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Physical performances of blended cements containing calcium aluminosilicate glass powder and limestone

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ABSTRACT

This work explores the suitability of calcium aluminosilicate (CAS) glass particles as an alternative to conventional supplementary cementitious materials (SCMs) such as fly ash and blast furnace slag. The reason for adding CAS glass particles to the cement blend is to reduce the CO_2 emission of cement production at the same level of performance. For this purpose, blended cement mortars containing 30 wt.% clinker replacement are characterized with respect to workability and mechanical performance. The results indicated that real emission reductions are possible, particularly for combinations of finely ground limestone and CAS glasses which resulted in significantly higher strengths than would be predicted from the individual contributions of each constituent.

1. Introduction

The production of Portland cement accounts for approximately 5% of the global anthropogenic CO_2 emissions [1–4]. For an efficient process ~2/3 of the CO_2 emission comes from the calcination of limestone which makes up about 80% of the raw materials. This is referred to as the “raw materials CO_2 emission” and accounts for 500–550 kg CO_2 per ton of cement clinker. The other major contributor is the “fuel-derived CO_2 emission” constituting 250–300 kg CO_2 per ton of clinker for an efficient kiln. The demand for cement, especially in developing countries, is expected to at least double by 2050 [1,4,5]. Therefore, emissions per ton of cement must be halved just to maintain the status quo. Several levers have been identified for achieving this, such as improved process efficiency, increased use of supplementary cementitious materials (SCMs), increased use of biofuels, and carbon capture and storage [4]. This paper deals with innovative SCMs based on calcium aluminosilicate (CAS) glasses and limestone. The incentive for this is that traditional SCMs such as fly ash and granulated blast furnace slag are already in short supply in some parts of the world such as Europe [1,3,6]. An important consideration in developing these new SCMs is that they must make a significant contribution to standard, early or 28 day concrete strengths since it makes little sense to lower the clinker factor by e.g. 30% if correspondingly more cement is needed to achieve a given concrete strength. In addition, the use of the new SCMs must of course provide a significant reduction in the overall CO_2 emissions associated with production of the blended cements compared to ordinary Portland cement (OPC).

Previous work by the present authors showed that CAS glasses produced from natural sources of clay, limestone and sand (CAS_{1N} and CAS_{9N} in Table 1) are pozzolanically reactive in a $Ca(OH)_2$ solution [7]. A chain-like silicate structure consistent with the C–S–H phase is detected by means of the ^{29}Si NMR and an Al containing hydration product consistent with the calcium aluminate hydrate phases formed during OPC hydration is detected by ^{27}Al NMR. The introduction of additional Na_2O into CAS_{9N} reduces the melting temperature of the glass and enhances its glass forming ability on cooling, in addition to increasing its grindability and pozzolanic reactivity [7]. In this work, the physical performance of blended mortars containing 30 wt.% clinker replacement is investigated. Blended cements containing only the CAS glasses or a combination of both glass and limestone are examined.

2. Experimental procedures

Commercially available cement containing approximately 96% clinker and 4% gypsum was used to prepare mortars for physical tests. The mineralogical composition of the clinker (Bogue) and the chemical composition of the cement are given in Tables 1 and 2. The content of free lime was measured by titration in alcohol. The preparation and characterization of the CAS glasses are described in [7]. The chemical compositions of the glasses and other SCMs are given in Table 1. Clay, limestone and sand were used as raw materials for the glass preparation. The clay was provided by Dantonit A/S, Odense, Denmark and the limestone and quartz sand were provided by Aalborg Portland A/S, Aalborg, Denmark. The subscript of the CAS

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