A SLUMP PREDICTION MODEL FOR FRESH CONCRETE BASED ON WATER RETAINABILITY AND FREE WATER CONCEPTS

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ABSTRACT

The aim of this study is to propose a model for predicting slump of fresh concrete. The major parameters which are utilized for predicting the slump value of fresh concrete are the ratio of paste volume to void content of aggregate phase (γ), free water content (W_{fr}), surface area of aggregate phase (S_{tagg}) and surface area of powder material (S_{pow}). It was found that the slump of fresh concrete varied linearly with free water content (W_{fr}) but nonlinearly with γ, S_{tagg} and S_{pow}. A mathematical model for predicting slump of fresh concrete was formulated and verified with the actual results obtained from various researchers, it was found that the model could be used to predict the slump of fresh concrete with a satisfactory accuracy.

INTRODUCTION

Generally, mix proportioning of concrete can be regarded as the process by which one selects the proportion of different constituents to give the required properties of quality concrete. The important properties of concrete are its workability in fresh state, performances in plastic and early age states, strength and durability in hardened state. Workability was sometimes taken to mean the degree of wetness of the mixture (Neville and Brooks, [1]) which concerned the relative mobility or ability of a fresh mixture to flow. Powers [2] proposed another definition as "Workability is the combined effect of properties of fresh concrete that determine the amount of internal work required for placement, compaction and resistance to segregation". However, there are no definite test methods which have been established for measuring the workability, therefore the consistency of fresh concrete has been evaluated. This study concentrated on the effect of material types and mix proportion on the workability of fresh concrete. Finally, the model for predicting slump of fresh concrete was proposed.

MODEL FORMULATION

Free water content had been verified to have linear relationship with deformability of self-compacting concrete [3]. In this study, free water content was also proved to have linear relationship with slump of normal concrete as shown in Fig. 1.

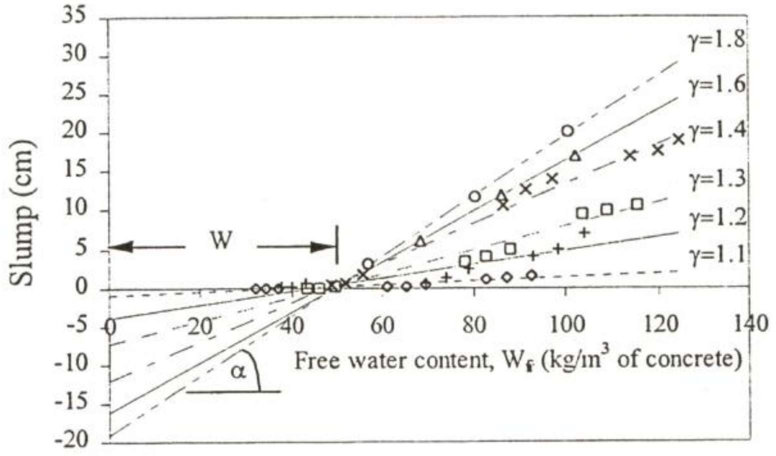

Fig. 1 Relationship between slump and free water content of fresh concrete

From the finding that slump value varied linearly with free water content, the linear equation was introduced in the following form to relate slump value with free water content,

$$SL = \alpha\,(W_{fr} - W_0) \tag{1}$$

where SL is the slump value of fresh concrete, cm,

α is the slope of slump-free water content curve of fresh concrete, cm/kg/m^3,

W_{fr} is the volume of free water in fresh concrete, kg/m^3,

W_0 is the amount of water just enough to overcome interparticle surface force among solid particles of fresh concrete, kg/m^3.

The slope of slump-free water content curve

It was found from the test results in Fig. 1 that slopes of the slump-free water content curves increased with the increase of ratio between paste volume and void content of compacted aggregate phase (γ). The ratio of paste volume to void content of compacted aggregate phase is defined as follows:

$$\gamma = \frac{V_p}{V_{void}} \tag{2}$$

where V_p is the volume of paste in the unit volume (1 m^3) of fresh concrete and V_{void} is the volume of void in the densely compacted total aggregate (fine and coarse aggregates) in the unit bulk volume (1 m^3) of aggregate assembly.

The volume of paste (V_p) can be derived from

$$V_p = V_c + V_w + V_{air} + V_{pow} \quad (3)$$

where V_c, V_w, V_{air} and V_{pow} are the volume of cement, water, air and other powder materials, respectively, in a unit volume (1 m^3) of concrete mixture.

The relationship between slopes of the slump-free water curves can be plotted as shown in Fig. 2 and expressed as the following equation,

$$\alpha = 3.573\gamma^4 - 21.34\gamma^3 + 46.74\gamma^2 - 43.916\gamma + 14.944 \quad (4)$$

As shown in Fig. 1, a greater slump was obtained from mixture with larger γ when considering mixture with a constant free water content due to larger distance among solid particles resulting in smaller interparticle surface forces. When γ is equal to 1.0, the mixture has volume of paste just equal to the void of mixed aggregate. So at this volume of paste, it does not lead to the flow of mixture. For that reason, it is reasonable to fix the slope of slump-free water content curve at the origin when γ is equal to 1.0, that is, no slump occurs in any mixtures with $\gamma = 1.0$.

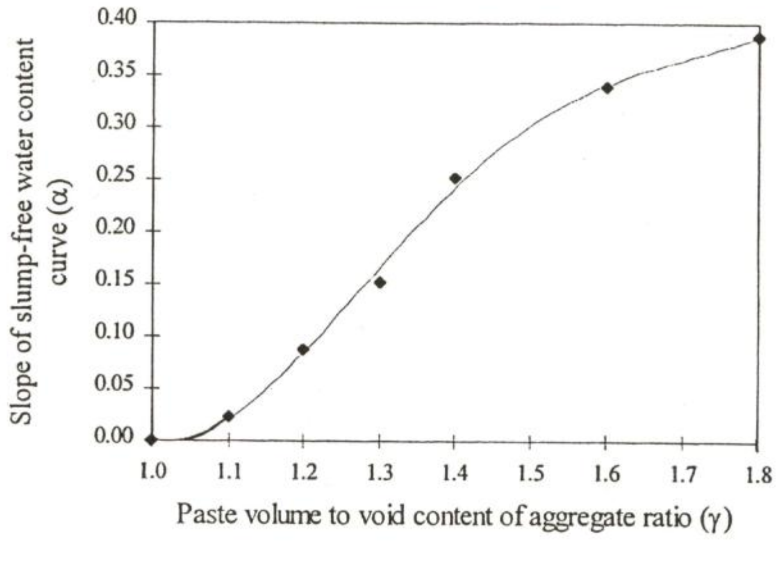

Fig. 2 Relationship between α and γ

Free water content in fresh concrete

According to Tangtermsirikul et al. [4], the free water content in the concrete mixture can be calculated by the following expression,

$$W_{fr} = W_u - W_{rp} - W_{ra}' \quad (5)$$

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

$$W_{rp} = \Sigma\beta_{pi}w_{pi} \quad (6)$$

$$W_{ra}' = \beta_s'w_s' + \beta_g'\,w_g' \quad (7)$$

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 aggregates, respectively,

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

The water retainability coefficient of powder material and the surface water retainability coefficient of aggregate can be expressed as the following

$$\beta_p = 1/\rho_p\left(0.0015(S_p)^{0.7545}\right) \quad (8)$$

$$\beta_s' = 2 \times 10^{-6}\,(S_s)^{0.9237} \quad (9)$$

$$\beta_g' = 2 \times 10^{-6}\,(S_g)^{0.9237} \quad (10)$$

where ρ_p is the specific gravity of powder material and S_p, S_s, S_g are specific surface area of powder material, sand and gravel, respectively, cm^2/g.

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.

The amount of water just enough to overcome interparticle surface forces among solid particles

From Fig. 1, it has been observed that at the point where the curve intercepts the free water content axis (W_0), the amount of free water of the mixture below this point does not produce slump in concrete. This is considered in this study that the amount of this free water is not enough to overcome the interparticle surface forces which include friction and cohesion between aggregate to aggregate and aggregate to powder materials. Since the interparticle surface forces vary with the numbers of feasible interparticle contact area among the solid particles, and particles with larger surface area result in larger contact area, then the interparticle surface forces can be considered to vary with the surface area of the solid particles possible to be in contact which is defined as effective surface area in this study. Then, the amount of water for balancing these interparticle surface forces (W_0) was expressed as the function of the effective surface area of solid particles as

$$W_0 = 8 \times 10^{-5} (S_{eff})^{0.7626} \quad (11)$$

where S_{eff} is the effective surface area of solid particles indicating the maximum possible contact area among the fine aggregates, coarse aggregates and powders, cm^2/m^3 of concrete.

The effective surface area of solid particles (S_{eff}) can be derived from

$$S_{eff} = S_{tagg} + \eta(S_{pow}) \quad (12)$$

where S_{tagg}, S_{pow} are the surface areas of total aggregates and total powder materials in concrete, respectively, cm^2/m^3 of concrete,

η is the effective contact area ratio indicating the ratio of surface area of powder materials which is effectively contacting around aggregates.

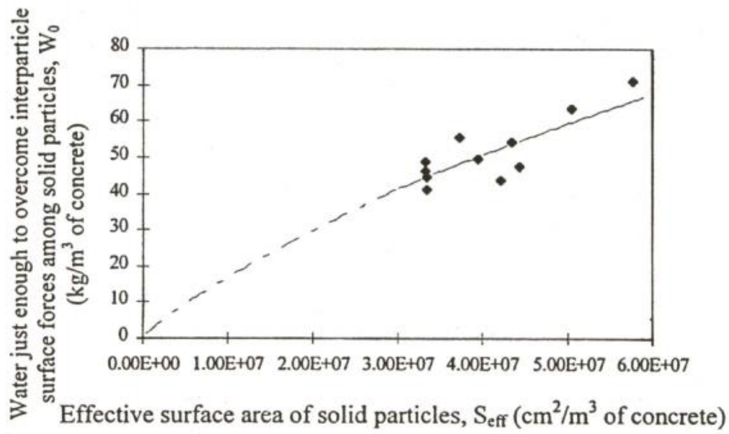

Fig. 3 Relationship between W_0 and S_{eff}

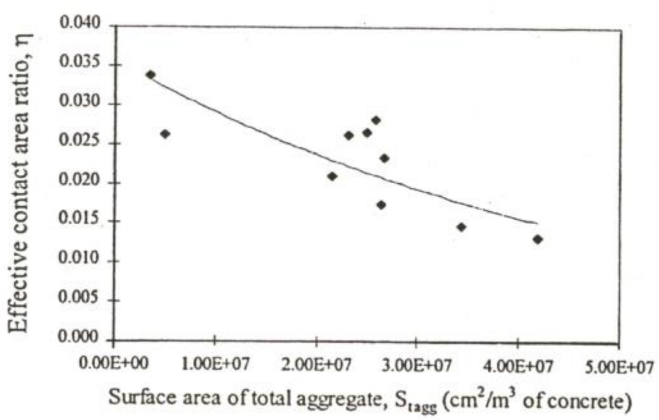

Fig. 4 Relationship between η and S_{tagg}

The function of η can be derived from the back computation of the data and expressed in the following form,

$$\eta = 0.026e^{-3\times10^{-8}(S_{tagg})} \quad (13)$$

From Eq. 1 to Eq. 13, it can be seen that the slump value of fresh concrete depends on four major parameters namely γ, W_{fr}, S_{tagg} and S_{pow}.

VERIFICATION TESTS AND RESULTS

Test results were mostly obtained from other researchers' studies [5, 6, 7, 8] whereas a few tests were conducted by the authors for obtaining slump data of fresh concrete with varied percent replacement of powder material, water to cementitious ratio and the ratio of paste volume to void content of compacted aggregate phase. After formulating and testing the accuracy of the model by comparing the predicted results from the model with the test results, it was found that the developed model could be used to predict the slump of fresh concrete with satisfactory accuracy as shown in Fig. 5.

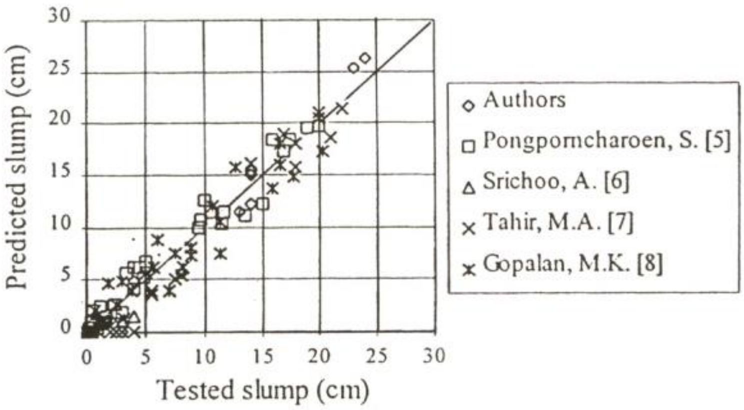

Fig. 5 Comparison between the predicted and tested slump of fresh concrete

CONCLUSIONS

Based on the proposed model and the verification tests, the following conclusions can be made.

1. It was confirmed in this study that the slump of fresh concrete varied linearly with free water content (W_{fr}) in the mixture when the ratio of paste volume to void content of aggregate phase (γ) was constant.
2. Free water content could be obtained from unit water content minus water retainability of powder materials and surface water retainability of aggregates.
3. The higher value of γ resulted in a greater slump of fresh concrete at the same volume of W_{fr}. This was due to larger distance between aggregate particles, resulting in smaller interparticle surface forces.
4. An equation for computing the slump of fresh concrete could be expressed in form $SL = \alpha\ (W_{fr} - W_0)$ as determined in model formulation.

5. The verification tests showed that the proposed model could be used to predict the slump of fresh concrete with a satisfactory accuracy.

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