Macedonian Pharmaceutical Bulletin, 72 (Suppl 1) 387 - 388 (2026)
Online ISSN: 1857-8969
DOI: 10.33320/maced.pharm.bull.2026.72.03.187
Short communication

Polymer-assisted stabilization of ZnO-rich filter dust and mill scale: An environmental and engineering approach

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Introduction

Steel production generates significant quantities of industrial by-products, including ZnO-rich filter dust and mill scale, which pose environmental challenges due to the presence of potentially hazardous heavy metals. Electric arc furnace dust typically contains zinc oxide together with trace elements such as lead and cadmium, raising concerns regarding safe handling, storage, and environmental impact (Piatak et al., 2015).

Conventional waste management approaches are increasingly constrained by stringent environmental regulations, emphasizing the need for sustainable strategies focused on stabilization and valorization of industrial by-products (Mymrin et al., 2017). Among the available techniques, solidification/stabilization methods are widely recognized as effective approaches for reducing contaminant mobility by improving physical integrity and limiting particulate dispersion (U.S. EPA, 2015).

Polymer-based stabilization represents a promising alternative in which polymer matrices act as binding agents through particle agglomeration mechanisms, improving material cohesion and reducing dust formation. In addition to environmental protection and waste management, such approaches may also offer potential for future utilization of stabilized residues in non-structural construction materials and sustainable engineering applications, including systems requiring improved cohesion and energy dissipation characteristics.

The aim of this study was to evaluate the feasibility of polymer-assisted stabilization of ZnO-rich filter dust and mill scale, with particular emphasis on reducing particulate dispersion and improving handling and storage properties.

Materials and methods

ZnO-rich filter dust and mill scale were obtained from a steel production facility in Skopje, North Macedonia, and used without prior purification. Stabilization was performed using three different biocompatible polymer liquid systems (S1, S2 and S3), prepared as solutions in distilled water. The polymer solutions were applied directly onto the particulate materials, enabling surface coating and inter-particle binding through agglomeration mechanisms. The stabilization process was carried out using different solid-to-liquid ratios depending on the material type. For ZnO-rich filter dust, a mass ratio of 5:1 (solid:liquid polymer) was applied, while for mill scale a higher ratio of 7:1 was used. Each polymer system was applied separately, resulting in three distinct formulations. The mixtures were manually molded into irregular rectangular block-like specimens and allowed to dry under ambient conditions.

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Dynamic viscosity of the polymer solutions was determined using an Anton Paar rheometer (MCR 92, Austria) equipped with a cone–plate system (P-PTD220/AIR, CP50-1; zero gap 0.104 mm). An appropriate sample volume (~20 mL) was loaded into the measuring system. Measurements (n=3) were performed at 25 ± 0.2 °C under controlled shear rate conditions for 15 s, with data recorded at defined time intervals (5-15 s).

The influence of polymer solution viscosity and solid-to-liquid ratio on stabilization efficiency was evaluated through comparative visual and morphological assessment, focusing on cohesion, friability and dust generation.

Results and discussion

Comparative visual and morphological assessment demonstrated the formation of agglomerated structures with varying cohesion depending on the applied polymer system. All treated samples showed reduced dust dispersion compared to untreated material, indicating improved particle binding and partial suppression of fine particle mobility, consistent with stabilization mechanisms reported for particulate industrial residues (U.S. EPA, 2015).

The use of three different polymer solutions resulted in distinct structural behaviors, demonstrating a clear dependence of stabilization efficiency on formulation under the applied experimental conditions. Rheological analysis showed apparent viscosity values of ~2750 mPa·s for S1, 3130 mPa·s for S2 and 3520 mPa·s for S3. Samples treated with the higher-viscosity polymer systems (S2 and S3) exhibited improved cohesion and reduced friability, whereas the lower-viscosity system (S1) showed partial fragmentation and a higher tendency for generation of loose particles. The polymer systems contributed primarily through surface coating and inter-particle adhesion mechanisms, promoting agglomeration and reducing the mobility of fine particles (Shi et al., 2011).

The applied solid-to-liquid mass ratios (5:1 for ZnO-rich dust and 7:1 for mill scale) influenced the structural characteristics of the stabilized materials. The lower ratio provided greater polymer availability for the finer ZnO particles, which require higher binder content due to their larger specific surface area, whereas the coarser mill scale was adequately stabilized at a 7:1 ratio. The incorporation of mill scale fragments within the agglomerated structures confirms the compatibility of the polymer systems with heterogeneous industrial residues. Samples with higher cohesion exhibited reduced surface degradation and improved resistance to mechanical disturbance during manual handling.

From an environmental perspective, reduced dust generation indicates lower potential for airborne dispersion of fine particulate matter. Although complete immobilization was not achieved, the treatment improved material stability and handling safety. Polymer-assisted stabilization therefore functions primarily as a dust suppression and cohesion-enhancing approach for temporary stabilization, storage, and transport of industrial residues (U.S. EPA, 2015). The results further indicate that particle size, polymer viscosity, and solid-to-liquid ratio are key factors influencing stabilization efficiency.

Conclusion

The application of viscous polymer-based stabilization improved the cohesion and handling properties of ZnO-rich filter dust and mill scale, reducing fine particle dispersion. Stabilization efficiency depended on polymer viscosity, particle size, and solid-to-liquid ratio. The obtained results also indicate potential for future non-structural engineering and sustainable construction applications. Further leaching and durability studies are required to assess long-term environmental performance.

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