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The pore fillability of cementitious materials and its application in predicting compressive strength of gap-graded blended cements

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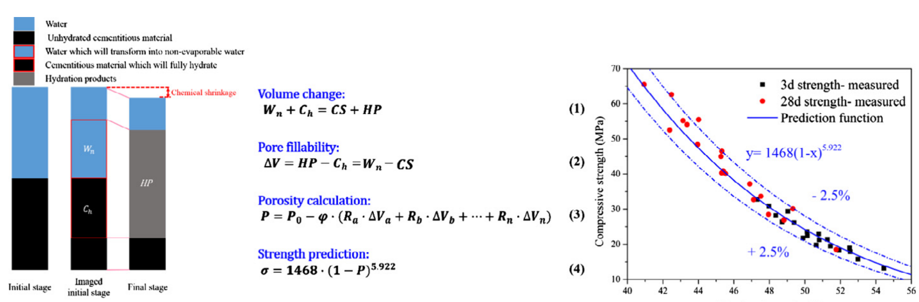
HIGHLIGHTS

- Pore fillability is deduced based on volume change of solid and liquid during hydration.
- Pore fillability was calculated by chemical shrinkage and non-evaporable water content.
- Fine fraction presented higher pore fillability than coarse fraction even at same hydration degree.
- The porosity can be calculated by pore fillability of each component and initial solid concentration.
- A power-type function was proposed to predict the strength of gap-graded blended cement.

GRAPHICAL ABSTRACT

According to the volume change of solid and liquid during hydration (Eq. (1)), the pore fillability of cementitious materials was calculated by chemical shrinkage and non-evaporable water content (Eq. (2)). Then the porosity of cement pastes was calculated from initial solid volume concentration and the pore fillability of cementitious components (Eq. (3)), and a power-type function based on the Balshin model was proposed to predict the strengths of cements (Eq. (4)). The strengths measured and predicted were consistent with each other very well, indicating pore fillability can be used to predict the strength of gap-graded blended cement (within 2.5% deviation).



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ABSTRACT

To utilize cementitious materials efficiently, pore fillability was defined as volume expansion of cementitious materials during hydration, and calculated according to its chemical shrinkage and non-evaporable water content. Relationship between hydration characteristics of cementitious materials and porosity of cement pastes was established, and then the compressive strength of gap-graded blended cements was predicted based on the pore fillability of cementitious components and initial solid volume concentration of cement pastes. The results showed that the pore fillability of cementitious materials increased dramatically with the increase of hydration time and the decrease of particle size. For a given hydration degree, pore fillability of cementitious materials mainly dominated by the size of fraction, fine fraction presented a much higher pore fillability than coarse fraction as outer products contribute to a higher proportion in the hydration products. The compressive strengths measured and predicted were consistent with each other very well, indicating pore fillability can be used for the strength prediction of gap-graded blended cement (within 2.5% deviation).

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1. Introduction

World-widely, there is an increasing trend toward utilization of pozzolanic by-products as supplementary cementitious materials (SCMs) in cement production or in concrete mixing directly [1]. Generally, blended cements have low early strength and comparable late strength with Portland cement [2–5], which limits the substitution level of SCMs. To utilize cementitious materials efficiently and reduce environmental impact during cement production, a gap-graded particle size distribution for blended cement was developed [6–9], then cementitious materials were suggested to be arranged in proper size fractions according to their hydration characteristics. As a result, both early and late mechanical properties of gap-graded blended cements can be comparable with or even higher than those of Portland cement, and the gap-graded blended cement pastes also present superior volume stability and cracking resistance compare with Portland cement pastes [10]. Therefore, high performance blended cements with large amount of SCMs can be prepared by utilizing cementitious materials efficiently. However, it is very complicated and time consuming to arrange cementitious material components in gap-graded blended cements by trail-and-error approach. It is expected to establish the relationship between hydration characteristics of cementitious material components and mechanical properties of blended cements.

Activity index [11,12], chemical and mineral compositions [13,14], glass content [15], active silica content [16], and particle size [17] were commonly used to evaluate the roles of SCMs in blended cement pastes. It should be noticed that the above evaluation criterions were all indirect methods. Specifically, activity index of SCMs, defined as compressive strength ratio of blended cement (under a given SCM replacement level) to Portland cement, just gave the evaluation of apparent properties of blended cement which cannot represent the hydration characteristics of SCMs directly. Glass content, chemical and mineral compositions are not suitable for evaluating the roles of SCMs during hydration as the hydration of SCMs also depends on the pore solution chemistry and temperature [18,19]. Active silica content of SCMs depends on the measurement condition to a great extent [20,21]. For instance, a gentler measurement condition usually leads to a lower active silica content for the same cementitious materials.

It's widely accepted that the properties of cement-based materials are mainly dominated by their pore structure [22–27] (the present study deals with the porosity, and pore size distribution will be discussed in another paper). Generally, the compressive strength of cement-based materials increased with the decrease of porosity in accordance with numerous proposed models [22–25]. Moreover, the drying shrinkage of cement pastes also decreased with the decline of the porosity due to the reduction of moisture migration [26,27]. Therefore, the key of efficient utilization of cementitious materials lied in linking the pore structure of cement paste with hydration characteristics of cementitious material components.

During the hardening of cement paste, hydration products mainly generate on the surface of particles, leading to particle-to-particle bridging or skeleton forming, and then the skeleton is densified gradually with the hydration of cementitious material components. It should be noted that Portland cement particles hydrate much more rapidly compared with SCMs [28,29], and then pozzolanic reaction between SCMs and portlandite generated during the hydration of clinker produces more hydration products and results in a denser microstructure. Pozzolanic reaction may also take place at the same time with hydration of Portland cement when ultrafine or high activity SCMs are incorporated into Portland cement [7,30]. The volume of solid increases gradually during hydration, resulting in pore refinement and microstructure densification, although total volume of reactants and products reduces slightly (the so called chemical shrinkage). In other words, the porosity of blended cement pastes, which dominate their mechanical properties, can be directly predicted based on initial solid volume concentration (or initial pore structure) and pore fillability of cementitious material components.

In this study, pore fillability of cementitious materials was defined as the volume expansion ratio per solid during hydration, and then calculated based on their chemical shrinkage and non-evaporable water content. The porosity of cement pastes was calculated from initial solid volume concentration of cement paste and pore fillability of each cementitious material component, and the compressive strengths of gap-graded blended cements were predicted by a nonlinear function established based on the pore fillability of cementitious material components. Furthermore, the accuracy of strength prediction method was validated by comparing predicted and measured strengths. The results provide a direct method to predict the mechanical properties of blended cements by linking the hydration characteristics of cementitious material components and the porosity of cement paste, which lay a

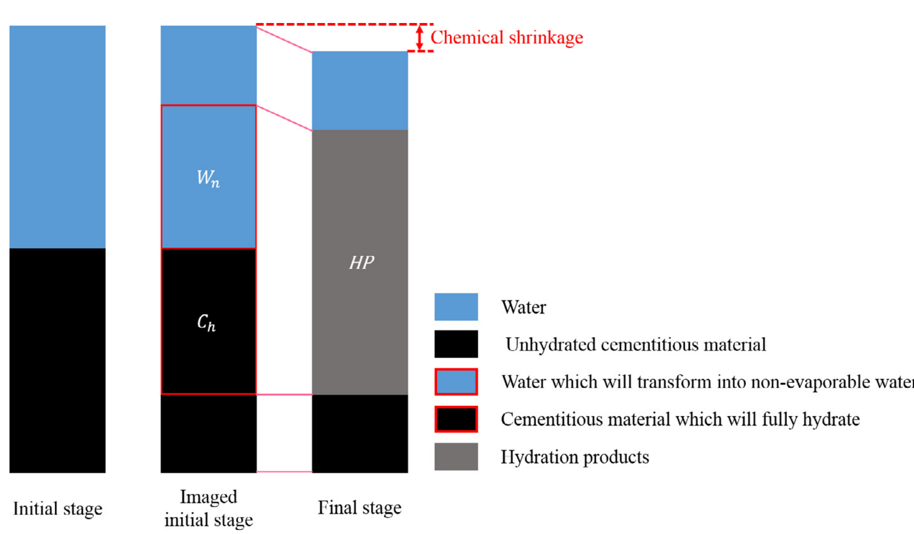

Fig. 1. The volume change of solid and liquid in cement paste before and after hydration.