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論 文

[1199] Effect of Water and Mixing Time on the Mixing Energy and Workability of Concrete Mixture

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1. INTRODUCTION

Water is considered one of the most important constitutions of concrete. However, only adding water to concrete constitution does not produce a workable mix. The mechanical action so called mixing which all solid particles and water can be dispersed throughout the mixture is always necessary. It has already been reported by the authors [1] that once water is added to the single material the mixing energy can be either enhanced or reduced depends greatly on particle size. In this study the following items have been clarified:
1) The effect of amount of water on the energy required to mix the mixture.
2) The effect of amount of water on the relative workability which is indicated by slump value of mixture.
3) The effect of mixing time on the slump value of mixture.

2. EXPERIMENTAL WORKS

All the experiments were carried out by a "Pan" type mixer which designed capacity of 50 liters and constant rotation speed as 74 rpm. The properties of materials used are listed in Table 1. All mix proportions of solid particles are given in Table 2. Mixing volume was approximately 25 to 30 liters. The mixing energy was defined as the increment of the electrical power consumption during mixing from the electrical power required to drive the empty mixer. The mixtures were mixed in dry state for 180 sec to ensure the uniform distribution of solid particles before adding water. For all the cases, mixing time and mixing energy were measured after water was added to the mixture. The experiments can be divided into 3 series as:
1) Different amount of water was added to the mixture in order to observe the mixing energy of mixture with different water content. Mixing time was kept constant at 180 sec.
2) Different amount of water was added to Mix.3, 12, 13 and 14. Mixing time was kept constant at 180 sec. The slump test was performed.
3) A certain amount of water was added to Mix.3, 12, 13 and 14. The slump test was performed at different mixing time. The water retainability and amount of water existing in the hydration products were also investigated.

3. EFFECT OF WATER ON MIXING ENERGY

It has already been reported by the authors [4] that the electrical power consumed during mixing of solid particles in dry state depended not only on the type of mixture but also on

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Table.1 Properties of materials used

	G20	sand	slag	cement
SSB (cm^2/g)	—	—	3940	3350
max.size (mm)	20.0	5.0	—	—
av. dia (mm)	10.15*	0.22*	0.00525**	0.00567**
Specific gravity, ρ	2.70	2.63	2.90	3.16
Retainability, γ^+ (%)	0.00	3.55	29.09	26.14
Absorption, α (%)	0.69	1.45	—	—
Water content, w (%)	0.24	0.18	—	—

* Calculated from equation given by Power.[2]
** Calculated from "Blaine value, SSB" as:

$$av.dia = \left(\frac{6}{\rho * SSB}\right)$$

\+ Obtained from test method proposed by Okamura.[3]
++ water is varied from 0-15 kg

Table.2 Amount of constituents of mixture

Mix no.	G20 (kg)	sand (kg)	slag (cement) (kg)	water++ (kg)
Mix 1	—	36.4	5.0	varied
Mix 2	—	36.4	10.0	varied
Mix 3	—	36.4	20.0	varied
Mix 4	—	36.4	30.0	varied
Mix 5	37.4	—	5.0	varied
Mix 6	37.4	—	10.0	varied
Mix 7	37.4	—	15.0	varied
Mix 8	37.4	—	20.0	varied
Mix 9	41.2	5.0	—	varied
Mix 10	41.2	10.0	—	varied
Mix 11	41.2	20.0	—	varied
Mix 12	—	36.4	(20.0)	varied
Mix 13	27.9	23.7	(13.0)	varied
Mix 14	27.9	23.7	13.0	varied

mix proportion. For comparison, the electrical power consumed per unit solid volume of wet mix (E_w,Wh/l) was normallized by that required by dry mix (E_d,Wh/l) of the same solid mix proportion to obtain the non-dimensional factor so called "Energy factor, Q".

$$Q = \frac{E_w}{E_d} \tag{1}$$

In general, the workable or plastic mix can not be obtained when amount of water in the mix is quite small. However, when amount of water exceeds a certain value so called water retained by solid particles, workable mix can be developed. The water retained by solid particles can be divided into two types namely "water retained as solid phase" and "water retained as liquid phase" [5]. The water retained as solid phase is water existing in the hydration products and absorbed by solid particles while the water retained as liquid phase consists of water retained by surface tension, trapped in agglomerated structure and surface irregularity. The total water retained can be estimated from the summation of water retained by each phase as in the following:

$$W_{retained} = W_{retained,liquid} + W_{retained,solid} \tag{2}$$

$$W_{retained} = \gamma_G M_G + \gamma_s M_s + \gamma_p M_p + (\alpha_G - w_G)M_G + (\alpha_s - w_s)M_s + (\alpha_p - w_p)M_p + W_{hyd} \tag{3}$$

where

γ_G	=	coefficient of water retainability of coarse particles
γ_s	=	coefficient of water retainability of sand
γ_p	=	coefficient of water retainability of cement or slag particles
W_{hyd}	=	amount of water existing in the hydration product (only for cement)
M_G,M_s,M_p	=	weight of coarse particles, sand and cement or slag respectively
α_G,α_s,α_p	=	absorption of coarse particles, sand and cement or slag respectively
w_G,w_s,w_p	=	water content of coarse particles, sand and cement or slag respectively

Because of water which can be retained by coarse particles is very small and negligible, γ_G is taken as 0. For cement and slag, due to their initially dry and their water absorption is much smaller than that can be retained on their surface by surface tension, α_p and w_p can also be neglected. Moreover, water existing in the hydration products is found very small during mixing operation (will be explained later). For these reasons, equation (3) can be simplified as:

$$W_{retained} = \gamma_s M_s + \gamma_p M_p + (\alpha_G - w_G)M_G + (\alpha_s - w_s)M_s \tag{4}$$

Consequently, free water which can be moved freely in mixture to produce the workable mixture can be estimated by subtracting the retained water from the total amount of water in mixture as:

$$W_{free} = W_{total} - W_{retained} \tag{5}$$

$$W_{free} = W_{total} - \gamma_s W_s - \gamma_p M_p - (\alpha_G - w_G) M_G - (\alpha_s - w_s) M_s \tag{6}$$

The results shown in Figs.1a to 1d, the "energy factor Q" are plotted against the amount of free water in mixture. It can be seen that the mixing energy can be enhanced from the energy required in dry state when water is added to mixture. This enhancement can be observed greater in richer mix because cohesive strength provided by small particles is higher. The maximum Q can be obtained when amount of free water is about "0". In other words, amount of water in mixture is the same as that can be retained by solid particles. The enhancement of mixing energy is believed to be contributed by non-uniform distribution of water in mixture so that the mechanism so called "Granulation process" [6] can be developed. This implies that movement of material in pan type mixer is somehow rolling movement. The size of granules can be increased while the number of granules can be reduced by increasing amount of water. At the maximum Q, the mixture becomes a lump mass and very sticky. If slump test is performed, almost no slump value can be detected.

When the value of free water become positive, the mixing energy can be significantly reduced and workable mixture can be developed. This is due to the reduction of cohesive force among solid particles because the interparticle distance can be increased with higher amount of water, especially among cement or slag particles. This decreases the resistance to movement of mixture. When amount of free water become too much, segregation is always taken place while mixing energy is comparatively unchanged.

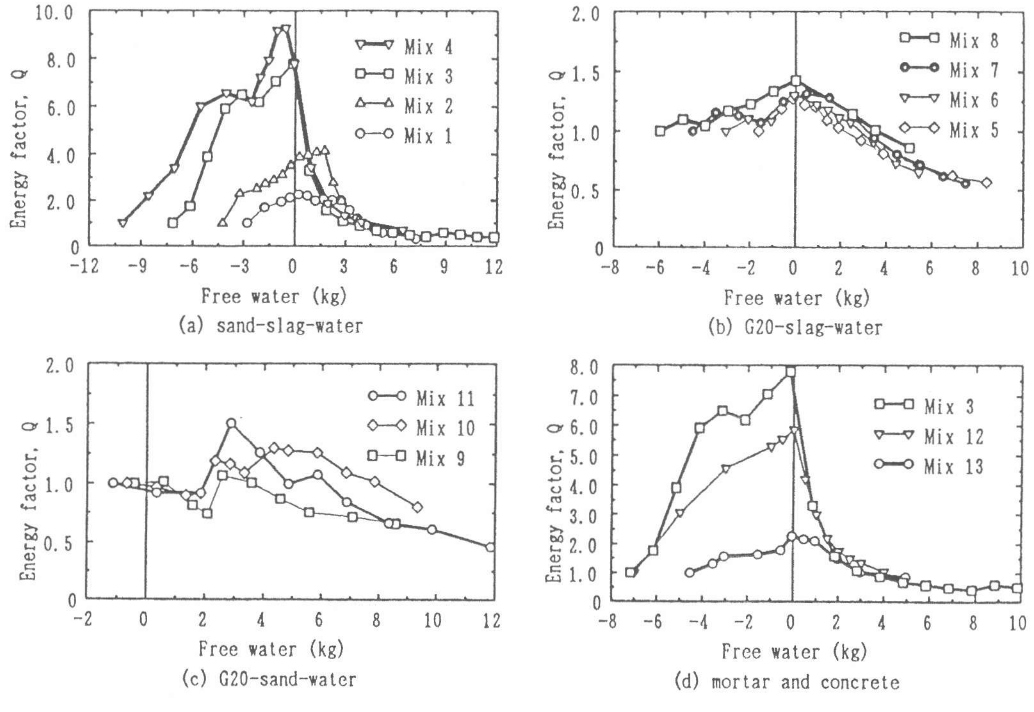

Fig.1 Effect of water on mixing energy of different mixtures at different mix proportions

However, the above phenomenon can not be observed in mixture of G20+sand+water. The granulation process can not be developed when small amount of water is added to mixture due to relative large particle size. On the other hand, the solid phase can be easily segregate when large amount of water is added due to inappropriate viscosity of mixture. This is mainly because no cement or slag particles exist in these mixes.

4. EFFECT OF WATER ON WORKABILITY OF MIXTURE

Most of the tests were performed for Mix 3, 12 and 13 as shown in Fig.2. Each point represents the average value of 2-3 experimental points. The average slump of mixture increases almost linearly with the amount of free water available in mixture. This observation is similar to that reported by Ozawa [7]. Considering Mix 3, 12 and 13, the fitting line of Mix 13 can not be drawn from the origin. This may be because of the presence of coarse particles, consequently, comparatively stronger aggregate structure is formed compared to the case of no coarse particles. As the results, larger amount of water is required to overcome the interparticle friction. By least square method the following relation can be obtained with coefficient of linear relation higher than 90% for all the cases:

$$\text{Slump} = 0.15\, W_{free} - 4.4 \quad \text{(Mix 13)}$$
$$\text{Slump} = 0.16\, W_{free} \quad \text{(Mix 12)}$$
$$\text{Slump} = 0.39\, W_{free} \quad \text{(Mix 3)}$$

where the unit for slump is in centimeter and free water in kg/m^3.

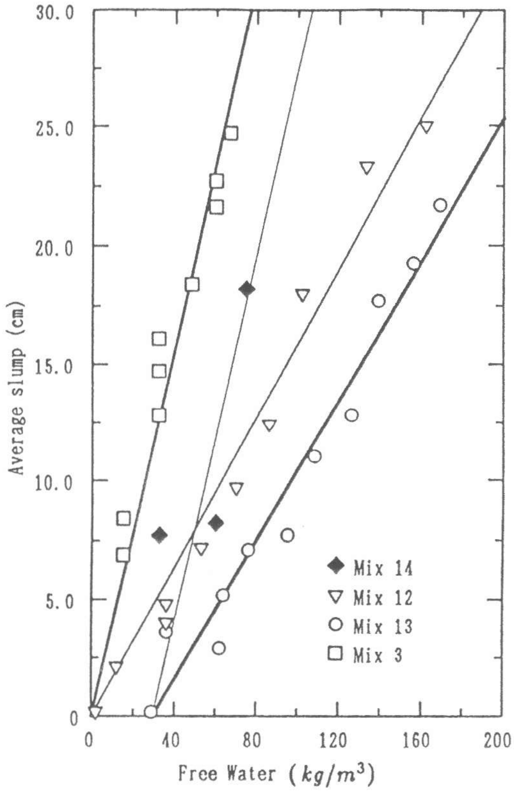

Fig.2 Free water and slump

Although Mix 3 and Mix 12 contain the same solid proportion, relation between free water and slump are quite different. For Mix 12 and Mix 13 the slope of the curves are very similar. This is because slag has been used for Mix 3 while cement for Mix 12, and mortar in Mix 13 is exactly the same as mortar in Mix 12. From this observation, the relation between free water and slump for Mix 14 can be estimated from those for Mix. 3 and Mix 13 as:

$$\text{Slump} = 0.39\, W_{free} - 4.4 \quad \text{(Mix 14)}$$

Unfortunately only 3 points are available, however, fairly agreement can be obtained.

5. EFFECT OF MIXING TIME ON WORKABILITY

As shown in Figs.3a and 3b, slump values of mixture can also be changed according to mixing time or total mixing energy although amount of initial free water in mixture was kept constant. For all the cases free water was approximately 40 kg/m^3 (calculated by eq.(6)). It can be observed that maximum slump value can be obtained if mixing time is long enough (or enough mixing energy). However, if mixing time is still prolonged (higher mixing energy) slump can be reduced.

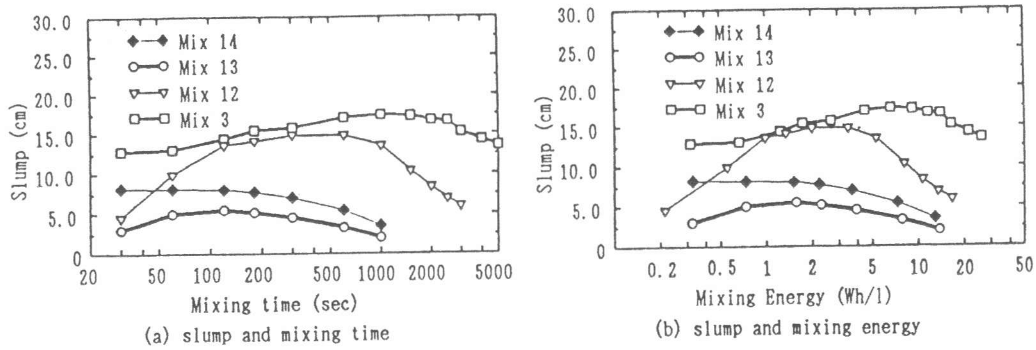

Fig.3 Effect of mixing time and mixing energy on slump

Since slump can be changed according to the amount of free water in mixture, one may expect this as one of the reasons responsible for the variation. Mix 12 was selected to test for the water retainability by centrifugal test [3] at different mixing time. The results shown in Fig.4a are test results at different acceleration levels. The retainability of mortar during mixing was estimated by extrapolating the results tested with several levels of centrifugal force at a certain mixing time as shown in Fig.4b. In both Figs.4a and 4b, the horizontal lines represent the calculated values. It can be seen that, during mixing, water retained by solid particles was not significantly changed with mixing time. However, at mixing time between 120-480 sec the retainability is almost constant, close to the calculated one and the lowest. This may indirectly imply that dispersion condition at those mixing time is comparatively better than shorter or longer mixing time. At shorter mixing time the agglomerate can not be fully broken while at longer mixing time the agglomerate is expected to be rebuilt.

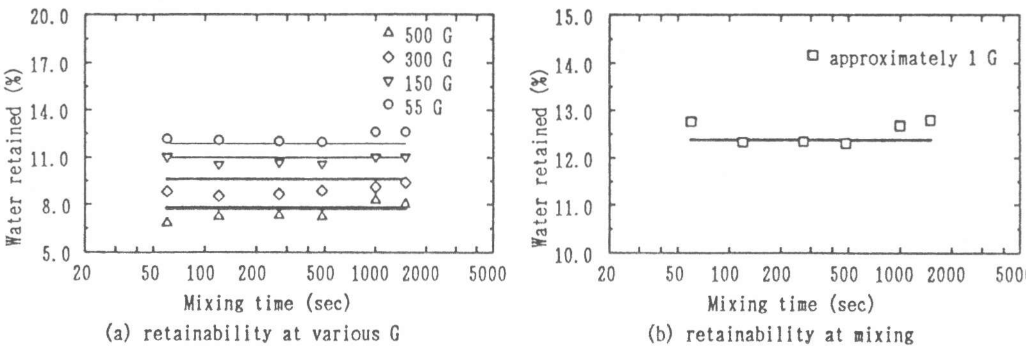

Fig.4 Water retained by solid particles at various acceleration levels

The amount of water existing in the hydration products was obtained by the test method proposed by Kjellsen [8]. The paste samples were taken from different elapsed time after water was added and then washed by acetone in order to stop hydration. Then samples were dried up at 105°C for 1 hr. in order to remove physically retained water and weighed. After that the same samples were burned at 1000°C for another 1 hr. and weighed. The weight difference between those after 105°C and 1000°C was defined as weight of water existing in the hydration products. The results shown in Fig.5 are always lower than 1%, which indicates that the effect of hydration on free water content is considered negligible.

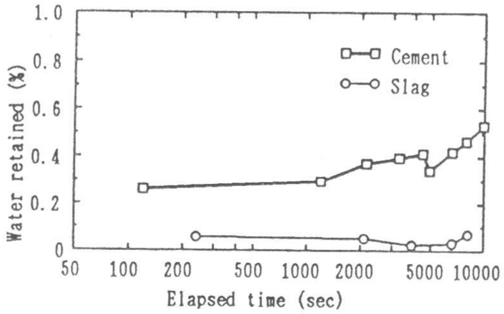

Fig.5 Water retained by hydration

6. CONCLUDING REMARKS

1) The maximum mixing energy can be observed when amount of water in mixture is equal to that can be retained by solid particles. However, it can be significantly reduced and workable mix can be developed by the existance of free water.

2) Relative workability of mixture, as indicated by slump value, can be increased linearly with amount of free water in mixture. Moreover, slope of that increment for both mortar and concrete are almost the same.

3) Cement and slag particles play important roles in order to prevent segregation and control the workability of mixture.

4) The slump value can also be changed according to mixing time or mixing energy because dispersion of solid particles can be changed. The change of free water with mixing time and hardening effect due to hydration are considered negligible.

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