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Comparative Study on Strength, Permeability and Sorptivity of Concrete and their relation with Concrete Durability

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Abstract *- The current study is carried out to investigate the performance of compressive strength, permeability and sorption and investigate the relation with durability of concrete in the presence/absence of silica fume under four different curing conditions. Effect of cement content was also studied at two different levels; 350 and 450kg/m*^{3}*. The concrete sorption was measured by determining its sorptivity coefficient as specified by ASTM C 1585. Test results indicated that concrete sorptivity decreased by 42.7% when cement content was increased from 350 kg/m*^{3} *to 450 kg/m*^{3} *for specimens cured in water for 28 days at 20*^{o}*C. Also, for the same cement content, utilization of 10% SF as a partial replacement of cement resulted in sorptivity decrease by 64.5% and 68.3% with cement content 350kg/m*^{3} *to 450kg/m*^{3} *respectively, for specimens cured in water for 28 days at 20*^{o}*C. Although specimens stored in air experienced 11.6% loss in compressive strength, the sorptivity increased by 80.4% while permeability increased by nearly 345.3%. Specimens with lower sorptivity possessed lower permeability, and higher compressive strength.*

Keywords: **Concrete Sorptivity; Compressive Strength; Durability; Permeability; Silica Fume; Curing Conditions.**

I. INTRODUCTION

Concrete is the most important element of the infrastructure and well-designed concrete can be a durable construction material. The durability of concrete is a major consideration in its application in aggressive environments for long service life. The importance of environmental condition on concrete structures should not be overlooked during the design phase. Often, concrete strength has been considered a surrogate for durability. Unfortunately, it is becoming apparent that this is not particularly true due to the rising costs for concrete maintenance all over the world. In recent years, there is a growing interest in the use of high-performance concretes, which provide overall durability and high strength [1, 2]. One method of estimating the durability of a porous material is by measuring the rate at which a fluid, gas or liquid permeates through the material under a given head of pressure (Permeability). Therefore, the measurements of the permeability of concrete were used as an indication of durability. The more quickly a fluid moves through the material, higher permeability, the lower anticipated durability. Similarly, if a fluid moves through the material at a very slow rate, low permeability, a high durability would be expected. Mehta [3], concluded that permeability is the key to all durability problems. It should also be kept in mind that concretes with identical strength provide the same permeability. Recently, there is a strong interest in finding better ways of assessing the properties of concretes through determining its durability. As the processes of deterioration in concrete are mediated largely by water, it would be useful to find a way of measuring a single as well as simple material property which can reliably reflect the ability of a material to absorb and transmit water by capillarity [4]. Due to incomplete compaction; concrete may form gel pores & capillary pores, which lead to low strength of concrete. Due to problems associated with the absorption and permeability tests, which measure the response of concrete to pressure, which is rarely the driving force of fluids entering in to concrete; hence there is a need for another type of test. Such tests should measure the rate of absorption of water by capillary suction; “sorptivity” of unsaturated concrete [5]. Sorptivity test was found to be an easy and quick test to measure the material property that characterizes the tendency to absorb and transmit water by capillarity. Also, it was found to be directly related to permeability. It determines the capability of an unsaturated concrete to water penetration by absorption when no head of water exist. Accordingly, minimizing sorptivity is important in order to reduce the ingress of chloride or sulphate into concrete. Sorptivity, or capillary suction, is the transport of liquids in porous solids due to surface tension acting in capillaries and is a function of the viscosity, density, surface tension of the liquid, and also the pore structure (radius, tortuosity and continuity of capillaries) of the porous solid. It is measured as the rate of uptake of water [6]. The curing condition was found to be a major issue which affects the variation of the sorptivity test results and consequently the reproducibility of the test. Sufficient curing is essential for concrete to provide its potential performance [7]. It has generally been accepted that curing is more important for concrete with mineral admixtures than for normal concrete, as the pozzolanic reaction between amorphous silica (in mineral admixture) and calcium hydroxide (liberated during cement hydration) needs water to continue. Also, water curing has more effect on the sorptivity than on the strength of concrete [8]. During the last decade, considerable attention has been given to the use of silica fume as a partial replacement of cement to produce high-strength concrete. Silica fume cement concrete was found to be extremely strong, impermeable, and very durable against freezing– thawing damage and salt water attack and was also highly abrasion resistant. Khatri and Sirivivatnanon [9] indicated that the addition of silica fume to Portland cement concrete marginally decreased the workability of concrete but significantly improved its mechanical properties. Meloleepszy and Deja [10] reported that silica fume mortar containing 5% and 10% silica fume was influenced by curing conditions. Utilization silica fume improves long-term strength and durability. It also enhances early strength as a result of the filling effect. The current research work is carried out to investigate the performance of compressive strength, permeability and sorption and the relation with durability of concrete in the presence/absence of silica fume under four different curing conditions.

II. EXPERIMENTAL PROGRAM

A. *Materials*

Cement

The cement used for all concrete mixtures was “Ordinary Portland Cement” which is manufactured locally and complies with Egyptian Standards. Locally produced silica fume was used for preparing silica fume concrete specimens. The chemical compositions of the cement and silica fume are given in Table I.

Table I: Chemical Analysis of the used Cement and Silica Fume

Properties	Portland cement		Silica Fume**
	Measured Values, (%)	Limits*, (%)	Content, (%)
SiO_2	21.0	-	96
Al_2O_3	5.3	-	1.10
Fe_2O_3	3.51	-	1.45
CaO	63.29	-	1.20
MgO	1.02	-	0.18
SO_3	2.12	≤ 3.5	0.25
Loss On Ignition	2.56	≤ 5.0	-
Na_2O Eq.	0.40	≤ 0.6	0.45
K_2O	0.12	-	1.20
Total	99.85	-	-
Cl^-	0.01	≤ 0. 1	-
C_3A	8.11	-	-

*Egyptian standard specifications for Portland cement No 4756-1-2013 "Standard Test Methods of Chemical Analysis of Portland Cement"

** Given by manufacturer data sheet.

Aggregates

Crushed dolomite was used in all mixes as coarse aggregate with 14 mm nominal size. Properties of the selected coarse aggregate are shown in Table II.

Fine aggregate used in this research work was natural sand that composed mainly of siliceous material. Physical and chemical properties are given in Table III.

Table II: Physical and Chemical Properties of the Used Dolomite

Property	Value	Limit*, (%)
Specific gravity	2.60	-
Bulk density, (t/m^3)	1.61	-
Materials finer than No. 200 sieve	0.9	< 3
Abrasion (Los Angeles)	21.5	< 30
Impact Value	17	< 30
Flakiness index	15.2	< 25
Elongation index	11.25	< 25
Absorption	2.06	< 2.5

* Egyptian Concrete Code of Practice (ECP 203-2007)

Table III. Physical and Chemical Properties of the Used Sand

	Property	Value	Limits*, (%.)
Physical Properties	Specific gravity	2.5	-
	Bulk density, (t/m^3)	1.71	-
	Fineness modulus	2.66	-
	Clay and fine dust content (%by volume)	2.7	< 4%
Chemical Properties	% Chloride	0.027	< 0.06
	% Sulphate	0.014	< 0.4

* Egyptian Concrete Code of Practice (ECP 203-2007)

B. *Concrete Mixtures*

The experimental program was carried out to investigate the relation between concrete sorptivity and its compressive strength and permeability. The concrete mixtures and curing conditions were designed to produce specimens with different sorptivity and strength in order to have a wide range of concrete qualities. The experimental program consists of two main groups (A & B) depending on the content of (cement+ silica fume). Where (A) denoted concrete specimens with 350 kg/m3 total cementitious materials (cement + silica fume), while (B) refers to specimens with 450 kg/m3 (cement + silica fume). Each group consists of three subgroups (I, II, III) according to the percentage of silica fume, namely 0%, 5%, and 10%. Table IV illustrates the constituents of different concrete mixtures. Specimens of each subgroup were subjected to four curing conditions.

Table IV: Test Groups and Concrete Mixtures Constituents

Mix I.D	*AI*	*AII*	*AIII*	*BI*	*BII*	*BIII*
Portland Cement, (%)	100%	95%	90%	100%	95%	90%
Silica Fume, (%)	0%	5%	10%	0%	5%	10%
W/(C+S.F) Ratio	0.60	0.63	0.57*	0.45	0.49	0.40*
Mix Constituents,(kg/m^3)						
Cement	350	332.5	315	450	427.5	405
Silica Fume	0	17.5	35	0	22.5	45
Crushed Dolomite	1260	1260	1260	1100	1100	1100
Sand	630	630	630	550	550	550

*Super plasticizer has been added to mixes with 10% silica fume to get the practical inquired slump.

C. *Preparation of Test Specimens*

The concrete constituents were mixed in a revolving drum type mixer for approximately three to five minutes to obtain uniform consistency. Additional mixing time of about two minutes was provided for the silica fume cement concrete mixtures to ensure homogeneity. After mixing, standard 150 mm cubes and 150 & 100 mm cylinder moulds were filled then consolidated by vibrating table. After casting, the specimens were covered with wet burlap and left in the casting room at 20^{o}C for 24 h. After that, specimens were demoulded and cured. The cast concrete specimens are described for each mix as follows:

- (12) Standard 150 mm cubes to determine compressive strength.
- (4) Standard 150 mm cylinders to determine permeability coefficient.
- (12) Standard 100 mm cylinders to prepare specimens for sorptivity test.

D. Curing of Concrete Specimens

After demoulding the specimens were cured according to the following conditions:

- Curing Condition 1: Curing in water at 20±2^{o}C for 28 days, then specimens were stored inside the lab under ambient conditions until testing.
- Curing Condition 2: An initial curing for 7 days at 20±2^{o}C in water, then specimens were kept inside the lab under ambient conditions until testing.
- Curing Condition 3: Moist curing for 28 days by covering specimens with wet burlap inside the lab under ambient conditions until testing.
- Curing Condition 4: Specimens were stored inside the lab and kept under ambient conditions until testing. The temperature was moderately controlled at 20^{o}C±2^{o}C, but humidity was uncontrolled and generally ranged between 50% and 80%.

E. Testing of Concrete Specimens

Durability of concrete is mainly governed by its ability to resist the penetration of aggressive solutions into the matrix. Therefore, concrete strength should not be the only measured property to specify concrete quality. In addition to concrete strength, water permeability of concrete should also be examined to explore its durability. Specimens with different constituents and subjected to different curing conditions were tested to determine then compressive strength and resistance to the ingress of water by determining sorptivity and permeability coefficients.

1. Compressive Strength

Compressive strength test was carried out according to ISO 4012 and BS 1881 Part 115.

2. Sorptivity Test

Sorptivity test is a very simple technique that measures the capillary suction of concrete when it comes in contact with water. The Sorptivity test was performed in accordance with the ASTM C 1585 [11]. This test is used to determine the rate of absorption (Sorptivity) of water by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water ingress of unsaturated concrete by capillary suction during initial contact with water. The rate of sorption is the slope of the best-fit line to the plot of absorption against square root of time. Sorptivity specimens were prepared by cutting a disc of 100 ± 6mm diameter with 50±3mm length. The discs were cut from the middle part of the 200mm long cylinder in order to have the minimum variation of the concrete quality and to ensure that the specimens would be a representative sample of the concrete quality). Prior the test, specimens were placed in a desiccator oven at temp.50 ±2ºC and RH 80 ± 3% for 3days. After that, specimens were put in contact with water from one surface and the other surface was sealed. Mass gain due to sorption was measured at definite intervals for the first six hours. Fig. 1, 2, and 3 show sorptivity test setup, drying of specimens, and sorptivity specimens during the test respectively.

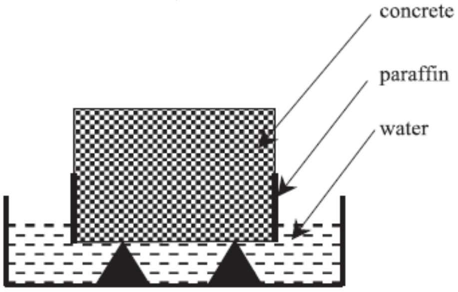

Fig.1. Schematic diagram of Typical Sorptivity Test Setup

Fig.2. Pre-Conditioning of Sorptivity Specimens inside the Drying Oven

Fig.3. Concrete Specimens during Sorptivity Test

3. Permeability Test

Although there are no prescribed test by ASTM and BS, the permeability of concrete can be measured by the automatic concrete water permeability device on cylinders of dimensions (150 × 150 mm) as shown in Fig 4. The sides of the specimen are sealed with epoxy and water under pressure is applied to the top surface only. The device applies a hydrostatic water pressure of 30 bars for a 6 hour. The water permeated through specimens is directly collected and measured in a graduated cylinder. By knowing the hydrostatic pressure, duration, specimen dimensions, and the permeated amount of water, it is possible to determine the permeability coefficient in cm/sec by applying Darcy's law:

$$K = \frac{Q \times H}{A \times T \times P}$$

Where:

Q = permeated water, cm^3
H = height of the specimen, cm
A = surface area of the specimen, cm^2
T = test time, sec
P = water head, cm

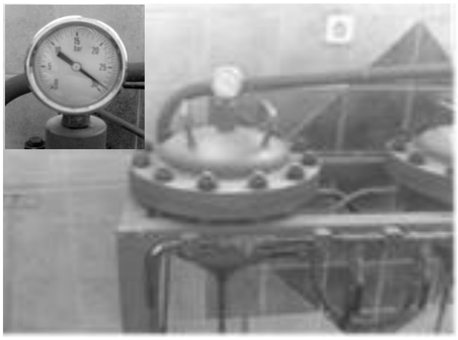

Fig.4. Automatic Device Used to Measure Coefficient of Permeability

III. RESULTS AND DISCUSSION

A. *Compressive Strength*

Compressive strength at age of 28-days was measured for concrete specimens of groups (A) and (B) subjected to different curing conditions and plotted in Fig.5. It can be shown that specimens' compressive strength increased as the SF content is increased regardless both cement content or curing condition. The highest gain in compressive strength of 538 kg/cm^2 has been achieved by specimen BIII (C.C 450kg/m^3, SF 10%, 28 days in water) while the lowest of 259kg/cm^2 was observed for specimen AI (C.C 350 kg/m^3, SF 0%, 28 days in air). The percentage of gain in 28 day compressive strength of group (A) under continuous water curing was 17.7% and 43.3% when SF was added by 5% and 10% respectively. In case of group (B), the percentage of gain was 12.8% and 32.8% when SF was added by 5% and 10% respectively. It can also be seen that compressive strength of all specimens was adversely affected when it was cured by air instead of water. Air curing resulted in reduction of compressive strength of group (A) by 11.6%, 3.2%, and 6% for specimens AI, AII, and AIII respectively. More remarkable reduction was observed for compressive strength of group (B). It decreased by 13.6%, 9%, and 11.3% for specimens BI, BII, and BIII respectively. The significant reduction in strength of group (B) that having higher cement content indicated the importance of water curing to allow further cement hydration and more contribution to strength gain by pozzolanic reaction between calcium hydroxide and SF. As it can be seen from Fig.5, the compressive strength of specimen AIII (420 kg/cm^2) is higher than that of BI (405 kg/cm^2) by 3.7% which means that 10% addition of SF gives almost the same gain in compressive strength resulted from 28% increase in cement content (from 350 to 450 kg/m^3). Compressive strength of specimens AI, AII, BI and BII which were cured in water for 7 days then in air up to 28 days showed a slight increase in compressive strength than specimens that were cured in water for 28 days. This is may be attributed to the apparent gain in strength due to friction generated between specimen's dry surface and machine plates.

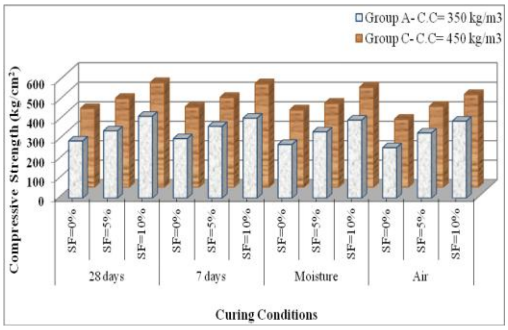

Fig.5. Variation in compressive strength of 0, 5 and 10% Silica Fume concretes subjected to different curing Conditions

B. *Sorptivity Test*

Sorptivity coefficient of concrete specimens of group (A) and (B) was measured according to ASTM C 1585 and plotted in Fig.6. The figures show the effect of curing conditions and content of SF on concrete sorptivity. It can be seen from both figures that the increase in cement content by 28.5% (from 350 to 450 kg/m^3) resulted in a decrease in sorptivity by 42.8%, 35.1%, 37.7%, and 52.6% for curing conditions 1, 2, 3 and 4 respectively. It can also be observed that the concrete sorptivity was remarkably decreased as SF content increased for all specimens under any of the four curing conditions. It decreased by 50.7% and 64.5% when SF was added as replacement of cement by 5% and 10% respectively for specimens of group (A) with curing condition 1. While it decreased by 38% and 68.4% when SF was added by 5% and 10% respectively for specimens of group (B) when it was cured under condition 1. It can be clearly observed that the effect of using SF even with relatively small amount (5%) can effectively reduce concrete sorptivity similar to that achieved by increasing the cement content or even more especially with lower cement content. This can be attributed to the filler effect of SF micro particles in addition to pozzolanic reaction between amorphous SF and calcium hydroxide precipitated during cement hydration. Both of these physical and chemical effects reflect a finer pore structure that would inhibit ingress of aggressive substances into the pore system. Concrete sorptivity was adversely affected by curing in air. It increased by 80% for specimen AI when it was cured in air rather cured in water for 28 days. The increase in sorptivity due to air curing was significantly less in case of specimen BI as it is increased by 49.4%. This negative effect can be attributed to the vital role of water in developing cement hydration in addition to its effect in elimination of micro cracking resulting from concrete shrinkage. The adverse effect of air curing on concrete sorptivity can be satisfactory compensated by utilizing SF as it can be seen from **Fig.7** and **8**. The sorptivity of specimen AI 13.8×10^{-3} mm/$sec^{1/2}$ increased to 24.9×10^{-3} mm/$sec^{1/2}$ due to air curing rather water for 28 days. The sorptivity has been recovered to 10.9×10^{-3} mm/$sec^{1/2}$ for specimen AI which was cured in air when SF is added by 10%. Similarly, sorptivity of BI 7.9×10^{-3} mm/sec$^{1/2}$ increased to 11.8×10^{-3} mm/sec$^{1/2}$ due to air curing. It decreased to 6.8×10^{-3} mm/sec$^{1/2}$ when SF is added by 10%.

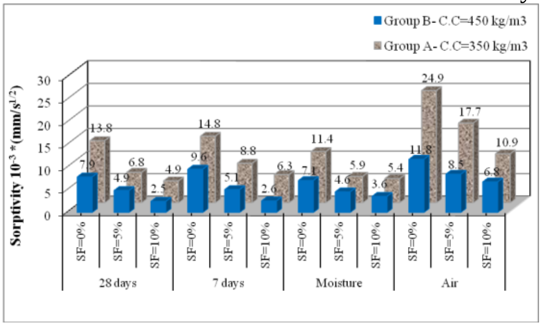

Fig.6. Variation in Sorptivity of 0, 5 and 10% Silica Fume concretes for group A & B subjected to different curing Conditions

Sorptivity test results of specimens of group (A) that were cured according to condition 2 (7 days only in water then in air) showed an increase in concrete sorptivity by 7.2%, 29.4%, and 28.6% for specimens AI, AII, and AIII respectively. The increase in sorptivity coefficient was insignificant for specimen without SF and was remarkable for specimens with 5% and 10% SF. This may be due to the need of pozzolanic reaction for prolonged water curing to proceed as well as the reduction in cement content that replace partially by SF. In case of group (B) the sorptivity increased by 21.5% for specimen BI when it was cured according to condition 2. While sorptivity of BII and BIII increased by only 4% under curing condition 2. This results indicate that short term water curing (7-day) can be sufficient to get same effect of 28 days water curing on concrete sorptivity of specimens with higher content of cement with 5% and 10% SF. Comparing sorptivity of AI with BI under curing condition 2, it can be shown that the increase in sorptivity due to this condition characterized by short term water curing was more pronounced for specimens BI that having relatively high cement content. This behavior can be attributed to the sensitivity of concrete with high cement content to drying and subsequent development of micro cracks as a result of shrinkage. Specimens AI and BI which were cured in moisture (condition3) showed less sorptivity coefficient than specimens subjected to 28-day water curing (condition1). This may be due the presence of calcium hydroxide which accumulated in pores and resulted in denser matrix. While in water curing, a significant amount of calcium hydroxide migrates from specimens pores into surrounding water resulted in less dense matrix. The relationship between concrete strength and its sorptivity for group (A) and (B) are displayed in **Fig.7** and **Fig.8**. As it can be seen specimens with higher compressive strength having lower sorptivity for specimens of group (A) and (B) under different curing conditions.

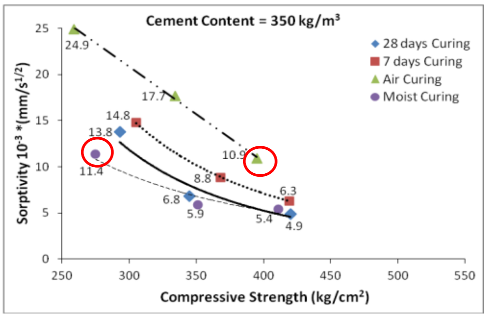

Fig.7. Sorptivity Coefficient versus Compressive Strength of Concrete with 350 kg/m^3 Cement Content

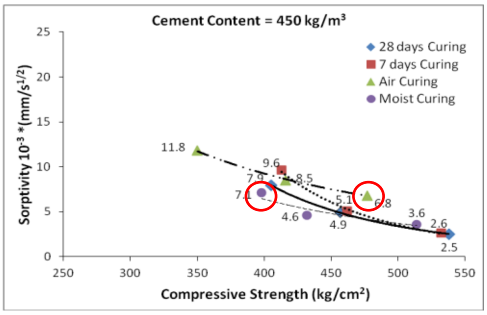

Fig.8. Sorptivity Coefficient versus Compressive Strength of Concrete with 450 kg/m^3 Cement Content

As concrete strength increases, the magnitude of specimens' sorptivity becomes closer except that of specimens cured in air. Sorptivity reduction rate decreased with the increase in compressive strength except specimens which were cured in air as sorptivity decreased with the same rate. One of the important results that can be shown in Figs.7 and 8 is that concrete with the same compressive strength do not necessary have the same coefficient of sorptivity. For instance, specimen of group (A) with compressive strength 395 kg/cm^2 that was cured in air having almost similar sorptivity coefficient as that of specimen with compressive strength 259 kg/cm^2 that was cured in moisture and specimen of group (B) with compressive strength 477 kg/cm^2 that was cured in air having almost similar sorptivity coefficient as that of specimen with compressive strength 398 kg/cm^2 that was cured in moisture. This also means that curing by water or moisture is considered a critical to sorptivity rather strength. This also means that concrete sorptivity is highly sensitive to curing rather than its compressive strength.

C. Permeability Test

Applying Darcy’s law, permeability coefficient was measured for concrete specimens of groups (A) and (B) subjected to different curing conditions and the results were plotted in Fig.9. As it can be seen, The lowest permeability of 0.36×10^{-9} cm/sec was attained by specimen BIII (CC 450kg/m^3, SF 10%, 28 days in water) while the highest of 15.41×10^{-9} cm/sec was gained by specimen AI (CC 350kg/m^3, SF 0%, 28 days in air). It can be clearly shown that permeability coefficient is significantly affected by curing condition, incorporation of SF, and cement content. Where permeability coefficient of group (A) increased by 145.1%, 60.4%, and 345.4% when specimens with 0% SF were cured under curing conditions (2), (3), and (4) respectively compared with condition (1). While it decreased by 28.6% and 68% for AII (5% SF) and AIII (10% SF) respectively under curing condition (1). On the other hand, the permeability coefficient of group (B) increased by 66.5%, 26.4%, and 170.6% when specimens with 0% SF were cured under curing conditions (2), (3), and (4) respectively compared with condition (1). While it decreased by 44.2% and 85.1% for BII (5%SF) and BIII (10%SF) respectively under curing condition (1). Specimens AI and BI which were cured in moisture (condition3) showed more permeability than specimens subjected to 28-days water curing (condition1) and less permeability than specimens subjected to 7-days water curing (condition2). Permeability results of group (A) that were cured under condition (2) (7 days only in water then in air) showed an increase in concrete permeability by 145%, 114.5%, and 63.9% for specimens AI, AII, and AIII respectively. In case of group (B) the permeability increased by 66.5%, 64.4%, and 61.1% for specimen BI, BII and BIII when it was cured under condition (2). It can also be seen that permeability of all specimens, same as sorptivity, was significantly affected by air instead of water. Air curing resulted in increasing of permeability of group (A) by 345.4%, 232.4%, and 336% for specimens AI, AII, and AIII respectively and 170.6%, 242.9%, and 619.4% for specimens BI, BII, and BIII respectively.

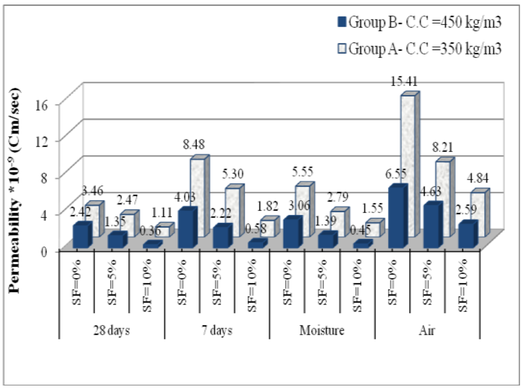

Fig.9. Variation in Permeability of 0, 5 and 10% Silica Fume concretes for group A & B subjected to different curing Conditions

With respect to the cement content, permeability coefficient decreased from 3.46×10^{-9} cm/sec to 2.42×10^{-9} cm/sec when cement content increased from 350kg/cm^2 to 450kg/cm^2. As it can also be seen from Figs. 13 and 14, the permeability of specimen AII (2.47×10^{-9} cm/sec) is almost the same as that of BI (2.42×10^{-9} cm/sec) which means that 5% addition of SF gives the same permeability resulted from 28.6% increase in cement content (from 350 to 450kg/m^3). Additionally, using 10% SF was more efficient in reducing permeability rather increasing in cement content as permeability reduced from 3.46×10^{-9} cm/sec (of specimen AI) to 1.11×10^{-9} cm/sec (of specimen AIII) while it decreased to 2.42×10^{-9} cm/sec (of specimen BI) when cement content was increased by 28.6%. As shown in Fig. 10 and 11, both sorptivity and permeability of all specimens of group (A) and (B) exhibited the same trend under different curing conditions and various SF content. However the sorptivity test is much simpler and does not need a special devise to be carried out which make sorptivity test more viable.

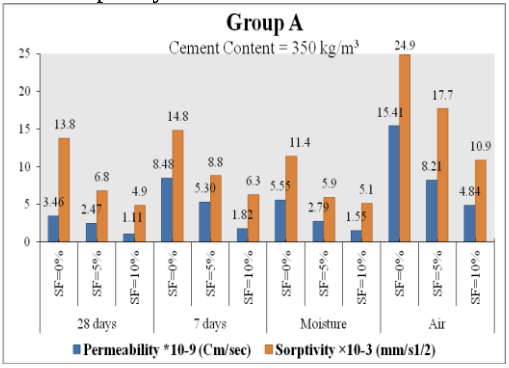

Fig.10. Effect of Silica Fume and Curing Conditions on Both Sorptivity and Permeability of Concrete with 350kg/m^3 Cement Content

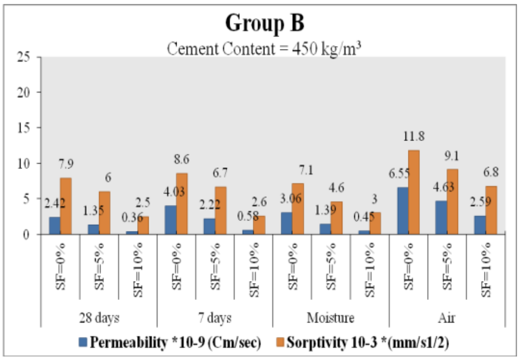

Fig.12. Effect of Silica Fume and Curing Conditions on Both Sorptivity and Permeability of Concrete with 450 kg/m^3 Cement Content

IV. CONCLUSIONS

The following conclusions could be drawn from the results obtained in this investigation:

(1) Both sorptivity and permeability of all specimens of group (A) and (B) exhibited the same trend under different curing conditions and various SF content. However the sorptivity test is much simpler and does not need a special devise to be carried out which make sorptivity test more viable.

(2) Concrete specimens with the same compressive strength don't necessary have the same coefficient of sorptivity.

(3) Curing by water or moisture is considered a critical to sorptivity rather strength.

(4) The effect of using SF at relatively small amount (5%) can effectively reduce concrete sorptivity similar to that achieved by increasing cement content by 28.6%.

(5) Short term water curing (especially moisture curing) can be sufficient to get nearly the same effect of 28 days water curing on concrete sorptivity for specimens with and without silica fume.

(6) Compressive strength of specimen with C.C. 350 kg/m^3 and 10% SF replacement gives almost the same gain in compressive strength resulted from 28.6% increase in cement content (from 350 kg/m^3 to 450kg/m^3).

(7) Silica fume significantly enhanced concrete strength and especially sorptivity and permeability-related durability of

the concrete. Concrete containing SF showed higher strength and lower sorptivity and permeability.

(8) Curing played a critical role in realizing the full potential of concrete. It is necessary to pay careful attention when using silica fume due to the fact that the performance of silica fume concrete are more sensitive to curing method.

(9) The comparison of the order of the variation in the concrete properties (strength, sorptivity coefficient, and permeability coefficient) pointed out that there is a strong correlation between them. The three measured concrete properties had similar tendency for both concretes in the absence/presence of silica.

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- “On The Optimal Designing of Some Families of Thin-Walled Bard", Int. IASS Symp. Copenhagen Denmark PP.237-244, September 1991.
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Publications

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Tasks & responsibilities

- Strategic Planning of quality management system
- Development of QA/QC plan and quality processes monitoring
- Creating automated management processes
- Define system development Needs / Analyze gaps between current and future states / Establishing goals and responsibilities / Align for vision, mission, and the Core value
- Lab competency enhancement in compliance with the technical and administration provisions of the international standard / Implementation, Monitoring, and adjust for continuous improvement

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