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ORIGINAL PAPER

Mechanical Properties of Dehydroxylated Kaolinitic Clay in Self-Compacting Concrete for Pavement Construction

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Abstract The high increase in the cost of cement has led to a reduction in concrete production in most developing and under-developed countries. Therefore, the need for a sustainable and cost-effective substitute for cement is necessary. This research focused on the application of dehydroxylated kaolinitic clay in the production of self-compacting concrete for pavement construction. The elemental and oxide composition of the cementitious material (cement and metakaolin) was assessed using atomic absorption spectrometry and a scanning electron microscope was used to determine the particle geometry. Six mixtures of SCC with 0%, 5%, 10%, 15%, 20% and 25% metakaolin replacement were incorporated into this concrete mix. The passing ability, segregation ability and the flowing ability of the fresh concrete were assessed. The strength properties of the various mixtures (compressive and flexural) of the samples were also assessed at 3, 7, 14, and 28 days. The rheological properties showed that the addition of dehydroxylated kaolinitic clay higher than 10% showed poor rheology. However, percentages greater than 15% gave a reduction in compressive strength and flexural strength. In a bid to encourage sustainability in road construction and adopt the use of eco-friendly material, metakaolin is a viable material.

Keywords Pavement · Self-compacting concrete · Metakaolin · Mechanical strength · Rheology

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1 Introduction

In line with the campaign for sustainability and the use of eco-friendly material in concrete road construction, the use of dehydroxylated kaolinitic clay in self-compacting concrete was espoused in this research. Dehydroxylated kaolinitic clay (DHKC) is obtained when kaolinitic clay is heated to a temperature of 650–900 °C. At this temperature, dehydroxylation takes place which is an endothermic process to form DHKC or dehydroxylated kaolin [1]. This material reacts chemically with hydrating cement due to its pozzolanic properties to form a modified paste microstructure with similar pozzolanic properties as silica fume, rice husk ash, fly ash, etc. [2]. In line with the use of other cementitious material, the use of DHKC has been found to have a good combination of properties [3]. Additionally, using this mineral material improved the workability, durability, strength, and cohesion of concrete structures [4].

Self-compacting concrete (SCC) is an innovation in the concrete construction industry. It is a quiet, cost-effective, energy saving, and low carbon footprint concrete due to the absence of vibrators [5]. According to the same author, SCC offers many advantages for the precast, prestressed concrete industry and cast-in-place construction such as low noise, less labor, faster construction, high strength etc. A lot of research has been done by [6–17] to mention a few on the application of self-compacting concrete. The use of DHKC in concrete production is enormous, and its application for structural application has proven to be satisfactory based on the strength and durability properties, but a dearth of literature exists on its use for pavement purposes. According to research by [18–21] strength and durability of concrete containing DHKC improved by assessing both chloride and sulfate attack. Accordingly, [1] worked on the combined effect of DHKC and silica fume on concrete strength. However, [22] and [23] developed statistical models for predicting the consistency of concrete incorporating Portland cement, fly ash and DHKC. The research of [24] experimentally studied a set of parameters of high-performance concrete (HPC) with DHKC. Researchers have reported [25] the synergistic effect of the use of fly ash, iron oxide, and DHKC as supplementary cementitious material in various proportions. They adopted the use of ordinary Portland cement (OPC), and the developed concrete was for structural application. However, this research focuses on the use of Portland limestone cement which conforms to [25] in the production of self-compacting concrete for road construction.

This is because of the dearth of literature on the application of self-compacting concrete in rigid pavement incorporating DHKC. The rigid pavement has numerous advantages over the flexible pavement but requires higher construction cost, and hence the replacement using a mineral with low-cost becomes paramount. This is required to make concrete affordable especially in developing countries with an abundance of kaolin.

This research assessed the mechanical properties of DHKC self-compacting concrete. Also, the use of Portland limestone cement was used instead of the conventional ordinary Portland cement (OPC). The goal of this research is to promote sustainability in pavement construction and reduce the cost of cement which is one of the most expensive constituents of concrete. Hence, this study assessed the mechanical properties of DHKC in SCC for pavement construction.

2 Methodology

2.1 Materials

Locally available Portland limestones cement type II conforming to [25] and [26] was used in the study. The DHKC used in this research was sourced from South Western Nigeria. Atomic absorption spectrometry was used in assessing the compound composition of the cement. SEM was used in assessing the elemental composition, particle geometry and the microstructure of the Portland limestone cement and the DHKC. Aggregates play a key role in concreting as suggested by [26, 27], and [28].

In this research, the coarse and fine aggregates of size 4.5 and 19.5 mm were used throughout the research. A polycarboxylate-based high-range water-reducing admixture (HRWRA), super-plasticizer according to EFNARC, [29] was used in this research.

2.2 Dehydroxylation of the Kaolinitic Clay

The dehydration process of kaolinitic clay to a very large extent depends on the particle size and crystallinity. According to [30, 31] the use of crystal size from scaning electron microscopy (SEM) is paramount for the characterization and application of kaolin. Comparative assessment of the crystal size was done according to the result obtained from the particle geometry of the kaolinitic clay and dehydroxylated kaolinitic clay.

Additionally, the physical beneficiation and characterization of the kaolinitic clay was done to ascertain the basic features like structural area, pore-volume sizes, circularity, convexity, etc. as this to a very large extent affects the structural properties and the characteristic bonds. The outcome of [31] using the same source of kaolin showed that 750 °C was the appropriate dehydroxylation temperature which was adopted in this research.

2.3 Mix Design

Mixing of ingredients and proportions were done according to EFNARC, [32]. The design matrix of this research involved varying the quantity of cement and DHKC. Six concrete mixes were compounded with DHKC replacement at 0%, 5%, 10%, 15%, 20% and 25%. A polycarboxylate based high-range water-reducing admixture (HRWRA), CONPLAST super-plasticizer according to the EFNARC [26] specification was used in improving the workability. One unit of plain SCC mixture was designed at a w/c ratio of 0.45 with fine and coarse aggregate prepared according to the rational mix design method. The rheology of the concrete was assessed using the slump cone, V-funnel and the L-box apparatus according to the specification of [32] and [26]. This was used in assessing the passing ability, segregation ability and the flowability of the concrete mixtures with 0%, 5%, 10%, 15%, 20% and 25% replacement of DHKC. In a bid to attain the desired workability using the [31] approach several trials were made varying the water-cement ratio and superplasticizer dosage while the mass of fine and coarse aggregate was kept constant. Molds of dimension 150 mm × 150 mm × 150 mm and 100 mm × 400 mm × 100 mm were used for both compressive and flexural tests,