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THE FILLING ROLE OF POZZOLANIC MATERIAL

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ABSTRACT

The filling role of pozzolanic material was analyzed in the paper. The influence of pozzolanic material on fluidity and strength of cement was also investigated. The fine pozzolanic material can increase the packing density and the amount of the water in surface layer, and decrease the amount of filling water. Superplasticizer can reduce the amount of the water in surface layer. The compound fine pozzolanic material and superplasticizer can reduce water demand and increase strength.

Introduction

Pozzolanic material is different from Portland cement (PC) mainly in three aspects:

(1) Lower specific density. The specific density of pozzolanic material is 2.0-2.4, about 65-77% of that of Portland cement.
(2) Smaller particle size. Compared with PC particle, pozzolanic material particles are smaller on average, with silica fume particle size of 0.1-0.2μ and pulverized fly ash particle size of 2-3μ.
(3) Pozzolanic activity. The pozzolanic material can react with $Ca(OH)_2$, to form C-S-H.

Much attention has been paid to the pozzolanic activity. As to physical properties of these materials, very little research has been done. Goldman and Bentur studied the properties of cementitious systems containing silica fume or carbon black [1]. Their results showed that the microfilling of the fine pozzolanic material may be more significant than the pozzolanic effect. Because, pozzolanic materials are usually finer than cement, naturally (e.g. silica fume) or due to grinding (e.g. fly ash etc.). Thus, their filling role should not be neglected, and will be discussed in the paper.

Influence of Pozzolanic Material Particle Size on Packing State of the System

Cement containing pozzolanic material may be regarded as a binary system. According to Aim and Goff model[2], there is a maximum packing density. The volume fraction (y_p*) of pozzolanic particles that furnishs the mixture with the maximum packing density may be calculated from the following equation:

$$y_p^* = \frac{1 - (1 + 0.9d_p/d_c)(1 - \varepsilon_0)}{2 - (1 + 0.9d_p/d_c)(1 - \varepsilon_0)} \tag{1}$$

When $y_p < y_p$*, ϕ, the packing density of system may be calculated from the following equation:

$$\phi = \frac{1 - \varepsilon_0}{1 - y_p} \tag{2}$$

When $y_p > y_p$*, ϕ may be calculated from the following equation:

$$\phi = \frac{1 - \varepsilon_0}{y_p + (1 - y_p)(1 + 0.9d_p/d_c)(1 - \varepsilon_0)} \tag{3}$$

where,

d_p--average diameter of pozzolan particle;
d_c--average diameter of cement particle;
y_p--volume fraction of pozzolan particle;
y_c--volume fraction of cement particle;
ε_0--void ratio when there is only one kind of particle.

It is clear that the packing density of the system depends on the diameter ratio of pozzolanic particle to cement particle. The less the ratio, the higher the packing density. The specific surface of cement is about 3000 cm^2/g, and its average diameter is about 6.45μm. The specific surface of fly ash is about 8000cm^2/g, and the average diameter is about 3.41μm. Therefore d_p/d_c is about 0.529. The average diameter of silica fume is about 0.1-0.2μm, and d_p/d_c is about 0.0155-0.0310. Such a small value of d_p/d_c will influence considerably the packing density of the system.

Results calculated from the equation (1)íó(2) and (3) are shown in Fig. 1, with silica fume providing better packing density of the system than fly ash.

Influence of Pozzolanic Material on Water Demand of the System

In fresh paste, the water may be divided into two parts. One is the filling water, which fills in the voids between the particles and does not contribute to the fluidity of paste. The other is the water in surface layer, which forms water film on the particle surface . The fluidity of paste depends on the thickness of water film.

The amount of the filling water is related to the packing density of system. The addition of pozzolanic material affects the packing density of system, thus may alter the amount of the filling water. The amount of the water in surface layer is related to the specific surface of system. Pozzolanic material, with specific surface greater than that of cement, increases the amount of the water in surface layer. If the specific surface of pozzolanic material is not very large, its addition decreases the amount of filling water but increases the amount of the water in surface layer. In general, the total amount of water is not changed. If the specific surface of pozzolanic material is very large, e.g. silica fume, although the filling water can be reduced, the total amount of water is increased due to the significant demand for the water in surface layer is increased greatly.

It is known that superplasticizer can decrease the water demand. More definitely, it can only decrease the water in surface layer but not the filling water. So the effect of superplasticizer is limited. In other words, the maximum ratio of decreased water exists. For pure cement, the maximum ratio is low because water in surface layer is smaller. For the cement containing pozzolan, the maximum and the minimum ratio of water to cement is related to the specific surface and content of pozzolan. The finer the pozzolanic material, the greater the maximum ratio. Because the addition of pozzolanic material enhances the packing density of the system and decreases the filling water, the minimum water/cement ratio can be smaller than that of the cement with no pozzolanic material.

The influence of superplasticizer on water demand of cement with or without additives is shown in Fig.2. The water/cement ratio of pure cement mortar is 0.44 when superplasticizer is not added and decreases as superplasticizer is added. The water/cement ratio of pure cement mortar is 0.36 when the content of superplasticizer is 0.6%, and will not drop from this. For the cement with 10% silica fume, the water/cement ratio is 0.54 when superplasticizer is not added, far higher than that of pure cement without superplasticizer; w/c is 0.35 when the content of superplasticizer is 0.7%, and approaches the minimum water/cement ratio of pure cement. It

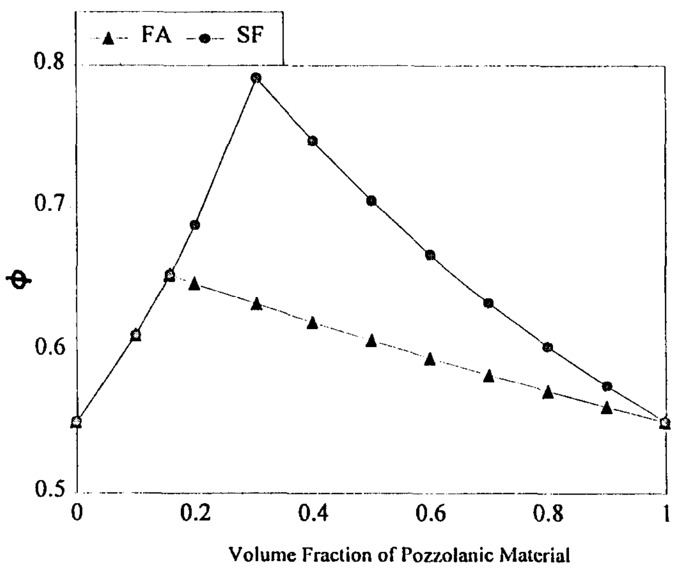

FIG. 1.
The relationship between packing density and the content of pozzolanic material.

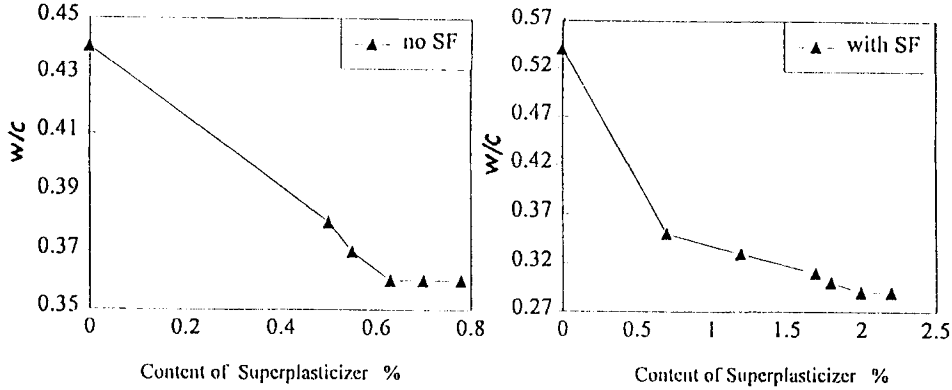

FIG. 2
The influences of superplasticizer on fluidity of cement mortar with or without silica fume.

is more important that water/cement ratio can drop continuously as the content of superplasticizer is raised. The minimum w/c can be as low as 0.29.

Influence of Pozzolanic Material on Strength

1. Physical Role of Pozzolanic Material at the Same w/c. As stated above, pozzolanic material has three characteristics, and therefore three effects. Its chemical effect, i.e. pozzolanic effect, has been discussed in some literature[3]. Its physical role, which includes lower specific density and smaller particle size, is addressed here.

Because the specific density of pozzolanic material is lower than that of cement, the porosity of the cement stone with pozzolan is lower than that with no pozzolan at same w/c, if the hydration is not considered.

Without hydration and the effect of specific density, the addition of pozzolanic material does not influence the porosity of cement stone at the same w/c, although it may change the packing state of the system. It may change the pore structure, where number of big pores is decreased, and the number of small pores is increased. This change is a function of the fineness of the pozzolan. The finer the particles, the more effective the role of silica fume.

2. The Physical Role of Pozzolanic Material at the Same Fluidity. As stated above, the addition of pozzolanic material influences the water demand, and thus affect the strength.

Results in Table 1 show that for same fluidity addition of silica fume greatly increase water demand and thus reduces (particularly 7 day) strength.

TABLE 1
The Influence of Silica Fume on the Strength of Mortar at Same Fluidity

No.	Content of silica fume %	w/c	Flexural strength MPa		Compressive strength MPa	
			7 day	28 day	7 day	28 day
A0	0	0.44	4.59	6.06	23.03	32.95
A1	10	0.54	3.96	6.59	19.25	31.90

TABLE 2
Effect of Silica Fume and Superplasticizer

No	Content of silica fume %	Content of superplasticizer%	w/c	Flexural strength MPa 3 day	7 day	28day	Compressive strength MPa 3 day	7 day	28 day
B0	0	0	0.44	3.26	5.73	7.26	14.35	28.70	41.35
B1	10	0.3	0.44	3.70	5.81	8.16	16.95	31.20	50.45
B2	0	0.7	0.36	4.54	6.25	7.68	25.30	40.90	51.50
B3	10	2.2	0.29	5.54	7.27	9.02	34.65	52.60	70.75

With superplasticizer, the filling role of pozzolanic materials will be complete, and increase strength greatly. The experimental results are shown in Table 2 . At the same w/c, the addition of 10% silica fume increases the flexural strength by 13%, 1% and 12% , and the compressive strength by 18%, 9% and 22% at 3 day, 7 day and 28 day respectively if 10%. In the case of constant fluidity, the flexural strength is raised by 39%, 9% and 6% , and the compressive strength by 76%, 43% and 25% at 3 day, 7 day and 28 day respectively, if only superplasticizer but no silica fume is added. The flexural strength can be raised by 70%, 27% and 24%, and the compressive strength by 141%, 83% and 71% at 3 day, 7day and 28 day respectively if 10% silica fume and 2.2% superplasticizer are added at the same time. The effect of the filling role of pozzolanic material is evident and significant.

Conclusion

Physical properties of pozzolanic materials are significant, especially the filling role. It can influence considerably the properties of cement material. The following conclusions can be obtained from theoretical analyses and experimental results:

(1) The addition of pozzolanic material influences the packing state, and decreases the amount of filling water. This role depends on the fineness of pozzolanic materials.

(2) Mixing water includes both filling water and the water in surface layer of the particles. The addition of finer pozzolanic materials can decrease filling water, but increases the water in surface layer. Superplasticizer can decrease the water in surface layer, however the amount of the filling water is not affected. Water demand can be greatly reduced when a fine pozzolanic material is added with a superplasticizer.

(3) The addition of a fine pozzolanic material reduces both pore sizes and porosity, and therefore raises strength.

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