



Influence of nucleation seeding on the hydration kinetics and compressive strength of alkali activated slag paste

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ABSTRACT

Addition of pure calcium silicate hydrate (C–S–H) to alkali-activated slag (AAS) paste resulted in an earlier and larger hydration rate peak measured with isothermal calorimetry and a much higher compressive strength after 1 d of curing. This is attributed to a nucleation seeding effect, as was previously established for Portland cement and tricalcium silicate pastes. The acceleration of AAS hydration by seeding indicates that the early hydration rate is controlled by nucleation and growth. For the experiments reported here, the effect of C–S–H seed on the strength development of AAS paste between 1 d and 14 d of curing depended strongly on the curing method. With sealed curing the strength continued to increase, but with underwater curing the strength decreased due to cracking. This cracking is attributed to differential stresses arising from chemical and autogenous shrinkage. Similar experiments were also performed on Portland cement paste.

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1. Introduction

Blast furnace slag is an industrial byproduct that has been used effectively as a partial replacement for Portland cement to improve the long term properties of concrete and to reduce the carbon footprint associated with cement manufacture [1–3]. Slag is a latent hydraulic material, meaning that it has little hydraulic activity when mixed with pure water, but becomes activated by the high pH of the cement pore solution so that it reacts along with the cement, forming similar hydration products. This activation is due to the increase in the solubility, and thus the dissolution rate, of glassy phases in the slag with higher pH [3,4]. The durability of concrete made with various blends of slag and cement has been monitored over periods of up to 40 years and found to be excellent [5]. Another approach is to activate pure slag by using chemicals such as sodium hydroxide, sodium silicate, or calcium carbonate to increase the pH [6,7]. Such alkali-activated slag (AAS) cement and concrete are even more desirable from an environmental standpoint, and can have beneficial properties such as high strength.

The hydration of slag forms calcium silicate hydrate (C–S–H) as its primary hydration product, as with Portland cement. However, in the case of slag the Ca/Si molar ratio is much lower, generally close to 1, and the degree of aluminum substitution is higher. The morphology of the hydration products is also different. AAS paste has a higher proportion of mesopores in the size range of a few nm, which create large shrinkage

stresses when they empty [3,8–13]. At the same time, AAS paste has less capillary pore volume than Portland cement paste made at the same water/cement ratio, leading to a lower permeability, particularly at early ages. Drawbacks to the use of AAS concrete include a greater amount of autogenous and drying shrinkage [9,12–14], susceptibility to cracking [8,9,15] and the cost of the activator [2,7,10,12]. A better understanding of the hydration mechanisms of blast-furnace slag is needed to develop new methods of activation and to optimize its properties.

Recently, it was shown that the addition of pure, laboratory-synthesized C–S–H accelerates the hydration of C₃S and Portland cement by seeding the hydration process, providing additional nucleation sites for the growth of hydration product [16]. Seeding with C–S–H is a useful way to investigate the early hydration mechanisms because the accelerating properties of the C–S–H seed rely on nucleation and growth being the rate limiting step in the hydration process. The presence of C–S–H has little or no effect on the composition of the pore solution, so if the rate-limiting step is the rate of dissolution of the cementitious component, then the seed should have little or no effect on the kinetics. However, if the reaction is nucleation and growth limited, then the seeding effect of the C–S–H will result in significant acceleration, as previously observed.

In the present study, the effects of C–S–H seed on the hydration kinetics and compressive strength development of AAS paste and OPC paste were investigated. For pure (non-activated) slag, the C–S–H seed has little effect, indicating that the rate of dissolution of the slag is rate controlling. However, when the slag is activated with sodium silicate (AAS), then the addition of C–S–H has an accelerating effect, significantly shortening the time to reach the early hydration rate peak. This provides the first unambiguous evidence that the AAS hydration process occurs by nucleation and growth, as is the case with C₃S and Portland cement.

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