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Towards Sustainable Mining: Geopolymer Formulations for Eco-Friendly Mine Waste Management and Recycling

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The demand for environmentally friendly materials in our habitat is a major challenge. Alkali activation, such as in geopolymers, offers a potential solution for waste valorization, providing an alternative to cement-based materials and contributing to the circular economy.

This study explores the use of mine waste from an abandoned Pb-Zn site in Northern Tunisia as an inexpensive and high adsorption capacity additive in the synthesis of geopolymers. The mine waste was used to replace metakaolin in the geopolymer formulations to minimize the environmental impact. Two types of metakaolin (commercial 1200S MK, AGS Mineraux, France and Portuguese Vicente Pereira, VPMK) were used in the formulations. Microstucture, mechanical properties, and Methylene Blue dye adsorption were studied.

Results revealed alarming concentration of potentially toxic elements in the mine waste (28.040 mg kg^{-1} Pb and 94.420 mg kg^{-1} Zn), presenting an environmental hazard and pointing up the need to stabilize these materials in order to prevent leaching. Mechanical behaviour at 28 days of curing was promising (up to 32MPa) in the case of the VP based metakaolin formulations. The microstructure, studied by SEM, is consisted of voids, macro and meso pores, giving the geopolymers a high adsorption capacity. The synthetized geopolymers were utilized for the adsorption of methylene blue (MB) by investigating the effect of the amount of the adsorbent and the shaking period. The batch kinetics study fitted best into the pseudo second order reaction kinetic model. In isotherm modelling studies, the Langmuir isotherm model was best fitted and was used to describe the mechanism of the adsorption. Samples with 40 wt.% VPMK and 100 wt.% MK showed the best adsorption capacity revealing the effect of the waste in the amelioration of the alkali-activated metakaolin based geopolymers and its potential in the restitution of metakolin.