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Abstract

High-Temperature, Bond, and Environmental Impact Assessment of Alkali-Activated Concrete (AAC) †

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Alkali-activated binder (AAB) has been extensively researched in recent years due to its potential to replace Portland cement (PC) and lower carbon footprint. However, major barriers to its commercialization are related to the inadequate characterization of mechanical properties and long-term durability. The mechanical and durability performance of AAB is highly influenced by its microstructure. There is minimal research on correlating the microstructural changes to the specimen-level performance of AAB [1]. Among AAB's primary advantages as a building material is its superior performance at high temperatures and lower environmental impact [2]. The performance of reinforced concrete to function as a composite at high temperatures is evaluated through its bond strength. Several studies reported the effect of mix proportions, curing conditions, and rebar specifications on the bond strength of thermal-cured alkali-activated concrete (AAC) [3–6]. However, there is no reported study on the bond strength of ambient cured (fly ash + slag)-based AAC. To validate the practical sustainability of AAC, life cycle assessment (LCA) can be used to evaluate the environmental impact.

Therefore, the present study evaluates the effect of varying precursor proportion (fly ash: slag varied as 100:0, 70:30, 60:40, and 50:50), activator modulus (Ms, varied as 1.0 and 1.4), and high temperatures (538 °C, 760 °C, and 892 °C) on the mechanical properties and microstructure of AAC. The microstructural characteristics are evaluated using X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDS). The effect of varying precursor proportions and Ms on the mechanical performance of AAC is evaluated through compressive strength, bond strength, flexural strength, and split tensile strength testing. The performance of AAB at extremely high temperatures is assessed in terms of residual compressive and bond strength. LCA of AAC is conducted using the ReCiPe 2016 methodology. Furthermore, since the commercialization of any novel alternative material depends on cost-effectiveness, a simplified cost analysis is performed.

The results from microstructural experiments show the formation of new crystalline phases and decomposition of reaction products when exposed to high temperatures, and they correlate well with the observed mechanical performance. The 28-day compressive strength with slag content is enhanced by 151.8–339.7%, depending on the mix. In ambient conditions, lower Ms improves mechanical performance. When exposed to high temperatures, specimens with a high slag content and a low Ms suffered significant deterioration. AAC with a fly ash: slag ratio of 70:30 and Ms of 1.4 is proposed as optimal from the results obtained in the present study [7]. The results reveal that the biggest impact on climate change comes from transport (45.5–48.2%) and sodium silicate (26.7–35.6%). Environmental impact is determined to be primarily influenced by sodium hydroxide. The proposed optimal AAC mix has a global warming potential 42.6 % lower than PC concrete [8]. A comparison with the default procedures in the International Reference Life Cycle Data System (ILCD) handbook reveals that the ReCiPe midpoint approach is more efficient in analyzing all impact categories, except freshwater ecotoxicity (FETP) and human toxicity potentials (HTPs). An evaluation of FETP and HTP is recommended with USEtox [9]. The proposed AAC mix has a higher cost than PC concrete in the present scenario. In contrast, if a carbon tax is enacted, the cost of the proposed AAC mix will rise by only 18.4%, whereas PC concrete prices will rise by 81.7%. This proposed AAC mix is an environmentally sustainable replacement for PC concrete specifically intended for applications requiring the superior high-temperature performance of reinforced concrete.

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