Pergamon

Cement and Concrete Research 33 (2003) 167–168

CEMENT AND CONCRETE RESEARCH

Discussion

A reply to the discussion by Cengiz Duran Atis of the paper "Very high performance concrete with ultrafine powders"☆

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Received 8 July 2002

The authors wish to thank the discusser not only on the detailed study he carried out but also on his positive valuation on the interpretation of the results presented on his paper. This would enable us to extend the arguments and clarify better our contribution. We will reply to all points of the discussion as follows.

(1) With respect to the first question of the discusser, namely, the heading title of our paper. Firstly, we would like to say that the main aim of our paper is the introduction of the making technology of very high performance cement-based materials with excellent mechanical properties and workability and great durability. Also, we place emphasis on the role of ultrafine powders in preparing very high performance cementitious materials. So the content presented in our paper is limited. The details are also mentioned in the introduction section of our paper.

Traditionally, concrete consists of cement, water, fine aggregate (sand), coarse aggregate (stone) or admixtures, etc. However, the maximum diameter of coarse aggregate varies with the different levels of compressive strength of concrete. For the sake of improving concrete compressive strength, we usually decrease the maximum diameter of coarse aggregate. For example, the maximum diameter of coarse aggregate in reactive powder concrete (RPC) is decreased even to about 600 μm [1]. Basing on this, we think that there does not exist an essential difference between concrete and mortar. In addition, we agree that the extent of high performance cementitious materials covers not only strength and workability but also durability. We presented only the excellent mechanical properties and workability of concrete because of the main aim in our paper, but this does not mean that we ignored its durability. Factually, concrete made by us is with great durability (for instance, no occurrence of carbonation, very low permeability).

(2) The third question asked by Atis is very good. It is well known that the ultrafine powders are effective in improving the packing density of particle mixtures, and the effect of relative diameters of two particles on the packing density of particle system is significant [2–4]. We also found an improvement in the relative density of paste caused by ultrafine powders. Our experimental result shows that the improvements resulted in relative density of paste for slag, fly ash and silica fume are about 0.6%, 1% and 3%, respectively, at 20% of content of powder/mass (see Fig. 1 of our paper) when compared to that of pure paste. This indicates that the improvement in relative density for silica fume is about five times and three times that of slag and fly ash, respectively. Therefore, from the point of this view, we think that the improvement in relative density due to lower mean diameter is important. Of course, we do not negate the role of particle shape in improving the relative density of mixtures.

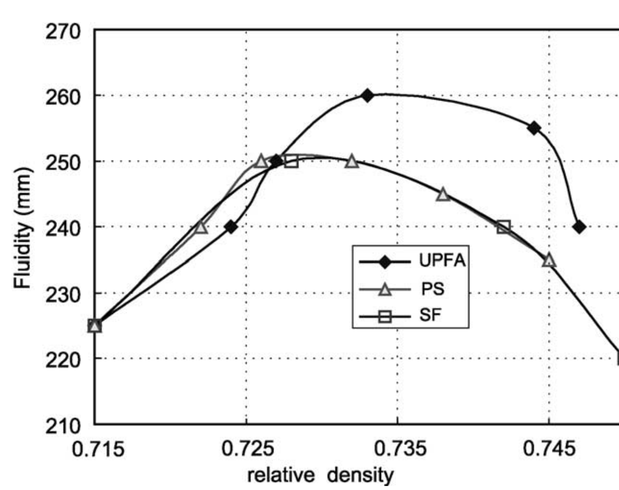

Fig. 1. The relation between relative density and fluidity in binary paste.

☆ Cem. Concr. Res. 32 (4) (2002) 601–605.

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0008-8846/03/$ – see front matter © 2003 Published by Elsevier Science Ltd.
PII: S0008-8846(02)00933-X

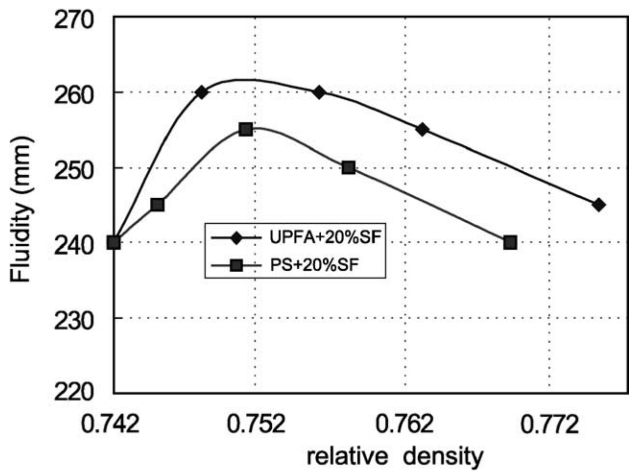

Fig. 2. The relation between relative density and fluidity in ternary paste.

Regarding the fourth question, we would like to say that we only tried to study the effect of W/B on relative density of paste in the area investigated, so the results do not fit all cases because the range of W/B studied is only 0.14–0.22. It is obvious that there always exists an optimal W/B that will get maximum relative density.

Truly, the relationship between fluidity and relative density of paste is an interesting one. We seem to get contradictory results (see Table 2 in our paper). Actually, there may be a complex relationship between fluidity and relative density of paste. We consider that fluidity of paste is influenced by many factors such as the thickness of water film layer wrapping around the particle surface, particle shape, etc. The improvement in relative density of paste reduces the water filled in space, so this results in the increment of the thickness of water film layer that benefits its fluidity. However, we have to consider the water requirement of ultrafine powder, which influences the fluidity of paste when ultrafine powders are added. At the same time, as to the different kinds of powders, the water requirement is various. So there is an optimal relative density which makes paste get best fluidity. And the optimal value of relative density varies with different powders. Figs. 1 and 2 show the experimental results of the relationship between relative density and fluidity of pastes blended with ultrafine powders [5]. If a certain ultrafine powder is effective in improving the relative density of paste, but its water demand ratio is high, the addition of a great quantity of this powder into mixtures will reduce the fluidity of paste. The results listed in the last three rows of Table 2 in our paper indicate this case. Therefore, the results in Table 2 do not fit all ternary systems with cement–silica fume–slag.

Regarding the discussion of the results in Table 3 (see the sixth question put forward by the discusser), we would like to say that cement-based materials with 200 MPa compressive strength and excellent workability require very low W/B and appropriate content of ultrafine powders and superplasticizer. We have made many experiments to obtain its compositions. Of course, compositions of very high peformance concrete (VHPC) were different when various raw materials were used. In our experiments, the sand-to-binder (cement and ultrafine powder) ratio is 1.2 by weight for all mixtures. The discusser shows his interpretation for the strength difference between two systems containing silica fume–slag and silica fume–fly ash, respectively. We think that the exact reason about the strength difference between the two systems needs to be further verified by more evidences because the curing regime may have different influences on the microstructures of these two different systems. In addition, we stated that ‘strength of system containing only silica fume increases with the increment of content of the silica fume’ under the condition that the water quantity is kept constant.

In addition, we agree on the seventh point mentioned by Atis. The length of the steel fiber (see Section 2.1.4) used by us in our paper is 12–15 mm. We will especially discuss the mechanical behavior in another paper so we only presented the result of the effects of steel fiber and tube on the strength of concrete. The strength test is measured according to GB177-85 (see Section 2.2.1 of our paper). That is to say, the dimension of specimen t is prism of $4 \times 4 \times 16$ cm for flexural strength test, and $4 \times 4 \times 6.25$ cm for compressive strength test and the area applied force is 4×6.25 cm^2.

(3) Owing to our ignorance, there are some faults in our paper. We would like to apologize sincerely for these and thank the discusser again for his correction. Here, we make some supplement and correction. (a) The content of SiO_2 of PFA is 52.7% not 21.7% in Table 1 of our paper. (b) The page no. for Ref. 5 in our paper is 1375–1381.

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