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Enhancement in self-compactability and stability in volume of entrained air in self-compacting concrete with high volume fly ash

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HIGHLIGHTS

- Ball-bearing effect of fly ash allows higher fine aggregate content in SCC.
- Ball-bearing effect of air bubbles further enhance self-compactability of concrete.
- Various types of air-entraining agent leads to different stability of air bubbles.
- Fly ash causes higher amount of instable large entrained bubbles.
- Spherical shape of fly ash also leads to instability of entrained air bubbles.

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ABSTRACT

An experimental study on the effect of entrained air bubbles on the enhancement of self-compactability in fresh concrete with high volume fly ash was investigated. The stability in terms of volume of entrained air bubbles was also analysed. In this paper, lower water retention and ball-bearing effect of fly ash and entrained air bubbles were considered to affect the self-compactability of fresh concrete. The results showed that higher fine aggregate content in mortar (*s/m)* of SCC can be employed as replacement ratio of cement with fly ash (*fa/p*) increases owing to the higher ball-bearing effect of fly ash, in spite of reduction in water to powder ratio (*w/p*). The ball-bearing effect of entrained air bubbles, with certain type of air-entraining agent (AEA), was also found to further enhance the self-compactability of fresh concrete with fly ash. However, the stability in volume of entrained air bubbles tended to be reduced as *fa/p* increased, due to higher amount of large entrained air bubbles produced. Apparently, the spherical shape of fly ash tended to cause the unification and escape of entrained air bubbles in SCC.

1. Introduction

Initially, self-compacting concrete (SCC) was developed to enhance the durability of concrete without the necessity for skilled labour [1]. However, to achieve adequate self-compactability, SCC requires suitable deformability and viscosity of the mortar and paste phases. Generally, the self-compactability of fresh concrete can be attained by 3 main methods. These methods include limiting the aggregate content, using low water-powder ratio and employing superplasticiser [1]. Subsequently, SCC usually requires higher cement content and dosage of superplasticiser, comparing to conventional concrete (Fig. 1), which leads to notably higher cost and reduction in the sustainability of SCC.

Currently, many studies aim to reduce the amount of cement in SCC for sustainability purpose. One of the main approaches to reduce the amount of cement is the employment of supplementary cementitious materials (SCMs). Many types of SCM have been employed into concrete to replace cement, such as fly ash. Since fly ash is a by-product of coal burning in a power plant, it is desired to be used more. Fly ash is also known to undergo pozzolanic and hydration reaction. These chemical reactions can maintain the required compressive strength of concrete as an appropriate replacement ratio of fly ash is employed [2–4]. Subsequently, fly ash is widely introduced into SCC due to its low cost and high performance as SCM [5,6].

Furthermore, air-entrainment was found to be another effective method for reducing the amount of cement in SCC [7–9]. Since the entrained air bubbles can replace a portion of volume of SCC, the

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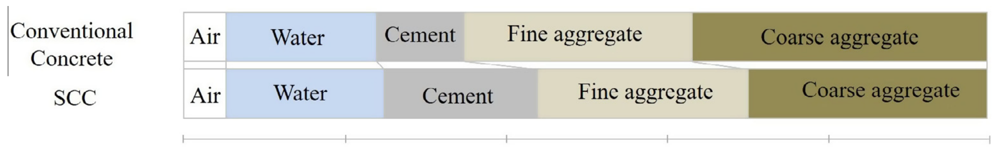

Fig. 1. Comparison between volumetric mixture proportion of self-compacting concrete (SCC) and normal concrete.

total volume of the all components, including cement, can be reduced in an equivalent volume. Besides, with suitable characteristics, the entrained air bubbles tend to enhance the self-compactability of fresh concrete. This allows higher fine aggregate content in mortar (*s/m*) of SCC for further cost reduction. Although air-entrainment can significantly decrease the compressive strength of SCC, with appropriate air content, adequate compressive strength can be attained [7].

Up to now, the effects of fly ash on fresh and hardened properties of SCC had been intensely studied [2,5,10–18]. Nevertheless, these studies tended to replace cement with fly ash directly, without increasing the aggregate content, as well as replacing aggregate with fly ash.

In this paper, the ball-bearing effect of fly ash on the self-compactability of fresh concrete was studied for increasing the fine aggregate content for further reduction in the amount of cement. Moreover, while the studied effects of entrained air bubbles on the self-compactability of fresh concrete did not include any SCMs, this paper showed the investigation on the combined ball-bearing effect of fly ash and entrained air bubbles. Additionally, the analysis on the stability of entrained air bubbles in terms of volume was presented.

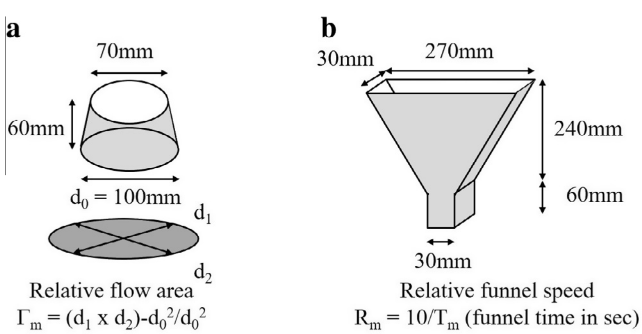

Fig. 2. Mortar flow cone test (a) and mortar funnel test (b).

2. Indices and test methods used for evaluating the ball-bearing effect of fly ash and entrained air bubbles in fresh mortar on self-compactability

2.1. Indices for evaluating flowability of fresh mortar

Fly ash had been shown to influence flowability of SCC by its ball-bearing effect and reduction in water demand due to its spherical shape [10,11,19]. This includes the change in deformability and viscosity of fresh mortar and hence the self-compactability of fresh concrete. The ball-bearing effect and lower water retention of entrained air bubbles had also been notified to affect the flowability of SCC [7–9].

The deformability and viscosity of the fresh mortar were determined by mortar flow and funnel tests, respectively (Fig. 2). The deformability of the fresh mortar was obtained in terms of relative flow area, Γ_m, while its viscosity was quantified in terms of relative funnel speed, R_m. These indices were also used to analyse the ball-bearing and water demand of entrained air bubbles.

2.2. Simple evaluation method for interaction between fresh mortar and coarse aggregate in SCC

A simple evaluation method for the interaction between fresh mortar and coarse aggregate in SCC in fresh mortar was developed to reduce labor, time and materials for testing [20]. This method involves employing model coarse aggregate into the fresh mortar testing. Glass beads with the diameter of 10 mm and volume of 20% by total volume of mortar was found to be effective for being used as model coarse aggregate. The self-compactability of fresh concrete was quantified in terms of the relative funnel speed of fresh mortar, R_m, and fresh mortar with glass beads, R_{mb} (Fig. 3). The degree of reduction in flowability of mortar due to the model coarse aggregate, $1 - R_{mb}/R_m$, was found to be correlated with the self-compactability of fresh concrete. Fig. 4 illustrates a unique correlation between the index, $1 - R_{mb}/R_m$, and the filling height of the concrete Box test [20]. The concrete Box test with obstacle R_1 (Five deformed rebars with nominal diameter of 10 mm) and the

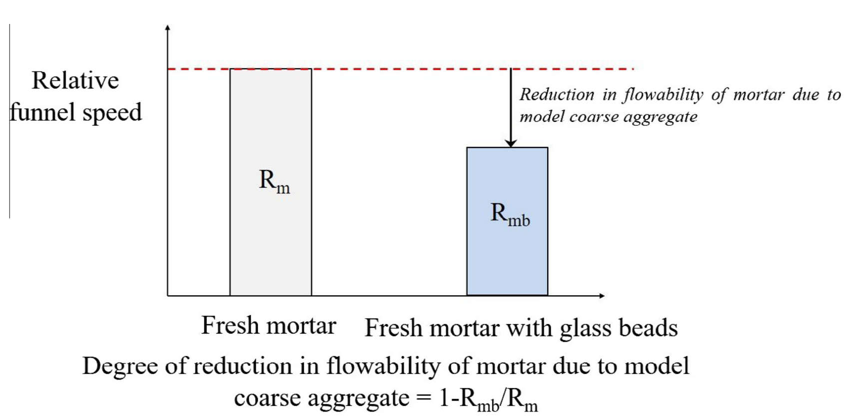

Fig. 3. Reduction in flowability of mortar due to the model coarse aggregate.