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Impact of microstructure on the performance of composite cements: why higher total porosity can result in higher strength

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Abstract
This paper describes the underlying principles behind the evolution in performance of ternary composite cements comprising Portland cement clinker, slag and limestone. By using the predicted phase assemblage as an input for the micromechanical model, the mechanisms underlying the evolution of mortar strength and Young's modulus were analyzed and quantified. This allowed the roles of hydrate assemblages and porosity distribution on the evolution of performance to be explained and quantified. Slag hydration results in the formation of a microstructure more efficient for development of compressive strength and elastic stiffness. Limestone further improves microstructure and enhances reactivity of the systems studied.

Keywords
Modelling; Continuum micromechanics; Hydration; Porosity; Slag; Limestone

1. Introduction

Composite cements are the most commonly used cement types in the building industry. The first generation of composite cements, i.e. two components (binary) systems, are now being replaced by ternary and quaternary systems, in which the clinker content has continuously decreased while the number of supplementary cementitious materials has increased [1] [2]. The hydration of the Portland cement clinker occurs simultaneously with the reactions of the supplementary cementitious materials (SCMs) [3], mutually influencing the reactivity of the components and impacting on the resulting hydrate assemblage and microstructure [3]. Research on hydration kinetics has revealed that SCMs impact the reaction kinetics and extent of the clinker reactions [4]. Later studies showed that simultaneous hydration of different SCMs in ternary and quaternary blends is complex since SCMs influence the hydration of other SCMs [5]. This requires a better understanding of the hydration processes and interdependencies in order to better predict performance of multi component composite cements [6][7]. The ability to predictively model the performance of these new cements is of utmost importance since the prescriptive approaches of the concrete industry, based mainly on experience gained with Portland cement concrete, will not be applicable to the new cements. Presently, modelling approaches are used to improve understanding of the hydration process and to correlate the predicted hydrates assemblages with cement performance [8].

Hydration models are well established, particularly based on the thermodynamic approach [9]. The use of thermodynamic calculations allows investigation of the effect of different variables e.g. changing composition of composite cements [10] [11] [12] [13] [14] [15] [16] or of temperature [17] [13] on the phase assemblage of cement systems. Using the kinetics of anhydrous phase dissolution enables calculation of the evolution of phase assemblage over time [18] [19] [20] [21]. Additionally, when incorporating the density of the anhydrous phases and hydrates, thermodynamic modelling also allows the volumes of solids, solution and chemical shrinkage to be determined [9]. Hence, thermodynamic modelling allows the impact of various parameters [9] on the pore volume evolution to be studied.