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Preliminary investigation on spent garnet as a novel supplementary cementitious material

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ABSTRACT

The escalating global demand for cement, a fundamental material in infrastructure development, has exacerbated environmental challenges, particularly through significant carbon dioxide (CO_2) emissions, which account for approximately 8.3 % of global anthropogenic CO_2 output. This research explores the potential of spent garnet powder, a byproduct of abrasive water jet machining, as a sustainable supplementary cementitious material (SCM) to mitigate these impacts. The spent garnet powder, characterized by a high concentration of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3), was subjected to rigorous analysis. X-ray Fluorescence (XRF) confirmed its chemical suitability for pozzolanic applications, while laser particle size analysis revealed a finer granulometry relative to Ordinary Portland Cement (OPC), which is advantageous for enhancing pozzolanic reactivity. Scanning Electron Microscopy (SEM) demonstrated the angular and irregular morphology of the garnet particles, which is conducive to improved interfacial bonding within the cement matrix. X-ray Diffraction (XRD) identified active mineral phases that are critical for promoting pozzolanic reactions, and Thermogravimetric Analysis (TGA) demonstrated the material's superior thermal stability, with minimal decomposition at elevated temperatures. Fourier Transform Infrared Spectroscopy (FTIR) identified strong silicon-oxygen (Si-O) and aluminum-oxygen (Al-O) bond structures, indicative of robust pozzolanic potential. The Strength Activity Index (SAI) and Frattini tests further substantiated the pozzolanic activity, revealing that a 10 % replacement of OPC with SGP not only enhances compressive strength but also meets the stringent requirements of ASTM C618. Additionally, the economic analysis underscores the cost-effectiveness of utilizing spent garnet powder, presenting a viable strategy for reducing both production costs and CO_2 emissions in the cement industry. This study conclusively positions spent garnet powder as a highly promising supplementary cementitious material, with significant implications for advancing sustainable construction practices and reducing the environmental footprint of cement production.

1. Introduction

The global demand for cement has experienced a steady rise, driven by the continuous growth of the world's population, resulting in a notable 194 % increase in global cement production over the past two decades [1]. Cement, a vital building component, plays a pivotal role in fostering a country's economy and development, with significant contributions from both developed and developing nations to its large-scale production. Projections indicate a potential surge in annual cement production to 4 billion tonnes by 2030 [2], and by 2050, a projected global output of 4682 million tonnes per year is anticipated, predominantly fueled by consumption in developing nations [3,4]. Nevertheless, the ecological footprint of cement manufacturing is becoming an increasingly pressing concern. Cement, commonly known as the 'adhesive' in concrete, constitutes 8.30 % of the overall anthropogenic carbon dioxide (CO_2) emissions globally [5–7]. The destruction of the

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