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Effects of superplasticizer type on packing density, water film thickness and flowability of cementitious paste

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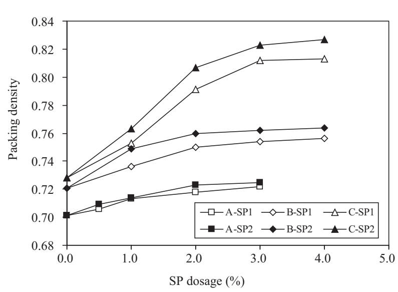
HIGHLIGHTS

- Different types of superplasticizer have different dispersion effects.
- They all have beneficial effects on packing density and water film thickness.
- Even at same water film thickness, they have different effects on flowability.
- This may be caused by different effectiveness in cohesiveness reduction.

GRAPHICAL ABSTRACT

Different types of superplasticizer have different effects on the packing density, water film thickness and flowability of cementitious paste, as illustrated in the diagram below, where SP means superplasticizer, SP1 is a naphthalene-based superplasticizer and SP2 is a polycarboxylate-based superplasticizer.



Packing density versus SP dosage

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ABSTRACT

Superplasticizer (SP) is nowadays an indispensable ingredient for the production of concrete. With SP added, the cementitious materials would be dispersed to reduce agglomeration, and thus the packing density, water film thickness (WFT) and flowability of the cementitious paste could be improved. However, there have been few studies on the effects of SP type on the packing density and WFT. This study aims to evaluate the roles of SP type in the packing density, WFT and flowability of cementitious paste. In the study, cementitious paste samples with three cementitious material compositions, two SP types (namely, a naphthalene-based SP and a polycarboxylate-based SP) and increasing SP dosages were tested. The test results showed that the addition of either type of SP would significantly increase the packing density and WFT, but the polycarboxylate-based SP is more effective than the naphthalene-based SP. Besides, the combined effects of SP and WFT on the flowability of cementitious paste were analyzed.

1. Introduction

Early in 1938, a plasticizer made with naphthalene sulfonate was patented in USA, which may be regarded as the predecessor of modern day superplasticizer (SP). In 1960s, a naphthalene-based SP was developed in Japan and a melamine-based SP was developed in Germany [1]. These SPs disperse the cementitious materials mainly through the electrostatic repulsion between particles produced by imparting similar electrostatic charges onto the particle surfaces. More recently, polycarboxylate-based SP made of synthetic molecules has also been developed; such SP disperses the cementitious materials through not only the electrostatic repulsion, but also the steric repulsion between particles produced by wrapping the

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particles with co-polymer side chains [2–4]. Generally, the polycarboxylate-based SP is more effective as a dispersing agent [5–8].

With SP added, the cementitious materials would be dispersed to avoid the formation of agglomerates. Hence, the SP can be added without changing the mix proportions to increase the flowability of the concrete. Alternatively, at the same flowability requirement, the water/cementitious materials (W/CM) ratio can be decreased to improve the strength and durability of the concrete, or the cementitious paste volume can be decreased to improve the dimensional stability and reduce the carbon footprint of the concrete. Because of these advantages, SP has become so popular that it is nowadays an indispensable ingredient for the production of almost all kinds of concrete, especially high-performance concrete [9–16]. It is only that with SP added, the concrete mix design would become more complicated.

In simple terms, a SP works by dispersing the solid particles in water. If no SP is added, the solid particles would tend to form agglomerates, thus causing the solid particles to be loosely packed. When a SP is added to disperse the solid particles, agglomeration would be reduced, thus allowing the solid particles to be more closely packed. Therefore, in theory, the dispersion effect of the SP should improve the packing density of the solid particles. Somehow, in practice, the dispersion effect may vary from one SP to another SP, indicating that the effect of SP on packing density improvement is dependent on the SP type. However, there have been few studies on such effect of SP on the packing density of cementitious materials. This is probably due to the lack of an appropriate test method for packing density measurement that is capable of incorporating the effect of SP.

The conventional methods of packing density measurement measure the packing density of the solid particles under dry condition [17–20]. These methods, which may be classified as the dry packing methods, are not applicable to materials containing fine particles because under dry condition, the fine particles tend to form agglomerates and the packing density so measured is very sensitive to the compaction applied [21]. More importantly, the effects of water and SP in the concrete mix cannot be included. To resolve these problems, the authors' research group has recently developed a new method, called the wet packing method, for measuring the packing densities of cementitious materials, fine aggregate, cementitious materials plus fine aggregate, blended fine and coarse aggregates and concrete mixes [22–26] with the effects of water and SP included. However, in the previous studies, only one type of SP was used and the SP dosage was often fixed at a certain percentage by mass of cementitious materials. So far, there has been little research on how the SP type and dosage would affect the packing density of cementitious materials.

By adding a SP, the solid particles in concrete would be dispersed to reduce the degree of agglomeration and increase the packing density. The increased packing density would then decrease the volume of voids between the solid particles, which are to be filled with water when the solid particles are mixed to produce concrete. As a result, at the same water content, there would be more excess water (water in excess of that needed to fill the voids between the solid particles) available for forming water films coating the solid particles to provide lubrication and increase the flowability of the concrete. Meanwhile, the SP would also reduce the cohesiveness of the concrete to increase the flowability of the concrete. Hence, the addition of a SP increases the flowability of a concrete mix through two additive effects: first, by increasing the packing density and thus the amount of excess water available to form water films; and second, by reducing the cohesiveness. However, to separately study these two effects, it is necessary first of all to evaluate the effect of SP addition on the amount of excess water and the water film thickness (WFT) in the cementitious paste.

In recent studies, with the packing density measured using the wet packing method, the WFT has been determined as the excess water to solid surface area ratio [27]. The authors' research group has demonstrated that the WFT is the single most important factor governing the rheology of cementitious paste [28], mortar [29] and concrete [30]. As any SP added would disperse the solid particles to increase the packing density and thus the amount of excess water, the SP should have significant effect on the WFT. However, it is believed that even at the same WFT, the SP type should have significant effect on the rheology. In other words, both the WFT and SP type should be playing certain roles in the rheology of superplasticized paste, mortar and concrete. Previous studies by the authors' research group have revealed that a polycarboxylate-based SP can have great effects on the rheology and cohesiveness of cementitious paste containing condensed silica fume [31] and cement-sand mortar [32]. However, the combined effects of WFT and SP type on the rheology of paste, mortar and concrete have not been studied yet.

In order to address the above issues, this research project was launched to study the effects of the SP type and SP dosage on the packing density, WFT and flowability of cementitious paste. For such research, a number of cementitious paste samples made with three cementitious material compositions, two SP types (a naphthalene-based SP and a polycarboxylate-based SP) and various SP dosages were tested by a wet packing method to measure their packing densities, and by a mini slump flow test to measure their slump and flow spread values.

2. Experimental details

2.1. Experimental program

To investigate the roles of SP type and SP dosage in the packing density, WFT and flowability of cementitious pastes, an experimental program was launched, in which three series of cementitious materials mixes, namely Series A, Series B and Series C, were tested, as summarized in Table 1. In Series A, ordinary Portland cement (OPC) was the only cementitious material used. In Series B, pulverized fuel ash (PFA) was added to replace part of the OPC and the PFA content was 20% by mass of the total cementitious materials. In Series C, condensed silica fume (CSF) was also added to replace part of the OPC, and the PFA and CSF contents were both 20% by mass of the total cementitious materials.

In all the three series, the packing density was measured by the wet packing method under three different testing conditions, namely, SP0, SP1 and SP2, as depicted in Table 2. For testing under condition SP0, no SP was added. For testing under conditions SP1 and SP2, a naphthalene-based SP (named as SP1) and a polycarboxylate-based SP (named as SP2) were added, respectively. In Series A, the SP1 or SP2 dosages were 0.5%, 1.0%, 2.0% and 3.0% by mass of cementitious materials whereas in Series B and C, the SP1 or SP2 dosages were 1.0%, 2.0% 3.0% and 4.0% by mass of cementitious materials, as depicted in the second column of Table 3. Moreover, to study the effects of SP on WFT and flowability of cementitious paste, a number of cementitious paste samples with a W/CM ratio by volume of 0.6 were produced to measure their WFT, slump and flow spread.

For easy identification, each paste sample was assigned a sample number. The sample number is in the form of X-Y-Z, where X (=A, B or C) denotes the series number, Y (=SP0, SP1 or SP2) denotes the testing condition and Z denotes the SP dosage (as a percentage by mass), as listed in the first column of Table 3.

2.2. Materials

Three types of cementitious materials, namely, ordinary Portland cement (OPC), pulverized fuel ash (PFA) and condensed silica fume (CSF), were used in the experiments. The OPC was a commonly used cement of strength class 52.5 N, which had been tested to comply with BS EN 197-1: 2011 [33]. The PFA was a classified ash,

Table 1
Proportions of cementitious materials by mass.

Series No.	Proportions of cementitious materials by mass (%)		
	OPC	PFA	CSF
A	100	0	0
B	80	20	0
C	60	20	20