Development and qualification of a novel process for the treatment and conditioning of spent ion exchange resins into geopolymers

Abstract

This work presents the development of a novel process for the treatment and conditioning of spent ion-exchange resins based on direct immobilization at ambient temperature. The process includes a pre-treatment step involving resin grinding to a particle size of approximately 100 μm, followed by its solidification within a geopolymer matrix specifically tailored for this type of waste.

A significant part of the research was dedicated to defining the geopolymer raw materials, molar ratios, and preparation protocol, as different variables, such as the alkaline solution equilibrium time and sealed-curing conditions, were found to strongly influence the properties of the final product. Then, two geopolymer matrices were selected according to key parameters relevant to waste conditioning, including compressive strength, water resistance, and thermal stability, for subsequent studies. The addition of inert fillers, particularly sand at 30 wt.%, was also investigated and shown to enhance structural compactness.
Parallel studies on the resin demonstrated that grinding significantly reduces its swelling behavior, enabling stable incorporation within the matrix. As a result, geopolymer wasteforms containing 30 wt.% resin successfully met the Italian Waste Acceptance Criteria.

Further investigations focused on enhancement strategies to improve performance and increase waste loading. Vacuum mixing improved paste homogeneity and mechanical properties, with samples containing 40 wt.% resin showing promising results as next-generation candidate wasteforms. In contrast, molding pressure did not prove effective under the tested conditions. Attempts to improve leaching resistance by treating the resin with hydrophobic additives were unsuccessful, confirming, as demonstrated in this work, that matrix optimization remains the most effective approach to enhance leaching resistance.

Overall, the results demonstrate the feasibility and effectiveness of geopolymer matrices for the safe immobilization of spent ion-exchange resins and provide a solid basis for future optimization studies aimed at further increasing waste loadings and improving long-term performance.