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論 文

[1209] New Aspects Affecting the Mutual Relation between Strength and Permeability of Concrete

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1. INTRODUCTION

It is essential that concrete should withstand the conditions for which it has been designed without deterioration, over a period of years. The permeability of concrete is influenced by the environment in which the concrete is exposed or internal factors within the concrete itself. The external factors can be physical, chemical or mechanical : they may be due to weathering, occurrence of extreme temperature, abrasion, electrolytic action, and attack by natural and industrial liquids and gases. The internal factors are alkali-aggregate reaction, volume change due to differences in thermal properties of aggregates and cement paste. The permeability of concrete largely determines the vulnerability of concrete to external agencies, so that in order to be durable concrete, the concrete must be relatively impervious.

The higher permeability of mortar or concrete in actual structures is due to the following reasons :

1. Formation of micro-cracks due to long-term drying shrinkage.
2. Rupture of interface bond between aggregate and paste due to unequal thermal stresses.
3. Cracks generated through construction stresses.
4. Due to volume changes caused in the concrete on account of various minor reasons.
5. Existence of entrapped air due to insufficient compaction.

In this paper the light is focused on the relation between permeability and strength of concrete by using local materials and using the water penetration depth method (input method) [1] to measure the permeability of concrete. Also, the effect of changing the mix proportions during mixing and casting on permeability and strength of concrete is highlighted.

2. EXPERIMENTAL WORK

Experimental tests have been carried out on standard concrete cylinders (diameter = 15 cm, thickness = 15 cm). Such cylinders were used to measure the concrete permeability to water. Also, axial compressive tests were carried out on standard concrete cubes (side = 15 cm) under static loading up to failure. The study takes into consideration the following parameters : cement content, sand-gravel (S/G) ratio, water-cement (W/C) ratio, nominal maximum size (N.M.S) of gravel, curing duration, specimens age and type and dose of available admixtures.

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Usually the concrete workability (slump) is predetermined, however, in this paper the reported value of the slump was actually measured and the range of actual measurement varied from no slump to 15 cm. Further, no attempt was made to determine the air content and porosity.

The depth of water penetration into a concrete specimen under a pressure of 10 bar (i.e hydraulic head equivalent to 100 m water column) has been determined by splitting the test specimen after 24 hours of pressure application and the mathematical relation between the permeability coefficient and penetration depth resulting in eq.1. Fig.1 shows sketch of permeability test apparatus.

$$K = X^2/(2ht) \qquad (1)$$

where:

K = permeability coefficient (m/s),
X = the greatest water penetration depth (m),
h = hydraulic head (m), and
t = duration of pressure application (sec).

Eq.1 is used to determine the value of concrete permeability to compare all the mixes. This equation does not take into consideration other parameters affecting the permeability coefficient of concrete such as size and distribution of the pores, open porosity, etc. Testing method and data taken for this paper are described in details in Ref.[2] and the experimental work was carried out in concrete laboratory, Constructions Research Institute, Water Research Center(WRC), Ministry of Public Works and Water Resources (MPWWR), Cairo, Egypt.

3. ANALYSIS AND DISCUSSION OF RESULTS

The analysis and discussion will illustrate to a considerable degree how the permeability of the concrete media is affected by some important parameters. Also, what is the possible mutual relationship between the most common measured properties of produced concrete and its corresponding permeability.

3.1 EFFECT OF MAIN PARAMETERS ON PERMEABILITY AND COMPRESSIVE STRENGTH OF CONCRETE

(1) Influence of cement content

From Fig.2, it is evident that the cement content has direct effect on both permeability and compressive strength of concrete. It is worthwhile to mention that the obtained test results coincide with that is obtained in previous research [3]. Permeability of concrete decreases as strength increases as a result of increasing the cement content.

(2) Influence of sand-gravel ratio

It is recognized that the permeability of aggregate itself effects the behavior of the concrete. If the aggregate has a very low permeability, its presence reduces the effective area over which the flow can take place. From Fig.3, it is obvious that the relationships are similar where permeability decreases as sand-gravel ratio increases up to a ratio of 1:2. Beyond this ratio permeability coefficient increases tangibly by increasing sand-gravel ratio. The same trend is the case with variation of compressive strength with the variation of the sand-gravel ratio. It is interesting to point out that the previous studies had examined certain aspects of the effect of sand-gravel ratio on the concrete properties, especially on the strength and permeability [4].

(3) Influence of curing duration

The interpretation of the results (see Fig.4) shows that the longer

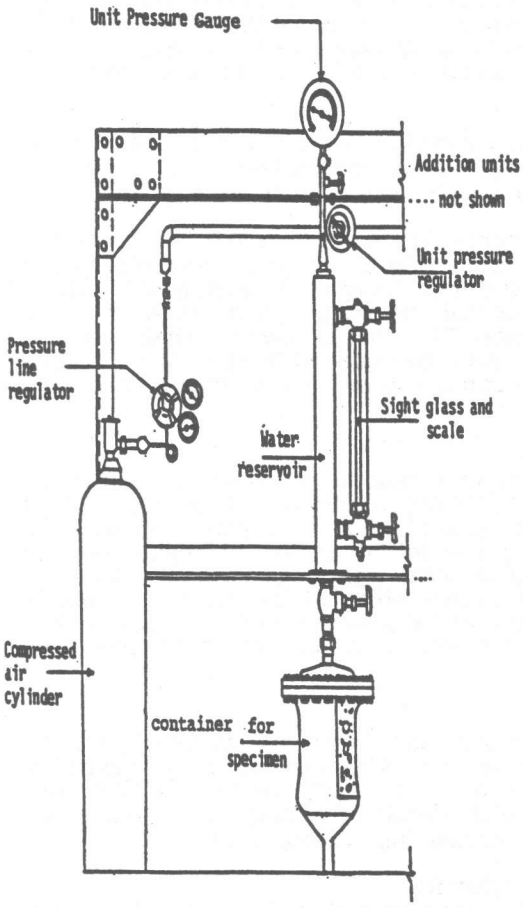

Fig.1 Sketch of permeability test apparatus.

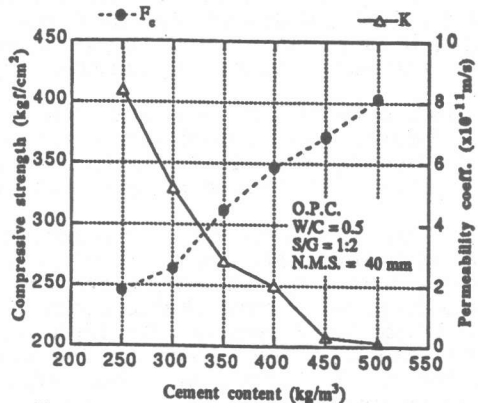

Fig.2 Permeability coeffeicient & compressive strength v.s. cement content.

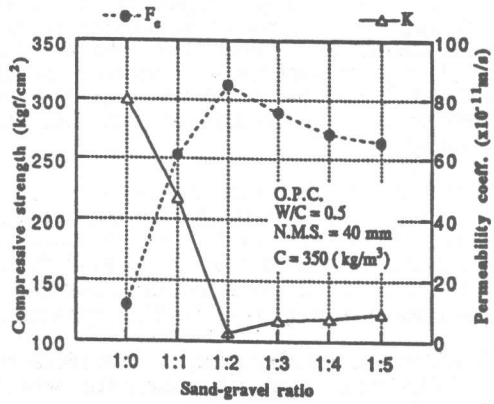

Fig.3 Permeability coefficient & compressive strength v.s. sand-gravel ratio.

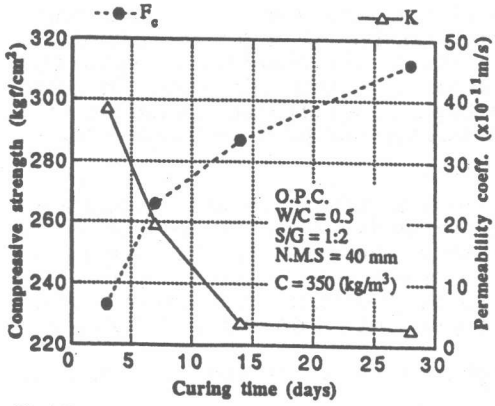

Fig.4 Permeability coefficient & compressive strength v.s. curing time.

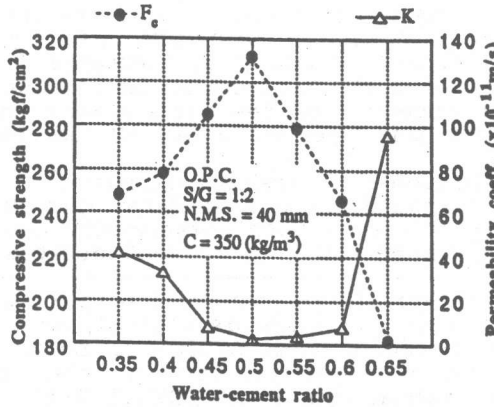

Fig.5 Permeability coefficient & compressive strength v.s. water-cement ratio.

the period during which concrete specimens are kept in water, the greater the final strength and the lower corresponding permeability become. From Fig.4, it is appeared that the permeability coefficient after 3 days curing equals about 14 times the permeability coefficient after 28 days curing.

(4) Influence of water-cement ratio

Concrete mix containing a minimum amount of water required for complete hydration of its cement, if it could fully compacted, would develop the maximum attainable strength and minimum permeability at any age.

Fig.5 indicates that for concrete mixes having W/C $\geq$ 0.5 the concrete strength increases as the W/C decreases. However, for concrete mixes having W/C $\leq$ 0.5 the mixes are dry and not completely compacted, which leads to give an unworkable concrete containing large percentage of voids and hence low strength with high permeability. It is obvious that the W/C ratio had adverse effect on the concrete permeability (see Fig.5). The scatter of the results is rather large properly due to the diversity of the hand compaction.

(5) Influence of concrete specimen age

In this research we are interested in practical problems of concrete tested at different ages under the same curing conditions. From Fig.6, it is evident that the strength of concrete grows over a lengthy period, the most rapid increase is observed during the initial period of hardening up to 28 days, and then the rate decreases with age. Also, it is indicated that the permeability of concrete is adversely affected by its age. This is ascribable to the completion of the hydration process which leads to the increase in the volume of gel and hence decrease the voids in the produced concrete.

(6) Influence of N.M.S.of gravel

From Fig.7, it is declared that the strength increases as the N.M.S. of gravel increases and also at the same time the concrete permeability decreases as the N.M.S. of gravel increases. It is interesting to point out that the obtained test results conflict with result of Pihlagavaara work [4]. This confliction is due to the different measuring concepts used.

(7) Effect of admixtures on concrete properties

The important purposes for which admixtures have been used in this research are:

1.Increase in strength.
2.Decrease in the permeability to liquids.

(a)Influence of permeability admixture*

Fig.8 indicates that the permeability of concrete decreases by increasing the dosage of admixture. Also, the compressive strength increasing as the dosage of admixture increases for a given mix proportion. When the surface of the concrete specimens was examined, a thin film white in color was observed on the surface with this type of admixture. Without any doubt, this layer will affect all the characteristics of produced concrete.

(b)Influence of strength admixture**

From Fig.9, it is declared that this type of admixture has a satisfactory effect on both permeability and compressive strength of concrete. The permeability coefficient decreases with the increase in dosage of

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*Water-proofing agent for concrete , works as plasticiser and water reducing agent, no chloride content, brown liquid with density 1.12 kg/liter. (Commercial name is ADDICRETE DM2).

** Super-plasticiser for concrete, complies with ASTM 494 A, B and G. (Commercial name is ADDICRETE BVS).

The two types are produced in Egypt. (CMB LEYDE company).

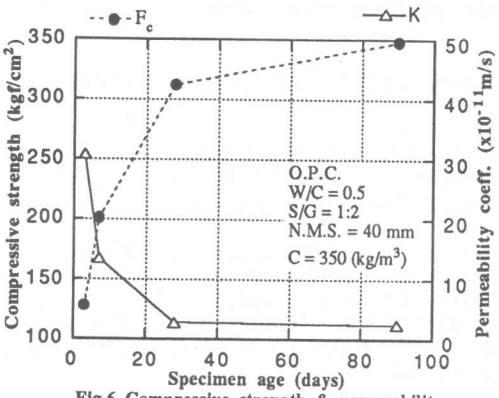

Fig.6 Compressive strength & permeability coefficient v.s. specimen age.

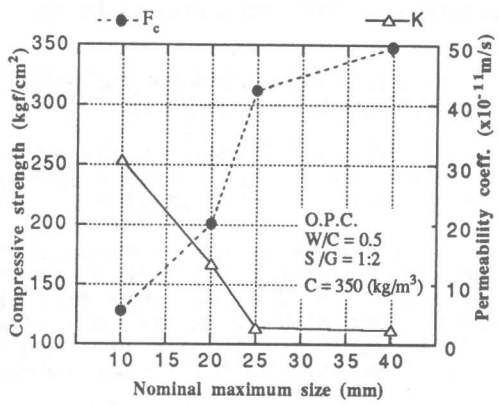

Fig.7 Compressive strength & permeability coefficient v.s. nominal maximum size.

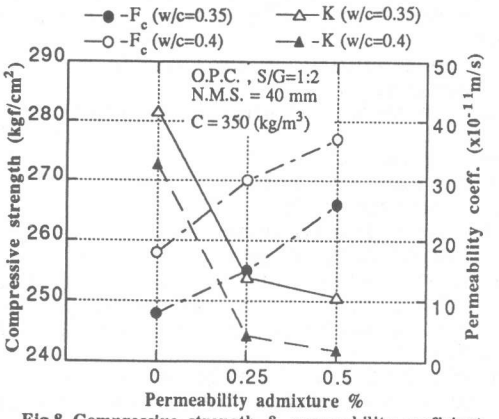

Fig.8 Compressive strength & permeability coeficient v.s. permeability admixture dosage.

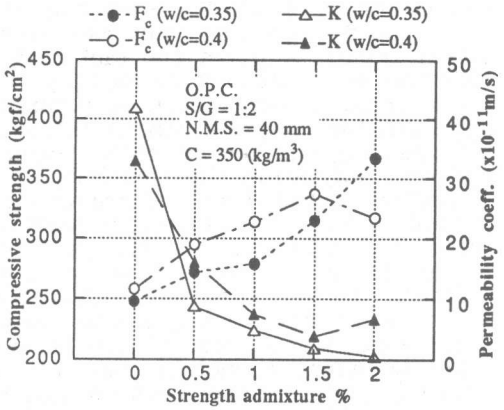

Fig.9 Compressive strength & permeability coefficient v.s. strength admixture dosage.

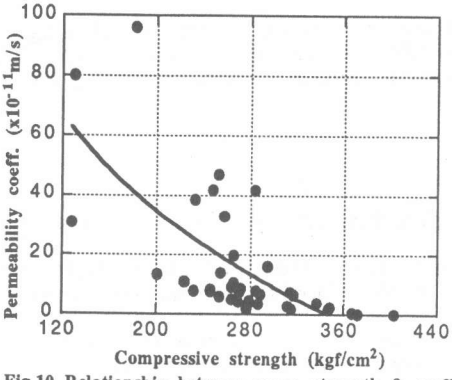

Fig.10 Relationship between comp. strength & coeff. of permeability for all concrete mixes.

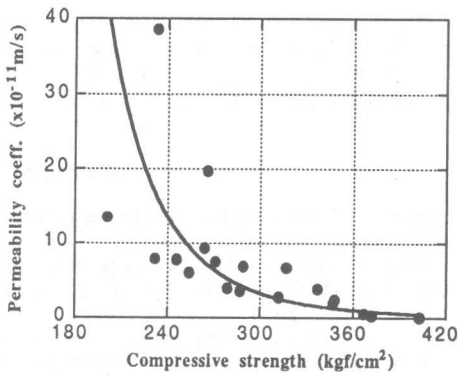

Fig.11 Relationship between comp. strength (>200kg/cm²) and permeability coeff. for mixes having slump >5cm.

admixture for both of w/c = 0.35 and 0.40. Also, the compressive strength increases with the trend as in the decrease of permeability.

4. MUTUAL RELATIONSHIP BETWEEN PERMEABILITY AND COMPRESSIVE STRENGTH OF CONCRETE

The obtained test results showed how the permeability of concrete is affected by its compressive strength in the trend that the increase of strength is accompanied with a decrease in the permeability.

Fig.10 shows the relationship between the permeability coefficient of concrete and corresponding compressive strength for all obtained test results. For practical considerations the concrete should have the minimum slump of 5 cm as well as a cube compressive strength of higher than 200 kgf/cm^2, therefore a new relationship between permeability coefficient and compressive strength was found as shown in Fig.11.

5. CONCLUSIONS

On the basis of experimental work, this paper comprises the test results of 47 mixes for strength and permeability with different parameters. The following are the main findings :

1.Test results support the fact that the permeability of concrete is a function in its quality defined by its strength.

2.For practical consideration, a minimum permeability and hence high strength for concrete can be achieved by :

a)Increasing the cement content and curing period.

b)Proper adjusting the richness, S/G ratio and W/C ratio.

c)Increasing the N.M.S. of gravel up to a certain limit.

d)Good mixing and compaction leading to high graded concrete.

e)Using certain and specific type with proper dose of admixtures.

3.Test results showed that strength admixture is more beneficial and effective rather than permeability admixture from both permeability and strength improvement point of view. So the preliminary tests should be carried out on any admixtures before using it.

4.The arbitrary acceptable limit of coefficient of permeability is 1.5×10^{-11} (m/s) [1] for concrete which can be achieved by adding admixtures or changing the concrete mix proportions.

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REFERENCES

1.Bureau of Reclamation Materials Laboratories Procedures Manual, Chapter 5, Section 37, Permeability.

2.Mohamed Anwar, "New Aspects Affecting the Mutual Relation between Strength and Permeability of Concrete ", M.Sc Thesis, Assiut University, Assiut, Egypt, 1991.

3.Jukka Vuorimen, "Application of Diffusion Theory to Permeability Tests on Concrete.", Magazine of Concrete Research, Vol.11, No.132, Sep. 1985.

4.Pihlajavaara, S.E.and Paroll, "On the Correlation Between Permeability Properties and Strength of Concrete." Cement and Concrete Research, Vol.5, pp. 321-328, 1975.