EVALUATION OF STRENGTH OF PERVIOUS CONCRETE MADE OF BLENDED CEMENTS

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ABSTRACT. The conservation of cement is one of most consequential stride in diminishing both energy exploitation and greenhouse gas emission. The usage of cement in structural applications can be reduced by using the product cementitious or pozzolonic material as a cement substitute. This drives the demands for cement production to drop nearly by 30%. This decline is reflected in overall lesser requirement of raw materials, savings in energy requirement for different process and probable gain in terms of lesser environment pollution and higher ecological sustainability. This research work attempts in saving material by making different blends of pervious concrete. Mineral admixture like fly ash (FA), limestone powder (LP), silica fume (SF) and metakaolin (MK) are added in mix replacing cement in 30% by volume of total cementitious material and keeping other parameters (a/c, w/c) constant. The binary combination of natural aggregates of size 6.3 mm to 4.75 mm are used to produce all the pervious concrete mixtures. The properties like compressive strength and ultra-sonic pulse velocity (UPV) measurements were determined after 7, 28, 56 and 90 days curing of pervious concrete specimens. The results of experimental investigation of cement based (binary and ternary) blends were encouraging in terms of strength of pervious concrete mixes making it suitable for sustainable pavement material.

Keywords Pervious concrete, mineral admixture, porosity, ultra-sonic pulse velocity, compressive strength

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INTRODUCTION

Pervious concrete seems to be one of the most viable ecologically sustained and viable solutions. A pervious concrete can

- Minimize the volume of adulterated runoff release into storm drains.
- Straight recharging of groundwater to retain aquifer levels.
- Spillway extra water to tree roots and terrain and reduce the need for irrigation.
- Attenuate filth and adulteration which infects watersheds and damage susceptible ecosystems.
- Eliminate hydrocarbon pollution from asphalt pavements and sealers.

In addition to storm water control, pervious concrete pavements assist in minimizing the urban heat island effects because they have an open cell structure. Pervious concrete pavements do not soak and hoard heat and then radiate it back into environment similar to asphalt surface. The unlocked void structure of the pervious concrete also let cold soil from below to cool down the pavement. Besides helping the environment, pervious concrete pavements are also safer for drivers and pedestrians because they soak water rather than allowing it to splash, it reduces aquaplaning without losing traction[1].

In literature the addition of cement additives to concrete as part replacement of cement are also termed as secondary raw materials, supplementary cementitious materials. These additives are available in enormous volume at lesser cost then cement thus making overall manufacturing high cost effective and suitable to reduce environmental effect of greenhouse gases and kiln dust and other pollutants.

Both structural strength and porosity are essential for mix design of pervious concrete and are generally made with locally available materials. Nguyen et al. [2] proposed the mix design on the presumptions that the cement paste only provides sufficient coating around the aggregates and does not fulfill the voids and gives the strength of 28 MPa. Paste volume is considered as essential parameter in guiding the compressive strength, the increase in paste volume resulted in improving the mechanical properties irrespective of aggregate size and for a given paste volume the usage of lower maximum size aggregate resulted in higher strength values [3-4]. In accordance with ACI 522R the mechanical strength of pervious concrete to be utilized in pavements should be generally in the range of 2.8-28 MPa. Furthermore the addition of sand up to 5% is efficient in increasing the compressive strength [5-6]. Polymer modified mixes exhibited delayed curing but the mechanical strength improves considerably [7].

The reasonable prediction of compressive strength based on previous studies is present; there is certainly a need to evaluate the strength of pervious concrete pavements from in-place concrete from mix proportion viewpoint. In this direction nondestructive testing such as UPV and RHT are inexpensive, easy, direct and valuable techniques for the characterization of cement blended composites. NDT is very expedient and suitable for engineering structures like pavement as it can assess the material properties without damaging its practicality. Use of NDT allows the evaluation of aged and deterioted structures and suitable for the quality control of new structures [8-10]; However, structure can be well analyzed by combining the NDT and laboratory evaluation [11]. NDT of cementitiously stabilized materials (CSMs) was studied through UPV found that the P-wave velocity decreases with decrease in density, whereas P-wave velocity increases with increase in curing time and binder content [12].

The outline of the test program planned for the research work is presented in Fig.-1. Main objective of the were

- Development of cement blended pervious concrete,
- Testing of Physical and mechanical Properties of all the prepared mixes for the investigation and evaluation.

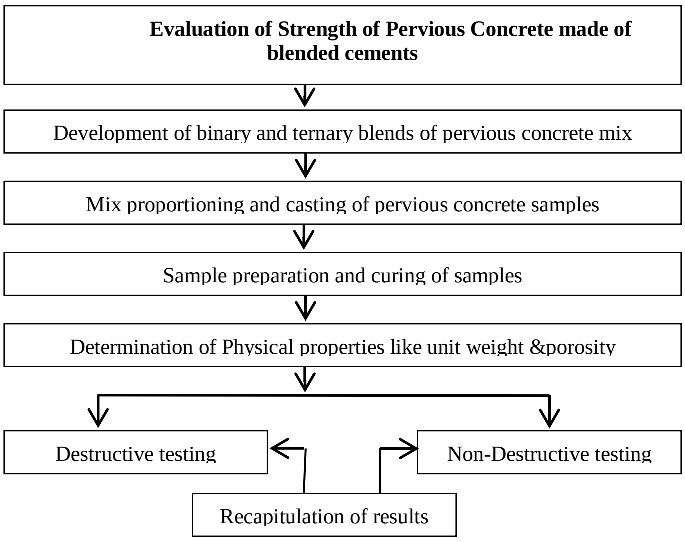

Figure 1 Outline of the research program

MATERIAL USED AND MIX PROPORTIONING

Ordinary Portland cement of 43 grade satisfying the requirements of IS: 8112-1989[13] was used in the study. Aggregates conforming to relevant Indian standard specifications are: 2386:1963 [14] and IS: 383-1970 [15] were used for preparation of concrete. The fine aggregate was natural sand, and crushed gravel was used as the coarse aggregate for all the concrete mixtures. Both fine and coarse aggregates were obtained from local sources. The Binary combination of coarse aggregate 6.3mm and 4.75mm were used to produce all the pervious concrete mixtures. The physical properties coarse aggregates are listed in Table-1. The pervious concrete mixture include the use of mineral admixture Class F fly ash, Silica fume , Metakaolin and Limestone Powder. The physical and chemical properties of FA, SF, MK and LP are presented in Table-2.

Table 1 Properties of aggregates of pervious concrete

PROPERTY	STANDARD	4.75MM	6.3MM
Unit weight	IS:2386	1.521	1.632
Water Absorption	IS:2386	1.59	1.56
Specific Gravity, OD	IS:2386	2.639	2.633
Specific Gravity, SSD	IS:2386	2.680	2.650
Apparent Specific Gravity	IS:2386	2.754	2.678

Table 2 Chemical and physical properties of mineral admixture LP, FA, SF and MK

COMPOSITION	LIMESTONE POWDER (LP)	FLY ASH (FA)	SILICA FUME (SF)	METAKAOLIN (MK)
SiO_2	<1%	56.5%	85-97%	52.1%
Al_2O_3	<1%	17.7%	-	41.0%
Fe_2O_3	<1%	11.0%	-	4.32%
$CaCO_3$	85-97%	-	-	-
CaO	48-54%	3.2%	< 1	0.39%
MgO	-	5.4%	-	-
Loss of ignition	42.50%	1.2%	4%	<1%
Physical properties				
Specific gravity	2.18	2.38	2.2	2.60

The present investigation on the cement blended pervious concrete mixes containing LP, FA, MK and SF as cement additives in different proportions, involved preparing seven mixes - control concrete (100% PC); binary blended mix combinations (70% PC + 30% LP) designated as ‘PL’ and (70% PC + 30% FA) designated as ‘PF’; ternary blended mix combinations (70% PC + 20% LP + 10% SF) designated as ‘PLS’; (70% PC + 20% LP + 10% MK) designated as ‘PLM’; (70% PC + 20% FA + 10% SF) designated as ‘PFS’ and (70% PC + 20% FA + 10% MK) designated as ‘PFM’ respectively. The mix combinations incorporating cement additives were prepared by replacing 30% of PC by weight with these additives in binary and ternary mode. Table-4 summarizes the concrete mix combinations used in this investigation.

Table 4 Summary of Mix composition of pervious concrete

	MIX	MIX COMBINATION	CEMENT	SAND, %	C(M)/A	W/CM	UNIT WEIGHT, KG/M^3	POROSITY, %
PC1	CONTROL	100%PC	380	10	0.250	0.34	1854.8	19.0
PC2	PF	70%PC+30%FA	266	10	0.250	0.34	1852.9	19.5
PC3	PL	70%PC+30%LP	266	10	0.250	0.34	1825.5	20.0
PC4	PFS	70%PC+20%FA+10%SF	266	10	0.250	0.34	1854.8	18.5
PC5	PFM	70%PC+20%FA+10%MK	266	10	0.250	0.34	1857.3	17.5
PC6	PLS	70%PC+20%LP+10%SF	266	10	0.250	0.34	1870.1	17.4
PC7	PLM	70%PC+20%LP+10%MK	266	10	0.250	0.34	1886.0	17.0

TESTING OF HARDENED CONCRETE

Physical Properties

Unit weight

The unit weights were measured on standard cylinder in surface dry condition. All specimen were kept inside the laboratory for 24 hours before the measurement. The weight was then calculated as the mass divided by the specimen bulk volume as described in ASTM C 1754.

Porosity

The weight of the standard cylinder was measured in submerged saturated condition after 24 hours. Then specimen is kept in oven until a constant weight is achieved.

The difference of the weight divided by the volume and density is calculated as per the formulae given below. Where P-porosity, W1-Oven dry weight of the specimen, W2-submerged weight of the specimen V1-volume of the sample, ρw-density of water,

$$P = 1 - \left(\frac{W1 - W2}{\rho w V1}\right) x\ 100\%$$

Destructive Mechanical Tests

Static compressive strength test

The test was conducted as per IS 516-1959 [16]specifications. Specimens surface water and grit was wiped off and projecting fins were removed. The dimensions were measured to the nearest 0.2mm and weight was noted. Standard cubes of 150×150×150mm specifications were used as specimen. The cubes are placed in the machine in such a way that the load is applied to opposite sides of the cubes as cast, that is not to the top and bottom. The axis of specimen is aligned with center of thrust of the spherically seated platen. No packing is used between test specimen and steel platen.

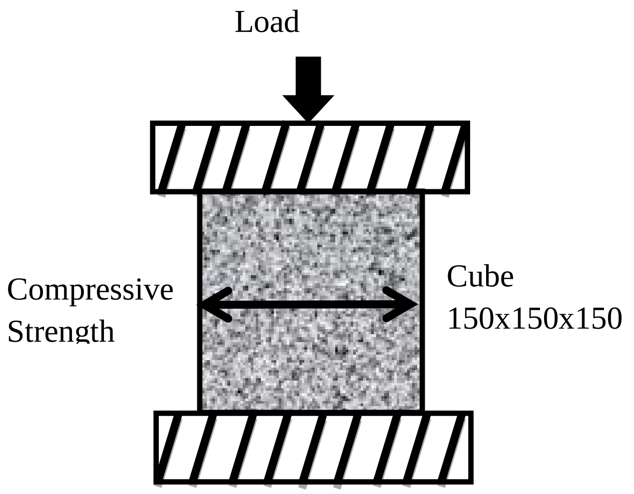

Fig. 2 Graphical representation of compressive strength

Non -Destructive Mechanical Tests

Ultrasonic pulse velocity (UPV)

The ultra-sonic pulse velocity test is conducted as per IS: 13311 (part 1)-1992[17] specifications. It's a non- destructive test for determining quality of strength of pervious concrete specimens. An ultrasonic pulse is passed through the pervious concrete specimen and time taken is measured. Concrete of higher density, uniformity and homogenous structure will yield higher velocity. The schematic representation of apparatus circuit has been illustrated in fig no 3

Figure 3 UPV Testing in laboratory

For each specimen the dynamic modulus of elasticity (Ed) is determined by the equation (1). Generally the value lies in the range 0.15-0.20 for conventional concrete. In this study the possions ratio is taken as 0.25 (21) as pervious concrete is weak and possions ratio of 0.25 is more suitable for porous concrete as determined by (chandrappa & biligiri) [18]. The dynamic modulus of elasticity (Ed) is calculated as following

$E_d = \frac{(1+\mu)(1-2\mu)}{(1-\mu)} \rho V^2$............... (1)

Where μ = poisson, ρ = unit weight (kg/m3) and V = ultrasonic pulse velocity (m/s).

RESULTS AND DISCUSSIONS

Compressive Strength

Table 4 shows the Results of compressive strength (CS) of binary and ternary mixes at all curing periods. The CS of binary mix containing LP is 7% higher than the mix containing FA at 7 days curing time. The probable reason could be LP having filler properties and thus increasing the early strength of the mix of pervious concrete. At 28 days, the effect of LP on strength development decreases and FA mix gives higher strength by 14%. The FA has fine particle size, smooth glassy texture and spherical shape and acts to plasticize concrete thus increasing the 28 days CS of mix PF [19].

The ternary blends of FA and SF (mix designated as PFS and PLS) have higher CS than binary blends (PL and PF) of FA and LP. The reason could be strong interfacial-transition zone due to strong bond formation by FA and SF. The ternary mix of LP and SF had the maximum CS among all the mixes at 28 days. SF reacts with CH (calcium hydroxide- a product of hydration of cement) and forms some additional C-S-H as secondary reaction product. This additional C-S-H densifies the microstructure of the cement paste. LP being filler, further densifies the microstructure and hence the mix shows the maximum strength among all the mixes .Fig.4 shows the relationship between Cs and Unit weight at all curing ages. Mixes having higher Unit weight shows increase in CS.

Table 4 Results of tests

MIXES	COMPRESSIVE STRENGTH, MPA				UPV, m/s			
	7d	28d	56d	90d	7d	28d	56d	90d
CONTROL	13.56	17.60	18.30	19.95	3592.5	3831	4006	4116
PF	12.47	15.59	16.83	17.84	3329.5	3636.5	3580	3710
PL	13.07	14.53	15.41	16.02	3489	3531	3692	3820
PFS	14.67	18.39	20.22	21.23	3807	3956	4122	4293
PFM	15.17	18.80	20.49	21.52	3837.5	3966.5	4138	4362
PLS	15.21	19.57	21.63	22.49	3916.5	3973.5	4161	4357
PLM	16.50	21.56	23.93	25.84	3996	4049	4219	4409

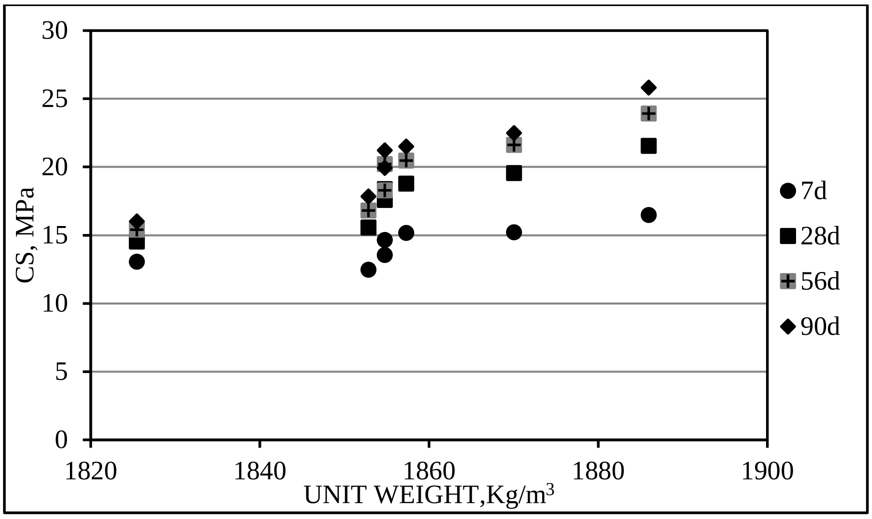

Figure 4 Relationship between Compressive strength and unit weight of all PC mixes

Ultra-sonic Pulse Velocity

The UPV values were utilized for evaluating the dynamic modulus of elasticity (E_{d}). Here poisson ratio (μ =0.25) was taken which is considered as more appropriate for pervious concrete [18]. The UPV and E_d values of pervious concrete mixes were found to be in the range of 3500-4500 m/s and 16-32 GPa respectively for all mixes under investigation. The E_d value depicts that the concrete quality is worthy in accordance with IS 13311 [17]. Figure 6 shows relationship between E_d and UPV for binary and ternary blend of cement. It is clearly evident that E_d increase as UPV increase as a linear relationship.

The UPV measurements are believed to be depending on mix parameters like properties of paste coating around the aggregate and properties aggregate. As the quality of cement paste increase, the mechanical properties like CS, Ultra sonic pulse velocity (UPV) also increase for all blends of pervious concrete.

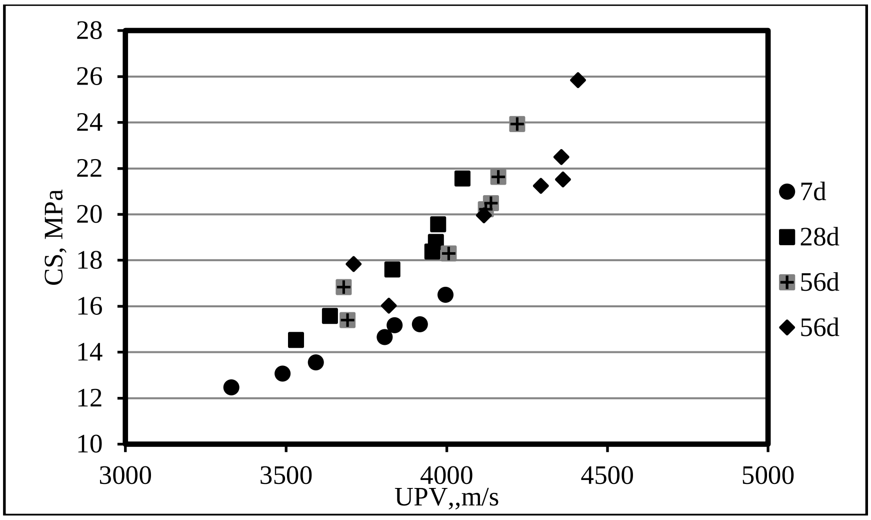

Figure 5 Relationship between Compressive strength and UPV of all PC mixes

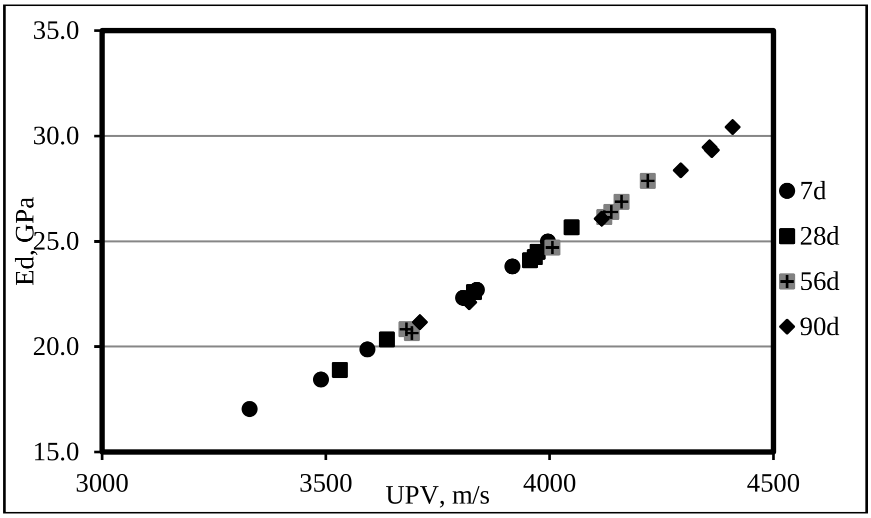

Figure 6 Relationship between Ed and UPV of all PC mixes

Figure 5 exhibits scatterplot of UPV versus CS. It can be stated that addition of a pozzolonic material into concrete affect both CS and UPV values along the same direction.

As stated earlier, the denser the mix; higher was the density and UPV measurement were also found to be higher. Figure 11 shows the relation of UPV versus density for all mix combinations. As observed, UPV values increases with increase in density. Although the variation in density are not significant as the constant volume of cementitious materials are used in all the blends of cement.

Binary blend of FA had higher value of UPV compared to PL since FA being a very fine glassy and spherical in shape had strengthen the paste and given higher UPV values. Ternary mixes have higher values are achieved compared to binary because of multiple effects of admixture presence. Among the ternary mixes; mix containing LP and SF had maximum UPV values. As we have already discussed above the combined effect of LP and SF on chemical composition and subsequent increase in CS, the same also hold true for higher UPV values of mix containing LP and SF at 28 days of curing. The results obtained are in sync with previous literature comparable to conventional concrete [20].

CONCLUSION

Present experimental investigation was to evaluate the mechanical propertied through destructive testing and non-destructive testing of the pervious concrete mixtures using binary and ternary mixes of FA, SF, MK and LP admixture as partial replacement (30% of cement in total) for 28,56,90 and 120 days water curing period. Nondestructive testing can be effectively utilized in assessing the strength of concrete. The compressive strength values are higher for ternary blends as compared to binary blends are in acceptable range. From the results, it is evident that trend of increase in CS is in direct relationship with unit weight, UPV and E_d.

Strength dynamic modulus of elasticity (Ed) which was derived from UPV technique is in the range 16-32 GPa for both binary and ternary blend of mixes for pervious concrete. It was highest for LP and SF based mix and the trend was found to be similar to CS measurement by destructive technique.

The study infers that non-destructive strength testing tool is a valuable technique for characterization of admixture based pervious concrete. The chapter shows that UPV can be used for different purposes like detection of defects, damage, density, uniformity and homogeneity assessment for in-place pervious concrete. The results of it are reliable and relatively inexpensive.

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