Calcined Shale as Low Cost Supplementary Cementitious Material

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Abstract Despite the various benefits of using metakaolin as a supplementary cementitious material (SCM), the high price of metakaolin limits its use in concrete to premium applications. However there are other sedimentary minerals, such as calcined shale, that may be able to fill the need for low cost, abundant SCMs in concrete construction. The study presented here investigated a low cost calcined shale, sourced from a lightweight aggregate producer, and compared its performance as an SCM to that of a commercially available metakaolin. The effect of both SCMs on compressive strength, resistance to alkali silica reaction and mixture workability were evaluated. Results show that, other than early age compressive strength, the performance of calcined shale in cementitious mixtures is comparable to that of metakaolin. Differences in behavior of the SCMs are discussed in the context of their chemical and physical properties.

Keywords Alternative SCMs · Natural pozzolans · Calcined clay · Metakaolin · Shale

1 Introduction

The benefits of metakaolin as a supplementary cementitious material (SCM) in terms of improving concrete strength and durability have been established in previous literature [1–4]. However, due to limited sources and a high demand of pure kaolinite from industries other than concrete, the price of metakaolin is very high. While the use of metakaolin as an SCM can become prohibitive due to its cost, there are other calcined sedimentary minerals that may be able to fill the need for low cost, abundant SCMs in concrete construction. Clay shale (referred to as shale

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elsewhere in this paper), a fine grained sedimentary rock formed from the compaction of clay minerals and other particulate debris [5, 6], can be one such promising, low cost SCM when calcined. Although previous research on the use of calcined shale as an SCM is limited, results from past studies are encouraging [7–9] and showed that the 28 day compressive strengths of specimens with calcined shale as a cement replacement were similar to those of control specimens made with only cement. The main motivation of the study presented here was to further investigate calcined shale as a low cost SCM and to compare its performance in terms of mortar compressive strength, resistance to alkali silica reaction (ASR) and mixture workability to that of the more well-known metakaolin SCM.

2 Materials and Methods

The calcined shale used for this paper, referred to as "Shale-T," was sourced from a lightweight aggregate producer in Texas, USA, and cost approximately $50/ton. The fine shale aggregate was crushed in the laboratory using Bico Inc. UA V-Belt Drive Pulverizer and passed through a No. 200 sieve (75 μm opening) before use. The metakaolin used, referred to as "Metakaolin-D," is a commercially available SCM, sourced from Missouri/Indiana, USA, with an approximate cost of $325/ton. Metakaolin-D is not a high reactivity metakaolin intended for silica fume replacement, but is marketed for general SCM use. Both SCMs passed the ASTM C 618 [10] criteria for Class N pozzolans. The X-ray florescence (XRF)-determined oxide compositions are shown in Table 1, along with moisture content (MC), loss on ignition (LOI) and median particle size (d_{50}). The cement used for all the mixtures was an ASTM C 150 [11] Type I portland cement from Texas, USA. The sand used for all mortar mixtures, except for those testing resistance to ASR, was standard graded sand from Ottawa in Illinois, USA. A sand containing quartz and chert from Texas, USA that has been shown to be reactive in previous literature

Table 1 Characteristics of the SCMs

	Metakaolin-D	Shale-T
SiO_2 (%)	51.66	65.43
Al_2O_3 (%)	35.23	14.55
Fe_2O_3 (%)	1.98	5.72
CaO (%)	0.57	2.44
MgO (%)	0.45	2.30
SO_3 (%)	0.06	0.39
Na_2O (%)	0.1	1.14
K_2O (%)	1.42	2.88
MC (%)	0.87	0.29
LOI (%)	1.04	0.36
d_{50} (μm)	17	23