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ORIGINAL ARTICLE

Investigating the properties of agro-waste fiber reinforced low calcium fly ash geopolymer composites: the effect of alkali treatment and nano-clay addition

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Abstract

This work investigated the effect of incorporating the alkali-treated *Phoenix sp.* fibers (PSFs) and nano-clay (NC) on the physico-mechanical, water, and thermal resistance properties of geopolymers composites. These composites were produced using low calcium fly ash-based geopolymer matrix and PSFs and NC as a reinforcing component. Findings showed that incorporating the alkali-treated fiber and NC significantly enhanced the mechanical characteristics of the composites compared to the control matrix and untreated fiber composites. Specifically, the composite containing 2 wt.% of NC improved their compressive strength by 40.53%, splitting tensile strength by 195.31%, flexural strength by 185.32%, and fracture toughness by 71.93% compared to the control matrix. Further, composites containing treated fiber and NC exhibit a significant reduction in water absorption (30.18%) and thermal conductivity (12.5%). An organised matrix-fiber interface was revealed by scanning electron microscopy (SEM) images, this elucidated the favourable mechanical qualities that were attained. Furthermore, load–deflection tests were performed to determine the viability of fly-ash-based geopolymer composites (FAGC) for structural applications. The findings indicate that reinforcing the alkali-treated PSFs and NC improves the overall performance of the FAGC. More importantly, this research promotes the sustainable use of agricultural and industrial wastes, as well as sustainable development.

Keywords Geopolymer · *Phoenix* sp. fiber · Alkali treatment · Nano-clay · Interfacial bonding

Introduction

Ordinary Portland Cement (OPC)-based products have been extensively employed in building sites due to exceptional strength and durability characteristics, as well as the readily available of raw substances [1, 2]. Every year, millions of tonnes of resources are used to produce a minimum of ten billion tonnes of concrete worldwide [3]. Concrete production demands more energy, and raw materials release CO_2 throughout their entire cycle [4, 5]. The OPC significantly impacts the environment, contributing over 6–8% of global CO_2 emissions. To overcome the aforementioned shortcomings, the cement industry needs to enhance the environmental friendliness of construction materials. Proposed alternatives to OPC, such as renewable resources (biomass like agro-wastes) and industrial waste, aim to increase the sustainability of the construction sector [6, 7]. Geopolymers (GPs), is a sustainable and environmentally friendly building material that promotes sustainability [8–10]. These GPs have considerable potential as an innovative and ecologically sustainable solution for a wide range of uses that include: CO_2 absorption, thermal and acoustic insulation, air and wastewater treatment, chemical catalysis, adsorption and removal of various contaminants and functioning as an eco-friendly substitute for traditional cementitious materials [11–13].

The GPs have gained global attention for their exceptional characteristics and ease of manufacture, which requires

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on fiber pull-outs, fiber breaking, fiber bridging, and interface debonding. Furthermore, a higher nano-clay content (3 wt.%) increases viscosity, which leads to poor diffusion and geopolymerization, creating weak spots and encouraging porosity. This reduces strength, increases brittleness, and weakens the interfacial bonding inside the composite. Finally, this research demonstrated that geopolymer composites containing treated PSFs and 2 wt.% NC could potentially be employed as an alternative material for thermal insulation and construction applications. A future study is planned to explore the properties of geopolymers reinforced with natural fibers that have been treated using eco-friendly chemicals.

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