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Addition of Silica Fume to Improve Strength of Cement Paste

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Abstract. This study measured the packing densities of 0 to 30% silica fume (SF) added cementitious materials and strength of the cementitious pastes with various water content. The results revealed that addition of silica fume up to a certain level has great effects on packing density and strength. In-depth analysis illustrated that a lower W/CM ratio would not always result in a higher cube strength, and the range between 0.05 and 0.07 μm would be the amount of water film thickness (WFT) for muximum strength.

1. Introduction

To improve the strength of cementitious materials paste, addition of superfine or ultrafine fillers to dense the structure is one of the strategy. Gao *et al.* [1] expressed with the use of superplasticizer the use of superfine slag could benefit the strength. Givi *et al.* [2] reported that blending a rice husk is of help for strength improvement. Binici *et al.* [3] proved adoption of fine pozzolanic additive could result in a higher strength. Aydin *et al.* [4] experimentally proved the strength would decrease if normal pulverized fuel ash was used, but the strength would increase if a superfine pulverized fuel ash instead of normal pulverized ash is used. Also, researcers [5-8] illustrated that the packing density could be improved when silica fume, ultrafine fly ash, ground limestone or ground slag was adopted. This benefit in packing densty pave a way for the use of less water content to increase the strength.

From the literatures mentioned above, it is clear that packing density improvement benefits the strength [9]. However, there is no systematic study on how addition of SF improves the strength through packing density improvement. To fill this gap, a study was launched to measure strength performance of cementitious paste containing SF. The benefit of the increase in packing density was then evaluated, as reported herein.

2. Materials

The materials ued inlude SF and cement, two cementitious materials, ordinary drinking water and SP. The PC and SF were brought loacally in Guangdong Province, China, while the SF was imported from North Europe. According to the supplier, the SF met the requirement of ASTM C 1240-03. To know the size distribution of cement and SF adopted, laser diffraction method was adopted and the results was graphically reported in Fig. 1.

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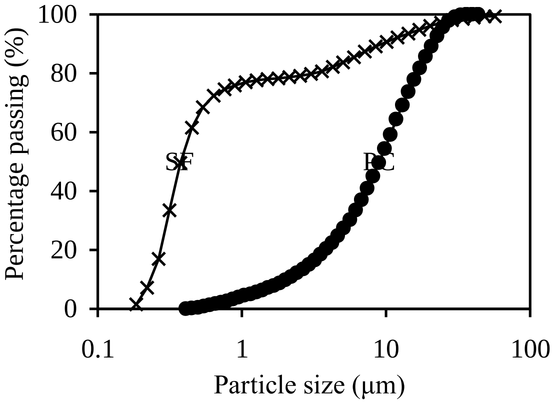

Fig.1. Particle size distributions of PC and SF

To solve the problem of agglomeration problem of ultrafine SF particles, a widely used polycarboxylate type SP was used to disperse the SF to increase the effectiveness of the SF as a filler [10]. Since the PC and SF have different densities, and its the the volume that is more important for controlling the performance. The amount of SP used in this study was set as 93.3 kg/m^3 of the cementitious materials.

3. Experimental program

In this study, the use of SF on packing densities, strength were evaluate and measured. The SF content was varied from 0 to 30 %, while the range of water to cementitious materials ratio was between 0.6 to 1.2.

4. Test method

4.1. Packing density

Following previous study and findings [11], the solid concentration was

$$. = \frac{M/V}{\rho_w u_w + \rho_{PC} R_{PC} + \rho_{SF} R_{SF}} \quad (1)$$

The meaning of the symbol in the equation (1) are:

M - mass of paste
V - paste volume
$_w$ - water density
u_w - water ratio
$_{PC}$ - solid densities of the PC
$_{SF}$ - solid densities of the SF
R_{PC} - volumetric ratios of PC
R_{SF} - volumetric ratios of SF

4.2. Strength

Cubes from various cementitious paste mixes were produced, and then load was applied to the cubes until its failure to obtain the maximum load as the compressive strength.

4.3. Particle size distribution optimization for improving packing density

Theoretically, the particle size distribution of cementitious materials shall be as close to an ideal model as possible. Up to now, many distribution models had been proposed, and the most widely used one is the modified Andreasen's or Funk and Dinger's equation [12]

$$CPFT = \left(\frac{D^m - D_S{}^m}{D_L{}^m - D_S{}^m} \right) \times 100\ \% \quad (2)$$

CPFT - percentage smaller than certain size

D - size of particle
D_L - size of biggest particle
D_S - size of smallest particle
m - distribution index

According to previous study [13], the best values of distribution modulus m for concrete was around 0.24 in Equation (1).

For the cementitious materials mixes in this study, as only 1% of particles was smaller than 0.13μm, while only 1% of particles was largerer than 40μm, the value of D_S and D_L in Equation (1) were set to 0.13μm and 40μm, respectively. The modified Andreasen's distribution thus obtained for the optimized particle size distribution is presented and plotted alongside the cementitious materials mixes with various SF content in Fig. 2. Results illustrated that the distribution of cementitious materials mixes with 25% SF or 30% SF best matches the optimized particle size. To proved this, packing density tests for various SF content was carried out, the results are presented below.

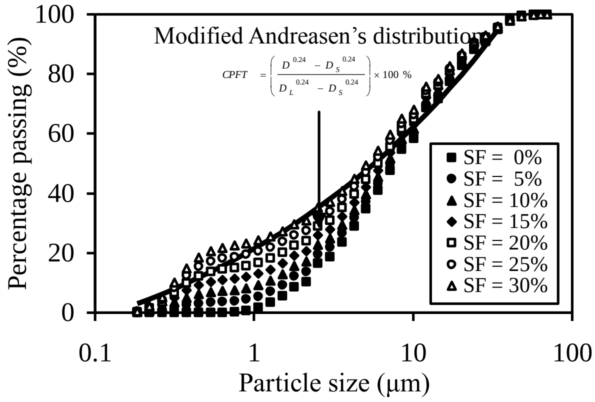

Fig.2. Distribution of particle size of cementieious materials with various SF content and Modified Andreasen's distribution

5. Experimental results

5.1. Packing density

According to this results shown in Fig. 3. at a SF content smaller than 10%, the packing density was linearly increased as the SF increased. At a SF content between 10% and 30%, the SF content is beneficial, it is only that when the SF content reaches 20%.

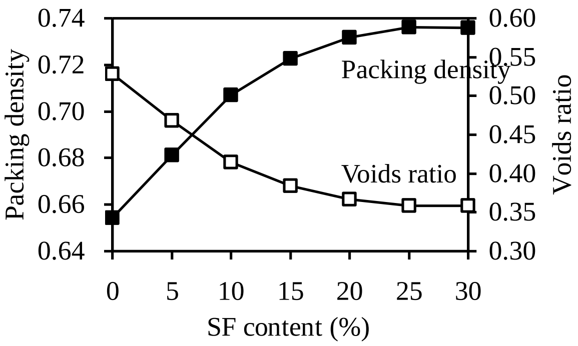

Fig.3. Packing density results at various SF content

5.2. Strength

The results are for various SF contents were shown in Fig 4. It demonstrated that reducing water conntent cannot always results in a higher strength. Results indicated that increasing SF content cannot always result in a higher strength.

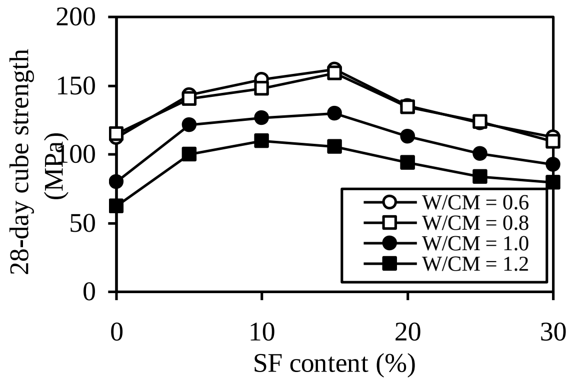

Fig.4. Variations of cube strength with SF content

5.3. Effects of WFT to strength

Generally, adoption of a lower water content could increase the strength. However, above strength results proved that there exists a limit for the water to cementitious materials ratio for each cementitious materials mix to be adopted. This is because the water added has to be sufficient for filling of voide. Therefore, the optimized water content to achieve the maximum strength depends on packing density.

Previous studies of the authors' research team have proved that WFT is the parameter determining the flowability of cementitious mix [14]. The WFT can be calculated by equation (3) - (5) shown below

$$\mathrm{WFT} = \frac{u_w'}{A_{CM}} \tag{3}$$

$$u_w' = u_w - u \tag{4}$$

$$A_{CM} = A_{PC} \times R_{PC} + A_{SF} \times R_{SF} \tag{5}$$

u_w' - ratio of excess water
u - ratio of voids
A_{PC} - area of the surface of PC per unit mass
A_{SF} - area of the surface of SF per unit mass
R_{PC} - ratio of PC by volume
R_{SF} - ratio of SF by volume

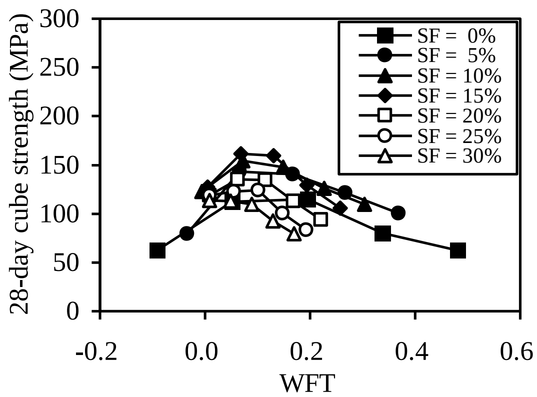

Fig.5. Variations of cube strength with WFT

6. Conclusion

1) Bleding SF for cementitious production could benefit the density of packing;
2) Bleding SF to cement could benefit the strength;
3) Lowering the water to cementitious materials ratio possibly decrease the compressive strength, and the range between 0.05 and 0.07 μm would be the amount of WFT for muximum strength.

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