse aggregates (single size or binary) with optimized volume of cement paste to coat the aggregates together. It has highly inter-granular pore structure which differentiates it from the traditional concrete. Being one of the alternatives for storm water management, pervious concrete has benefits in the environmental, road user, and construction domains [1]. Apart from the aforementioned benefits, sustainability is also important concern in the construction industry and there is significant demand on conservation of natural resources, recycling of construction and demolition waste, reducing waste generation and utilize the industrial waste.

From the past studies it is observed that the strength can be increased by adding small fraction of sand (5-7%), addition of silica fume (SF) [2], fibers [3], inclusion of pozzolonic materials [4] and polymer modification [5], but the main disadvantage is that it considerably reduces the porosity and permeability. These modifications increase the mechanical strength but momentously decrease the porosity and permeability of pervious concrete mixes.

In pervious concrete the weakest interface is in between cement paste and aggregate. The strength and durability properties are significantly influenced by these interfaces .The strength with acceptable porosity and permeability (as described in ACI 522R) could be achieved by exercising the paste-aggregate interfacial zone. The densification microstructure of cement paste by incorporating mineral admixtures (MA) increases the adhesion strength between paste and aggregate. The MA like fly ash (FA), silica fume (SF), metakaolin (MK) reacts with products of hydration mainly calcium hydroxide to form calcium silicate hydrates.

Balance between mechanical strength and ability to drain water mainly associated with porosity and permeability needs considerable attention in preparing pervious mixes. Porosity and permeability could be achieved by using single size or gradation of aggregates. The particle size, their surface characteristics and morphology of each type of cement admixture significantly affect the properties in hardened concrete, but for achieving decent strength and water drain ability, balancing of both is required. Fewer mineral admixtures like rice hush ash (RHA), ground granulated furnace slag (GGBS), SF and FA alone or in binary combinations with cement have been studied and utilized in the past for pervious concrete [6-8]. Therefore an extensive study to investigate the use of different binary and ternary blends of mineral admixtures in pervious concrete is evident.

In this investigation different combination of mineral admixtures are used in cement to prepare various mixes of pervious concrete. The present study deemed in determining the effective utilization of blended mineral admixtures and its effect on mechanical properties, porosity and permeability of pervious concrete. The research objectives of experimental investigation are as follows:

- Estimate the effect of blended mineral admixture on permeability and porosity of pervious concrete at 28, 56 and 90 days curing.
- Evaluation of effects of blended mineral admixture on mechanical strength properties of pervious concrete at 7, 28, 56 and 90 days curing.

II. RESEARCH SIGNIFICANCE

Globally, the increasing use of concrete which is non porous is preventing ground water recharging, weakening the tree roots, allowing chemical effluents and industrial wastes to mix in water streams and generating several other ecological problems while increasing use of cement is putting pressure on world resources and finding replacement of raw materials especially industrial wastes with required properties is an important aspect to be investigated. The cement manufacturing process is also very energy intensive and consume high energy and release high quantity of pollutants. Hence it is of utmost importance to find solutions to these sustainability issues and pervious concrete using supplementary cementitious material seems to address some of these. It is noteworthy that previous studies on pervious concrete aimed producing binary blends by using single mineral admixture (mainly fly ash, Rice husk ash and silica fume). The current study proposes study of pervious concrete using binary and ternary blends of cement using supplementary cementitious admixture (fly ash, silica fume, and metakaolin and limestone powder) possessing required physical, mechanical and hydrological properties. The study of said objectives would help in understanding and underlining the effect of substitution of cement by mineral admixture and positive results would help in increasing the confidence of construction industry and mind share for subsequent wider application of pervious concrete in low usage applications all around the world.

III. EXPERIMENTAL PROGRAM

A. Materials and mixture Proportioning

This study includes seven different mixtures using OPC grade 43 and binary combination of two different aggregates sizes (passing 9.5 mm retained in 6.3 mm and passing 6.3 mm retained on 4.75 mm) in the ratio 60:40. Aggregate used were supplied by local suppliers and aggregate properties have been given in Table I. Cement blends were proportioned in accordance with the method described in ACI-522R using four different mineral admixtures (MA) which comprise of fly ash, limestone powder, silica fume and metakaolin. The physical and chemical properties of MA have been provided in Table II. Along with control mix two binary cement blends using FA and LP and four ternary blends consisting FA, LP, MK and SF were produced for present research. Each binary blend consists of 70% of cement and 30% of FA and 30% of LP respectively and is designated as PL and PF. Water to Cementitious ratio and aggregate to cement ratio were taken as 0.34 and 4.0. Additionally 5% of sand by weight of total aggregate and to improve workability 0.1 % of superplasticizer (BASF Masterglenium sky 8233) by weight of cementitious material is used in the pervious concrete mixtures. The summary of mixture proportioning has been provided in Table III.

TABLE I
LABORATORY DETERMINED PROPERTIES OF AGGREGATE USED IN THE PERVIOUS MIXES

Size of aggregates	Percentage used in the mixes	Water absorption	Specific gravity	Standard
6.3mm	60	1.56	2.65	IS:2386
4.75mm	40	1.59	2.68	IS:2386

TABLE II
CHEMICAL AND PHYSICAL PROPERTIES OF MINERAL ADMIXTURES LP, MK, SF AND FA USED IN PERVIOUS MIXES

Composition	Silica (SiO_2)	Aluminium oxide (Al_2O_3)	Ferrous oxide (Fe_2O_3)	Calcium carbonate ($CaCO_3$)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Loss of ignition	Specific gravity
Fly ash (FA)	56.7%	17.7%	11.0%	-	3.1%	5.4%	1.2%	2.37
Limestone Powder (LP)	<1%	<1%	<1%	85-97%	48-54%	-	42.50%	2.18
Silica fume (SF)	85-97%	-	-	-	< 1%	-	4%	2.2
Metakaolin (MK)	52.1%	41.0%	4.32%	-	0.39%	-	<1%	2.6

TABLE III
SUMMARY OF MIX COMBINATIONS OF PERVIOUS CONCRETE MIXES

Mix	Total CM Kg/m^3	Aggregates Kg/m^3	w/c	Percentage of Sand	Percentage of Cement(itious) Material					a/cm ratio
					OPC	FA	LP	SF	MK	
PC	380	1541	0.34	5	100					4.0
PF	266	1541	0.34	5	70	30				4.0
PFS	266	1541	0.34	5	70	20		10		4.0
PFM	266	1541	0.34	5	70	20			10	4.0
PL	266	1541	0.34	5	70		30			4.0
PLS	266	1541	0.34	5	70		20	10		4.0
PLM	266	1541	0.34	5	70		20		10	4.0

B. Fabrication and curing of specimens

The pervious concrete standard cubes (150×150×150mm) were produced to determine mechanical properties and standard cylinder (100mm diameter x 200mm) to determine unit weight, porosity and permeability.

In rotating drum mixer all the ingredients cement, aggregates, sand and mineral admixture were dry mixed to get uniform mixtures and then water was added with SP to get uniform blend. Prepared fresh mix of pervious concrete was added in the desired mold and vibrated for 2-4 sec and then compacted using standard proctor hammer. Immediately after casting the samples, the molds were covered with plastic sheets and left untouched in the laboratory for 24 hours. After 24 hours, all the samples were de-molded and placed in water tank for curing for 7, 28, 56 and 90 days. The casted samples are shown in Figure 1.

Figure. 1 Photographic view of casting of specimens of pervious concrete mixes in laboratory

C. Testing of hardened properties

Unit weight

The unit weight was calculated as per ASTM C1754 [9] specifications. Standard cylinder molds of 100 mm diameter x 200 mm were taken as specimen for unit weight and permeability tests. All the specimens were kept in laboratory for a day to ensure that specimen were in surface dry condition. The unit weight was derived as the mass divided by bulk volume of cylindrical specimen.

Porosity

Specimen Standard cylinder of 100 mm diameter and 200 mm height was taken for porosity measurement. The porosity of all pervious concrete samples was determined by the method described in previous literature [10]. The pores available in concrete which are not connected to the surface and do not contain water are closed or isolated pores in the pervious concrete. Effective (open) pores are connected to the surface and to the other pores and provide regular path for water to flow through them like an indiscernible tube. The equations (1) and (2) were used to calculate open and closed porosity of the concrete sample.

$$P_{open} = 1 - \left(\frac{W_2 - W_1}{\rho w V_1}\right) x\ 100\% \quad \ldots\ldots\ldots\ldots (1)$$

$$P_{closed} = 1 - \left(\frac{W3 - W1}{\rho w V1}\right) x\ 100 - P_{open} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. (2)$$

Where P_{open} is the open porosity (%), P_{close} is the closed porosity (%), respectively. W_1 - Weight of the specimen under water, W_2 - Weight of the specimen following 24 hours air exposure, W_3- Weight of the oven dried specimen, V_1- Volume of the specimen, ρ_w- Density of water.

Permeability

To ascertain the permeability of pervious concrete, self-synthesized falling head permeameter shown in Figure 2 was used as per the method given by Deo et al.[11]. The standard test specimens were cylinders of (100 mm dia. × 200 mm) specifications. The outer surface of the specimen was sealed with help of polythene to stop flow of water along the sides of cylinder surface. The time water took to flow through the sample was noted down at falling head. The average of 3 readings was taken. The specimen was inserted in the apparatus as shown in Figure 4. A calibrated cylinder (0 mm to 300 mm) was placed above specimen for measuring the height. The water was filled in setup but the valve was kept open. Once the water come out of other side, the valve was closed and water was filled to a height of 300mm (h1). To take the reading, the valve was opened and time taken by water to flow from 300 mm height to 0 mm height (h2) was noted with the help of stop watch. The average value of these readings was considered as't', which was utilized to calculate coefficient of permeability. The permeability coefficient was calculated using Darcy's law as given below:

$$k = \frac{A1L}{A2\ t} ln \frac{h1}{h2} \quad \text{……….. (3)}$$

Where, k (mm/sec) - Coefficient of permeability, A2 (mm^2) - Area of cross section of specimen, A1 (mm^2) - Area of cross section of stand pipe, h1- Initial water level, h2 - Final water level, t - Time in sec for water to reach from h1 to h2.

Figure. 2 Photographic view of falling head permeability apparatus used for determining permeability of samples

Compressive and split tensile strength

IS:516-1959 [11] specifications were used for compressive strength testing and IS:5816 [12] for split tensile strength test at 28 and 56 days of curing. Standard cubes of 150×150×150 mm specifications were used as specimen in compressive strength testing machine (as shown in Figure 3) to measure the maximum load for breaking of specimen.

Figure. 3 Photographic view of compressive testing of pervious concrete cubes in the laboratory

Flexural Strength

Standard beam of 100×100×500 mm dimension was used as standard specimen as per IS:516-1959 [12] at 28 and 56 days of water curing stages. Flexure strength of all mixtures was determined by 4- point flexure test

(Figure 4). The specimen was dried and placed on the loading points. Smooth surface other than hand finished surface was placed in contact with loading points. These two loadings were lowered from above at a constant rate until sample failure. Average of three specimens was taken as representative value of flexure strength of each mix. The sample after flexure test is shown in Figure 7.The flexure strength was calculated by equation (4):

$$R = \frac{3\,P\,a}{b\,d^2} \quad \ldots\ldots\ldots\ldots (4)$$

Where, R-flexure strength MPa, P (N)- load at failure, a (mm) distance between supporting and loading point-b (mm) width, d(mm)-depth of specimen**.**

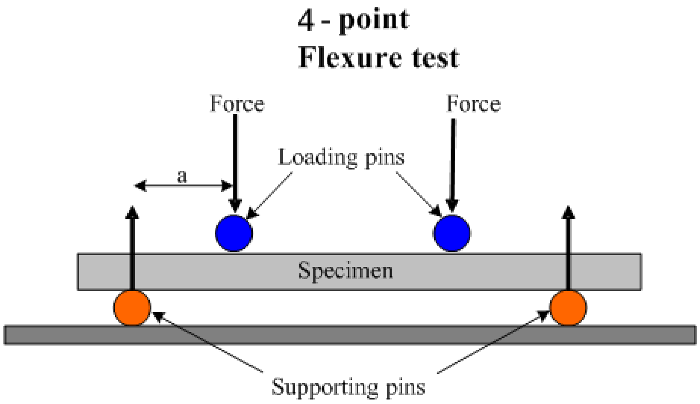

Figure. 4 Schematic illustration of flexure strength testing used in the present work

Figure. 5 Failure path of beam specimen after flexure testing

IV. RESULTS AND ANALYSIS

A. Influence of cement blends on physical properties

The results for average unit weight (UW) are given in Table IV. The unit weights are in the range 1825-1886 kg/m^3. Figure 6 shows the results obtained for effective and closed porosity of all pervious mixtures. The effective porosity lies in the range 18.5±2 kg/m3 of all pervious mixes. It is observed that the closed (isolated) porosity is 40-60 % of the effective porosity. Both types of porosities are important to determine as they help in determining the water assessable and non-assessable pores in concrete. Relationship between effective porosity and UW shows that they are in direct relationship with each other (Figure 7. Regression coefficient r^2 =0.761 shows that the trend is well negatively correlated. Similar trend are obtained in the previous findings by Joshaghani et al. [10]. This can be due to the same type of compaction method used for all mixes and the differences are not so significant.

TABLE IV
SUMMARY OF RESULTS OBTAINED FOR THE MIX COMBINATIONS UNDER INVESTIGATION

Mix	Compressive Strength, MPa				Split tensile strength, MPa		Flexure strength, MPa		Unit weight kg/cum	Closed porosity %	Effective porosity %	Total Porosity %
	7d	28d	56d	90d	28d	56d	28d	56d				
PC	13.56	17.60	18.30	19.95	2.65	3.04	2.14	2.37	1855	8.8	19	28
PF	12.47	15.59	16.83	17.84	2.58	2.97	2.03	2.22	1852	9.9	19.5	29

PFS	14.67	18.39	20.22	21.23	2.82	3.16	2.19	2.40	1855	11.7	18.5	30
PFM	15.17	18.80	20.49	21.52	2.88	3.25	2.21	2.42	1857	9.5	17.5	27
PL	13.07	14.53	15.41	16.02	2.57	2.74	1.97	2.05	1825	9.9	20	30
PLS	15.21	19.57	21.63	22.49	2.91	3.30	2.25	2.49	1870	9.7	17.4	27
PLM	16.50	21.56	23.93	25.84	2.98	3.50	2.35	2.63	1886	9.7	17	27

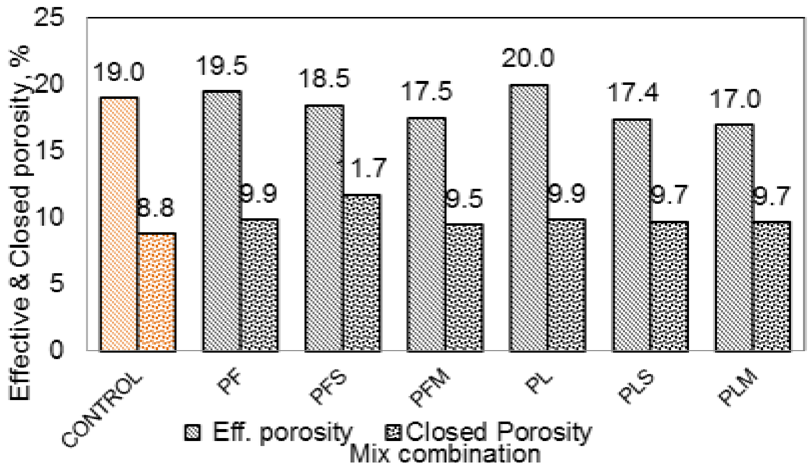

Figure 6 Effective and closed porosities of all pervious concrete mixes

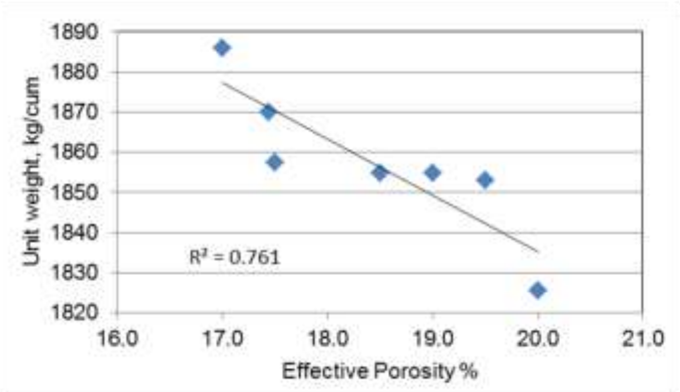

Figure 7 Relationship between unit weight and effective porosity

B. Influence of mix combination on permeability

The Figure 8 exhibits the results for permeability coefficient obtained for all pervious mixes at all curing periods. Three curing period were selected to determine the long term effect of curing on permeability. The permeability coefficient (k) obtained are in the range 7.7-12.2 mm/sec at 90 day curing which is in sync with specification of ACI -522 R. Effective porosity helps in achieving the permeability but isolated porosity do not contribute in permeability. Figure 9 shows relationship between effective porosity and permeability. The values of k were also observed to be directly related with effective porosities. The permeability decreased by 2-6% from 28 to 56 days and 1-4% from 56 to 90 days of curing. With increasing curing period the permeability coefficient is seen decreasing this may be due to the reduced size of water assessable pores. This is believed that the smaller size of pores created by smaller aggregate get narrower with time which slightly reduce the permeability. . Although, fall is insignificant with curing age or permeability coefficient (k) is unaffected with curing. The results of permeability are in range fulfilling the requirements of pervious concrete.

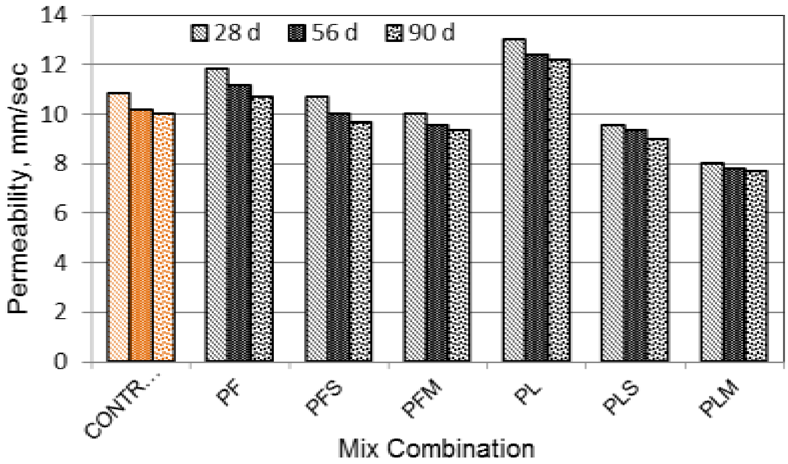

Figure 8 Variation of permeability with curing time of all pervious mixes

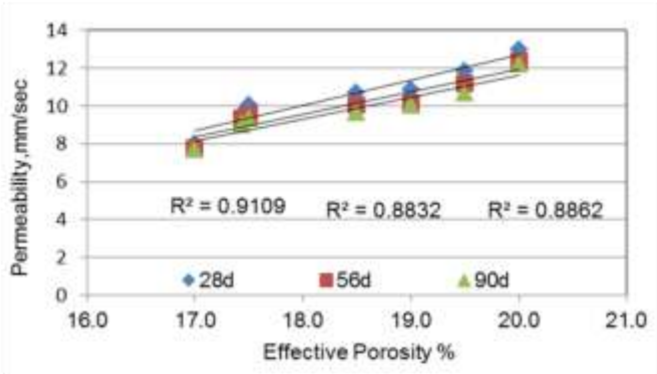

Figure 9 Relationship between permeability and effective porosity

C. Influence of mix combination on compressive strength

Figure 10 shows the results obtained for compressive strength (CS) of pervious concrete 7, 28, 56 and 90 days of curing. The Table IV provides results for mechanical strength test obtained in the laboratory. The results are in the range 12.47-16.50 MPa, 14.53-21.56 MPa, 15.41-23.93 and 16.02-25.84 MPa at 7, 28, 56 and 90 d respectively. The maximum CS was attained by the ternary blend PC containing LP and MK and lowest for binary blended PC containing LP. Higher strength development in ternary blended pervious concrete (PLM) could be due to the higher pozzolonic activity due to addition of small percentage (10%) of MK and LP acting as filler material which enhances the microstructure of cement paste. Higher rate of strength development was seen at 28d rather than at 56d or 90d. Due to the addition of MA, maximum hydration takes place at 28d and decreases with time. The partial substitution of MA as cement replacement helps to achieve higher strength compared to control mix in case of ternary blends. The smaller size of mineral admixture increases the fluidity of concrete mixture. Combining two mineral admixtures with cement helped in achieving higher strength.

The inclining trend of compressive strength was obtained at all curing age. Compressive strength directly related to the total pores available in the concrete rather than connected and isolated pores. Mixes with comparatively higher porosity possess lower compressive strength (Figure 11). The results obtained are in sync with previous literature [13].

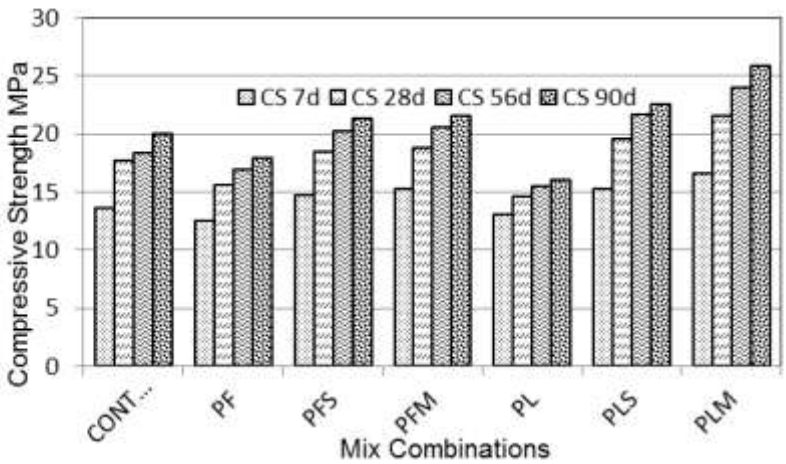

Figure 10 Compressive strength developments of pervious mixes at 7, 28, 56 and 90 days of curing

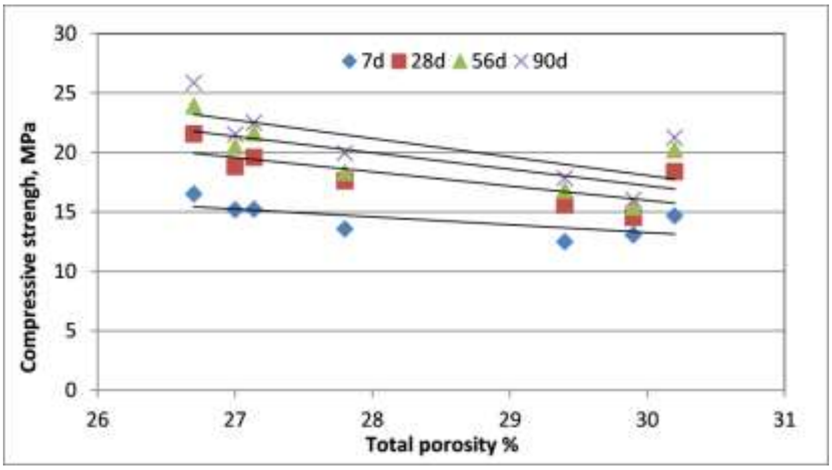

Figure 11 Variation of compressive strength as function of Total porosity

D. Influence of mix combination on split Tensile strength

The bar graph Figure 12 shows the results obtained for split tensile strength (STS) at 28d and 56d of curing. The results are in the range (2.57-2.98) MPa and (2.74-3.5) MPa respectively at 28d and 56d of curing. The maximum STS were obtained for ternary blends mix designated as PLM and lowest for binary blend designated as PL at both the curing days. The rising trend was observed for STS with curing age which is similar to compressive strength trend. This could be due to the higher pozzolonic activity and smaller particle size of limestone and metakaolin as compared to cement which increase the packing density (by reducing interstitial voids) of paste which helps in achieving higher strength at both curing ages. The variation in effective porosity is in the range 18.5±2.0% as aggregate gradation is same in all investigating mixtures. STS were higher for the mixes having comparatively lower porosity at both curing periods and is well correlated with total porosity (Figure13). The similar results were achieved using Portland cement alone in pervious concrete [14].

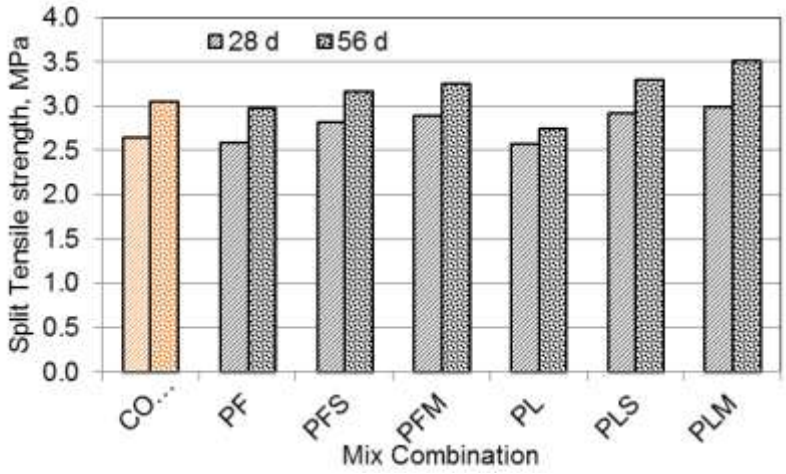

Figure 12 Split tensile strength development at 28 and 56 days of curing

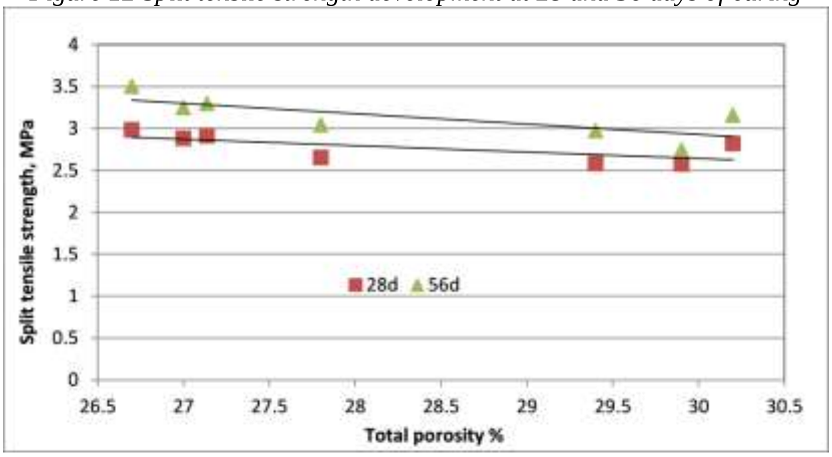

Figure 13 Variation of split tensile strength as function of total porosity

E. Influence of mix combination on flexure strength

As shown in Figure 14 the flexure strength (FS) are in range 1.97-2.35 MPa for 28 days and 2.05-2.63 MPa for 56 days of curing for all pervious concrete mixtures. It is observed that the binary mix containing limestone powder had lowest flexure strength and ternary mix containing limestone and metakaolin (PLM) had highest strength. The increase in flexure strength from 28 to 56 days is in range of 4%- 12%, the binary having the lowest growth at 4% while maximum being for ternary mixes. Compared to control mix, the flexure strength growth in ternary mixes is approximately 2-10% at 28 days and 1-11% at 56 days curing period. The ternary mixes containing FA (PFS and PFM) have lead almost similar flexure strength while mix containing LP and MK (PLM) gives highest flexure strength. The effect of MK was seen to be substantial in enhancing mechanical strength for all curing periods. The combined filler effects of LP and MK contributes in filling voids of cement paste and as a result highest compressive and flexure strength of PLM mixes among all the cement blends. The variation of flexure strength was well correlated with total porosity for all mixtures (Figure 15). The results obtained corroborate well with previous research findings [15].

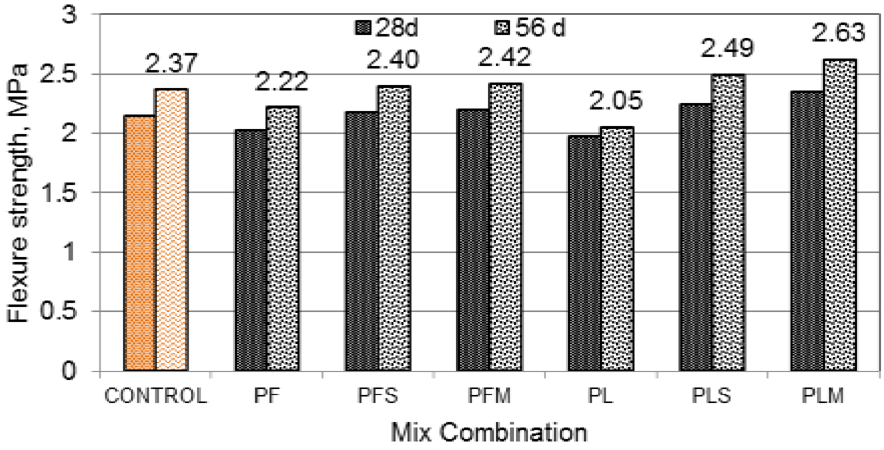

Figure 14 Flexure strength developments at 28 and 56 days of curing

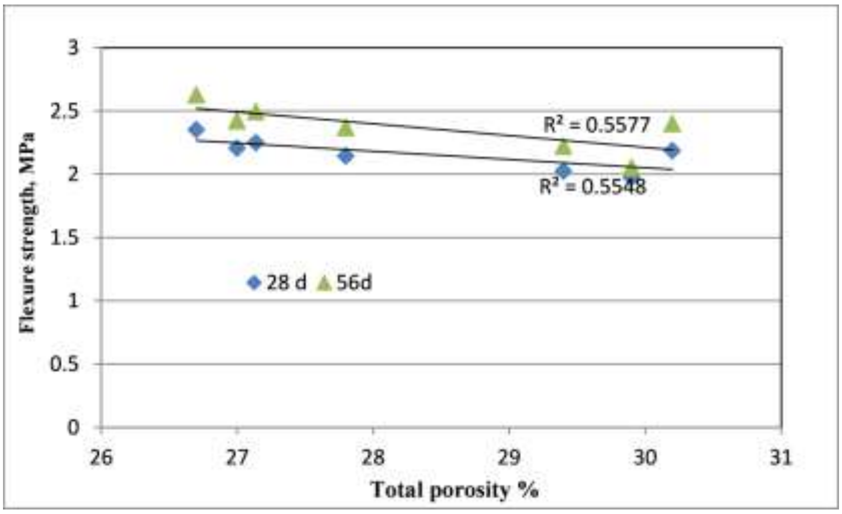

Figure 15 Variation of flexure strength as function of Total porosity

V. CONCLUSION

Aim of the present experimental program was to ascertain the effect of cement blended pervious concrete on the hydrological and mechanical properties of pervious concrete with curing time. Pre-established testing methods were employed in order to define the different properties of cement blended pervious concrete. Based on the experimental investigation the main findings are as listed below:

- The unit weight and effective porosity are in the range 1825-1886 kg/m^3 and 18.5±2.0% respectively. They are seen directly related to each other. Closed porosity is (40-60) % of effective porosity for all mixtures.
- Permeability of all the mixtures lies in between 7.7-13 mm/sec at all curing days and decrease insignificantly with time.
- The compressive strength increases with curing age and decreases with increase in porosity. Higher strength was achieved for ternary blended pervious concrete than binary blended pervious concrete. The compressive strength in binary blends was lower compared to control mix at all curing days.
- The split tensile strength lies in the range 2.57-3.5 MPa being highest for PLM and lowest for binary blend PL. Ternary blends (PFS & PLS) have higher STS than binary (PF & PL) and control mixtures at 28 and 56 days of curing. Similar trend as of compressive strength is attained for STS with curing time.
- The flexure strength obtained are in range 1.97-2.35 MPa for 28 days and 2.05-2.63 MPa for 56 days of curing. The mechanical properties (CS, STS and FS) increase with curing age.
- Ternary blend of limestone namely PLM is the best performer among all the mixes and significant properties improvement was seen compared to control mix at all curing period. Strength development was observed to increases with curing time considerably.

The binary and ternary blends have shown similar properties as conventional pervious concrete. The use of mineral admixture as partial replacement is an effective way in saving the materials with adequate strength and sufficient hydrological properties. This study is limited to use of mineral admixture with constant mixture proportioning so it can be further extended to use of variety of mineral admixtures with different replacement levels. Further ternary mixture with different replacement ratio and quaternary blends can also be attempted by making it cost effective.

Acknowledgement and funding sources:
The authors gratefully acknowledge the support of Prof. S.P.Singh and other staff members of Concrete Structures Laboratories at Dr B. R Ambedkar National Institute of Technology, Jalandhar, India during the experimentation work reported in the present investigation. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors**.**

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