WATER RETAINABILITY AND FREE WATER IN FRESH CONCRETE

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ABSTRACT

This paper explains the concept of water retainability and free water content in fresh concrete mixture that are the main factors affecting consistency of fresh concrete. The volume of free water can be obtained by deducting the water which is retained by solid particles from the total water in the fresh concrete mixture. Surface area of the solid particles is considered to be a major control parameter for water retainability of the solid particles. Surface area of powder materials can be obtained from the measured specific surface area by air permeability method (Blaine fineness). Surface area of the aggregate particles is computed from the gradation curve by assuming that its shape is spherical, then the angularity factor (ψ) is applied to account for the effect of irregularity of the aggregate particles. The water retained by powder material can be easily evaluated by finding a point of lowest water to powder material ratio by weight that initiates slump of the paste which was made from the powder material. The surface water retainability of aggregate is derived from the back analysis of the measured slump data.

INTRODUCTION

Concrete properties can be simply considered into fresh state and hardened state. The properties of fresh concrete are significant in the construction stage while the properties of hardened concrete are important for the whole service life. However, both properties can not be considered separately because they are inter-related. The appropriate workability is a vital requirement for any concrete of good quality. The traditional method for mix proportioning of fresh concrete is based on the trial mix method, especially for concrete with various types of powder materials. It is beneficial if a consistency prediction model can be established to minimize the processes of mix proportioning. Glanville et al. [1] define the workability as that property of the concrete that determines the amount of useful internal work necessary to produce full compaction. The term "useful internal work" in this definition means the work that is required to overcome the internal friction between the individual particles in the concrete. In practice, there are numerous factors affecting concrete consistency such as maximum size of aggregate, gradation, shape and fineness of solid particle, etc. Free water content is also a major parameter in considering consistency of fresh concrete. It is well known that the consistency of fresh concrete increases if the unit water content of the concrete is increased. However, it is also known that solid particles have capability to retain some water both inside and on the surface of the solid particles. Thus, the concept of water retainability and free water in fresh concrete must be explicitly explained.

CONCEPTS OF WATER RETAINABILITY AND FREE WATER

Free water content

Water in the fresh concrete mixture is considered to be divided mainly into 2 types, namely water retained by solid particles and free water. Water retained by solid particles means the amount of water that is retained by solid particles and moves together with the solid particles. This type of water consists of water absorbed in the solid particles and water adsorbed at the surface of the solid particles. The water consumed by hydration is neglected in the prediction of initial slump due to its small amount. Free water is then defined as the rest of the water which can travel independently of the solid particles. This free water is considered to affect the consistency of fresh concrete.

The concept of water retainability will be used instead of the absorption and adsorption. The water retainability is absorption plus the adsorption. Therefore, it can be simply concluded that the free water content (W_{fr}) in the concrete mixture can be calculated by the following expression.

$$W_{fr} = W_t - W_r \tag{1}$$

where W_t is the total water content in the mixture which also includes the water absorbed in the aggregate particles, kg/m^3 of concrete,

W_r is the water retainability of all solid particles, kg/m^3 of concrete.

Since it is more convenient in practice to implement the aggregate in saturated surface dry condition, also the unit water content is more familiar than the total water content (W_t). The following equation may be applied, instead of Eq. (1), to compute free water content

$$W_{fr} = W_u - W_{rp} - W_{ra}' \tag{2}$$

where W_u is the unit water content in the mixture, kg/m^3 of concrete,

W_{rp} is the water retainability of powder materials, kg/m^3 of concrete.

W_{ra}' is the surface water retainability of aggregates, kg/m^3 of concrete.

The water retainability of powder materials and the surface water retainability of aggregates can be expressed as in the following equations:

$$W_{rp} = \Sigma\beta_{pi}w_{pi} \quad (3)$$

$$W_{ra}' = \beta_s'w_s'+\beta_g'w_g' \quad (4)$$

where β_{pi} is the water retainability coefficient of powder material type i,

w_{pi} is the absolutely dried weight of powder material type i, kg/m^3 of concrete,

β_s', β_g' are the surface water retainability coefficients (excluding absorption) of fine and coarse aggregate, respectively,

w_s', w_g' are the saturated surface dried weights of fine and coarse aggregate, respectively, kg/m^3 of concrete.

TESTS AND DETERMINATION OF WATER RETAINABILITY

Determination of water retainability of powder materials

In this study, an easy method for estimating water retainability of powder materials is introduced by finding a point of lowest water to powder material ratio by weight (w/p) that initiates slump of the paste using a mini-slump test. This method can be stepwise conducted by mixing the powder paste with a guessed value of water to powder material ratio starting from low ratio so that the mixture has zero slump. Then place a portion of mixture, approximately one third of the volume of the mold, in the mold (a metal mold in the form of a frustum of a cone with dimensions as follows : 40 ± 3 mm inside diameter at the top, 90 ± 3 mm inside diameter at the bottom, and 75 ± 3 mm in height) and tamp it 25 times with a tamper (a metal tamper weighing 340 ± 15 g. and having a flat circular tamping face 25 ± 3 mm in diameter.) Place the other two portions of mixture and tamp it until the mold is full. Immediately after filling, remove the mold from the mixture by raising it carefully in a vertical direction and measure the slump of the mixture. Repeat the entire step by increasing the water to powder material ratio until slump is initiated. The water to powder material ratio which initiates slump is a water retainability coefficient (β) of that powder material. This method is applied to find the water retainability coefficient of all powder materials in this study. It is noted here that water retainability of powder materials tested by this method means the minimum amount of water which is required to overcome the interparticle surface force (cohesion and friction) of the powder materials under its self-weight.

Determination of surface water retainability of fine and coarse aggregates

The surface water retainability of fine and coarse aggregate can be derived from the back computation of the data obtained from test results and the data from other researchers' studies [2,3,4]. It is assumed in this study that water retainability of solid particles is the function of specific surface area of the solid. For powder materials, specific surface area is tested by air permeability method (Blaine fineness). However, for aggregate, due to the irregular shape of the aggregate particles, the exact surface area of aggregate is difficult to measure directly. An indirect method can be used to compute surface area of aggregate by assuming that the shape of aggregate particles is spherical. The specific surface area of aggregate on spherical shape basis can be calculated from the gradation curve as expressed in the following equation:

$$S_0 = \frac{\pi D_{av}^{\ 2}}{w} \qquad (5)$$

where S_0 is the specific surface area of aggregate on spherical shape basis, cm^2/g,

D_{av} is the average diameter of the aggregate particles, cm,

w is the average weight of the aggregate particles, g.

The average diameter of the aggregate particles (D_{av}) and its average weight (w) can be computed from

$$D_{av} = \frac{\Sigma D_i M_i}{\Sigma M_i} \qquad (6)$$

$$V_{av} = \frac{\pi}{6} D_{av}^{\ 3} \qquad (7)$$

$$w = \rho V_{av} \qquad (8)$$

where D_i is the average of size group dimensions between the upper sieve and the sieve i which aggregate particles are retained, cm,

M_i is the percentage of retaining on the corresponding sieve of the aggregate group i, (%),

V_{av} is the average volume of the aggregate particles, cm^3,

ρ is the specific gravity or density (SSD) of the aggregate, g/cm^3.

The angularity factor (ψ) which represents the ratio of the specific surface area of a certain size group of irregular particles to the specific surface area of the same size group of spheres is then applied to account for the irregularity of the particles. Loudon [5] found that angularity factor of a certain size group was related to the void content of aggregate as

$$\psi = 1 + 4.44(\varepsilon - 0.42) \quad (9)$$

where ε is the void content in a single size-group in the loose state of the aggregate.

As in the above concept, the actual specific surface area of irregular aggregate (S) can be estimated by multiplying the angularity factor (ψ) to the specific surface area of the assumed spherical aggregate calculated from sieve analysis (S_0) as:

$$S_s = \psi_s \times S_{so} \quad (10)$$

$$S_g = \psi_g \times S_{go} \quad (11)$$

where S_s, S_g are the specific surface areas of irregular fine and coarse aggregates, respectively, cm^2/g,

ψ_s, ψ_g are the angularity factors of fine and coarse aggregates, respectively,

S_{so}, S_{go} are the specific surface areas of the assumed spherical fine and coarse aggregates calculated from sieve analysis, respectively, cm^2/g.

Therefore, total surface area of aggregate (S_{tagg}) can be computed from

$$S_{tagg} = S_s w_s + S_g w_g \quad (12)$$

where w_s, w_g are the saturated surface dried weight of fine and coarse aggregate, respectively, kg/m^3 of concrete.

Materials

Table 1 and Table 2 show the physical properties of powder materials, fine aggregate and coarse aggregate used in the experiments.

TEST RESULTS AND DISCUSSIONS

Water retainability of powder materials

As mentioned in concept of water retainability and free water, β_p is a water retainability coefficient of powder material that is equal to the value of water to powder material ratio by weight that initiates slump of paste. The water retainability of powder material depends on many factors, such as porosity of particle, surface condition of particle, particle shape and size. In this study, surface condition of particle, particle shape and particle size are reasonably considered in order to relate with the specific surface area of the powder materials. Therefore, the water retainability of powder materials is evaluated from the specific surface area of the powder materials. The effect of porosity of powders is still not considered in this study. Test results of the water retainability coefficient of powder materials is shown in Table 1.

The relationship between the water retainability coefficient of powder material (β_p) and the specific surface area of powder material (S_p) is shown in Fig. 1 and can be expressed as in Eq. (13),

$$\beta_p = 1/\rho_p \left(0.0015(S_p)^{0.7545}\right) \quad (13)$$

where ρ_p is the specific gravity or density of powder material, g/cm^3.

From this relation it can be found that if the surface area of particle is higher, the water retainability of powder material is also higher.

Table 1 Physical properties of powder materials used in this study

Type of powder	Physical properties					
	Specific gravity	Blaine fineness (cm^2/g)	% Retaining on sieve No. 325	Moisture content (%)	β_p by weight	β_p by volume
Cement (C)	3.15	3122	8.60	0.11	0.23	0.7245
Lignite fly ash (FA1)	1.90	1824	44.50	0.12	0.21	0.3990
Lignite fly ash (FA2)	1.93	2076	43.88	0.07	0.20	0.3860
Lignite fly ash (FA3)	2.28	2347	NA	NA	0.18	0.4104
Lignite fly ash (FA4)	2.16	1646	NA	NA	0.18	0.3888
Lignite fly ash (FA5)	1.88	1498	NA	NA	0.21	0.3948
Anthracite fly ash (FA6)	2.26	2575	12.60	0.37	0.31	0.7006
Pumicite (PU)	2.36	2557	45.27	0.52	0.29	0.6844
Metakaolin (MK)	2.38	9169	NA	0.44	0.52	1.2376
Rice husk ash (RHA)	2.15	8240	74.85	1.28	0.69	1.4835

Table 2 Physical properties of fine and coarse aggregates adopted in this study

Type of aggregate	Physical properties					
	Bulk specific gravity (SSD)	Bulk specific gravity (dry)	Apparent specific gravity	Absorption (%)	Fineness modulus	Maximum Size (mm)
S 1	2.60	2.58	2.63	1.18	2.41	4.75
S 2	2.61	2.59	2.66	1.10	2.52	4.75
S 3	2.58	2.55	2.62	1.13	2.46	4.75
S 4	2.44	2.41	2.48	1.25	3.01	4.75
S 5	2.67	2.65	2.71	1.10	1.68	4.75
G 1	2.71	2.69	2.75	0.78	NA	19
G 2	2.73	2.70	2.77	0.93	NA	19
G 3	2.73	2.71	2.77	0.88	NA	19

Note : S and G are natural river sand and crushed limestone, respectively.

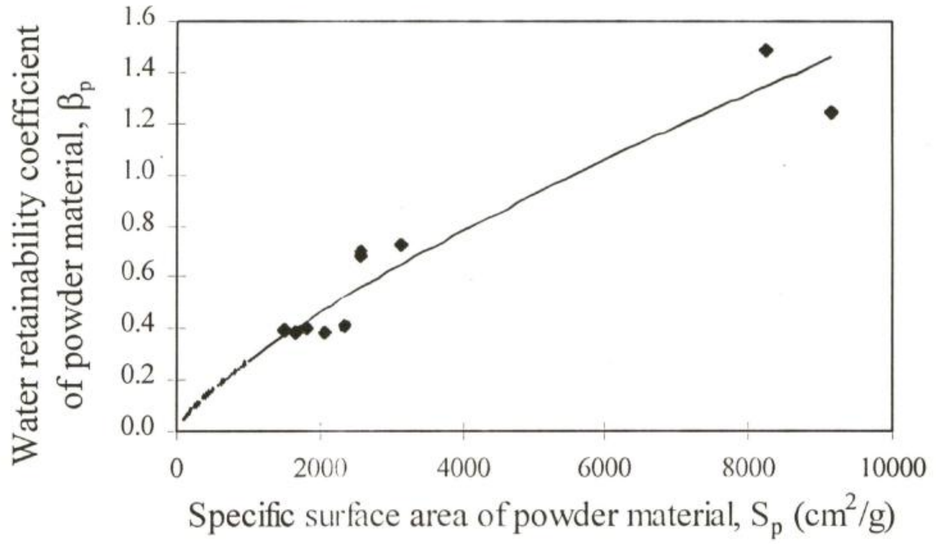

Fig. 1 Relationship between water retainability coefficient and specific surface area of powder material

Water retainability of fine and coarse aggregates

From the back analysis of various slump test results using the slump prediction model, the relationship between the surface water retainability coefficient and specific surface area of aggregate can be obtainend as in Eq. (14),

$$\beta_{agg}' = 2 \times 10^{-6} (S_{agg})^{0.9237} \quad (14)$$

where β_{agg}' is the surface water retainability coefficient (excluding absorption) of aggregate and S_{agg} is specific surface area of aggregate, cm^2/g. In case of fine aggregate, β_{agg}' and S_{agg} are equal to β_s' and S_s, respectively. Also in case of coarse aggregate, β_{agg}' and S_{agg} are equal to β_g' and S_g, respectively.

It is assumed in this study that since the fine and coarse aggregates are not much different in the view point of physical properties except the particle size, the same relationship between water retainability and surface area can be applied to both fine and coarse aggregates.

In practice, the water retainability of coarse aggregate is negligible because the surface area of coarse aggregate is just about 5% of the surface area of fine aggregate. Therefore, the water retainability coefficient of coarse aggregate is much smaller than those of the fine aggregate and powder materials.

CONCLUSIONS

The following conclusions can be drawn based on the conducted test and analytical results:

1. The water retainability of powder materials can be simply evaluated by applying the mini-slump test method, finding a point of lowest water to powder material ratio by weight (w/p) that initiates slump of the paste.

2. The water retainability of all solid particles is higher when the specific surface area of the solid particle is higher.
3. The effect of the surface water retainability of coarse aggregate on the unit water content of concrete mixture is small compared with sand and powder materials.

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