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Modeling of early age behavior of blast furnace slag concrete based on micro-physical properties

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ABSTRACT

A multi-scale system called DuCOM was enhanced to model behaviors of blast furnace slag (BFS) concrete. Tests on the strength and micro–hygro–physical properties of BFS concrete and Portland cement concrete were conducted. The current model was found to underestimate the strength of BFS concrete at later ages owing to underestimation of the water content inside C–S–H gel pores. To remedy this, enhanced modeling of porosity allowing proper simulation of the porosity of the BFS paste matrix and higher strength development at later ages is proposed. Furthermore, based on the enhanced porosity model, the moisture loss and pore size distribution of the BFS paste matrix were investigated. The pore size distribution was found to be coarser than the test at later ages in the model, resulting in overestimation of moisture loss. Hence, the pore size distribution was enhanced as well, allowing simulation of a finer pore structure of the BFS matrix. Finally, verifications showed that the enhanced model better predicts water desorption, moisture loss and drying shrinkage behaviors.

1. Introduction

Blast furnace slag (BFS), which is a by-product obtained during steel manufacture, is widely used as a mineral admixture in cement in Japan. It is broadly recognized that BFS concrete has many advantages, including lower permeability, better chloride resistance and higher strength at later ages. However, some disadvantages are also reported [1–3], such as larger shrinkage that tends to induce cracking and decrease durability. Besides, when insufficient water is supplied during curing, the hydration process may be greatly retarded and the strength reduced significantly. Therefore, in order to promote broader application of blast furnace slag, further study of the properties of BFS concrete is in order.

Strength is regarded as one of the most valuable indexes in concrete engineering because it is associated with most other properties and can provide an overall indication of quality. Strength is closely tied to the reactivity of cement, and higher strength usually derives from a higher degree of hydration. However, when we switch to BFS blended cement from Portland cement concrete, it seems insufficient to attribute strength development only to the hydration process. For instance, it is well known that under room temperature when Portland cement (PC) is replaced partially by BFS, strength decreases at an early age while higher strength can be achieved at a later age. On the other hand, researchers [4–8] indicate that the hydration degree of slag ranges from 30% to 70% after long time curing such as 1–2 years, which is lower than that of Portland cement. Obviously BFS gains higher strength than PC at a later age, even if the hydration degree is lower than that of PC. This variance of strength could be explained by the pore structure of hardened cement paste. Microscopic observation [9–11] by Scanning Electron Microscopy (SEM) indicates that the BFS matrix with full curing has a denser structure than PC, and porosity analysis such as Mercury Intrusion Porosimetry (MIP) [12–15] also shows that at a later age the pore distribution curve moves towards a much finer diameter. Therefore, dense pore-structure can be considered to contribute more than hydration for the strength of BFS at later ages. Actually, other properties of BFS that differ from PC may be also related to the pore-structure. The moisture loss of BFS under drying conditions is reported to be less than that of PC [15,16], which can be explained by finer pores and stronger retention of water. It is also reported that drying shrinkage of BFS is larger than PC, especially for those cases with sufficient curing [17–20]. This larger shrinkage deformation can be attributed to the finer pore structure, because higher capillary tension force may be induced in the paste. Therefore, if one aims to evaluate or predict the macro-properties of BFS concrete based on micro-information, proper modeling and simulation of its microstructure are necessary.

At the Concrete Lab of the University of Tokyo, a computational system called DuCOM, which couples thermo–hygro–physical information of cementitious composites with a multi-scale constitutive model, has been developed by Maekawa et al. [21]. With this analytical system, properties over the whole life of concrete such as strength, shrinkage, creep, carbonation, and chloride penetration, can be predicted based on

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