

CO₂-neutral carbothermic reduction, basicity optimization, and controlled solidification to tailor microstructure and particle morphology for superior performance as a sand substitute in mortar.

Cluster of Excellence
Recycling



Green Zinc develops CO₂-neutral, zero-waste routes for recovering valuable metals from secondary resources by replacing fossil coke with renewable reductants and by valorising all by-products through targeted slag conditioning. Detailed characterization enables tuning of slag composition and cooling/conditioning to immobilize hazards and engineer application-ready properties.

Slag Reinvented

Global demand for construction aggregates continues to rise, while natural sand resources are subject to growing environmental and regulatory constraints that make extraction costlier. At the same time, by-products from non-ferrous metallurgy, especially complex slags rich in silicates and oxides, offer strong potential as engineered sand substitutes. Their melt-derived structure and adjustable chemistry enable transformation into granular, hydraulically active materials through basicity control and cooling strategies. This dual benefit reduces pressure on natural resources while creating a sustainable use for industrial residues from high-temperature processes.

To support the transformation of complex slags into aggregate-like materials, a tailored pyrometallurgical approach is employed. As illustrated below, the process begins with carbothermic reduction to recover residual metals and refine the slag composition. By adjusting key parameters such as basicity through targeted additions and furnace control, the slag's chemical and mineralogical profile is tuned for further processing. The molten material is then tapped and cooled using defined solidification strategies to shape the final particle properties essential for its reuse as "slag sand" in construction materials.

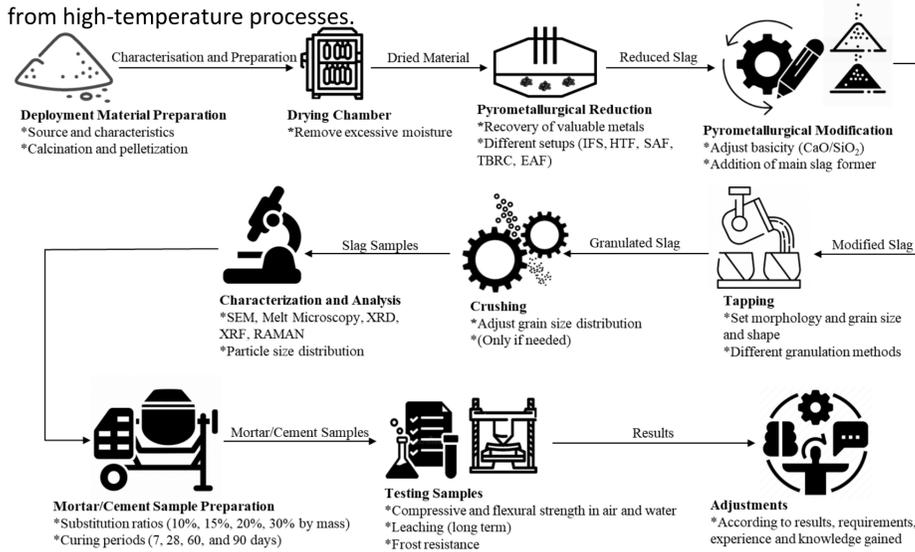


Figure 1: End-to-End Approach from Slag Refinement to Application in Cementitious Systems

Granulation Strategies and Morphology Control

To highlight the influence of solidification dynamics, both wet and dry granulation methods were employed, offering a strong contrast in cooling rates and their impact on slag transformation. Cooling rate plays a decisive role in determining the microstructure, grain size, and particle shape of the material. These features can be adjusted through controlled granulation techniques, which

are essential for producing a particle size distribution comparable to natural sand. For optimized use as sand substitute, a higher amorphous phase content is desirable, as it enhances hydraulic reactivity. Wet granulation proved superior in this regard, consistently producing glassier slag with better bonding potential.

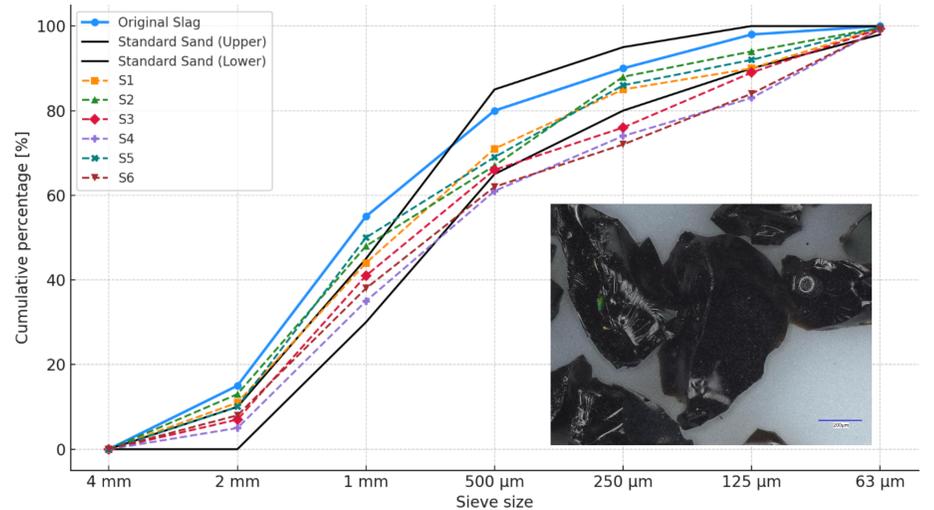


Figure 2: Grain size distribution (S1-S6) vs. sand limits with microscopic view of original slag.

While wet granulation improved phase composition, it did not sufficiently control particle shape. To address this, a custom-designed granulation disc was implemented during the quenching process, enabling direct influence over grain morphology. This approach allowed

shaping of the particles during rapid cooling and yielded largely spherical granules within the targeted size range. A scale-up of the system is currently underway to support extended trials and application-oriented evaluation.

Conclusions and Outlook

The targeted recovery of valuable metals was successfully achieved, and the resulting slags were processed to match desired grain size distributions. Detailed characterization confirmed suitable morphological properties and phase compositions for further valorization. Key steps remain before deployment in construction materials. Notably, particle shape requires further refinement through scalable granulation combined with quenching strategies. Only then can mortar samples incorporating the modified slag be produced and tested for application-specific properties. Planned

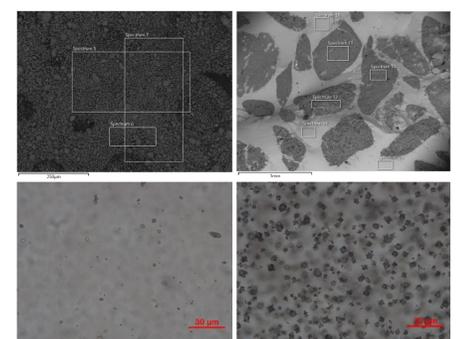


Figure 3: SEM images (top) and transmitted light microscopy images (bottom) of wet-granulated slag (left) and dry-granulated slag (right)

long-term studies will assess leaching behavior, mechanical strength, and durability under freeze-thaw and water exposure conditions.

Carbon-Neutral Metal Recovery

Slag from lead smelters was selected as input material, containing residual nonferrous metals that were targeted for recovery. Reduction trials were conducted in both a high temperature resistance furnace (HTF) and an induction furnace smelter (IFS) using biochar as a sustainable carbon source. Instead of operating with an excessive carbon surplus, the process was designed to approach defined residual oxide thresholds, approximately 1.5 weight percent PbO and 4 percent ZnO. These values represent a process and cost-efficient sweet spot that balances

recovery efficiency with optimal downstream slag conditioning for further valorization.

Table 1: Experimental Setup for Reduction and Modification

	Lead slag	Carbon carrier	Crucible	Al ₂ O ₃ pure	CaO pure
	[kg]	[kg]	[-]	[kg]	[kg]
Slag 1 (IFS)	5.0	0.5	Graphite	-	-
Slag 2 (IFS)	5.0	0.5	Silicon Carbide	0.6	-
Slag 3 (IFS)	5.0	0.5	Silicon Carbide	0.6	1.8
Slag 4 (HTF)	5.0	0.5	Ceramic	-	-
Slag 5 (HTF)	5.0	0.5	Ceramic	0.6	-
Slag 6 (HTF)	5.0	-	Graphite	0.6	0.8

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