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Properties of hybrid cementitious composite with metakaolin, nanosilica and epoxy

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HIGHLIGHTS

- HCC mix showed a significant reduction in water absorption by 2.78%.
- HCC reduced porosity by 13.62% compared to the control specimen.
- HCC reduces air permeability by 39.57%.
- The total average water soluble chloride ion was lower by 43.67%.

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ABSTRACT

The compressive strength and durability potentials of hybrid cementitious composites (HCC) that contain metakaolin (MK), produced in the laboratory using raw kaolin, nanosilica and epoxy resin was the main focus of this research study. The HCC specimens contain 10% metakaolin (MK), 1% colloidal nanosilica (CNS) and 1% epoxy resins and the specimens were examined for early ages of 7, 28, and 90 days of exposure in both water and seawater. The durability properties investigated in this research study comprise of water absorption, intrinsic air permeability, chloride penetration and porosity. All tests were conducted to assess the influence of MK, CNS and epoxy on the compressive strength and the durability properties of the HCC specimens. The result showed that HCC specimens with 10% MK, 1% CNS was durable relative to all the properties. Nevertheless, the addition of both natural fibers (coconut and oil palm fruit bunch fibers) and synthetic fiber (bar chip fiber) has a slight negative impact on the durability properties of HCC specimens. Conclusively, the results showed that the menace of water, liquid and gas transportation by water absorption, capillary suction, porosity, chloride penetration, and intrinsic air permeability of HCC were lesser than that of control specimen.

1. Introduction

Metakaolin, is produced from natural Kaolin and it is different from other cementitious material that are industrial by-products. When raw Kaolin is heated to between 700 °C and 900 °C, the kaolin is calcinated, thus losing a certain percentage of hydroxyl water therefore transform into MK [1]. The MK, like silica fume (SF) reacts with calcium hydroxide, which is formed in the cause of Portland cement hydration thereby generating supplementary cementitious products which change the chemical composition of the concrete as well as improve the overall properties of the concrete materials [2,3].

The most used supplementary cementing material (SCM) especially, in self-consolidating concrete are fly ash, silica fumes, slag while the use of MK is actually infrequent [4,5]. In a similar manner, in the production of engineered cementitious composites (ECC), fly ash was pronounced as the proper and needed ingredient [6]. Metakaolin owns a particle size that is finer than cement, even though not similarly fine as silica fumes [7]. In comparison to SF, it embraces a creamier texture, less bleed water and better surface finishes [8]. Most research work conducted with the incorporation of MK as cement replacement showed that the pozzolanic reactivity result in an improvement in the performance of mortar and concrete. In the reaction that contains cement, the (C-S-H), calcium silicate hydrates are produced as a gel that infiltrates pores, stimulating refinement as a consequence of the decline in average pore size. The outcome can be seen in the interfacial transition zone (ITZ) between the binder and the aggregate hence densification.

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Thus, the process of the pore refinement and ITZ densification brings about the enhancement of the mechanical strength and decrease in capillary water absorption, as well as an improved chemical resistance and durability improvement. Many of the authors, [9,10] that carried out research using MK as cement substitute concur with the fact that MK causes a decrease in the workability, hence, high range water reducing admixture (HRWRA) is required. The admixtures enhance the workability of the mix until the desired fresh concrete characteristics were visually observed.

Colloidal nanosilica (CNS) depicts small particles amorphous SiO_2 core with a hydroxylated surface that is insoluble in water. The size of the particles is varied between 1 and 500 nm making it easier to stay suspended in liquid or fluid material medium devoid of any resolutions. In a nutshell, the synthesis technique can be exploited to control some parameters such as specific surface area and size distribution [11]. The particles nano-scale can yield an amazing properties enhancement from the conventional grain-size materials of the same chemical components. Nanosilica is frequently applied to polymer reinforcement to augment the toughness, modulus, weather-ability and flammability [12,13].

The performance enrichment ability of nanosilica is accomplished by means of two major mechanisms. The first mechanism is that the ultrafine particles of the nanosilica have the capacity to fill the microscopic voids that exist between the particles of cement therefore advance the cementing properties and instituting a less porous structure. Equally, the curing procedure allows the nanosilica to react with $Ca(OH)_2$ produced during cement hydration to yield additional calcium silicate hydrate [14]. Additionally, the thoroughly dispersed nanosilica particles could serve as nucleation centers for cement hydrates, a feature which can cause an acceleration of the hydration process. The nanoparticles stimulate the configuration of small sized uniform C-S-H clusters. They could as well improve the aggregate contact zone structure which yields better aggregates and cement paste bonds [15].

As a result of these aforementioned features of nanosilica, that is, the filling effect, which reduced porosity and the pozzolanic reaction, that contributes to the use of calcium hydroxides for supplementary CSH formation, nanosilica could be used as an admixture in the production of the HPC with improved compressive strength, surface resistance, reduced permeability and dry shrinkage [16]. In this research study, colloidal nanosilica was used to enrich the durability properties of the HCC specimens with the incorporation of MK.

In the modern-day concrete constructions and repairs, the part of polymers are intensifying day by day. The incorporation of a polymer substance in concrete or mortar improves the strength, the resilience, chemical resistance, durability properties, the impermeability of such concrete or mortar [17,18]. All these properties make the polymer concrete or mortar appropriate for various structural and non-structural use and repairs of concrete members, pre-cast products, waterproofing, decorative finishes, pavement overlay, bridges and industrial floors and anticorrosive [17]. Quite a lot of thermoplastic or preferably thermosetting polymers are engaged in improving mortars and concrete. They are mostly in a variety of forms such as liquid resins, latexes, water soluble, homopolymers and copolymers [19]. Due to the promising features of epoxy resin, it was engaged in this study as partial cement replacement along with the MK and CNS.

This study lay emphases on the influence of these three cementitious materials on the durability properties of hybrid cementitious composites observed under two different curing regimes. The HCC has basic features which are in the pattern of the existing engineer cementitious composites.

2. Objectives

This study focused on the compressive strength and the durability properties of a hybrid cementitious composite at the early ages. The HCC is produced by the replacement of binder weight with 10% MK, 1% colloidal nanosilica (CNS) and 1% epoxy resin without hardener. These percentages were decided after a series of trial test by means of rational mix design to arrive at the optimal mix ratio. A trial mixed was conducted with the aim of achieving a target optimum strength at an early age by selecting the optimum proportion of cement, MK, water, fine aggregates, CNS and epoxy. A rational mix design proportion was employed whereby the MK, CNS and epoxy were varied in proportion to each other. The mix was designed to have a compressive strength of between 65 N/mm^2 and 70 N/mm^2 at 28 days.

3. Material and experimental methods

3.1. Materials

3.1.1. Metakaolin

The MK was produced in the laboratory using the purified Kaolin that was sourced locally. The process of calcination of the kaolin into metakaolin was as described in another publication [20]. The mean particle size diameter is (d_{50}) of 2.0 μm and a specific gravity of 2.6. Table 1 shows the chemical properties.

3.1.2. Cement

The Ordinary Portland cement is ASTM Type I Portland cement. The physical properties include median particle size value of 6.14 μm, blaine specific surface area of 270 m^2/kg and the specific gravity was 3.02. The initial setting and final setting times of 115 are 310 min respectively. The physical and chemical properties of the cement comply with ASTM Standard C150 specifications [21]. The chemical composition highlight is shown in Table 2.

3.1.3. Nanosilica

The colloidal nanosilica (CNS) is a product of Sigma–Aldrich product, Ludox AS-40 colloidal silica that has 40 wt by% solution in water. It has a total weight of 60.08 g/mol. Table 3 shows the physical and chemical properties.

Table 2
Chemical composition of Ordinary Portland Cement (%).

Constituents	Ordinary Portland Cement
Lime (CaO)	64.64
Silica (SiO_2)	22.40
Alumina (Al_2O_3)	3.60
Iron Oxide (Fe_2O_3)	2.90
Magnesia (MgO)	1.50
Sulphur Trioxide (SO_3)	2.14
Na_2O	0.05
K_2O	0.80
Loss of Ignition	0.64
Lime saturation factor	0.92
C_3S	52.82
CS	19.65
C_3A	4.64
C_4AF	8.82

Table 1
Chemical properties of metakaolin produced in the laboratory (% weight).

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
53.03	0.93	35.63	1.81	0.02	0.57	0.04	0.04	1.88	0.06

The LOI (Loss on ignition) = 1.99% obtained in compliance with BS EN 15935 (2009).