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Effects of fly ash, mixing procedure and type of air-entraining agent on coalescence of entrained air bubbles in mortar of self-compacting concrete at fresh state

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HIGHLIGHTS

- Spherical shape of fly ash leads to easier movement and coalescence of air bubbles.
- Careful selection of AEA type can reduce coalescence of air bubbles.
- Addition of AEA after SP can inhibit coalescence of air bubbles.
- Possible method in quantifying the degree of coalescence of air bubbles.

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ABSTRACT

In this paper, an empirical study aimed at preventing the coalescence of fine entrained air bubbles in the fresh mortar of self-compacting concrete (SCC) containing fly ash is reported. The time of addition of the air-entraining agent (AEA) during mixing is also investigated. Various types of AEA are also studied. In implementing the experiment, mortar flowability is assumed to affect the coalescence of fine air bubbles.

The air size distribution of the air-entrained SCC mortar in the fresh state is determined by an Air Void Analyser (AVA). Changes in the air size distribution over a 120 min period are analysed to evaluate bubble coalescence. The results suggest that the use of fly ash in the SCC can result in a higher degree of coalescence of the fine air bubbles. The various types of AEA resulted in air bubbles with different degrees of coalescence. Further, adding the AEA to the mix after the superplasticiser (SP) inhibits the coalescence of air bubbles. Evidently, the degree of coalescence of air bubbles can be reduced by careful selection of the AEA and the mixing procedure.

1. Introduction

The production of durable concrete relies on compaction being correctly carried out by skilled labourers. However, the availability of labourers with such skills has gradually fallen. To address these problems, self-compacting concrete (SCC) was developed [1].

Self-compacting concrete is a concrete with the ability to flow throughout the formwork for a structure without the need for compaction and without segregation or bleeding. To achieve adequate self-compactability, SCC must have suitable characteristics including filling ability, passing ability and stability. Typically, these characteristics are given to fresh concrete by using a low water-to-powder ratio, limiting the aggregate content and employing superplasticisers. As a result, higher content of cement is required in SCC, as compared to conventional concrete, as presented in Fig. 1. This leads to considerable increase in cost and impact on the environment.

At the present time, various approaches are being studied for lessening the cement content required in SCC. These studies aim to reduce the cost and environmental impact of SCC. The employment of fly ash to partially replace cement in SCC is known to be advantageous in reducing the impact on the environment as it is considered to be a by-product of coal-burning power plants [2,3]. Besides, fly ash, through its spherical shape, is known to improve the flowability of the fresh concrete [4,5]. Higher amounts of fine aggregate can also be used in SCC, as a result of the ball-bearing

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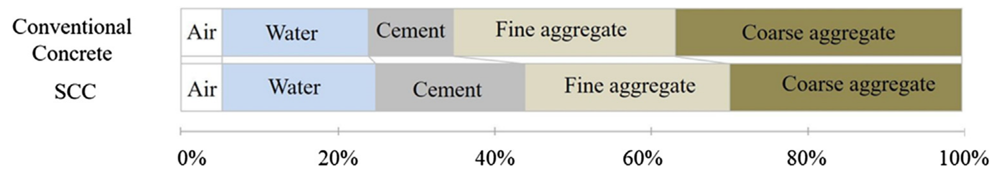

Fig. 1. Mix proportions of conventional concrete and self-compacting concrete (SCC) in volume.

effect of fly ash [5]. Therefore, cement content required in SCC can be further reduced.

An alternative approach is air entrainment, which is beneficial because it reduces the cement content as a proportion of the total volume of concrete, which is increased by the inclusion of air bubbles [6]. Moreover, concrete self-compactability can be enhanced by the entrainment of air bubbles with suitable characteristic. This allows the fine aggregate content to be increased and therefore, cement content required in SCC can be further reduced. It has been suggested that suitable entrained air characteristics are mainly related to how fine the air bubbles are [7,8]. Also, although the compressive strength of SCC can be considerably reduced by air entrainment, adequate strength can be attained by choosing a suitable air content [6].

The combined effects of fine air bubbles and fly ash on the improvement in concrete self-compactability has already been investigated [9,10]. Further, the aggregate content can be increased through this combined effect [10].

However, the air size distribution has been shown to be essential to the concrete flowability [8,10]. Besides, finer air bubbles have been notified to be able to enhance the self-compactability of the fresh concrete. Also, large entrained air bubbles have been found unstable when present in higher proportions and they escape easily, which leads to reduced volumetric stability of the entrained air [11]. These unstable entrained air bubbles have been found to be less effective than smaller entrained bubbles in enhancing the freeze-thaw resistance of SCC. It appears that small entrained air bubbles become coalesced over time, forming large and unstable air bubbles [10,11]. The presence of fly ash in the mix tends to reduce the air volumetric-stability. This can be caused by higher content of large air bubbles produced and the coalescence of small bubbles [10]. Therefore, it is crucial to consider the coalescence of entrained air bubbles to maintain the volume and size of the entrained air.

Thus far, the effect of the coalescence of small bubbles into large unstable ones on the volumetric stability of entrained air has been considered in mortar with and without fly ash [10,11]. Nevertheless, these studies did not quantify variations in the degree of coalescence of entrained air in mortar with various AEAs and mixing methods.

In this paper, the degree of coalescence of fine air bubbles is determined in various SCC mortar mixture proportions, in terms of the degree of decrease in the content of small bubbles over time. The increased coalescence of fine air bubbles caused by the presence of fly ash in the mix is clarified. The coalescence of fine air bubbles in SCC mortars with various AEAs is also studied. Additionally, the preferred sequence for AEA addition during mixing is investigated with the aim of reducing coalescence.

2. Test method and indices for the effects of fly ash, mixing procedure and air-entraining agent type on the coalescence of entrained air bubbles in mortar of SCC

2.1. Indices for controlling fresh mortar flowability

Entrained air bubbles and fly ash have been found to affect the flowability of fresh mortar, owing to the reduction in water demand and their effects on reduction in friction between solid particles. These influences lead to changes in the flowability as well as the self-compactability of SCC [4–10,12,13]. Mortar flowability is assumed to be determined by deformability and viscosity. In this research, the deformability of fresh mortar is quantified in terms of relative flow area (Γm) in a mortar flow cone test, while the viscosity of fresh mortar is measured in terms of relative funnel speed (Rm) through the funnel test, as illustrated in Fig. 2. These indices are used to investigate and control the effects of entrained air bubbles and fly ash on the mortar flowability.

2.2. Materials and testing for analysing effects of fly ash, mixing procedure and type of air-entraining agent on air bubble coalescence

2.2.1. Materials

Table 1 shows the type and properties of the materials used in the experiments conducted in this research. The powder materials

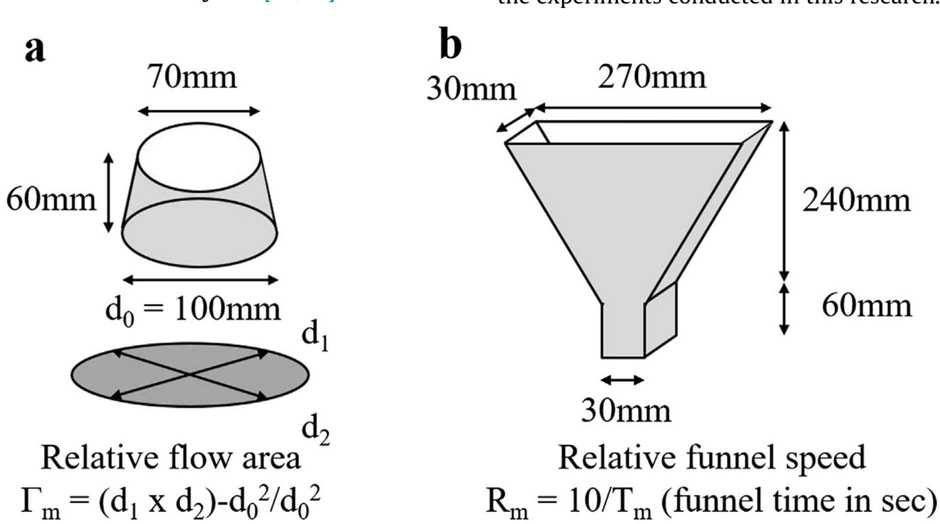

Fig. 2. Mortar flow cone (a) and funnel test (b).