A Multiple Study of Water Absorption of Self Consolidating Concrete, Considering Elapsed Time and Aggregate Packing Factor

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ABSTRACT

One of the most important applications of self consolidating concrete (SCC) is in offshore structures especially deep piles which are in direct contact with the aggressive conditions. As a result, examining volumetric and capillary water absorption as a measure of durability is of great importance.

Since aggregate packing factor (PF) is an effective parameter on the properties of hardened SCC including water absorption, in this study 10 mix designs with packing factors from 1.1 to 1.19 were made. Standard 3.94×3.94 in cubes were used in order to measure volumetric and capillary water absorption. Tests were executed at different intervals including both short and long periods

According to the results, two main conclusions were drawn. In the field of PF, it was concluded that by increasing PF which results in linear decrease of both critical percolation ratio and paste thickness, water absorption will decrease. In the case of elapsed time, it was observed that both volumetric and capillary water absorptions have a linear relation with the root of time. The slope of each line differs between short-term and long-term periods due to different mechanisms of water absorption during these periods.

Keywords: Self consolidating concrete, Capillary water absorption, Volumetric water absorption, Aggregate packing factor, Short period of elapsed time, Long period of elapsed time, Percolation ratio, Paste thickness

INTRODUCTION

Nowadays using concrete technology makes it possible to construct various structures with different applicability and versatile architectures. Producing and using concrete is somewhat simple and inexpensive, hence producing concrete is developed all around the world. As appose to it using conventional concrete always had special problems. One of the most important problems is vibration, since it requires sophisticated workers. This is more obvious when casting in sections with highly congested reinforcement or inaccessible parts of structure such as deep piles. It also causes intense sound pollution.

The development of Self-Compacting Concrete (SCC), also referred to as ‘‘Self-Consolidating Concrete’’ and ‘‘High-Performance Concrete’’, has recently been one of the most important developments in the building industry. It is a kind of concrete that can flow through and fill gaps of reinforcement and corners of moulds without any need for vibration and compaction during the pouring process. This capability, in conjunction with the absence of the noise associated with vibration within a precast/prestressed concrete plant, creates a new atmosphere of production opportunities. SCC is a high-performance concrete in the plastic state. It takes less energy to move the material (lower shear stress) (viscosity) and should not separate or segregate. A material that takes less energy to move will require fewer workers or finishers to produce a quality precast/prestressed unit. SCC has the potential to allow reallocation of manpower and increased production with existing resources. When SCC is placed in a form, its motion may be a creeping movement or a rapid flow. Because of this style of flow, the surface finish between the form and the concrete can be exceptionally smooth, creating a much-improved form finish over conventional concrete. Technically, SCC has many advantages over normal production concrete used in precast/prestressed concrete plants. It is well-suited for producing both vertical and horizontal components with block-outs and crowded reinforcing. SCC is applicable for production of architectural and textured surfaces. Some precast plants are reporting using SCC in nearly 100 percent of their production and expect further opportunities for SCC with the industry acceptance of an SCC specification.[1] Precast structures are now widely used in almost every field of construction. One of the most significant uses of such members is in the structures which are in direct contact with water. Precast concrete columns, piers and caps used in bridge construction, large retaining walls, shoreline protection, storm sewer outlets, stream channel walls, drop structures and erosion-stopping structures (wave barriers) as well as precast concrete modular floating pier are some examples of these members. Hence the durability of concrete used to produce such precast structures becomes important and needs to be studied.

Fig. 1 Edison Bridge Ft. Meyers, Fla, Showing Precast Concrete Columns and Caps

Pioneering work in the development of SCC was carried out by Okamura[2] and Okamura and Ouchi[3]. An important point to be noted here is that since it is only about two decades that this type of concrete has been produced there is serious need for research to be done in this field.

Until now various SCC mix design methods have been proposed. More recently, Su et al.[4] developed an alternative method for composing SCC, this method starts with the packing of all aggregates (sand and gravel together), and later with the filling of the aggregate voids with paste. The method is easier to carry out, and results in less paste. This saves the most expensive constituents, namely cement and filler, and concrete of ‘‘normal’’ strength is obtained. This will also favour the technical performance of the concrete, as the largest possible volume of aggregate is advantageous in regard to strength, stiffness, permeability, creep and drying shrinkage. A basic parameter in this method is aggregate Packing Factor (PF), which is defined as the ratio of mass of aggregate of tightly packed state in SCC to that of loosely packed state. Clearly, PF affects the content of aggregates in SCC.

A higher PF value would imply a greater amount of coarse and fine aggregates used, thus, decreasing the content of binders in SCC. Consequently, its flowability, self-compacting ability and compressive strength will be reduced. On the other hand, a low PF value would mean more binder content which will result to higher drying shrinkage. It also causes raising the cost of materials. Therefore, it is important to select the optimal PF value in the mix design method so as to meet the requirements for SCC such as workability and durability, and at the same time taking economic justification into consideration.

Because of special applications of SCC in structures which are in direct contact with aggressive conditions such as offshore structures, durability of SCC is more significant in comparison with conventional concrete. An important feature of durability is water permeability which is measured by capillary and volumetric water absorption tests. Effect of PF on water absorption of SCC can be determined by considering the effect of PF on the pore structure of SCC which has a direct influence on its water absorption.

Concrete is typically viewed as a two phase composite material consisting of discrete aggregates dispersed in a continuous cement paste matrix. However, the influence of aggregates on the microstructural development of the cement paste, and thus the ultimate properties of the concrete, has been somewhat neglected.

The effect of concrete's porosity on its resistance to degradation is quite complex. In determining the rate of ingress of an aggressive medium into concrete, the distribution of the pores in the cement paste portion of this composite has to be considered, especially their size and connectivity. In concrete and mortar this pore structure is affected by the presence of the aggregate.

Using mercury intrusion porosimetry (MIP), Winslow et al.[5] showed that the pore structure of paste developed in the presence of aggregate is quite different from that of neat cement paste. The aggregate-paste interface, or "transition zone", has a definite effect on the pore size distribution due to its considerably higher porosity and the larger pores that it contains. The effects of the transition zones on the transport properties should depend on the aggregate content.

When the transition zones are isolated by a less porous bulk paste, the rate of transport should be significantly lower than if the transition zones overlap, which would create a continuous path of low resistance to penetration. This interconnection has been referred to as "percolation". As evidence of such percolation, Winslow et al.[5] observed that the MIP results for mortars depend on the sand content, with the intrusion curves for sand contents higher than some critical value showing a disproportionate increase in the volume of larger pores.

The goal of the present research is to examine the effect of PF on compressive strength and water absorption of self consolidating concrete using Su et al.[4] mix design method. Aggregate Packing Factor affects the amount of aggregate contents in SCC mixture. As a result, it can affect mechanical and permeability properties of SCC such as compressive strength, capillary and volumetric water absorption.

EXPERIMENTAL PROGRAM

MATERIALS

Properties of Aggregates

Physical properties of all classes of aggregates are shown in Table 1. Grading of river sand and coarse aggregate (crushed gravel) are shown in Table 2.

Table 1 Physical Properties of Aggregates

Aggregate class	Silica sand (between No. 200 and No. 100 sieves)	River sand	Coarse aggregate
Specific Gravity	2.63	2.78	2.63
Water absorption (%)	9	2.5	1

Table 2 Grading of Aggregates

Sieve	No. 100	No. 50	No. 25	No. 16	No. 8	No. 4	3/8 in
River Sand (%)	3.72	21.21	38.46	50.84	74.81	96.84	100
Coarse aggregate (%)	-	0.64	0.78	1.28	5.77	55	98.05

Properties of Other Components

Portland cement type I with specific gravity of 3.15, a mineral additive (Lime stone powder) finer than N0. 100 sieve, specific gravity of 2.5 and water absorption of 11.1% were used in this study. Super plasticizer (SP) and Viscosity Modifying Admixture (VMA) with polycarboxylate basis were used.

PRELIMINARY STUDY

The packing index of a granular mix is defined as the solid volume φ in a unit total volume. The higher the packing index, φ, the lower the voids. Many composites, like concrete, are made up of granular inclusions embedded in a binding matrix. The aim is often to combine grains in order to minimize the porosity, which allows the use of the least possible amount of binder. The packing index of a polydisperse grain mixture depends on three main parameters:

- The size of the grains considered (described by the grading curves);
- The shape of the grains;
- The method of processing the packing.[6]

In order to determine the maximum packing index (φ), various mixtures of gravel, river sand and silica sand were prepared. Loose densities and specific gravities of aggregate mixtures were obtained using ASTM C29 and C127 methods respectively. More details are mentioned in Table 3.

Calculating this index, optimum aggregate fraction of any aggregate class was derived so that the maximum packing state of aggregates can be obtained.

Table 3 Aggregate Mixtures Used in Packing Index Test

Aggregate Mix No.	Gravel	River sand	Silica sand	Bulk density (Ib/ft^3)	Density (Ib/ft^3)	Packing index (φ)
1	50%	45%	5%	116.120	164.191	0.707
2	50%	40%	10%	112.499	164.191	0.685
3	50%	35%	15%	119.116	164.191	0.725
4	45%	45%	10%	114.996	164.191	0.700
5	45%	40%	15%	119.803	164.191	0.730
6	40%	50%	10%	115.995	164.191	0.707
7	40%	45%	15%	117.556	164.191	0.716
8	35%	50%	15%	117.930	164.191	0.718

LABORATORY PROCEDURE

According to Su et al.[4] research, ten packing factors for ten different mix designs were selected (1.1 to 1.19). In first six mixtures (PF=1.1 to 1.15) by increasing PF, cementitous materials content was decreased instead. In the last five mixtures (PF=1.15 to 1.19) by increasing PF, limestone powder content was decreased.

For each mixture 4, 3.94×3.94×3.94in cubic specimens for capillary water absorption test, 4, 3.94×3.94×3.94in cubic specimens for volumetric water absorption test and 3, 5.91×11.81in cylindrical specimens for compressive strength test were cast and 28 days cured in water pool.

In order to measure the volumetric water absorption, according to ASTM C642, after curing, the specimens were put in an oven at a temperature of 110 ˚C for 24 hours. Repeated measurements were made to confirm that additional oven drying does not result in significant additional weight loss. After that the mass of each specimen was recorded as its dry mass. To measure the volumetric water absorption, the specimens were submerged and their masses were measured after 10, 30, 60 and 120 min and also 1, 2, 7 and 14 days after drying the surface moisture.

In capillary water absorption test, preparation conditions of specimens were the same as that of volumetric water absorption test. To measure the height of capillary water absorption, the specimens, according to RILEM method[7], were put in water in a way that only 0.39 in of their height were in water. After 3 and 6 hours and also 1, 2, 7 and 14 days and after drying their surface moisture, the mass of specimens were measured to determine the height of capillary water absorption.

It must be mentioned that for each fresh concrete mixture, L-Box, Slump Flow and V-Funnel tests were executed. Results are shown in the Table 4.

Table 4 Mix Designs (Water/Cementitous Materials = 0.4)

Mix No.	Gravel (Ibs/yd^3)	River sand (Ibs/yd^3)	Silica sand (Ibs/yd^3)	Lime stone powder (Ibs/yd^3)	Cement (Ibs/yd^3)	Silica fume (Ibs/yd^3)	SP (Ibs/yd^3)	VMA (Ibs/yd^3)	L-Box ratio $(\frac{H_2}{H_1})$	Slump flow (in)	V-Funnel time (sec)
MD1	1208.5	1292.8	397.8	101.1	637.1	70.8	10.1	3.4	1.00	31.9	1.5
MD2	1218.7	1304.6	401.2	101.1	611.9	68.0	10.1	3.4	1.00	31.9	1.32
MD3	1230.1	1316.9	405.2	101.1	583.7	64.8	10.1	3.4	0.79	31.1	1.85
MD4	1241.1	1328.7	408.9	101.1	556.9	61.9	10.1	3.4	0.43	25.2	2.5
MD5	1252.0	1341.2	412.5	101.1	530.4	59.0	12.6	3.4	0.70	31.5	2.66
MD6	1263.0	1352.2	416.0	101.1	503.8	56.0	12.6	3.4	0.43	31.1	2.53
MD7	1274.1	1364.0	419.7	76.7	503.8	56.0	12.6	3.4	0.62	30.1	3.28
MD8	1285.1	1375.7	423.2	52.3	503.8	56.0	12.6	3.4	0.56	28.7	4.94
MD9	1296.0	1387.5	427.0	27.8	503.8	56.0	12.6	3.4	0.44	28.9	4.5
MD10	1307.0	1399.2	430.5	3.4	503.8	56.0	12.6	3.4	0.28	27.6	5.03

RESULTS AND DISCUSSION

ABSORPTION VERSUS ELAPSED TIME

Tests which directly measure the rate of water absorption, such as the Covercrete Absorption Test (CAT)[8] and the Initial Surface Absorption Test (ISAT)[9] typically fit the total water uptake to the following equation:

$$W/A=St^{1/2}+S_0 \qquad (1)$$

where W is the volume of water absorbed, A is the sample surface area exposed to water, W/A is then equivalent to height of capillary water absorption. S is the sorptivity coefficient, t is time and S_0 is a correction term added to account for surface effects at the time the specimen is placed in contact with the water. Such tests are made over a period of less than one hour. Clearly, measurements over such short periods of time will only probe surface effects and cannot provide sufficient information for the modeling of capillary transport over longer periods, which is needed for service life prediction[10].

Capillary water absorption (W/A) versus root of elapsed time (3-24hr) is shown in Fig. 2. Values of S ,S_0 and correlation coefficient (R^2) for a short period of time (3-24hr) are shown in Table 5.

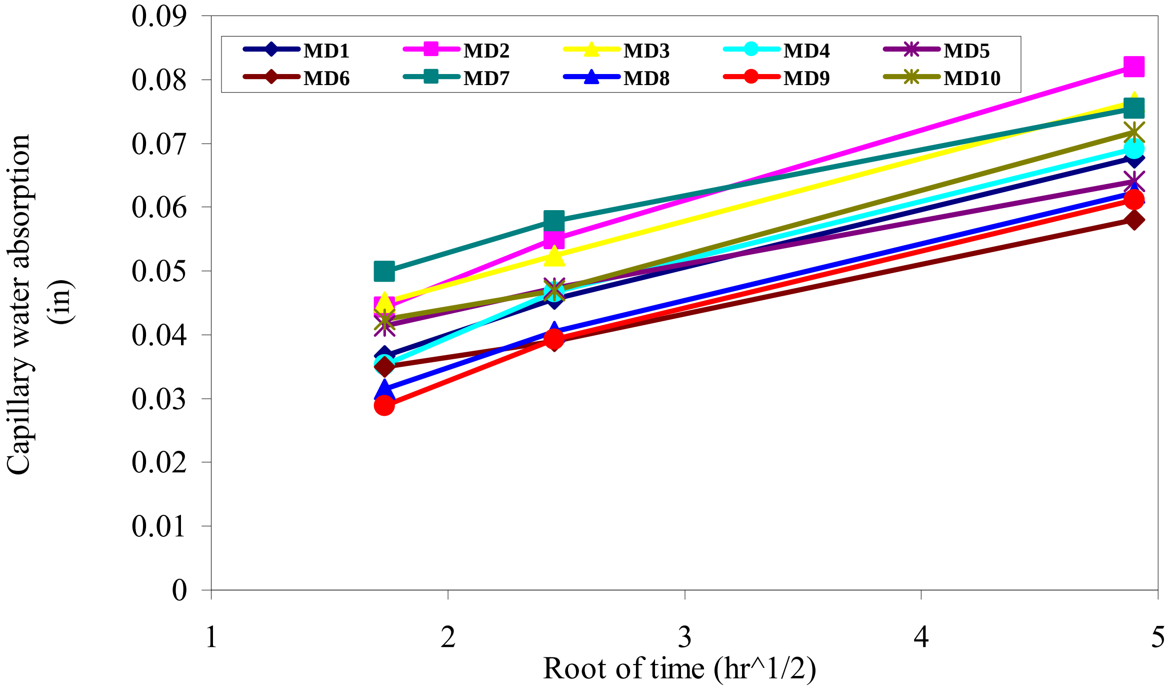

Fig. 2 Capillary Water Absorption Versus Root of Time (3-24hr)

Table 5 Details of Trend Lines of Fig. 2

Mix No.	MD1	MD2	MD3	MD4	MD5	MD6	MD7	MD8	MD9	MD10
S	0.010	0.012	0.010	0.010	0.007	0.007	0.008	0.009	0.010	0.009
S_0	0.021	0.025	0.028	0.019	0.029	0.021	0.037	0.016	0.013	0.025
R^2	0.996	0.996	1.000	0.986	0.999	0.997	0.992	0.995	0.989	0.994

However, in this work it was observed that the Eq. 1 is applicable for longer periods of time. Capillary water absorption (W/A) versus root of elapsed time (48-336hr) is shown in Fig. 3. Values of S, S_0 and R^2 for a long period of time (48-336hr) is shown in Table 6.

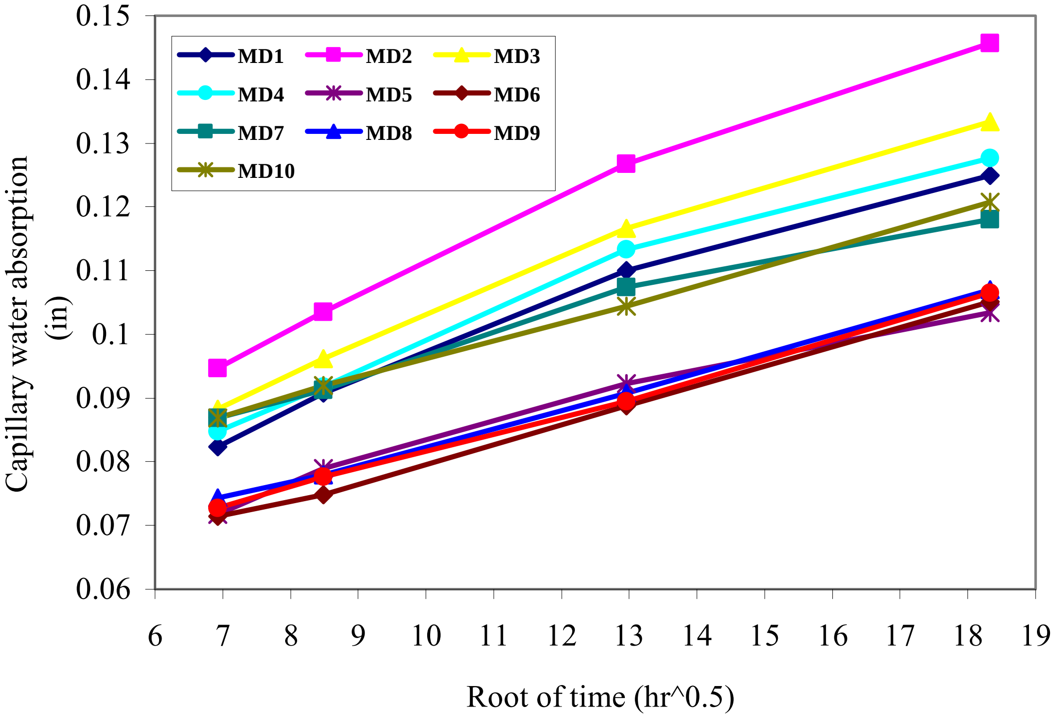

Fig. 3 Capillary Water Absorption Versus Root of Time (48-336hr)

Table 6 Details of Trend Lines of Fig. 3

Mix No.	MD1	MD2	MD3	MD4	MD5	MD6	MD7	MD8	MD9	MD10
S	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.003
S_0	0.059	0.065	0.062	0.060	0.055	0.050	0.068	0.054	0.052	0.067
R^2	0.983	0.989	0.989	0.980	0.981	0.999	0.981	0.999	0.998	0.999

Moreover, it was observed that the relation between the percentage of volumetric water absorption versus root of elapsed time is linear over both short and long periods. Note that ASTM C642 suggests a mass-based method but here the method is altered to a volumetric-based one using Eq. 2.

$$A_v = \frac{V_w}{V_s} \times 100\% \tag{2}$$

Where A_v is the percentage of volumetric water absorption, V_w is the volume of absorbed water and V_s is the volume of one specimen (0.035 ft^3). As it was cited above, the relation between A_v and root of elapsed time can be expressed by Eq. 3.

$$A_v=S_v t^{1/2}+S_{v0} \tag{3}$$

Values of S_v , S_{v0} and R^2 for both short and long periods are shown in Table 7 and Table 8 respectively.

Table 7 Details of Trend Lines of A_v Versus Root of Time (10-120min)

Mix No.	MD1	MD2	MD3	MD4	MD5	MD6	MD7	MD8	MD9	MD10
S_v	0.343	0.316	0.293	0.341	0.186	0.208	0.165	0.228	0.185	0.243
S_{v0}	1.083	1.652	1.423	1.010	1.523	1.677	1.624	1.465	2.013	1.436
R^2	0.980	0.971	0.977	0.986	0.927	0.947	0.980	0.969	0.992	0.913

Table 8 Details of Trend Lines of A_v Versus Root of Time (2880-20160min)

Mix No.	MD1	MD2	MD3	MD4	MD5	MD6	MD7	MD8	MD9	MD10
S_v	0.007	0.008	0.007	0.008	0.006	0.006	0.005	0.006	0.005	0.005
S_{v0}	6.606	6.017	5.629	6.095	3.983	4.560	4.020	4.858	4.825	4.715
R^2	0.981	0.992	0.990	0.994	0.984	0.983	0.986	0.982	0.979	0.979

In both cases, the slope of trend line differed over two distinctive periods that was referred to as short and long periods before. It can be discussed considering the absorption process. In the first period, the absorption rate is higher since it occurs due to inter-aggregate porous structure that have a relative larger diameter in comparison with other existing pores, thus they will be filled with water in the first few hours. The subsequent absorption occurring in the second period initiates from the cementitous paste gel pores which are significantly thinner than the inter-aggregate pores. Consequently, the absorption rate is lower in the long period.

In the case of capillary water absorption according to Nicos et al.[10] absorption rate (S) is proportionate to the average radius of capillary tubes due to the following equation.

$$S \propto \sqrt{\frac{r\gamma\cos\theta}{\mu}} \tag{4}$$

Where r is the average radius of capillary tubes, γ is the unit weight of fluid, θ is a static contact angle and μ is the fluid viscosity. In the present work γ, θ and μ are constant because of the same laboratory condition for all the tests. Hence, S is only a direct function of r resulting in greater values of S in the first period and smaller values in the second period.

In the other case, the mechanism of absorption resembles that of the seepage of water inside of soil. In general, the average velocity, V, of the fluid, in a porous medium such as soil or concrete, may be obtained from Darcy's law:

$$V=Ki \tag{5}$$

Where K is coefficient of permeability and i is hydraulic gradient.

In our tests i is approximately constant during both periods. Considering V as a measure of absorption rate (S_V) of concrete, it is quite obvious that S_v is a direct function of K. We know from soil mechanics[11] that K depends on some parameters of porous medium including size and diffusion of pores and saturation ratio. Since in the first period of volumetric water absorption larger pores absorb water and the saturation ratio is small, the value of K would be higher than that of the second period causing a higher rate of water absorption.

ABSORPTION VERSUS CRITICAL PERCOLATION RATIO

Considering a binary granular mixture for which two successive diameters d_i and d_{i+1} may be close to each other, the critical percolation ratio is defined as $\lambda^* = d_{i+1} / d_i$ for which i+1 grains may percolate through the i ones. If the i grains are fully packed spheres as shown in Fig. 4(a), we have $\lambda^* = \frac{2}{\sqrt{3}} - 1 \approx \frac{1}{6.46}$. As it can be observed from Fig. 4(b), by increasing the critical percolation ratio the voids between aggregate increase.

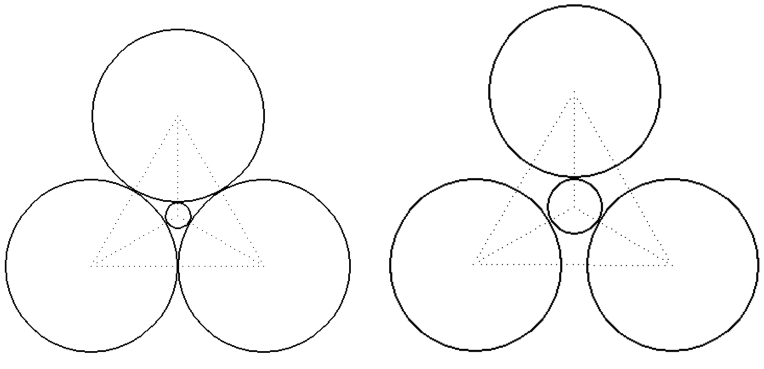
(a) (b)

Fig. 4 Binary Virtual Packing Pattern, In Which the Fine Grain May Percolate Through the Coarse Grain Packing (a). Increase of the critical Percolation Ratio, λ^*, Due to the Lower Volume of Coarse Grains (b).

Generally for a granular mixture containing n classes of aggregate critical percolation ratio can be calculated from the following quotient:

$$\lambda^* = \frac{2}{\sqrt{3}} + \sqrt[3]{\frac{K}{K+1+\frac{\log(d/D)}{\log(\lambda^*)}}} \tag{6}$$

$$K = \sum_{i=1}^{n} K_i = \sum_{i=1}^{n} \frac{\phi_i/\phi_i^*}{1-\phi_i/\phi_i^*} \tag{7}$$

Where λ^* is critical percolation ratio, K is compaction index, K_i is the contribution of class i of aggregate to the compaction index, ϕ_i is proportion(in volume) of the i fraction related to the total volume of the container, ϕ_i^* is the maximum proportion of the i fraction for fixed values of the other ϕ_j $(i \neq j)$, D is the maximum diameter in a poly-disperse mix and d is the diameter of particles in a mono-disperse mix, or minimal diameter in a poly-disperse mix[6].

As a matter of fact the critical percolation ratio is a measure of the amount of connected porosity in the concrete microstructure which is an important media for concrete permeability.

Using the above equation λ^* was calculated for all mix designs and the PF versus λ^* diagram was drawn as follows.

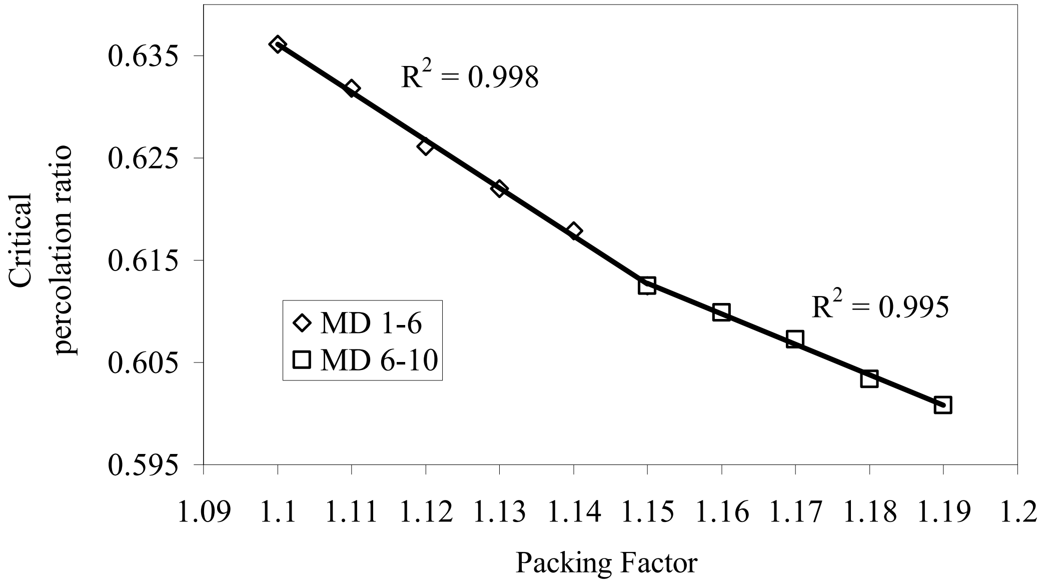

Fig. 5 Critical Percolation Ratio Versus Packing Factor

As it can be observed percolation ratio will decrease when increasing PF, so the water absorption of the specimens must decrease in general by increasing the PF. Examining the subsequent diagrams clearly reveals this fact. It must be noted in all subsequent diagrams that the values of 14 days capillary and volumetric water absorption are used to plot Figs. 6 and 7.

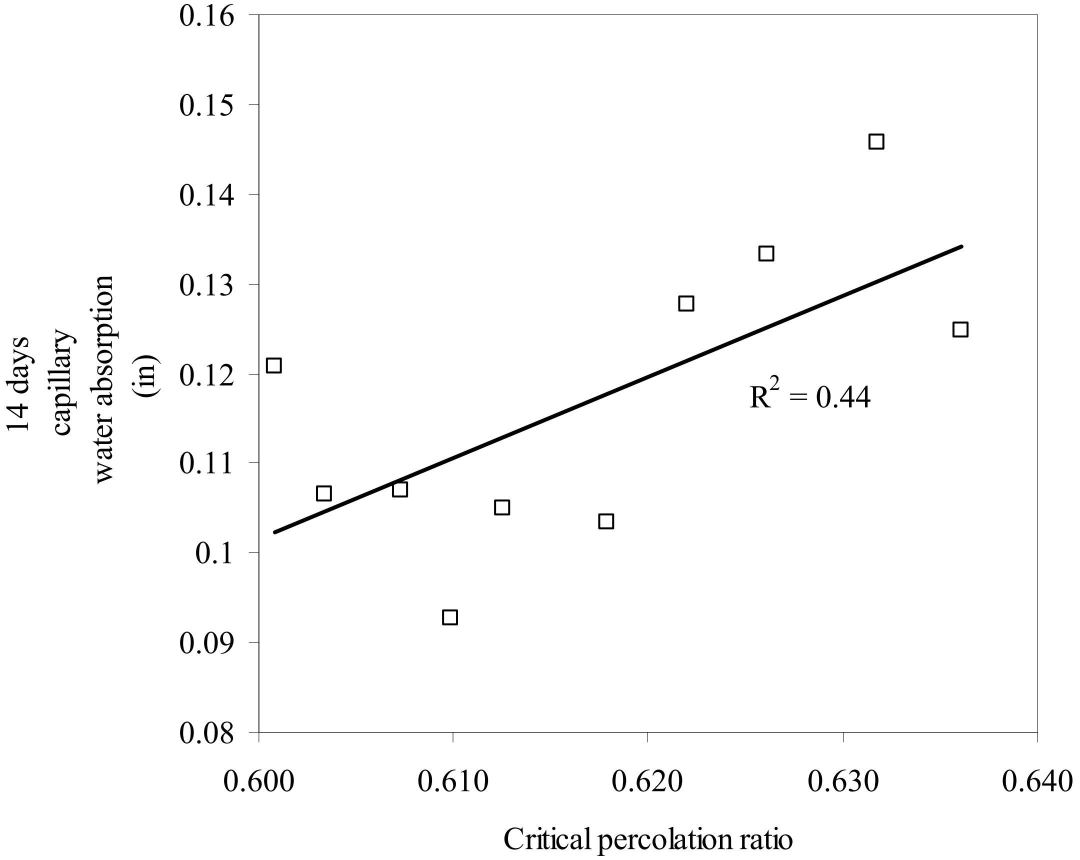

Fig. 6 14 days Capillary Water Absorption Versus Critical Percolation Ratio

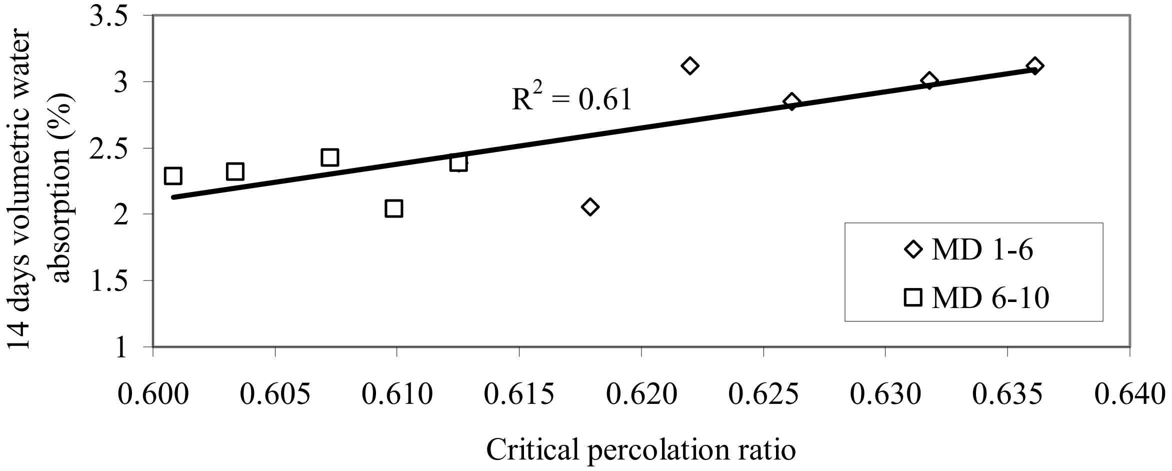

Fig. 7 14 days Volumetric Water Absorption (%) Versus Critical Percolation Ratio

This phenomenon can also be interpreted using the concept of the paste thickness. The "average thickness" of the paste layer can be calculated by dividing the volume of paste in a mix by the surface area of the aggregates in that mix. If one imagines a mix with a constant paste volume, then an increased aggregate volume will mean a greater total volume and a greater surface area, and hence a thinner layer of paste spread across that surface area. This quantity is not actually the thickness of paste around each aggregate; but is useful for rationally sampling various aggregate contents. The volume of the freshly mixed paste was calculated from the mass of its constituents by assuming a specific gravity of 3.15 and 2.20 for cement and silica fume respectively. The surface area of the aggregate was calculated from the particle size distribution given in Table 2 assuming spherical particles[12].

Average paste thickness was calculated for all mix designs and its diagram versus PF was drawn as follows.

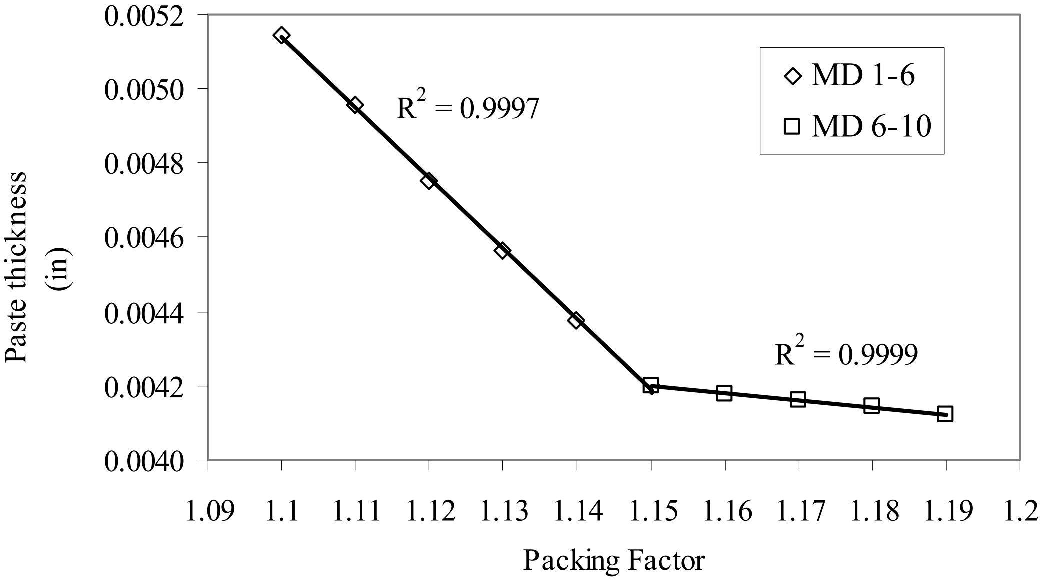

Fig. 8 Paste Thickness Versus Packing Factor

As it is observed this diagram is so analogous to that of percolation ratio versus PF diagram, thus when PF is increased the paste thickness will decrease. Consequently the porous microstructure in the transition between aggregates and cement paste will diminish. As a result, as we interpreted in the preceding lines water permeability will decrease when increasing PF.

There are two noticeable exceptions in both figures that must be discussed. MD5 and MD7 mix designs do not fulfill the rule that were mentioned before. It is not a certain reason but probably it can be explained by taking the rheology of these two mix designs into consideration.

Since the superplacticizer content is increased in MD5 in comparison with MD4, the slump flow of MD5 has increased. Consequently the flowability of MD5 has increased and it was better compacted than MD4. So, less porous structure was formed in MD5 and less permeability was observed. Such comparison can be done between the L-Box ratios of these two mix designs. These discussions are valid when comparing MD5 with MD6.

Comparing MD7 with MD6 and MD8, it is observed that MD7 L-Box ratio is significantly higher than those of MD6 and MD8. So, because of the same reason that mentioned for MD5, it has less porous structure and consequently less water absorption.

COMPRESSIVE STRENGTH

Considering data from compressive strength test, it can be observed that all mix designs fall in nearly the same range of compressive strength (4050-5050 psi), namely PF dose not have any special effect on compressive strength. In other words one can say that in the six first mix designs by substituting some volume fraction of cementitous materials with aggregate content and in the last five mix designs by substituting some volume fraction of limestone powder content with aggregate content no significant change occurred in the compressive strength of specimens.

It must be noted that W/C.M ratio is constant for all mix designs but W/Powder ratio differs for various mix designs.

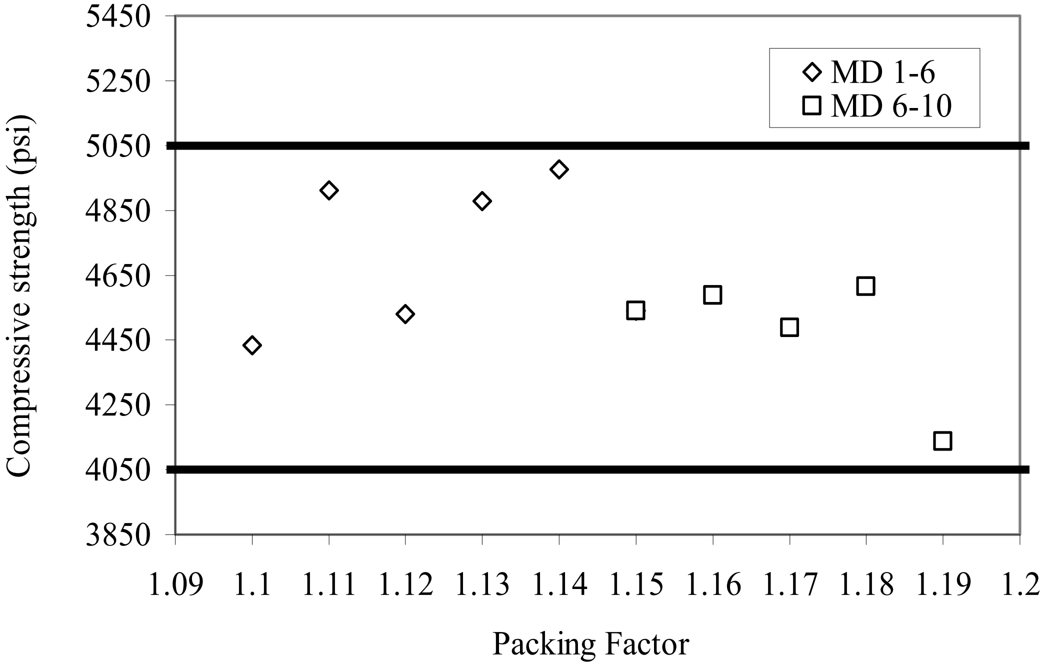

Fig. 9 Compressive Strength Versus Packing Factor

CONCLUSIONS

According to the foregoing paragraphs the following conclusions can be drawn:

In this work by using both theoretical basis and experimental data it was shown that capillary water absorption is related to the root of elapsed time via linear equation. Rate of absorption differs over two specific periods. A short period which lasts less than one day and a long one that continues up to the end of test process. This difference originates from the fact that the size of pores which absorb water during the short interval is larger than those that work in the other one. Since the rate of absorption is directly proportionate to the radius of pores, the absorption rate is greater in the first interval.

Having observed the results of volumetric absorption test, it was revealed that the volumetric water absorption has also a linear relation with the root of elapsed time. Along the same line with capillary water absorption, volumetric water absorption rate is different for short and long periods of elapsed time. Short intervals of time have a higher absorption rate. A probable reason for this phenomenon can be the variations of coefficient of permeability of concrete during the absorption process which is due to the variations of absorbent pores sizes and saturation ratio of specimens. According to Darcy's law for the seepage of fluids inside of porous mediums, variation of K can directly influence the rate of fluid discharge inside a porous media.

Generally by increasing aggregate packing factor in self consolidating concrete, both capillary and volumetric water absorption, have descending rate that can be justified by using the percolation or paste thickness concepts.

One of the most important conclusions to be considered is the fact that rheology is a basic characteristic in self consolidating concrete that can affect all other properties of this concrete such as mechanical and permeability properties. Since this type of concrete is not vibrated by external mediums, it must be completely capable of compacting itself. Otherwise it will not achieve the required properties.

In this research by reducing 21.4% of the consumption of cementitous materials in first 6 mix designs and replacing aggregates instead of limestone powder in last 5 mix designs, the produced concrete was more economical without losing any of its required properties.

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