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Scrap-Based Steelmaking: Integrating AI, Life Cycle Assessment and Critical Raw Materials to Advance Circular Strategies

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High-performance forged components (e.g., steam-turbine shafts) demand tight control of microstructure and creep behaviour. In industrial development, however, parameter selection and qualification frequently involve iterative loops (trial batches, rework and occasional scrap), which translate into avoidable material and energy losses. AID4GREENEST project tackles this challenge by combining data-centric AI and physics-informed modelling to support earlier and more reliable decision-making across the steel value chain. Although simulation-based tools such as FE thermal modelling are currently well-established in forging companies, artificial intelligence has emerged as a natural progression to optimize product design. In this way, the trial and error approach can be minimized by selecting the most appropriate manufacturing parameters route to achieve the desired properties in the final product.

To understand the environmental impact of these innovations, an analysis of a non-optimized process is proposed as the basis of the study. The study includes a life cycle assessment (LCA) to assess the environmental footprint of manufacturing steam shafts from recycled steel, highlighting how existing residue streams at Reinosa Forgings & Castings are revalorized, contributing to the circular economy. The analysis initially follows a 'cradle-to-gate' approach, prioritizing processes such as EAF melting, refining, and casting, proposing scenarios to measure the impact of by-product revalorization. Primary data was collected directly from industrial operations, supplemented with secondary data from Ecoinvent v3.11, and modelled using Umberto 11.15.2. The assessment of environmental impacts was based on the production of one tonne of ingot as the functional unit. Initial results indicate that RFC's processes where residue streams are revalorized present a reduction on environmental impact of as much as 15% in comparison with processes performed elsewhere where these streams are disposed as waste.

As an added value for industrial decision-making, the LCA inventory is also screened from a Critical Raw Materials (CRM) perspective, identifying and tagging input streams that fall under the EU CRM framework. In the EAF route assessed, this includes materials associated with electrode consumption (graphite), CaF_2-based additions (fluorspar), and selected alloying-related inputs (e.g., Ni-, Mn- and V-bearing additions). This enables reporting, alongside conventional impact indicators, a simple "CRM intensity"per tonne of ingot and the scenario-driven change in CRM exposure when circular residue management and yield-related improvements are implemented. Finally, by utilizing the synergies of AI-tools, LCA, and CRM screening, the present study provides quantified evidence to support both environmental performance and reduced dependency on critical material supply chains.

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