論 文

[1163] EFFECT OF FINE PARTICLES AND WATER ON THE ENERGY CONSUMPTION DURING MIXING

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1. INTRODUCTION

Mixing is generally considered as one of the most important processes for concrete engineering, however, the mechanism of mixing is not yet well known. It has already been reported by Uomoto et al.[1,2] that the inspection of the distributions of coarse particles and mortar in concrete is not enough to evaluate the good mixing. Moreover, it has also been found that the properties of concrete in both fresh and hardened state can be changed largely according to the input mixing energy (electrical power consumption) per unit volume of concrete in spite of the type of mixers.

This paper presents the effect of fine particles and water on electrical power consumption during mixing based only on the experimental results as the original point to deal with mechanism of mixing for mortar and concrete in the near future. The experiments were conducted by mixing of each constituent of concrete as a single material and as a mixture of each single material with finer particles and water.

2. EXPERIMENTAL OUTLINE

The experiments were carried out with "Pan" type mixer which capacity was designed as 50 litres and constant rotation speed of 74 rpm. The properties of materials used are shown in Table 1. The mixing energy is defined as the increment of the electrical power consumption during mixing from the electrical power required to drive empty mixer. The mixer was loaded with different volume in case of mixing single material, while in case of mixture without water, 30 litres of coarse (or fine) particles were loaded at the beginning and fine (or coarse) particles were gradually added in order to obtain the different combination of mixture.

For binary mixture of each single material with water, the amount of water was also gradually added to the 30 litres of solid particles. Sand with different size combination were tested to determine the effect of particle size to the cohesion due to water in mixture. Slag was used on behalf of cement in order to avoid the hardening effect during mixing.

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Table 1 Properties of materials used in this study

Size (mm)	G20 (%)	G13 (%)	Sand#1 (%)	Sand#2 (%)	Sand#3 (%)	Sand#4 (%)	Sand#5 (%)	Slag (%)
15.0 - 20.0	20	--	--	--	--	--	--	--
10.0 - 15.0	77	48	--	--	--	--	--	--
5.0 - 10.0	3	52	--	--	--	--	--	--
2.5 - 5.0	--	--	--	20	28	40	100	--
1.2 - 2.5	--	--	--	30	43	60	--	--
0.6 - 1.2	--	--	17	20	29	--	--	--
0.3 - 0.6	--	--	34	15	--	--	--	--
0.15 - 0.3	--	--	23	7	--	--	--	--
< 0.15	--	--	26	8	--	--	--	100
F.M.	7.18	6.50	1.42	3.17	4.00	4.40	5.00	(3940)
Wu	1.550	1.545	--	1.820	--	--	--	1.050
S.G.	2.70	2.70	2.63	2.63	2.63	2.63	2.63	2.90

F.M. = Fineness modulus ; Wu = Unit weight (kg/litre)
S.G. = Specific gravity ; ( ) = Blain value (cm^2/g)

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 MIXING OF SINGLE MATERIAL

It was found that the relation between total electrical power consumption per unit solid volume (Wh/V_s) with time is always linear as shown in Fig.1. All the plotting points in Fig.2 represent the slope of that relation for different mixing volume. The use of solid volume was based on the assumption that in mixing of solids the energy was consumed mainly by the interparticle friction due to surface roughness to introduce movement of particles during mixing.

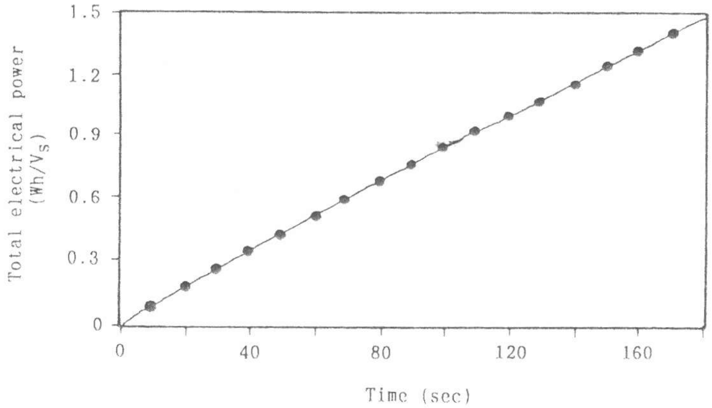


Fig.1 Total energy consumption per unit solid volume with time

Among the solids, it was found that coarse aggregate (G13 and G20) consumed the maximum electrical power while slag consumed the minimum. However, the pattern of the curve was also found different between coarse and fine particles. This may be due to the different movement pattern (particle's velocity) as well as particle size and surface roughness.

Although the energy consumption for mixing slag and water were close together. It was found that the absolute total electrical power consumption for water was almost constant in all mixing volume, while for slag increased with mixing volume. This may be because the mixer was not appropriate for mixing only water due to the rotation speed, thus within the experimental range the difference was not large enough.

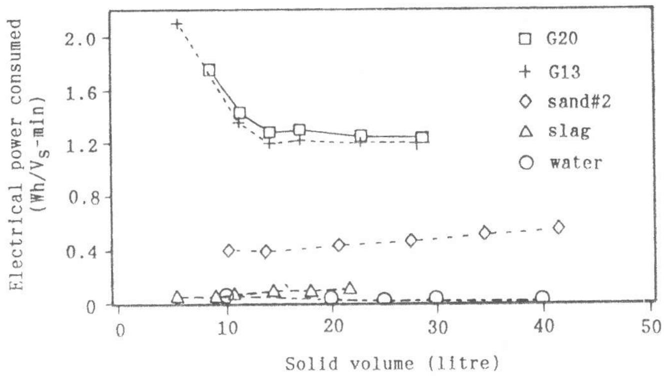


Fig.2 Energy consumed by each single material per unit solid volume

3.2 EFFECT OF FINE PARTICLES ON THE ELECTRICAL POWER CONSUMPTION

It was also found that the total electrical power consumption per unit solid volume has linear relation with time as in the case of mixing of single material (Fig.1). As shown in Fig.3, all the experimental results were normallized by dividing the energy consumption of mixtures by the energy consumption of coarse particles alone (energy consumption per unit solid volume) in order to obtain the energy factor. The results of G13 and G20 with sand#2 were combined together because the reduction of electrical power consumed were found almost indentical. It can be clearly seen that once finer particles were added to the system of coarse particles the energy consumption will gradually decrease (when V_{sf}/V_{st} or ratio between solid volume of fine particles and total solid volume in mixture varied from 0.0-0.5). On the other hand, if coarser particles were added to the system of fine particles (when V_{sf}/V_{st} varied from 1.0-0.5) the adverse effect can be observed from the gradual increase of the energy consumption. This phenomenon can be seen in all the cases of mixture in this study.

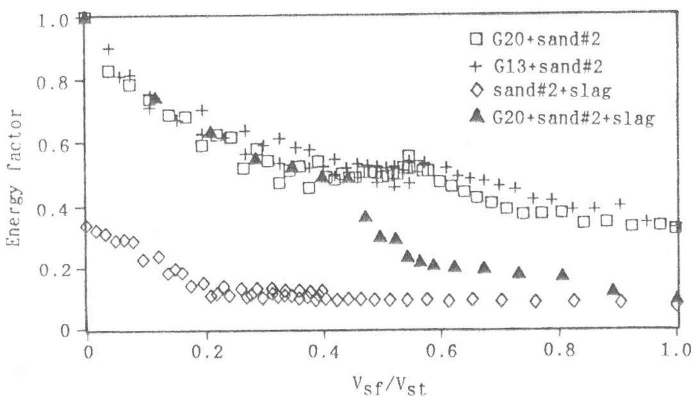


Fig.3 Effect of fine particles on the reduction of energy

It is believed that the mechanism so called interparticle percolation, the penetration of the smaller particles through the larger particles simply due to gravity or subjected to some movement, plays an important role in the reduction of energy consumption of mixture. This mechanism will result in higher fluidity of mixture consequently decreasing in power required by the mixer [3].

The higher fluidity of mixture containing fine particles may be caused by the entrapment of the fine particles in mixture in the clearance between coarse particles during mixing. The interparticle friction will be changed from completely coarse-coarse interaction to become a combination of coarse-coarse and coarse-fine interaction. Once the value of V_{sf}/V_{st} increase above certain value or increase in the amount of fine particle, the amount of fine particles in mixture may become too much and thus the mixture behaves just in the same manner with the fine particles in between the coarse particles and the interparticle friction may be controlled mainly by the fine-fine interaction (see Fig.4).

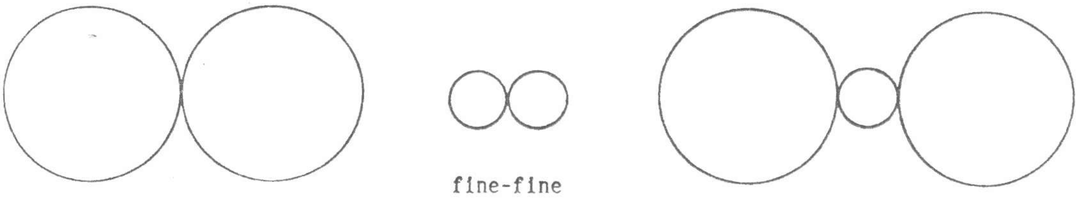
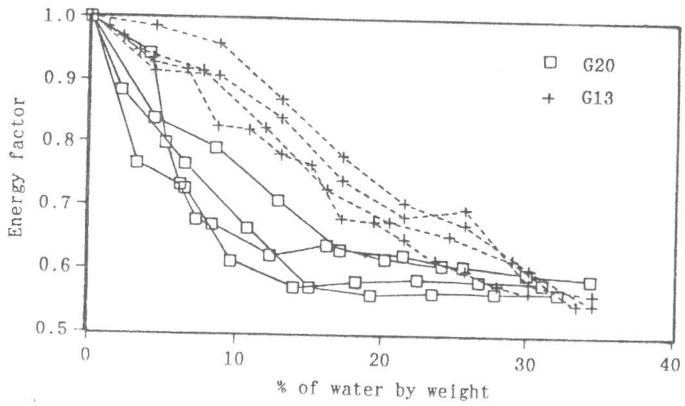


Fig.4 The interaction between particles

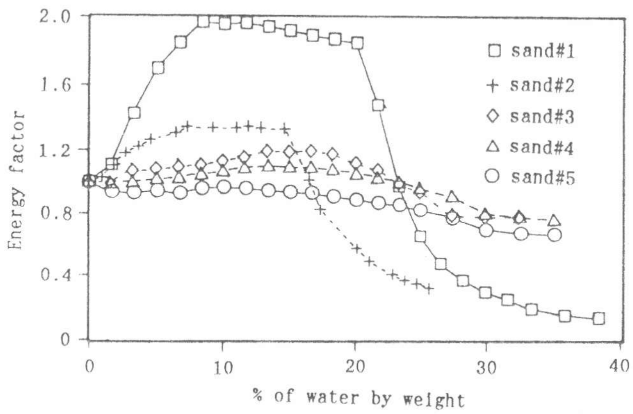
3.3 EFFECT OF WATER ON THE ELECTRICAL POWER CONSUMPTION

The role of water is considered very important for concrete engineering especially in fresh stage. For mixing process, water is supposed to behave as a media to promote the uniformity, to lubricate the interparticle contact as well as to introduce the attractive force between small particles or powder by the overlapping of the adsorbed layers of neighboring particles [4]. The experiments in this chapter were performed in order to study the effect of water to each type of material separately.

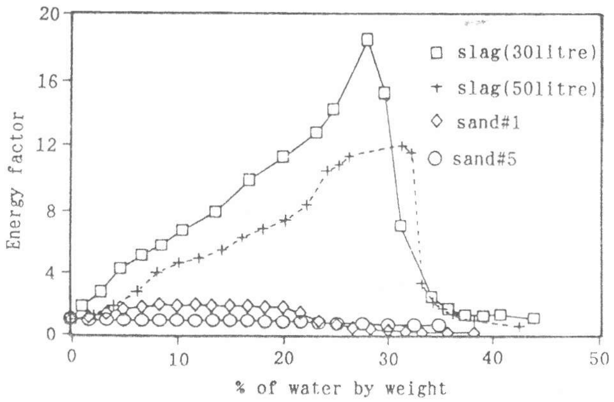
It was found that the total energy consumption per unit solid volume still has linear relation with time as in Fig.1. The results are shown in Fig.5a to 5c. All the results were also normalized to obtain the energy factor by deviding the energy consumption of mixture (each single material with water) by the energy consumption of that single material in dry state. It is clearly seen in Fig.5a that the energy consumption can be reduced significantly with different reduction pattern for G13 and G20. This phenomenon can not be explained clearly at this time, however, it is reasonable to conclude that water behave as a lubricant for the interparticle contact in both the cases of G13 and G20. In case of sand, the pattern of the energy consumption were changed significantly with gradation (see Fig.5b). It can be observed that only sand#5, which all particles are greater than 2.5 mm, has no enhancement of the energy consumption. Thus we may say that water will behave as a lubricant for the interparticle contact if the particle size is larger than, approximately, 2.5 mm. For sand#1, sand#2, sand#3, sand#4 and slag, the enhancement of the energy consumption can be observed. This may be due to the effect of the attractive force between small particles. The enhancement of the energy consumption can be found greater if water was added to the finer particles, for example, the energy factor can become as much as 18 times for slag and about 2 times for sand#1.



(a)



(b)



(c)

Fig.5 Effect of water on the energy consumption

Moreover, it can also be observed that the amount of water required by slag (30 litre) was about 28% in order to reach the highest energy factor whereas about 10% was required by sand#1. This may be attributed to the effect of total surface area of particles. The higher surface area can be found in case of slag, more water will be required in order to coat all the particle surface. If higher amount of water is still added, the energy factor will be suddenly decreased due to the diminution of attractive force between particles.

4. CONCLUDING REMARKS

The results obtained from this study can be summarized as in the following :

1) The linear relation between total energy consumption per unit solid volume and time can be observed for all the tests.

2) Among the solids, the maximum electrical power is consumed by coarse aggregate while the minimum is consumed by slag.

3) The energy consumption during mixing can be reduced significantly by adding some fine particles as well as water to increase the fluidity of mixture. However, in the case of mixture of fine particles which contain the particle size smaller than 2.5 mm and water, adverse effect can also be observed due to attractive force between those small particles.

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