論 文 内 容 の 要 旨

The production of durable concrete has been known to require appropriate compaction by skilled labours. However, the number of skilled labour has gradually reduced. Therefore, self-compacting concrete (SCC) was initially developed, in 1988 to enhance the durability of concrete without the requirement for skilled labour. SCC is the concrete which can flow throughout the formwork without any compaction, segregation and bleeding. SCC generally requires a higher proportion of cement in the mix, as compared to conventional concrete, in order to maintain adequate compactability characteristics. This leads to higher cost as well as greater impact on the environment. Considerable efforts have been made by a number of researchers to find ways of reducing the cement content of SCC.

One of the main approaches to reduce the cement content is to include fly ash in the mix. By enhancing the flowability of the concrete and encouraging the pozzolanic reaction, fly ash is useful as a replacement for cement in SCC. 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. If the entrained air bubbles have suitable characteristics, they too can help to improve the flowability of the fresh concrete.

These understandings highlight the potential for combining fly ash with entrained air bubbles for a further reduction in cement content in self-compacting concrete. However, fly ash can have a significant influence on air entrainment in the fresh concrete, which points to the need for an investigation into the combined effects of fly ash and entrained air bubbles on the self-compactability of fresh concrete. Furthermore, the disturbance to air entrainment caused by fly ash can also affect the volumetric stability of the entrained air. Volumetric stability is another characteristic that is essential to SCC, since it affects flowability retention and certain properties of the hardened concrete.

In order to effectively improve the self-compactability of fresh concrete by air entrainment, various methods for enhancing the entrainment of fine air bubbles are investigated. The research also includes the study into the influences of fly ash on enhancement in self-compactability of non-air-entrained concrete. This intends to investigate the potential of fly ash in reducing the required cement content in SCC. Additionally, this can aid the investigation on the combined effects of fly ash and entrained air on the self-compactability of the fresh concrete. Additionally, the effects of air size distribution on the volumetric stability of entrained air bubbles in fresh mortar of SCC are studied. The effects of fly ash on the reduction in volumetric stability of the entrained air are also clarified. Besides, the enhanced entrainment of fine air bubbles for improvement in volumetric stability of entrained air in fresh concrete is also examined.

In this research, the effects of entrained air bubbles and fly ash on the reduction in friction between mortar and model coarse aggregate were empirically investigated to reflect their potential in enhancing the self-compactability of the fresh concrete. Single-size glass beads were used as model coarse aggregate. The mortar flow and funnel testing were conducted to attain the indices for controlling the flowability of the mortar. The dosage of superplasticiser and water to powder volumetric ratio were altered to keep the flowability of every mortar mix proportion, in a series of experiments, to be in the same range. Air measurement by gravimetric method was also used to measure air content of the fresh mortar. The air content of every air-entrained mortar mix proportion was controlled to be in the same range by adjusting the dosage of the air-entraining agent. Certain mortar mix proportions were selected to verify the effects of fly ash and entrained air bubbles on the enhancement in self-compactability of the fresh concrete by the concrete tests. The self-compactability of the fresh concrete was quantified in terms of the concrete fill height obtained from the Box-test. The size distributions of the entrained air bubbles in mortar at fresh state, obtained from Air Void Analysis (AVA), were used to evaluate the results. The change in the air size distribution over time was used to clarify the effects of enhanced entrainment of fine air bubbles for improvement in volumetric stability of the entrained air bubbles in the fresh mortar of SCC. Various methods for enhancing the entrainment of fine air bubbles in this research include the selection in the types of air-entraining agent and mixing methods, as well as the employment of the defoaming agent. The main differences in the considered mixing methods consist of different sequence in the addition of the admixtures to prevent the disturbance of the superplasticiser on air-entrainment.

The requirement in adjustment of the air size distributions due to the difference in air content obtained from AVA and gravimetric method have been pointed out. Two methods for adjusting the air size distribution obtained from AVA were proposed. The first method considers the difference in the air content obtained from AVA and gravimetric method as large air (>1500μm). The second method adjusts the air size distributions obtained from AVA towards that from Linear Transverse Method (LTM). Both proposed methods have suggested similar tendency of results.

The results have indicated that the selection in the types of air-entraining agent, mixing method, as well as the employment of defoaming agent can enhance the entrainment of fine air bubbles and reduce the friction between mortar and model coarse aggregate. Besides, the efficiency of the entrained air bubbles on the reduction in friction between mortar and model coarse aggregate is suggested to be mainly depended on the air size distribution. Fine entrained air bubbles, with the size smaller than 450μm, are found to be able to reduce the friction between mortar and model coarse aggregate, owing mainly to the relatively free motion in shear between mortar and model coarse aggregate with fine air bubbles acting as compressible bearings. On the other hand, large air bubbles, with the size larger than 450μm, tends to increase the friction between mortar and model coarse aggregate. Large air bubbles may be easily deformed due to the compression of the aggregate. This leads to the shorter distance between the aggregate and, therefore, higher stress on the mortar matrix. Additionally, a unique relationship has been shown between fine to coarse air bubbles volumetric ratio, with the critical size of 450μm, and effects of entrained air bubbles on the reduction in friction between mortar and model coarse aggregate.

The spherical shape of fly ash is also capable of reducing the friction between mortar and model coarse aggregate. The influences of fly ash may include the ball-bearing effect and reduction in contact area between solid particles. The concrete Box-test has also suggested that the effects of fly ash on the reduction in friction between mortar and model coarse aggregate can allow higher fine aggregate content in self-compacting concrete.

The results also suggest that the friction between mortar and model coarse aggregate tends to be more sensitive to the air size distributions than that to content of fly ash. This may be attributed to relatively free motion in shear of between mortar and model coarse aggregate with fine entrained air bubbles acting as compressible bearings, while fly ash may physically interact with the aggregate. Furthermore, the deformation of large air bubbles may result in higher stress on the mortar matrix and increase in friction between mortar and model coarse aggregate, whereas fly ash is solid and does not deform.

The combined effects of fly ash and fine entrained air bubbles can further promote the reduction in friction between mortar and model coarse aggregate. A unique relationship between fine to coarse air bubbles volumetric ratio, with the critical size of 450μm, and effects of entrained air bubbles on the reduction in friction between model coarse aggregate and mortar with fly ash has also been shown. However, the reduction in friction between model coarse aggregate and mortar with fly ash tends to be less sensitive to air size distribution, as compared to that in mortar without fly ash. Owing to the spherical shape of fly ash, lower stress and friction are created between fly ash, as compared to cement, and other solid particles. This may result in lower effectiveness of fine entrained air bubbles, acting as compressible bearings for reducing friction between finer particles of fly ash, as compared to cement, with the aggregate. Besides, with coarser particles than fly ash, cement may cause higher deformation of large air bubbles. This may lead to smaller distance between the aggregate and higher stress on the mortar without fly ash, as compared to that with fly ash.

The reduction in friction between mortar and model coarse aggregate, through the combined effects of fly ash and fine entrained air bubbles, can enhance the self-compactability of the fresh concrete. Besides, evidently, a higher aggregate content in self-compacting concrete with fly ash is made possible through the effects of fine entrained air bubbles. This means the required cement content in self-compacting concrete can be reduced, resulting in the reduction in cost and impact on the environment.

The volumetric stability of the entrained air bubbles depend mainly on both the escape of large and unstable air bubbles, with the size larger than 1500μm, and coalescence of fine entrained air bubbles, with the size smaller than 1500μm. The reduction in fine entrained air bubbles, with the size smaller than 1500μm, in fresh mortar over time may primarily attributed to the coalescence of the fine air bubbles to form larger ones. Consequently, a unique relationship is suggested between the decrease in air content and volume of large air bubbles, with the size larger than 1500μm, after the coalescence of fine entrained air bubbles, with the size smaller than 1500μm, is taken into account.

The employment of fly ash has been found to reduce the volumetric stability of entrained air bubbles in the fresh mortar through higher amount of large air bubbles, with the size larger than 1500μm, being produced. The spherical shape also leads to the reduction in surface area to restraint the movement of air bubbles. This may cause a higher degree of reduction in the volume of the entrained air bubbles as the coalescence and escape of fine entrained air bubbles, with the size smaller than 1500μm, can be easily occurred. Nonetheless, the enhanced entrainment of fine air bubbles can improve the volumetric stability of entrained air in fresh mortar of SCC with fly ash.