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A REALISTIC EVALUATION OF PERMEABILITY AND TENSILE STRENGTH FROM COMPRESSIVE STRENGTH IN CEMENT SAND MIXES

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ABSTRACT

This paper presents output of an experimental research program to relate various properties of cement sand mixes with its compressive strength. Since a designer always knows the target compressive strength, the findings of this paper immediately provide him with a realistic estimate of the remaining important properties of cement sand mixes.

This investigation includes cement sand mortars and micro-concretes, each of two different varieties. Cement sand mortars were made of four different proportions whereas micro-concretes were of two different proportions. Three water cement ratios with varying dosage of super plasticizers were also used for each of the six mixes. The proportion of 1:6 cement sand mortar was studied in further detail by adding water proofing compound (WPC i.e. Impermo) and silica fume in different proportions. The relationships between cylindrical compressive strength, split tensile strength and water permeability have been established.

Keywords: compressive strength; tensile strength; permeability; cement sand mixes

1. INTRODUCTION

The cement sand mortar (CSM) is used as:

- A construction material (ferrocement, for example),
- To conceal the defective workmanship,
- To cover unsound/ low cost core material and
- To reduce the harmful environmental effects.

The outer layer of structural concrete also consists of mortar, which accumulates when aggregate settles differentially on the inner surface of formwork during the compaction of fresh concretes. When concrete is exposed to aggressive media, the outer mortar layer provides initial surface resistance to degradation.

Tensile strength and permeability of CSM determine its effectiveness to meet the above objectives. Whenever an induced principal tensile stress (due to load, environment or any

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other cause) exceeds tensile strength of the mortar, a crack in the direction perpendicular to the principal tensile stress initiates and mortar ceases to resist any significant stress in the direction of principal tensile stress. This process continues, until principal tensile stress becomes smaller than the tensile strength of the mortar. The effect of cracking on permeability may be termed as damage induced permeability. The inherent and induced permeabilities play a crucial role in the protection of core material from the aggressive chemicals attack and determine service life of cement composites. Furthermore, cracking of mortar increases permeability of water, which results in reduction of service life of a structure component. Therefore to control the cracking of mortar, one has to use either a rich mortar or it should be suitably reinforced or both. To control inherent permeability of mortar, performance improver may be included, which reduces permeability of mortar layer by refining its pore structure.

Permeability of concrete or mortar is higher than the permeability of cement paste because micro-cracks are present in the transition zone between aggregates and cement paste [Mehta and Monteiro [1]]. A reduction in maximum size of aggregate reduced the permeability of concrete [Murata [2] 1965]. Cracked concrete and increase in volume concentrations of aggregate showed increase in its permeability [Bazant et al. [3]; Nyame [4] 1985; Norton and Pletta [5]. Permeability of concrete also increased due to increase in water cement ratio [Norton and Pletta [5]; Goto and Roy [6]]. The permeability of concrete is not a simple function of its porosity but depends also on the size, distribution and continuity of pores [Neville [7]]. Use of pozzolanic materials reduces the permeability of concrete due to conversion of calcium hydroxide {Ca $(OH)_2$}, otherwise soluble and leachable into cementitious compound [Shetty [8]]. Bamforth [9] found semi - logrithmic relationship between permeability and compressive strength of 1 day cured concretes. He also revealed that a substantial lower values of permeability can be achieved with light weight aggregate. Available published information on permeability of concrete may help in estimation of inherent mortar permeability. But, strength estimation from similar information may not be justified.

Since permeability test is fairly tedious therefore, it is desirable to obtain an estimate of inherent permeability indirectly. In view of demand of longer service life and precise assessment of threshold time for start of corrosion in a structure and also to fill some of the existing knowledge gaps, this research program was planned and executed. Various mixes were tested for compressive strength, split tensile strength and water permeability. Two different size cylindrical specimens along with cubical specimens were also tested to study the effect of size and shape of the specimens on strengths. Finally, relationships between cylindrical compressive strength, tensile strength and water permeability are established.

2. EXPERIMENTAL PROGRAMME

2.1 Materials

Ordinary Portland cement conforming to IS: 8112-[10] along with two types of fine aggregates (i.e. river sand conforming to IS: [11]-1992 and crushed stone dust conforming to IS: [11]-1992 and IS: [12]-1980) was used in this investigation. Sieve analysis test results of fine aggregates are given in Table 1. Fineness moduli of river sand and stone dust were 2.59 and 1.71, respectively. Coarse aggregate of maximum 10 mm size was used to produce micro-concretes. Two performance improvers (PI) i.e. Impermo and silica fume were also used in CSM of 1: 6 proportion to study their effect on strength and improvement in permeability. Sieve analysis test results of cement, Impermo and silica fume are given in Table 2. Super plasticizer, SP-3000 of Asian Laboratories conforming to IS: 9103-[13] was also used.

Table 1. Sieve analysis test results of sand and stone dust

I.S. Sieve size	Percentage passing (sand)	Percentage passing (stone dust)
4.75 mm	99.7	100.0
2.36 mm	94.7	99.4
1.18 mm	72.1	85.1
600 μ	45.7	80.2
300 μ	22.2	49.9
150 μ	7.0	14.5

Table 2. Sieve analysis test results of cement, Impermo and silica fume

I. S. Sieve size	Percentage passing (Cement)	Percentage passing (Impermo)	Percentage passing (Silica fume)
90 μ	98.3	99.7	100.0
75 μ	93.5	78.0	98.7
45 μ	30.0	50.5	87.0

2.2 Mix proportions

Mix proportions used in the study are given in Table 3. These mixes were intended to give a flow value in the range of 0 to 10% at 27±2°C [ASTM C 230/C230M-[14]; ASTM C 1437-[15]. The prefix M and S refer to micro-concrete and CSM, respectively. The identifiers A and B apply to river sand and stone dust aggregates, respectively. Roman numbers refer to a particular mix proportion and numerals refer to variable water/ cement ratios.

Total number of micro-concrete, CSM (plain) and CSM (1:6-modified) samples tested for strengths were 12, 24 and 36 respectively. The details are given in upper, middle and lower part of the Table 3.

Table 3. Details of mixes

Item of study	**Aggregate type**	**Mix proportion**	**Mix No.**	**W/C ratio**	**Super plasticizer dosage**	**Performance Improver dosage**
Micro-concrete CSM (Plain)	River sand (Stone dust)	1:1.0:2.0	MA-I1 (MB-I1)	0.27 (0.37)	2 %	None
			MA-I2 (MB-I2)	0.31 (0.43)	1 %	
			MA-I3 (MB-I3)	0.35 (0.45)	None	
		1:1.4: 2.4	MA-II1 (MB-II1)	0.31 (0.40)	2 %	
			MA-II2 (MB-II2)	0.35 (0.45)	1 %	
			MA-II3 (MB-II3)	0.40 (0.50)	None	
		1:3	SA-III1 (SB-III1)	0.34 (0.49)	2 %	
			SA-III2 (SB-III2)	0.39 (0.54)	1 %	
			SA-III3 (SB-III3)	0.45 (0.57)	None	
		1:4	SA-IV1 (SB-IV1)	0.49 (0.65)	2 %	
			SA-IV2 (SB-IV2)	0.54 (0.77)	1 %	
			SA-IV3 (SB-IV3)	0.60 (0.86)	None	None
		1:6	SA-V1 (SB-V1)	0.66 (0.94)	2 %	
			SA-V2 (SB-V2)	0.69 (0.99)	1 %	
			SA-V3 (SB-V3)	0.74 (1.04)	None	
		1:8	SA-VI1 (SB-VI1)	0.80 (1.10)	2 %	
			SA-VI2 (SB-VI2)	0.85 (1.15)	1 %	
			SA-VI3 (SB-VI3)	0.90 (1.20)	None	
CSM (1:6-modified)		1:6	SA-VII1 (SB-VII1)	0.60 (0.77)	2 %	Silica fume, 2.5%
			SA-VII2 (SB-VII2)	0.65 (0.80)	1 %	
			SA-VII3 (SB-VII3)	0.70 (0.83)	None	
			SA-VIII1	0.62	2 %	Silica fume,

Item of study	Aggregate type	Mix proportion	Mix No.	W/C ratio	Super plasticizer dosage	Performance Improver dosage
			(SB-VIII1)	(0.82)		
		1:6	SA-VIII2 (SB-VIII2)	0.67 (0.85)	1 %	5.0%
			SA-VIII3 (SB-VIII3)	0.72 (0.90)	None	
			SA-IX1 (SB-IX1)	0.68 (0.90)	2 %	
		1:6	SA-IX2 (SB-IX2)	0.73 (0.95)	1 %	Silica fume, 7.5%
			SA-IX3 (SB-IX3)	0.77 (1.00)	None	
			SA-X1 (SB-X1)	0.60 (0.80)	2 %	
		1:6	SA-X2 (SB-X2)	0.65 (0.85)	1 %	Impermo, 1%
			SA-X3 (SB-X3)	0.70 (0.90)	None	
			SA-XI1 (SB-XI1)	0.64 (0.87)	2 %	
		1:6	SA-XI2 (SB-XI2)	0.69 (0.92)	1 %	Impermo, 2%
			SA-XI3 (SB-XI3)	0.75 (1.02)	None	
			SA-XII1 (SB-XII1)	0.64 (0.90)	2 %	
		1:6	SA-XII2 (SB-XII2)	0.69 (1.00)	1 %	Impermo, 3%
			SA-XII3 (SB-XII3)	0.80 (1.05)	None	

Note: Numbers in parenthesis correspond to stone dust aggregate.

The effect of super plasticizer dosage on permeability was not considered as variable parameter in this study. Therefore, only those samples, which were of without super plasticizers, were used in permeability study. Thus, the number of micro-concrete, CSM (plain) and CSM (1:6-modified) samples tested for permeability were 4, 8 and 12, respectively. The details of these samples (only bold written) are also given in upper, middle and lower part of the Table 3.

Each sample for strengths test consisted of 12 small cylindrical, 12 large cylindrical and 6 cubical specimens while permeability sample was consisted of 6 disc specimens. Cylindrical specimens were tested for compressive and tensile strength tests, cubical for compressive strength only and disc specimens for permeability testing. Three specimens of each sample were tested at 7 as well as at 28 days to find an average value.

2.3 Test specimens

Cubical test specimens of 50 mm size for compressive strength, cylindrical test specimens of 50 mm diameter x 100 mm high and 75 mm diameter x 150 mm high were prepared using steel molds to determine compressive and tensile strengths. Disc specimens of 100 mm diameter x 50 mm thick were prepared for permeability test. All the mixes were prepared in planetary mixer conforming to ASTM: [16]-1999 and specimens were cast in vertical position. The molds were filled in two layers and compacted by a table vibrator. Capping of the cylindrical specimens was done by means of a glass plate, after about 4 hours of casting. The glass plate (8 mm thick and 100 mm square in size) was coated with oil. A stiff paste of neat cement was used as capping material. The specimens after casting/ capping were covered with wet gunny bags.

After 24 hours, the specimens were removed from the molds and stored in water at 27±2°C until the time of testing. The specimens were removed from water just before testing. Any loose sand grains or incrustations if found, were removed from the faces. Compressive and tensile strengths were determined by testing the specimens in saturated surface dry condition.

3. TESTING PROCEDURE

Universal testing machine (UTM) of 1000 kN capacity was used in testing the rich mixes. This UTM works in four ranges i.e. 0-100 kN, 0-200 kN, 0-400 kN and 0-1000 kN for static loading. Lower ranges were used in testing the specimens. The lean mixes were tested on compression testing machine with a proving ring of 50 kN capacity. The loading was monotonically increased so that failure of the specimens was reached within 2 to 3 minute.

3.1 Compressive strength

The cylinders and cubical specimens were tested to determine compressive strength. These tests were carried out after placing cylindrical specimens vertically between the loading surface of compression testing machine and load was applied along the vertical height until failure of the cylinders (Figure 1). Those faces of cubical specimen were loaded that were in contact with plane surfaces of the mold.

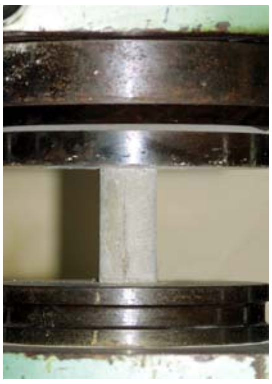

Figure 1. Compressive strength test

3.2 Split tensile strength

Only cylindrical specimens were used to determine tensile strength of the mixes. The cylindrical specimens were placed horizontally between loading surface of the compression-testing machine and load was applied along the vertical diameter until failure of the cylinders. In order to reduce the magnitude of high compressive stress near the point of application of the load, narrow packing strips of plywood of 30 mm wide, 3 mm thick and 150 mm long were placed between the specimen and loading platens of the testing machine (Figure 2).

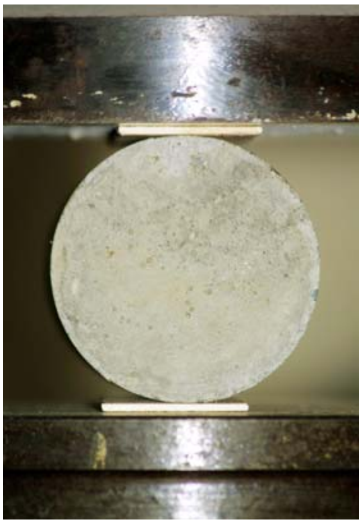

Figure 2. Tensile strength test

3.3 Permeability test

Although several papers on concrete permeability have been published [Norton and Pletta [5]; Goto and Roy [6]; Ruettgers [17]; Figg [18]; Dhir et al. [19]; Ludirdja et al. [20], yet no standard test method appears to be available for permeability test. It also seems that no ASTM guideline is available. The permeability equipment conforming to IS: [21] (Reaffirmed in 1999) was used in the study (Figure 3). This equipment consisted of a water pressure vessel, compatible compressor and 6-permeability units. Each permeability unit consisted of a specimen container ring of 100 mm diameter and 50 mm height, held between a bottom plate and a water cell. The hydraulic head was obtained by connecting the units to a compressor through a water pressure vessel. Pressure regulator and a pressure gauge were also included between the water pressure vessel and permeability units. The tests were conducted at 27±2°C and water percolated through the specimens was collected in containers.

Test specimens, after removing from the curing tank, were thoroughly cleaned with a wire brush to remove all laitance. Thereafter, they were air-dried so that sealant could adhere satisfactorily. The diameter and thickness of the specimens were then measured to the nearest 0.02 mm. Two diameters and two thicknesses, each were measured in perpendicular direction and average of these was used in computations. A hot mixture of wax and rosin in the proportion of 1:3 was coated on curved surface of the specimens as sealing compound. The specimens were coated in such a way that water pressure was applied on one face and amount of water permeated the specimen and emerged from the opposite face was measured. These coated specimens were inserted in warm permeability units. The sealing compound at the time of insertion worked as lubricant, while after cooling as sealant. To check water tightness of the seal, the units were inverted after bolting the cover plates and an air pressure of 20 m head of water was applied from below. A little water was pored on the top face of the specimen, to detect any leak through the seal. Leaked specimens were resealed and rechecked if found necessary.

Figure 3. Permeability test

A constant pressure head was applied to water in the reservoir and the specimens were tested with the regulator pressure gauge. Magnitude of the test pressure head was varied from 50 to 150 m head of water. Lower values were used for specimens with higher permeability while higher values were used for specimens with relatively less permeability. In the beginning, water-percolating rate through the specimens was not constant. But, at steady rate of flow, discharged water through the specimens was collected in containers separately, for a fixed duration.

Flow rates in concrete are normally very slow, resulting in laminar rather than turbulent flow. Laminar viscous flow described by the following Darcy's Eq.:

$$K = \frac{Q}{AT(H/L)} \tag{1}$$

Where,

K = co-efficient of permeability, m/sec;

Q = quantity of water percolated over the entire period of test after the steady state has been reached, m^3;

A = area of the specimen, m^2;

T = time, seconds and

H/L = ratio of pressure head to thickness of the specimen, both in the same units.

4. EXPERIMENTAL RESULTS AND DISCUSSION

Average compressive and tensile strengths of sand and stone dust mixes are given in Table 4 and 5 respectively, while average co-efficients of permeability of these mixes are given in Table 6. A comparison of the test results shows that sand mixes produced high compressive and tensile strengths with low permeability than the stone dust mixes for all mix proportions without PIs. This is due to higher demand of water by stone dust for producing a mix of comparable workability. It is also found on comparison that increase in size of the cylinder did not affect compressive and tensile strengths significantly. The ratio of compressive strengths of 50 mm diameter cylinder to compressive strength of 50 mm cube varied from 0.69 to 0.92.

Compressive and tensile strengths of all mix proportions (without PI) increase due to increase in cement content and age of the mixes. But, co-efficient of permeability of all mix proportions (without PI) decrease due to increase in both.

Micro-concrete may be used in place of very high rich mortars. It is not only economical but also more versatile as a construction material. Micro-concrete of 1:1.4:2.4 was found relatively more permeable than the cement sand mortar of 1: 3, although the former has relatively higher strength. It revealed that a concrete of comparable or slightly higher strength was more permeable than the mortar. This may be attributed to the presence of coarse aggregate.

Compressive strength of sand mix containing 2.5% silica fume remains unaffected. But, an increase in the dosage of silica fume beyond 2.5% reduces the compressive and tensile strengths. The reduction in strength appears to be proportional to the dosage. The compressive and tensile strengths of stone dust mixes remain practically constant. The reduction in permeability of sand and stone dust mixes appears proportional to the silica fume dosage. But, on comparison it is noticed that addition of silica fume reduces relatively more permeability of sand mixes at 7 days and stone dust at 28 days.

Addition of Impermo (PI) in sand mixes increased compressive strength and reduced tensile strength at 7 and 28 days. While, in stone dust mixes, almost no change in compressive strength at 7 days and reduction in compressive strength at 28 days and tensile strength at 7 and 28 days. Change in percentages of Impermo did not affect strengths significantly. Impermo addition reduced permeability of sand mixes at 7 and 28 days and of stone dust mixes at 28 days only. While, at 7 days in stone dust mixes, it increased permeability. Increase in percentages of Impermo produced relatively lower permeability. But, beyond 2 %, reduced a little permeability of stone dust mix and nil of sand mix at 28 days.

The effect of 1% and 2% dosages of super plasticizer on compressive and tensile strengths is summarized in Table 7.

Table 4. Average compressive and tensile strengths of sand mixes

Mix No.	Compressive strength (MPa)						Tensile strength (MPa)			
	50mm×100mm Cylinder		75mm×150mm Cylinder		50 mm Cube		50 mm×100mm Cylinder		75mm×150mm Cylinder	
	7-D	28-D	7-D	28-D	7-D	28-D	7-D	28-D	7-D	28-D
MA-I1	33.2	43.4	33.9	45.0	41.1	53.1	5.7	7.4	5.7	7.5
MA-I2	30.6	41.3	32.2	41.9	38.0	50.1	5.2	6.7	5.2	6.7
MA-I3	28.3	36.7	28.9	38.2	34.7	44.9	5.0	6.6	5.0	6.6
MA-II1	29.6	40.9	31.7	42.5	36.3	49.2	4.8	6.7	5.1	6.7
MA-II2	28.1	38.2	29.5	38.1	30.8	47.3	4.6	6.1	4.7	6.1
MA-II3	18.8	26.4	21.0	27.5	20.9	29.7	4.0	5.2	4.2	5.6
SA-III1	25.1	39.2	24.7	36.0	34.5	45.8	4.3	5.6	4.4	5.9
SA-III2	24.6	36.8	24.0	31.5	28.4	42.2	3.8	5.1	4.1	5.3
SA-III3	17.7	24.8	19.5	25.7	19.5	28.0	3.5	4.6	3.7	4.7
SA-IV1	20.2	27.5	18.3	23.6	23.8	33.5	3.8	4.9	3.5	4.7
SA-IV2	17.5	24.5	15.9	21.0	19.5	27.9	3.4	4.5	3.2	4.2
SA-IV3	14.5	22.2	13.9	19.2	17.2	26.3	3.2	4.3	3.1	4.0
SA-V1	11.7	15.1	11.9	16.1	13.6	18.5	2.6	3.9	2.8	3.7
SA-V2	9.1	13.1	9.9	13.5	10.8	15.3	2.4	3.5	2.6	3.4
SA-V3	8.5	11.6	8.5	12.6	9.6	13.7	2.2	3.3	1.9	3.1
SA-VI1	7.8	12.9	8.9	14.6	9.5	15.3	1.9	3.0	1.9	3.1
SA-VI2	7.6	11.3	8.1	12.1	8.5	12.8	1.6	2.4	1.5	2.4
SA-VI3	6.2	10.5	7.0	11.1	7.1	11.5	1.4	1.9	1.3	2.0
SA-VII1	10.9	14.3	11.5	15.3	13.1	20.0	2.5	3.3	2.7	3.6
SA-VII2	9.4	12.7	9.6	12.4	12.9	17.6	2.1	2.7	2.2	2.9
SA-VII3	8.5	11.7	8.7	11.4	11.0	15.5	2.0	2.6	2.0	2.7
SA-VIII1	9.6	12.7	9.7	12.5	12.7	16.6	2.1	2.8	2.1	2.8
SA-VIII2	8.4	11.5	8.8	11.7	10.8	14.7	1.7	2.2	1.7	2.2
SA-VIII3	6.7	9.3	7.6	10.0	9.7	12.6	1.5	2.0	1.5	2.0
SA-IX1	8.8	14.3	9.4	12.5	11.6	18.5	2.0	3.0	2.0	2.9
SA-IX2	7.3	12.2	7.3	11.0	9.7	16.0	1.7	2.6	1.5	2.4
SA-IX3	6.2	9.8	5.7	9.5	7.9	13.2	1.4	2.3	1.3	2.1
SA-X1	14.4	19.2	15.3	19.4	17.5	23.0	2.5	3.3	2.6	3.3
SA-X2	11.6	15.0	11.8	15.9	13.9	19.4	2.4	3.1	2.3	3.0
SA-X3	10.5	13.9	11.1	12.6	11.7	16.2	1.9	2.8	1.9	2.5
SA-XI1	13.7	19.0	15.1	19.9	15.7	22.6	2.7	3.6	2.6	3.3
SA-XI2	11.2	14.9	11.5	16.9	13.5	18.8	2.4	3.1	2.3	3.0
SA-XI3	10.1	13.8	9.8	14.5	11.4	16.1	2.0	2.8	1.9	2.5
SA-XII1	13.5	18.9	15.0	19.6	15.6	23.7	2.4	3.2	2.5	3.3
SA-XII2	11.1	14.8	11.5	16.6	13.4	20.2	2.2	3.0	2.1	2.8
SA-XII3	9.2	13.5	9.7	12.7	10.8	16.0	2.0	2.6	1.8	2.3

Table 5. Average compressive and tensile strengths of stone dust mixes

Mix No.	Compressive strength (MPa)						Tensile strength (MPa)			
	50 mm×100mm Cylinder		75mm×150mm Cylinder		50 mm Cube		50mm×100mm Cylinder		75mm×150mm Cylinder	
	7-D	28-D	7-D	28-D	7-D	28-D	7-D	28-D	7-D	28-D
MB-I1	31.3	41.6	31.0	40.1	42.4	54.7	5.4	7.1	5.1	6.7
MB-I2	29.3	39.2	26.7	37.7	39.2	52.3	4.5	6.3	4.4	5.9
MB-I3	23.3	34.3	22.9	35.2	28.5	41.8	3.7	4.8	3.7	4.8
MB-II1	30.9	39.6	27.1	35.2	33.5	47.5	4.8	6.5	4.6	5.9
MB-II2	24.9	32.5	23.0	29.6	27.3	39.1	4.3	5.6	4.3	5.6
MB-II3	20.0	30.6	20.8	28.4	22.3	37.6	3.4	4.8	3.6	4.7
SB-III1	17.6	29.2	18.2	26.7	20.8	34.5	3.2	4.8	3.5	4.6
SB-III2	16.0	26.3	16.4	25.0	19.9	33.0	2.8	4.1	3.2	4.2
SB-III3	13.1	22.2	14.7	22.9	17.1	28.1	2.6	3.9	2.8	3.7
SB-IV1	14.5	24.2	16.6	24.1	19.3	31.0	2.4	4.2	2.2	3.8
SB-IV2	11.9	19.8	13.1	20.1	14.4	24.8	2.1	3.6	2.2	3.6
SB-IV3	11.0	18.6	11.5	16.4	13.1	22.1	1.8	3.1	1.7	3.0
SB-V1	10.3	15.6	9.1	13.7	11.5	17.9	1.9	2.6	1.7	2.5
SB-V2	7.4	12.6	7.8	12.3	10.1	15.9	1.6	2.5	1.5	2.2
SB-V3	6.2	10.8	6.4	9.5	7.0	11.9	1.5	2.1	1.5	1.9
SB-VI1	5.6	7.2	5.4	7.5	6.3	9.2	1.5	1.9	1.6	2.0
SB-VI2	5.3	7.1	5.3	7.3	6.0	9.1	1.3	1.7	1.1	1.6
SB-VI3	5.0	6.6	5.0	6.7	5.9	8.1	1.0	1.4	0.9	1.2
SB-VII1	8.3	11.2	8.4	11.5	9.4	14.2	1.7	2.2	1.9	2.5
SB-VII2	7.2	10.4	7.8	10.8	8.0	13.1	1.5	2.1	1.5	2.1
SB-VII3	5.4	8.9	5.5	9.0	6.3	10.6	1.2	2.0	1.3	1.9
SB-VIII1	7.6	12.6	7.1	11.5	9.7	15.1	1.7	2.5	1.5	2.5
SB-VIII2	6.2	10.4	6.5	10.9	7.9	13.5	1.3	2.0	1.4	2.2
SB-VIII3	5.5	9.0	5.6	9.3	6.6	10.9	1.2	1.9	1.3	1.9
SB-IX1	7.6	12.8	7.8	13.3	9.2	15.3	1.5	2.5	1.6	2.7
SB-IX2	6.5	11.0	6.8	11.5	8.1	13.7	1.3	2.1	1.5	2.3
SB-IX3	5.5	9.4	5.6	9.4	6.5	11.2	1.2	2.0	1.4	2.1
SB-X1	9.0	11.8	9.0	12.4	10.6	15.1	1.7	2.5	1.6	2.5
SB-X2	7.1	10.8	7.3	11.4	8.8	13.9	1.5	2.4	1.4	2.2
SB-X3	6.8	9.7	6.5	10.0	8.0	12.0	1.3	1.8	1.3	1.9
SB-XI1	8.3	11.4	8.6	12.1	10.0	13.7	1.5	2.4	1.6	2.3
SB-XI2	6.8	10.3	6.2	9.9	7.7	11.9	1.4	2.3	1.3	2.1
SB-XI3	5.4	9.2	5.0	8.3	6.4	10.3	1.1	1.7	1.1	1.8
SB-XII1	8.5	11.5	9.1	12.2	10.4	14.3	1.5	2.2	1.4	2.1
SB-XII2	6.9	10.7	6.5	10.3	8.3	12.2	1.3	2.0	1.3	2.0

SB-XII3	6.1	9.8	6.3	8.6	6.8	11.0	1.1	1.7	1.1	1.7

Table 6. Average co-efficient of permeability for sand and stone dust mixes

Sand mix			**Stone dust mix**		
Mix No.	**Water permeability (m/sec)**		**Mix No.**	**Water permeability (m/sec)**	
	7 Days	**28 Days**		**7 Days**	**28 Days**
MA-I3	3.740E – 13	2.382E – 13	MB-I3	1.114E – 11	4.088E – 12
MA-II3	5.582E – 13	3.712E – 13	MB-II3	1.691E – 11	8.510E – 12
SA-III3	4.637E – 13	2.928E – 13	SB-III3	1.108E – 10	7.944E – 12
SA-IV3	8.391E – 12	1.037E – 12	SB-IV3	1.932E – 10	1.986E – 11
SA-V3	1.844E – 10	4.106E – 12	SB-V3	5.609E – 10	7.500E – 11
SA-VI3	4.580E – 10	1.468E – 11	SB-VI3	7.325E – 10	2.060E – 10
SA-VII3	4.559E – 11	4.659E – 13	SB-VII3	5.050E – 10	1.019E – 11
SA-VIII3	4.308E – 11	2.703E – 13	SB-VIII3	3.711E – 10	8.264E – 12
SA-IX3	3.237E – 11	1.419E – 13	SB-IX3	1.682E – 10	2.803E – 12
SA-X3	9.821E – 11	9.006E – 13	SB-X3	1.659E – 09	6.866E – 11
SA-XI3	4.739E – 11	6.115E – 13	SB-XI3	9.547E – 10	4.543E – 11
SA-XII3	3.981E – 11	6.089E – 13	SB-XII3	7.942E – 10	3.590E – 11

Table 7. Factored strength due to different dosage of super plasticizer

Dosage of plasticizer	Plain mixes		Silica fume mixes		Impermo mixes	
	Sand	Stone dust	Sand	Stone dust	Sand	Stone dust
			Compressive strength			
0 %	1.00	1.00	1.00	1.00	1.00	1.00
1 %	1.07-1.49	1.06-1.25	1.09-1.26	1.12-1.33	1.08-1.21	1.05-1.25
2 %	1.17-1.58	1.10-1.66	1.23-1.45	1.26-1.40	1.36-1.46	1.17-1.54
			Tensile strength			
0 %	1.00	1.00	1.00	1.00	1.00	1.00

1 %	1.02-1.21	1.04-1.31	1.05-1.15	1.04-1.23	1.10-1.24	1.17-1.34
2 %	1.13-1.52	1.23-1.48	1.25-1.40	1.13-1.36	1.19-1.33	1.31-1.42

5. ANALYTICAL STUDY

On detailed analysis of tensile and compressive strengths, it is found that the tensile strength of various proportions of mixes lies in between 8.9 and 18.2 % of compressive strength. This may be described by a polynomial relationship given in Eq. (2).

$$y = A\left(x\right)^2 + B\left(x\right) + C \qquad (2)$$

where,

y = split tensile strength of a mix, MPa;

x = cylindrical compressive strength of the mix, MPa and

$A, B\ and\ C$ = parameters.

The values of $A, B\ and\ C$ for the test results are given in upper part of Table 8. R-squared value for the test results and Eq. (2) is above 0.925, which indicated that the relationship correlates excellently with the test data.

Table 8. R-Squared value and parameters A, B, C, D and E

Property	**Superpl-asticizer**	**Age**	**Mix type**	**R^2-Value**	**A**	**B**	**C**	**D**	**E**
Tensile strength	2%	7 Days	Sand	0.9903	0.0001	0.0864	0.5523	-	-
			Stone dust	0.9823	0.0006	0.0693	0.4968	-	-
		28 Days	Sand	0.9300	0.0010	0.0213	1.6838	-	-
			Stone dust	0.9957	0.0008	0.0558	0.7380	-	-
	1%	7 Days	Sand	0.9599	0.0001	0.0805	0.5782	-	-
			Stone dust	0.9889	-0.0003	0.1024	0.2517	-	-
		28 Days	Sand	0.9259	0.0002	0.0633	1.0423	-	-
			Stone dust	0.9877	0.0004	0.0763	0.5391	-	-
	Nil	7 Days	Sand	0.9877	-0.0020	0.1697	-0.0194	-	-
			Stone dust	0.9759	-0.0013	0.1263	0.1004	-	-
		28 Days	Sand	0.9366	-0.0002	0.1101	0.4540	-	-
			Stone dust	0.9901	-0.0013	0.1344	0.0369	-	-
Permeability	Nil	7	Sand	0.9183	-	-	-	1E-05	5.4843

		Days	Stone dust	0.9549	-	-	-	9E-08	2.7767
		28 Days	Sand	0.9153	-	-	-	2E-08	3.2247
			Stone dust	0.9680	-	-	-	2E-08	2.3276

Analysis of test results for permeability and compressive strength showed that a power relationship of Eq. (3) exists between the two properties.

$$z = D\, x^{-E} \tag{3}$$

where,

z = permeability of a mix, m/sec;

x = cylindrical compressive strength of the mix, MPa and

D *and* E = parameters.

The values of D and E for the tested results are given in lower part of Table 8. The values of parameters decrease with increase in age of the mix and also with the decrease in fineness modulus of the aggregate. R-squared value for the test results and the relationship {i.e. Eq. (3)} is above 0.915, which showed that the relationship correlates well with the test data.

The Eqs. (2) and (3) are further validated by comparing the predicted tensile strength and permeability of concrete, with the available test results in the literature. Constants of the Eqs. and R-squared values of the same are tabulated in Appendix A.

6. CONCLUSIONS

This paper presents results of an experimental study on mortars in which aggregates of different fineness modulus are used. Effect of age, water-cement ratio and use of admixtures like silica fume and super plasticizer and performance improver on strengths and permeability of mortar has been studied. Some major conclusions are as follows:

1. Sand mixes of relatively same flow value given higher strength than the stone dust mixes, for all mix proportions without performance improvers.
2. Strength increases and permeability decreases due to increase in cement content and progress of hydration of cement as indicated by the age of specimen at the time of testing.
3. Micro-concrete mixes are found to possess higher permeability than the cement sand mortar even though their strength is similar.
4. Beyond 2.5 % addition of silica fume in sand mixes and any addition of silica fume in stone dust mixes reduced compressive and tensile strengths. The reduction is more pronounced in compressive and tensile strengths of sand mixes than stone dust mixes. Addition of silica fume reduces permeability but its effect was relatively more in sand mixes at 7 days and stone dust mixes at 28 days.
5. Impermo addition in sand mixes increased compressive strength and reduced tensile strength at all ages. In stone dust mixes, almost no change is noticed in compressive strength at 7 days but compressive strength at 28 days and tensile strength at all ages reduced. Variation in dosage of Impermo did not appear to affect strengths

significantly. Impermo addition reduced permeability of sand mixes at all ages and stone dust mixes at 28 days only. Increase in dosage beyond 2% produced marginal reduction in permeability of stone dust mix and nil of sand mix at 28 days.

6. Tensile strength of the mixes was found to lie in between 8.9 and 18.2 % of compressive strength. It can also be predicted by the Eq. (2).
7. A relationship between permeability and compressive strength of the mixes is given in Eq. (3).

7. DESIGN RECOMMENDATIONS

Results of this study and the following guidelines may be used, depending upon the environmental conditions:

1. Use of plain mix (without PI) either of high tensile strength or of medium tensile strength with reinforcement, is recommended for dry regions.
2. A mix of low tensile strength with reinforcement than a mix of high tensile strength is recommended for use in high seismicity areas.
3. Use of PI in marine environment is almost necessary to enhance the durability of cement products. Impermo can be used only when fine aggregate are relatively coarser while silica fume can be used with coarser as well as with fine aggregates. Impermo (1%) or silica fume (<2.5%) may fulfill the requirement of durability. But, appropriate dose of PI will depend upon volume and gradation of fine aggregate.

APPENDIX – A

Name of author	Mix reference/ curing condition	D	E	R^2-Value
	Study of permeability			
Dhir et al. [19]	E1	2.0E-12	3.4561	0.9870
	E2	8.0E-13	3.0950	0.9898
	E3	9.0E-13	3.0665	0.9959
	E4	1.0E-13	2.3320	0.9911
Bamforth [9]	S1 to S6	0.0017	4.6623	0.8744
	Study of strength			
Name of author	A	B	C	R^2-Value

Bamforth [9]	0.0001	0.0196	0.6352	0.8755
Mehta and Monteiro [1]	-0.0003	0.0831	0.2487	0.9992
	-0.0004	0.0810	0.9624	1.0000

REFERENCES

1. Mehta, P.K., and Monteiro, P.J.M., Concrete Microstructure, Properties and Materials. Indian Concrete Institute (First Indian Edition), 1997, pp. 120-122.
2. Murata, J., Studies on the Permeability of Concrete. RILEM Bulletin, **29**(1965) 47-54.
3. Bazant, Z.P., Sener, S., and Kim, J.K., Effect of Cracking on Drying Permeability and Diffusivity of Concrete. ACI Materials Journal, Sept. 351-357, 1987.
4. Nyame, B.K., Permeability of Normal and Lightweight Mortars. Magazine of Concrete Research, No. 130, **37**(1985) 11-48.
5. Norton Jr., P.T., and Pletta, D.H., The Permeability of Gravel Concrete. Journal of the American Concrete Institute, **27**(1931) 1093-1132.
6. Goto, S., and Roy, D.M., The Effect of W/C Ratio and Curing on the Permeability of Hardened Cement Paste. Cement and Concrete Research, No. 4, **11**(1981) 575-579.
7. Neville, A.M., Properties of Concrete. Pearson Education (Singapore) Pte. Ltd., 2003, pp. 483-497.
8. Shetty, M.S., Concrete Technology. S. Chand and Company, New Delhi, 1992, pp. 343-346.
9. Bamforth, P.B., The Water Permeability of Concrete and its Relationship with Strength. Magazine of Concrete Research, No. 157, **43**(2001) 233-241.
10. Indian Standard: 8112-1989, 43 Grade Ordinary Portland cement-Specification (First Revision), Bureau of Indian Standards, New Delhi.
11. Indian Standard: 1542-1992 (Reaffirmed 1999), Sand for Plaster-Specification (Second Revision), Bureau of Indian Standards, New Delhi.
12. Indian Standard: 2116-19805, Specification for Sand for Masonry Mortars (First Revision), Bureau of Indian Standards, New Delhi.
13. Indian Standard: 9103-1999, Concrete Admixtures–Specification (First Revision), Bureau of Indian Standards, New Delhi.
14. ASTM C230/C230M. Standard Specification for Flow Table for Use in Tests of Hydraulic Cement, 1998.
15. ASTM C1437. Standard Test Method for Flow of Hydraulic Cement Mortar, 2001.
16. ASTM C305. Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency.
17. Ruettgers, A., Vidal, E.N., and Wing, S.P., An Investigation of the Permeability of Mass Concrete with Particular Reference to Boulder Dam. ACI Journal, March-April, **31**(1935), pp. 382-416.
18. Figg, J.W., Methods of Measuring the Air and Water Permeability of Concrete. Magazine of Concrete Research, No. 85, **25**(1973) 213-219.
19. Dhir, R.K., Hewlett, P.C., and Chan, Y.N., Near Surface Characteristics of Concrete.

Magazine of Concrete Research, No. 147, **41**(1989) 87-97.

20. Ludirdja, D., Berger, R.L., and Young, J.F., Simple Method for Measuring Water Permeability of Concrete. ACI Materials Journal, **86**(1989) 433-439.
21. Indian Standard: 2645-1975 (Reaffirmed 1999), Specification for Integral Cement Water proofing Compounds (First Revision), Bureau of Indian Standards, New Delhi.