Construction and Building Materials 144 (2017) 1–12

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Enhanced entrainment of fine air bubbles in self-compacting concrete with high volume of fly ash using defoaming agent for improved entrained air stability and higher aggregate content

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HIGHLIGHTS

- Defoaming agent enhances the entrainment of fine air bubbles in SCC with fly ash.
- The entrainment of fine air bubbles improves the air stability in SCC with fly ash.
- Higher amount of fine air enhances the self-compactability of concrete with fly ash.
- Ball-bearing effect of fine air allows higher aggregate content in SCC with fly ash.

ARTICLE INFO

Article history:
Received 19 November 2016
Received in revised form 13 February 2017
Accepted 8 March 2017

Keywords:
Self-compacting concrete
Self-compactability
Fly ash
Ball-bearing effect
Water retention
Aggregate content
Entrained air bubbles
Defoaming agent

ABSTRACT

This paper presents an experimental study on the use of a defoaming agent (DA) to promote entrainment of fine air bubbles for improved volumetric stability of entrained air in self-compacting concrete (SCC) with fly ash. The possibility of increasing the aggregate content of self-compacting concrete with fly ash through the ball-bearing effect of fine entrained air bubbles is also investigated. Lower water retention and the ball-bearing effect of both fly ash and entrained air bubbles are considered to affect the self-compactability of fresh concrete. The results suggest that, generally, the employment of DA improves the stability of entrained air bubbles owing to the reduced entrainment of large air bubbles. The self-compactability of fresh concrete with fly ash is found to improve as dosage of DA increases, due to the ball-bearing effect of fine entrained air bubbles. Evidently, a higher aggregate content is also made possible through use of a certain type of air-entraining agent (AEA), due to the lower amount of large entrained air bubbles.

1. Introduction

Self-compacting concrete (SCC) was initially developed, in 1988 as a means to enhance the durability of concrete without the requirement for skilled labour [1]. In order to achieve adequate self-compactability, the mortar and paste phases in SCC are required to have suitable deformability and viscosity. Self-compactability is typically attained in fresh concrete by limiting the aggregate content, using a low water-powder ratio and employing a superplasticiser [1]. Therefore, SCC usually requires a higher cement content as compared with conventional concrete (Fig. 1). This leads to significantly higher costs and poorer sustainability in terms of the environment.

Currently, many approaches to reduce the amount of cement used in SCC are being studied with the aim of reducing its environmental impact. A commonly used approach is to employ fly ash as a partial replacement for cement in SCC. Since fly ash is a by-product of coal-burning power plants, its use as a cement replacement is known to be beneficial in environmental terms. Also, through the pozzolanic and hydration reactions, the required compressive strength can be maintained if an appropriate fly ash replacement ratio is chosen [2–4]. Hence, fly ash is a widely used ingredient in SCC [5,6]. Furthermore, the ball-bearing effect of fly ash can allow the employment of higher fine aggregate content

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http://dx.doi.org/10.1016/j.conbuildmat.2017.03.049
0950-0618/

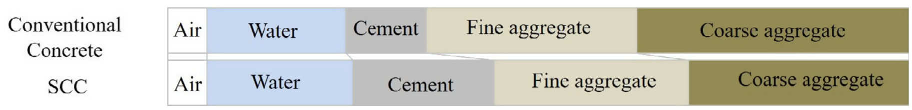

Fig. 1. Comparison of volumetric mix proportions of self-compacting concrete (SCC) and normal concrete.

of mortar (s/m) in SCC [7]. This can further reduce cement usage and reduce environmental impact.

Air-entrainment has also been found to be an effective way to reduce the usage of cement in SCC [8–10]. Since entrained air bubbles increase the total volume of the SCC, the volume of all other components, including cement, can be reduced in an equivalent volume. Also, the fine aggregate content of the mortar (s/m) can be increased if air bubbles with suitable characteristics can be entrained; this can further reduce cement usage. Even though increasing the air content can significantly reduce the compressive strength of SCC, a suitably chosen air content allows adequate compressive strength to be obtained [8].

The effects of fly ash on the fresh and hardened properties of SCC have been extensively studied [2,5,11–19]. The ball-bearing effect of fly ash on the self-compactability of fresh concrete has also been clarified, allowing a higher fine aggregate content to be used in SCC [7]. Further, the effects of air-entrainment on enhancing the self-compactability of fresh concrete, both with and without fly ash, have been studied [8–10,20]. However, fly ash was found to increase the amount of large entrained air bubbles [20]. Furthermore, it was noted that the spherical shape of fly ash causes the unification and escape of entrained air bubbles. This is known to reduce the stability of entrained air content in SCC [20,21].

Seemingly, a defoaming agent (DA) can reduce the air content in non-air-entrained SCC by destabilising the walls of air bubbles [22,23]. Thus, air bubbles easily combine and escape from the concrete. Also, DA was found to be able to eliminate large entrained air bubbles in SCC, when a suitable mixing method was used [24]. Although the size distributions of the entrained can be influenced by various factors [25], these suggest the potential of DA to reduce the proportion of large air bubbles (Fig. 2), which are less stable than small air bubbles, in air-entrained SCC with fly ash [21].

In this paper, the ability of a DA to reduce the proportion of large entrained air bubbles and enhance the stability of the entrained air in SCC with an increased volume of fly ash is clarified. The ball-bearing effect of the fine entrained air bubbles on the self-compactability of fresh concrete with fly ash is also studied with the aim of increasing the aggregate content, for further reduction in cement content.

2. Indices and test method used for evaluating the Ball-bearing effect of fly ash and entrained air bubbles on Self-compactability of fresh mortar

2.1. Indices for evaluating flowability of fresh mortar

Fly ash and entrained air bubbles are known to influence the flowability of SCC through the ball-bearing effect and reduction in water demand due to their spherical shape [7–12]. These influences on flowability include changes in the deformability and viscosity of the fresh mortar, as well as in the self-compactability of the fresh concrete. In this work, fresh mortar deformability was determined by the mortar flow test in terms of relative flow area, Γ_m (Fig. 3), while fresh mortar viscosity was determined by the funnel test in terms of relative funnel speed, R_m. These indices were used to analyse the ball-bearing effect and reduction in water demand resulting from the use of both fly ash and entrained air bubbles.

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

In order to reduce the amount of labor, time and materials required to test the self-compactability of fresh concrete, a simple evaluation method for the interaction between fresh mortar and coarse aggregate in SCC has been developed [26]. This method entails adding spherical glass beads, with smooth surface, as models of the coarse aggregate into the fresh mortar for testing the mortar-coarse aggregate interaction. The effective diameter of the glass beads used is 10 mm and they are added in the proportion of 20% by total volume of mortar [26]. The self-compactability of the fresh concrete is then quantified in terms of the relative funnel speed of the fresh mortar, R_m, and the fresh mortar with glass beads, R_{mb} (Fig. 4). The degree of reduction in mortar flowability due to addition of the model coarse aggregate, $1-R_{mb}/R_m$, is found to have a unique correlation with the self-compactability, in terms of fill height, of the fresh concrete, as illustrated in Fig. 5 [26]. The fill height was determined by the concrete Box Test with obstacle R_1 (five deformed rebars of 10 mm nominal diameter) using concrete with a coarse aggregate content to concrete volumetric ratio (g/c) of 0.30 (Fig. 6). For concrete with the

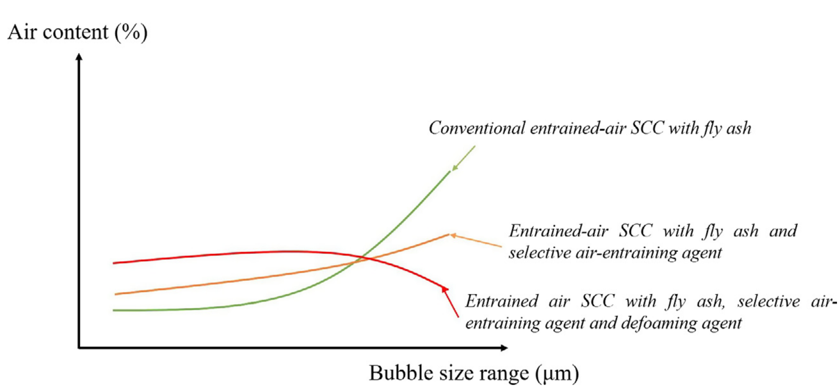

Fig. 2. Potential effect of defoaming agent in reducing the proportion of large entrained air bubbles in SCC with fly ash.