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Utilization of Acid Mine Drainage Sludge in Metakaolin-Based Alkali-Activated Mortars: Sulfate Interactions, Efflorescence Behavior, and Metal Immobilization

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Introduction

The management of acid mine drainage sludge (AMDS), a sulfate-rich waste generated during the treatment of mining effluents, represents a significant environmental challenge due to its high content of potentially mobile contaminants [1]. While geopolymers (GP) have shown potential for contaminant immobilization [2], the effects of incorporating sulfate-rich residues such as AMDS into these systems remain largely unexplored. In particular, the high sulfate content may interfere with geopolymerization reactions and affect material performance.

Objetives

This study evaluates the incorporation of AMDS from copper mining into metakaolin-based GP, focusing on reaction mechanisms, physical and mechanical properties, efflorescence behavior, and heavy metal immobilization.

Methodology

AMDS was incorporated into a metakaolin-based GP mortar at contents ranging from 0 to 15 wt.% relative to the solid precursor. The resulting materials were analyzed using isothermal calorimetry, XRD, FTIR, SEM, density, porosity, compressive strength (3, 7, and 28 days), efflorescence analysis, and leaching tests with metal analysis by TXRF.

Results and Discussion

The results showed that increasing AMDS content progressively reduced heat release, indicating inhibition of geopolymerization due to the consumption of Na^+ by sulfates and the formation of sodium sulfate [3].

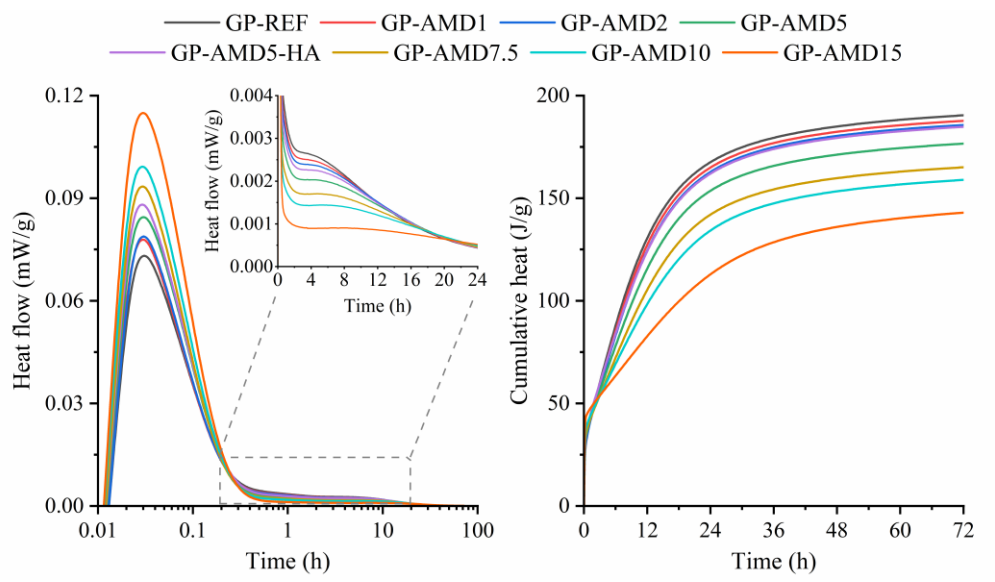


Figure 1. Isothermal calorimetry results

Consequently, porosity increased and bulk density and compressive strength decreased with AMDS addition, driven by alkali consumption, matrix dilution, and increased pore volume. Efflorescence was not observed up to 5% AMDS, suggesting a capacity of the matrix to retain sodium sulfate, but became significant at higher incorporation levels. Despite these effects, leaching tests demonstrated a reduction in the leaching of Fe, Cu, Zn, and Mn by more than 99.97% upon incorporation into the mortars, even at the highest AMDS content (15%).

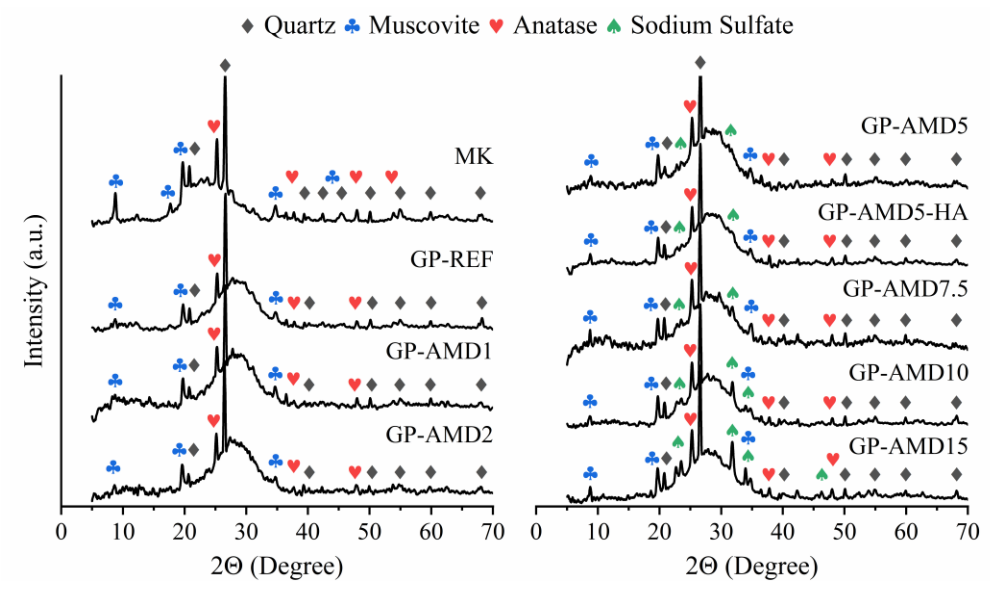


Figure 2. XRD results

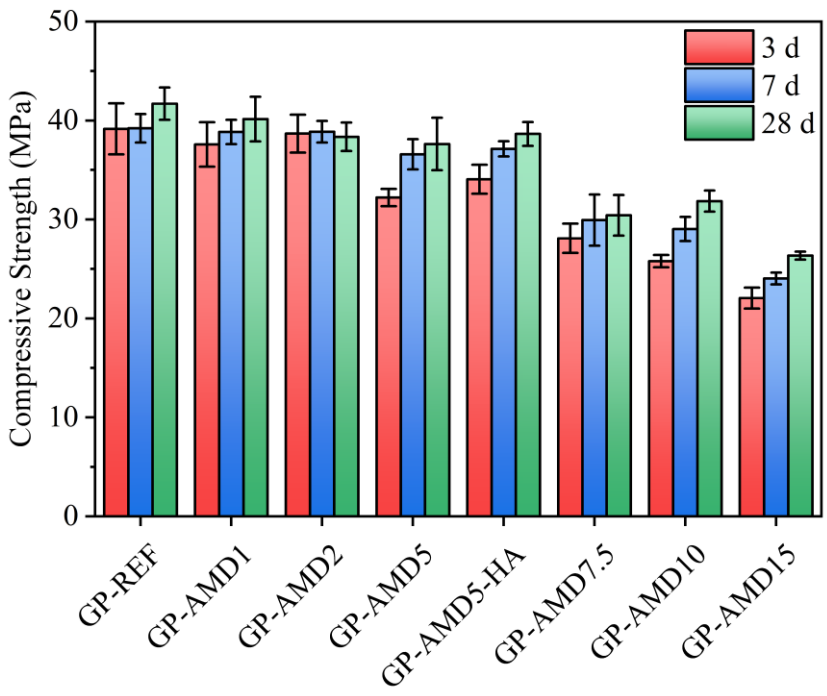


Figure 3. Compressive strength results

Conclusions

The findings highlight the importance of controlling sulfate content to balance reaction efficiency and mechanical behavior, providing a mechanistic basis for the use of sulfate-rich mining residues in GP. Notably, the exceptional immobilization of heavy metals underscores the potential of GP systems as a promising solution for managing mining waste and promoting environmental protection.

References and Acknowledgments

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