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Hydrometallurgical Recycling Approach for spent Refractories from the Nonferrous Industry

Introduction

Refractories are crucial ceramic materials in metallurgical processes, protecting equipment against extreme heat, chemical, and mechanical wear. During use, they degrade and form infiltrated heterogeneous residues. Spent refractories in the nonferrous industry contain valuable metals like copper and nickel. Despite this, spent magnesia chrome refractories are largely landfilled due to their heterogeneity. Developing a recycling approach to recover metals and a reusable refractory fraction would be sustainable, but challenging. Therefore, a robust processing approach to handle variable compositions and impurities is needed.

Materials, Methods, and Solution Approach

The investigated spent magnesia chrome refractories from nonferrous copper and nickel industry were provided by RHI Magnesita. Aim of the project is:

- To recover valuable metals and,
- Generate a refractory fraction for reuse in refractory production.

Beforehand a thorough characterization, shown in Figure 1, of the residue was performed using X-Ray fluorescence analysis and X-Ray diffraction, as well as secondary electron microscopy to determine the elemental, and phase composition of the spent refractories. These methods are also applied for the products from the various recycling steps. Biased on the obtained information, further processing steps, supported by thermodynamical calculations, were planned.

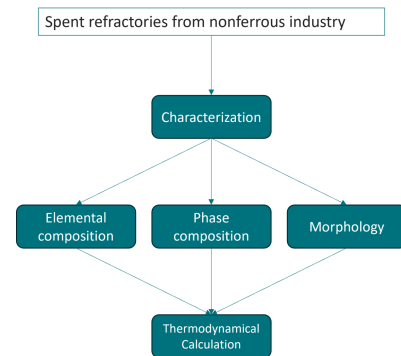


Figure 1: Flowsheet of the spent refractory characterization

The recycling approach shown in Figure 2 starts with a mechanical beneficiation step to recover unaltered refractory fraction for reuse. The contaminated fraction from the separation step is further treated in a leaching step, where intruded metals are dissolved, and a solid residue suitable for reuse in the refractory production is separated. Furthermore, the resulting leachate is purified to recover valuable metals like copper and nickel, for reuse in metal production. The final step is an acid regeneration, simultaneously recovering the acid for reuse in the leaching step and producing a magnesium product.

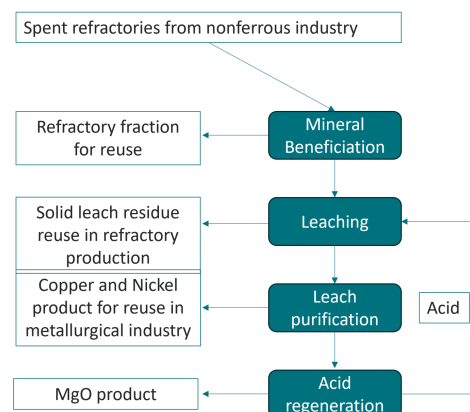


Figure 2: Flowsheet of the recycling approach for spent refractories from the nonferrous industry



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Research focus: Recycling of spent refractories from nonferrous metallurgy

Christian Doppler Laboratory for selective recovery of minor metals using innovative process concepts



Selective Chromium Recovery from steelmaking slags via engineered artificial minerals

Introduction

The annual production of crude-steel continues to rise, accompanied by increasing amounts of slag. Steel is mainly produced via the oxygen furnace ("BOF") route and the electric arc furnace ("EAF") route, generating slags with complex chemical compositions. Recovering valuable metals such as chromium through engineered artificial minerals ("EnAMs") is therefore a promising field of research. However, the conditions controlling chromium incorporation and enrichment into stable mineral phases need to be investigated.

Research Objective

The aim of this research is to recover Chromium through a combined pyrometallurgical treatment and a mineral-beneficiation, by forming a magnetic spinel enriched in Cr (Figure 1).

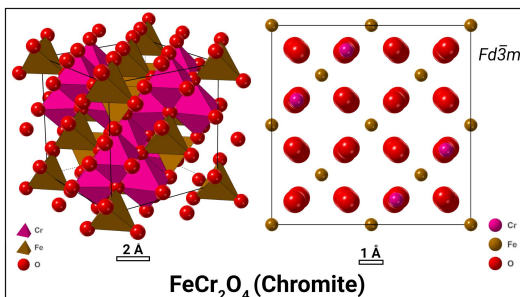


Figure 1: Spinel structure, cubic close packed arrangement of oxygen anions with partial occupation of the tetrahedral and octahedral sites

Investigated pyrometallurgical parameters:

- Additives (MgO, Al₂O₃, SiO₂, CaO)
- Slag basicity CaO/SiO₂ ("C/S")
- Oxygen partial-pressure pO₂
- Slag viscosity
- Temperature regime

Followed by a mineral-beneficiation of the modified slag, which is a selective enrichment step, to form a

- Cr-enriched phase → feedstock for FeCr
- Cr-depleted phase → secondary raw material for the construction industry (Figure 2).

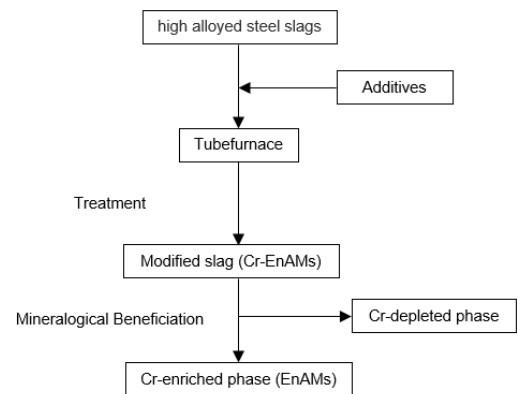


Figure 2: Overview of the planned recovery process

Results

The formation of chromium enriched spinel phases in BOF-slags, was verified by research carried out in the CD-Laboratory for the company partner voestalpine. This basic mythology is now adapted to high alloyed steel slags. A SEM image of a formed spinel can be seen in Figure 3.

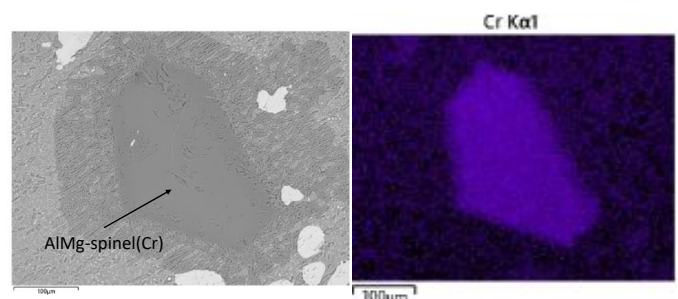


Figure 3: SEM image and corresponding Cr elemental map showing chromium enrichment in an (Al,Mg)-spinel phase in treated BOF slag



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for selective recovery of minor metals using innovative process concepts



voestalpine
ONE STEP AHEAD.

aufbereitung / recycling / prüftechnik
ARP



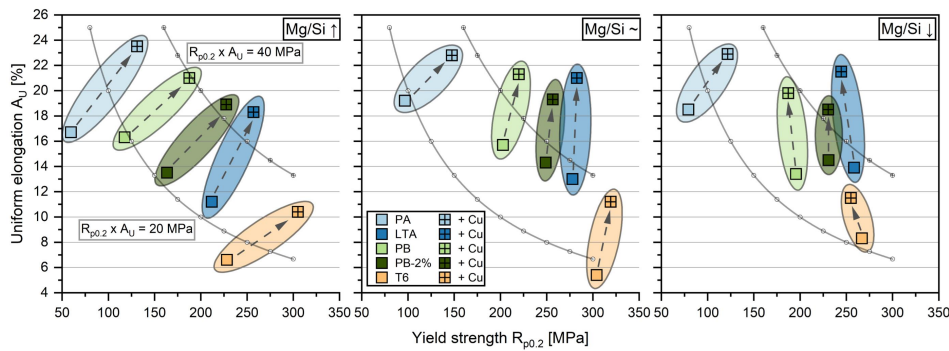
Unraveling the potential of Cu addition and cluster hardening in Al-Mg-Si alloys

Acta Student Award 2024

Motivation & Concept

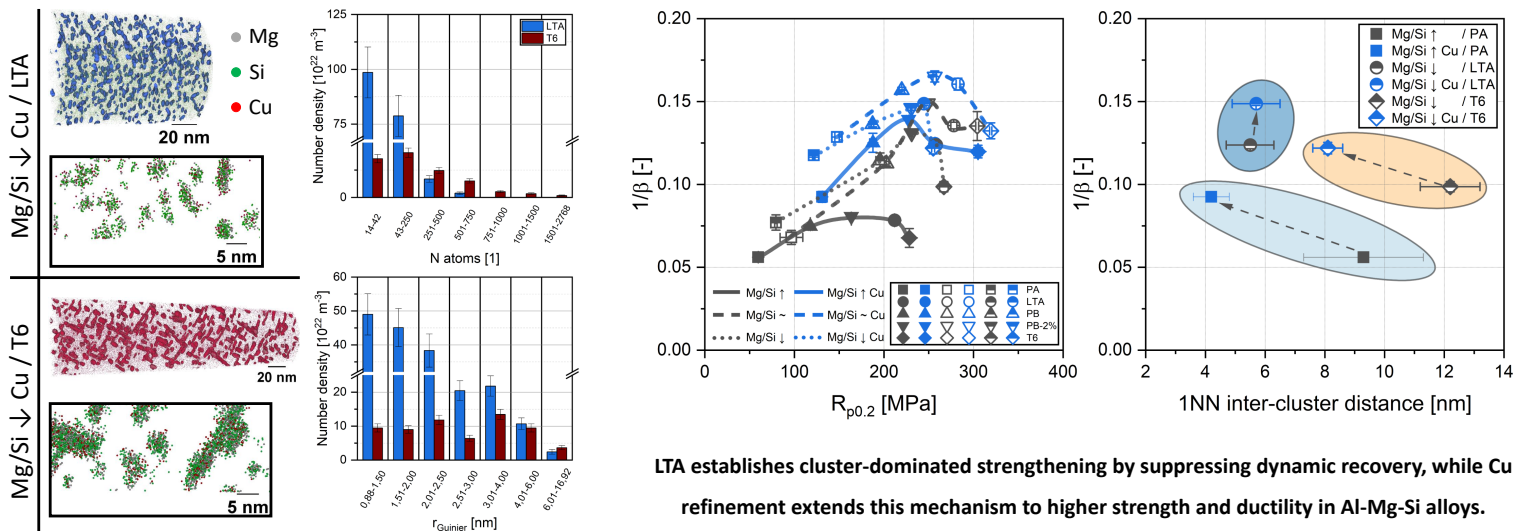
- Conventional aging** → Conventional T6 aging maximizes strength but limits strain hardening.
- Cluster hardening** → Clusters provide strength without early loss of strain hardening.
- Cu addition** → Enhances dislocation storage and delays dynamic recovery.

Mechanical response



- Long-term aging at lower temperatures (LTA – 42d@100°C) achieves yield strength comparable to T6 (2h@185°C).
- In the extremal case cluster hardening (LTA) plus the addition of Cu quadruples elongation.
- Enhanced ductility originates from sustained strain hardening.

Microstructural evidence



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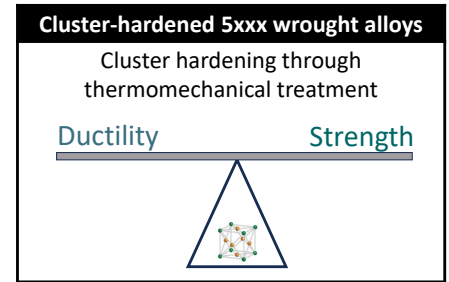
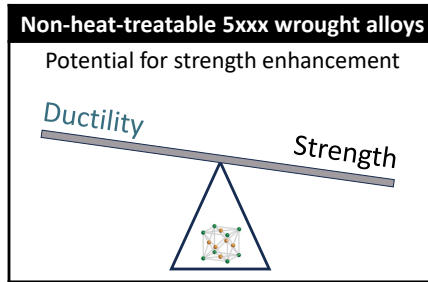
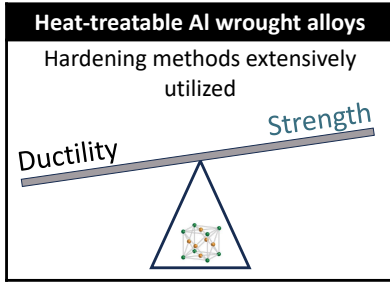


- Nanoscale cluster formation in aluminum alloys – Strength and formability
- High-magnesium “superlight” aluminum systems
- Solid carbon from methane pyrolysis – Structural characterization and impurity removal for energy and material applications



Structure-Property relationships in Al-10Mg alloys

Motivation & Concept



- Lightweight potential** → Reduced density with remarkable strength — ideal for advanced lightweight design.
- Solid-solution strengthening** → High Mg content impedes dislocation motion and suppresses dynamic recovery, resulting in pronounced strain hardening.
- Cluster hardening** → Mg-rich clusters form during deformation, providing additional strengthening.

Experimental

Sheets of 5182 and 5182-10Mg alloys (Table 1) were produced by hot and cold rolling. The analyzed states (Table 2) were As-Quenched (AQ), 10% pre-deformed ($\epsilon = 10\%$), and 10% pre-deformed plus paint-bake after soft annealing ($\epsilon = 10\%/PB$).

Table 1: Chemical composition of 5182 and 5182-10Mg alloys.

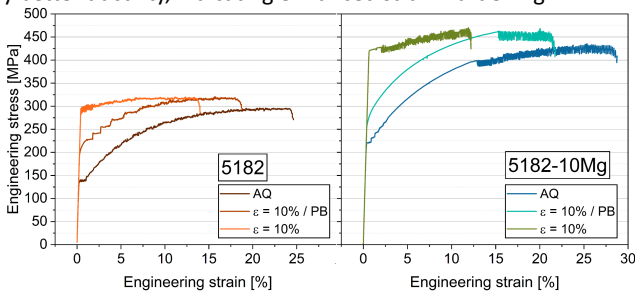
Alloy	Mg	Si	Fe	Mn	Zn	Cr
5182	4.82	0.09	0.15	0.40	0.02	0.06
5182-10Mg	10.60	0.07	0.14	0.40	0.02	0.06

Table 2: Parameters of the heat treatments applied with process sequence from left to right.

Condition	Soft annealing + WQ	Pre-deformation	Artificial aging
AQ	500°C/450°C, 1h	-	-
$\epsilon = 10\%$	500°C/450°C, 1h	10%	-
$\epsilon = 10\% / PB$	500°C/450°C, 1h	10%	185°C, 20min

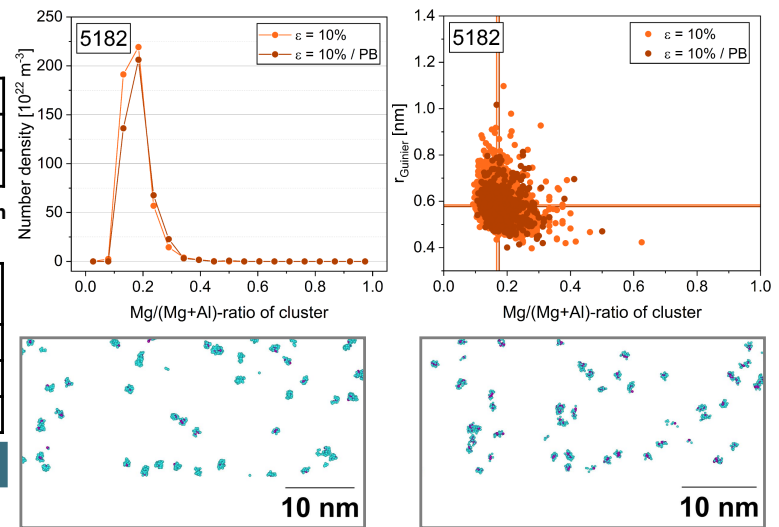
Tensile strengths and strain hardening

Mg addition strongly increases strength. In both alloys, pre-deformation ($\epsilon = 10\%$ and $\epsilon = 10\%/PB$) raises yield and tensile strength but reduces elongation compared to AQ. Alloy 5182-10Mg exhibits higher strength and slightly better ductility, indicating enhanced strain hardening.



Cluster formation after plastic deformation

Atom probe results show deformation-induced Al-Mg clustering in 5182. Cluster density is similar in both states, while paint-bake causes partial dissolution of larger clusters, likely due to vacancy annealing.



The study reveals that plastic deformation promotes Al-Mg clustering, which can be modified during heat treatment. Tensile testing of 5182-10Mg confirms the strong strengthening potential of high-Mg 5xxx alloys. Further advanced characterization of 5182-10Mg is essential to understand the underlying mechanisms. Optimizing deformation and heat-treatment parameters will enable better control of cluster evolution and enhance the mechanical performance of high-Mg aluminum alloys.



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- Nanoscale cluster formation in aluminum alloys – Strength and formability
- High-magnesium “superlight” aluminum systems
- Solid carbon from methane pyrolysis – Structural characterization and impurity removal for energy and material applications



Reinventing Slag: Sustainable Processing of Secondary Metallurgical Resources for Alternatives to Natural Sand

The Sand Challenge and the Slag Opportunity

Slag is produced in large quantities in high temperature metal production and is a reliable but often underutilized material stream. With targeted metallurgical processing and controlled granulation, it can be transformed into engineered aggregates for sustainable construction. At the same time, natural sand, which is essential for cement and concrete, is facing increasing environmental and regulatory constraints. This creates a clear opportunity to use slag based engineered aggregates as a sustainable alternative to natural sand.



Figure 1. Slag landfill in North Macedonia (left), and the Gambian coast affected by sand extraction (right)

Sustainable Slag Processing and Metal Recovery

The slag processing approach starts with targeted metal recovery. In this step, residual nonferrous metals can be recovered by carbothermic reduction using bio-based carbon (biocoke) instead of fossil petroleum coke. The slag chemistry is then adjusted in a controlled manner, and the molten slag is subsequently granulated and cooled under defined conditions to tailor particle size, morphology, and phase composition for use in cementitious systems.



Figure 2: Conceptual illustration of the slag treatment process applied to 40 kg of slag, including the major output materials.

Environmental and System-Level Impact

This approach links lower-carbon metallurgy with sustainable construction materials. Renewable carbon can reduce CO₂ emissions during slag treatment, while the use of slag as a sand substitute lowers the demand for natural aggregates and supports the circular use of by-products. The integrated concept combines metal recovery, emission reduction, and sustainable material use within one process chain.

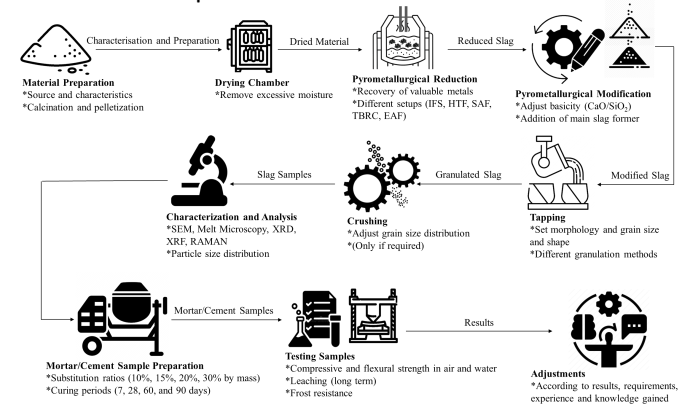


Figure 3: End-to-end approach to slag refinement and application in cementitious systems

Towards Cement Applications

Current work focuses on mechanical performance, freeze-thaw durability, and long-term leaching behaviour. First results are highly promising, showing compressive strength comparable to or exceeding conventional natural sand systems. Leaching remains well below legal limits, confirming effective metal immobilization within the slag matrix. Slag-derived granulates show strong potential as sustainable alternatives to natural sand in cementitious materials.

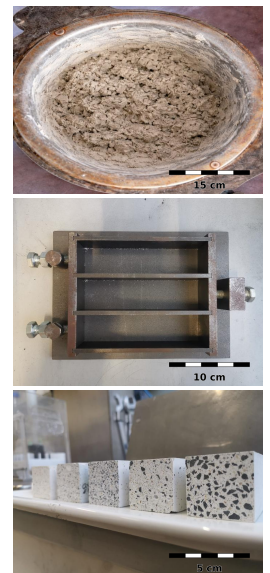


Figure 4: Preparation of mortar samples



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From Mining Waste to Wealth: Sustainable Metallurgical Technologies for Copper and Gold Recovery

Utilization of mine wastes with high As content

Historic mine waste piles contain significant amounts of polymetallic ore minerals that represent both an environmental challenge and a valuable secondary resource. In addition to copper and precious metals, these tailings may contain critical and strategic raw materials such as lead, zinc, chromium, tungsten, and indium, while also including harmful elements like arsenic that must be properly managed. This project aims to develop environmentally sustainable and cost-effective technologies to recover copper, gold, and other critical metals from polymetallic sulphide waste by evaluating combined smelting and leaching methods, testing them at the batch scale, and outlining a pathway for industrial-scale application.

1. Characterization of the Study Area

Mining waste characterization determines its physical, chemical, and mineralogical properties to assess environmental risks and the potential recovery of valuable metals.

Table 1. Mineral composition of the samples

Aspect	Description
Material type	Cu–As–Au tailings containing both sulfide and oxide minerals with gold present in multiple forms
Sulfide reactivity	Contains some acid-generating sulfides
Buffering capacity	High carbonate content buffers acidity and maintains alkaline conditions
pH condition	Alkaline environment with a pH of approximately 8.5
Acid drainage risk	Limited potential for acid drainage due to carbonate buffering
Arsenic behavior	Arsenic is stable and largely immobile
Oxidation stage	Early stage of oxidation
Overall classification	Fresh, carbonate-buffered sulfidic tailings rather than oxidic tailings
Material character	More similar to waste rock than to fine tailings



Au [ppb]	990.45
Cu [ppm]	2977.8
As [ppm]	2234.9
S [wt.%]	0.53
Fe [wt.%]	4.62
Mg [wt.%]	0.9
Mn [ppm]	0.19
Ca [wt.%]	10.5
Ag [ppm]	1.19

Fig 1. Outcrop Sample, and the chemical composition of the material investigated

4. Metallurgy process

Analysis of flotation products determines copper, gold, and arsenic content. Acid leaching and smelting recover the metals through integrated hydro- and pyrometallurgical methods, including hydrogen-based reduction (Fig 2).

2. Mineral processing

After detailed waste characterization to determine metal and mineral distribution, the process applies pretreatment through crushing and wet grinding (<100 µm). Bulk flotation then concentrates sulfides, which account for about 70 wt.% of the copper minerals. Batch rougher flotation tests in kinetic mode evaluate flotation conditions after selection of an appropriate collector reagent scheme.

3. Arsenic removal

Mining waste samples of various grain sizes were treated with UPW, 0.1 M HNO₃, 0.1 M NaH₂PO₄, and 3wt.% H₂O₂, with and without hematite nanoparticles (HNPs), to evaluate arsenic removal. Filtrates were analyzed by ICP-MS and INAA. **0.1 M HNO₃** showed the highest efficiency, removing up to **87.6wt.% As**, while HNPs provided only minor improvement and became less effective at higher concentrations due to aggregation.

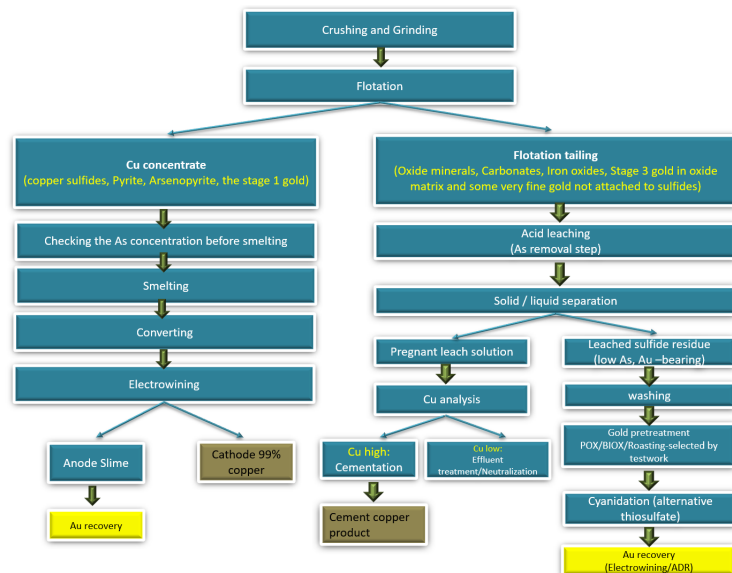


Fig 2. Integrated flowchart, from mining waste to recovery

5. Conclusion

In conclusion, combining hydro- and pyrometallurgy with geometallurgical planning enables efficient, sustainable metal recovery, safe arsenic separation, and supports circular economy practices (Fig 2).



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Biocoke Utilization in Metal Recycling Metallurgy

Sustainable and Environmental Friendly Approach

Introduction

Pyrometallurgical processes have been major contributors to CO₂ emissions, resulting in global warming and adverse environmental impacts. This is primarily attributed to the extensive use of fossil fuels, such as coal and coke, as both reductants and energy sources for metal production.

From a circular economy perspective, the valorisation of biocoke in pyrometallurgical processes offers a promising route for the recycling of metallurgical wastes, including slags, sludges, and metal-bearing dusts such as steel mill dust and lead slag.

Replacing fossil fuels with biocoke, a sustainable and CO₂-neutral carbon source in metal recycling processes represents an innovative approach that supports sustainability, circular economy principles, and environmentally responsible metal production

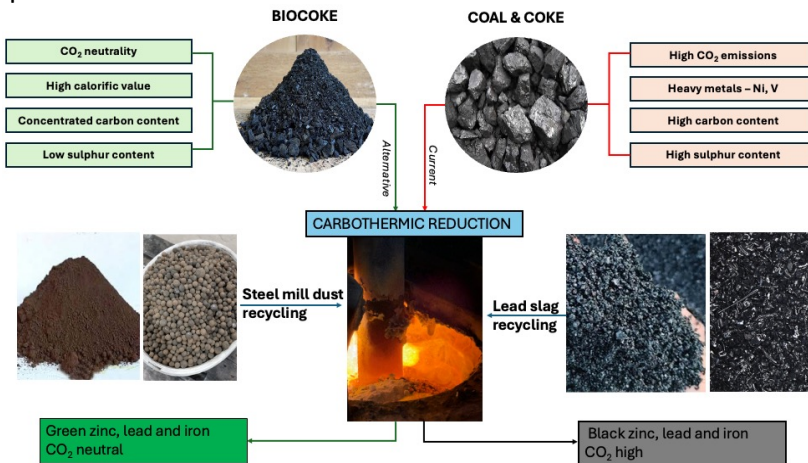


Figure 1: Flowchart diagram of biocoke and fossil coke and coal as reductants with pros and cons in metal recycling metallurgy

Biocoke has challenges like *high reactivity, low density and poor mechanical strength* and was addressed via **microgranulation** to surface modify the biocoke to desired properties for effective utilization during reduction.

Steel mill dust was recycled in a submerged arc furnace with modified biocoke, untreated biocoke and petroleum coke as reductants.

Successful application of biocoke as a reductant

Biocoke Preparation

Pretreatment techniques

- Microgranulation
- Briquetting

Metal Recycling

Metallurgical wastes

- Steel mill dust
- Lead slag

Zinc, Lead & Iron recovery

CO₂ neutral processes

Outcomes

Modified biocoke with 3 wt.% binder performed satisfactory similar to petroleum coke. Modified biocoke can substitute fossil fuels with 99.33 % ZnO and 96.97 % Fe₂O₃ recovered in steel mill dust recycling. This was determined by comparison of the carbon based reductants efficiency by calculating % metal reduced by the end of reduction process as shown in Figure 2.

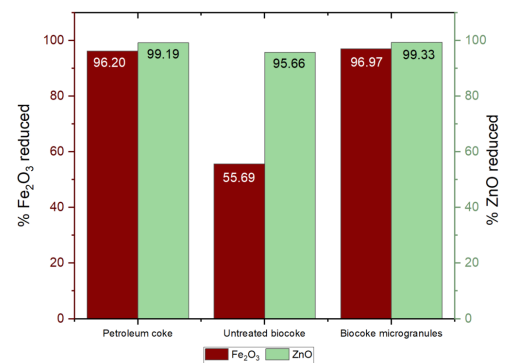


Figure 2: Comparison of carbon based reductants for steel mill dust recycling



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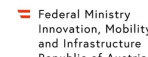
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In Situ Electrothermal Microscopy of Metals

Visual live observation of phase transformations and structural changes - down to atomic resolution - including electrical conductivity investigations.

Testing **current** and **heat limits** of **thin film** conductors. Right: Heating destroys 10 nm thick gold by island forming. The resistivity curve of the film during biasing is tracked.

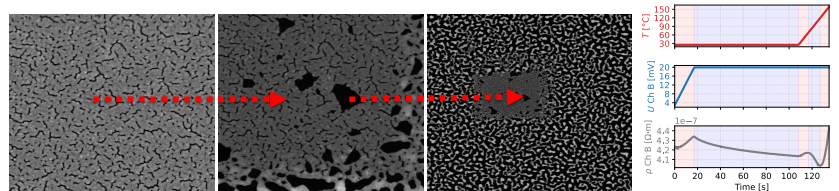
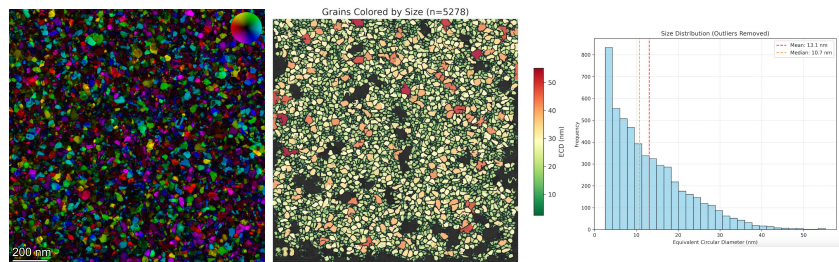
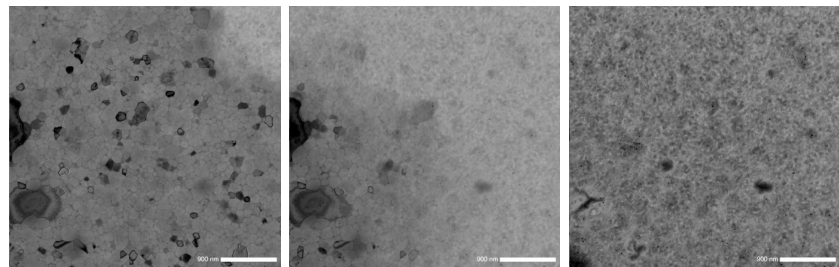


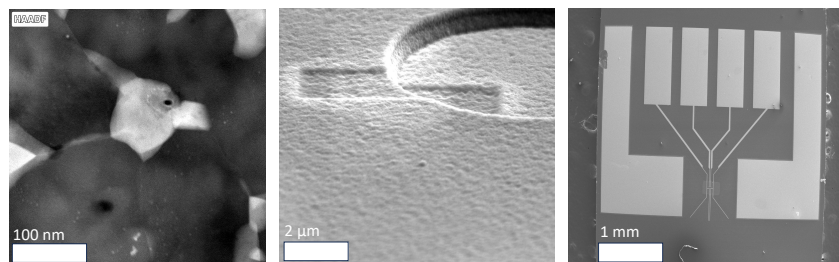
Image segmenting crystallite analysis by **neural networks**. Right: Nanocrystalline aluminium thin film micrograph measured by differential phase contrast STEM. Grain segmentation and histogram of equivalent circular diameters of grains.



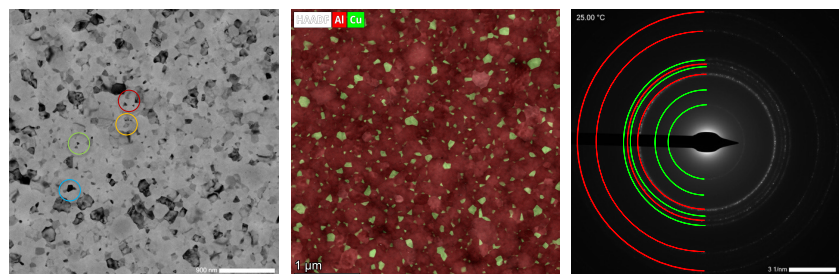
Phase transformation detected by *in situ* bright field transmission electron microscopy. Proof of melting by conductivity curve and in situ diffraction measurement. Right: Nanocrystalline aluminium copper alloy melts and can be visualized as a video.



Nano modification of materials via **electron** and **focused ion beam**. Right: Metals are sputtered directly on customized electrothermal chips. First: TEM local e-beam heating. Second: SEM/FIB Ga⁺ trimming. Third: SEM overview of electrothermal TEM chip

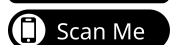


Heat treatment can lead to **grain growth** and **precipitation**, which can be tracked by **visual**, **diffractional** and **chemical TEM** analysis. Right: Polycrystalline aluminium-copper alloy forms Al₂Cu (θ)-precipitates at the grain boundaries. First: TEM-BF, Second: STEM-EDX, Third: TEM-SAED



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- In Situ TEM | Electrothermal Phenomena of Metals | Data Analysis



Closing the loop – Spent mixed acid recovery

Pretreatment of spent mixed-acid solutions and investigation of the behaviour of their constituents during spray roasting

The closure of previous open process streams, e.g. acid containing waste-waters, by implementing pretreatment and regeneration steps, thus creating circularity within the process flow is seen as an enormous potential to decrease the economical and ecological impact of processes. This is illustrated by the preservation of critical resources like virgin lixiviation agents, impact minimization of hazardous residuals on the environment while simultaneously reducing costs for waste-water treatment as well. As a result of the mentioned advantages, one major work package of the Christian Doppler Laboratory for selective recovery of minor metals in innovative processes focusses on such industrial residues, such as in this case mixed acid solutions, and their recovery. As to evaluate and develop such an acid loop, depicted in Figure 1, several preconditioning steps such as selective distillation and further rectification of certain constituents are necessary as to gain a solution which can be regenerated by e.g. spray roasting. For evaluating this regeneration step, a thermogravimetric investigation in combination with thermodynamic calculations regarding the stability

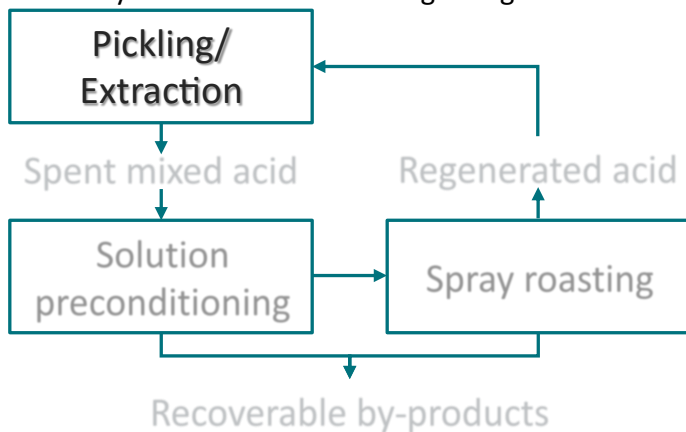


Figure 1: Recovery concept for spent mixed acid

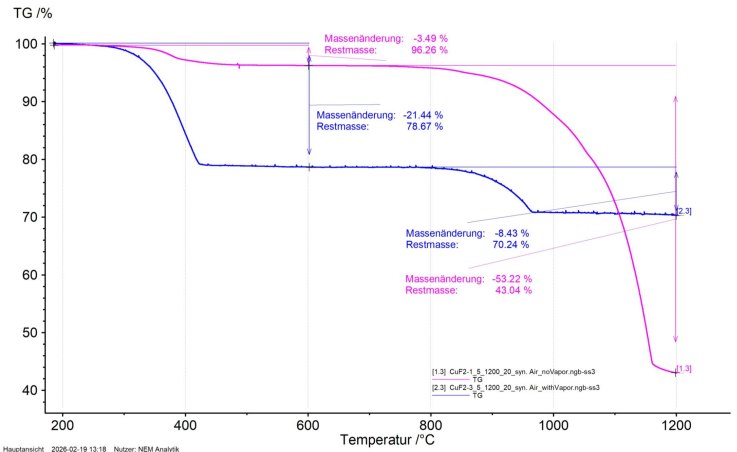


Figure 2: Thermogravimetric analysis of CuF_2 under water vapour and synthetic air atmosphere

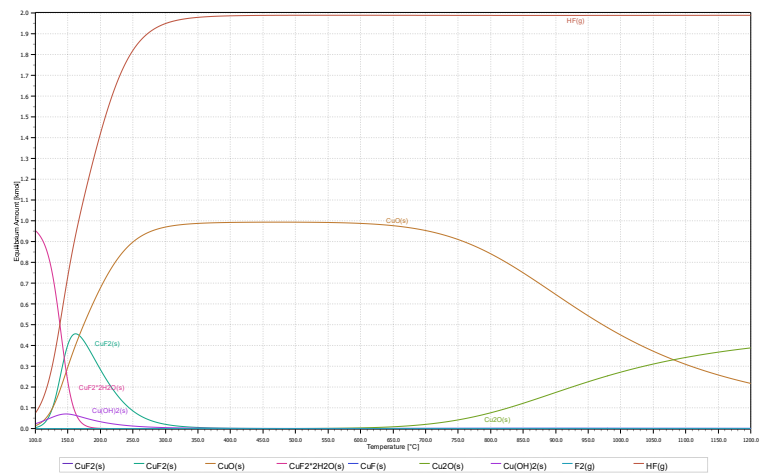


Figure 3: Thermodynamic calculations of the stability of CuF_2 and subsequent phases under water vapour and synthetic air atmosphere

of the species contained in the solution during spray roasting conditions. An example for both mentioned investigations, can be observed in Figure 2 and Figure 3 respectively. The combination of these result allows a predication of the feasibility regarding the regeneration potential of the investigated solution.



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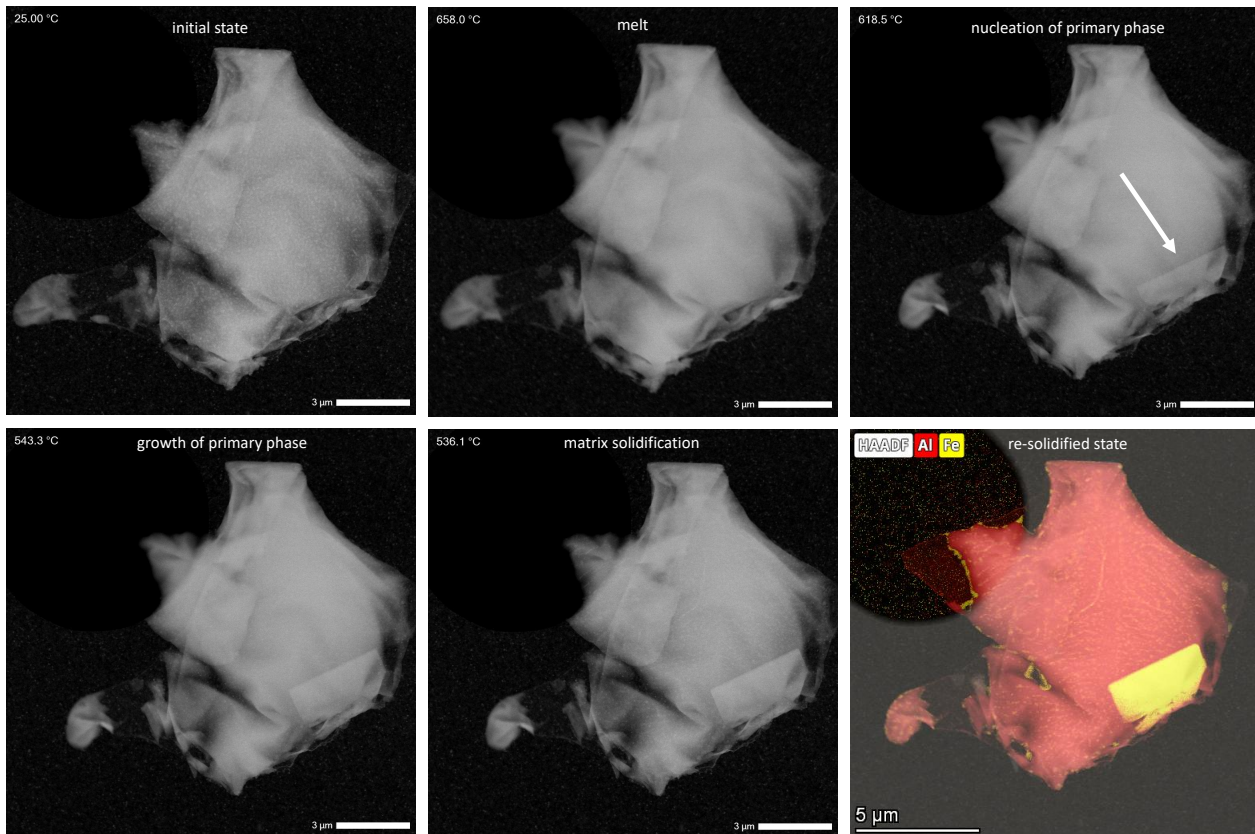
Christian Doppler Laboratory for selective recovery of minor metals in innovative processes concepts
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Research focus:

- Hydrometallurgical recovery of critical metals from metallurgical liquid process streams
- Investigation and evaluation of spent mixed acid mixtures for spray roasting and acid recovery



In situ STEM investigation of solidification and primary phase formation in an Al-Fe-Si alloy



The solidification and primary-phase formation behaviour of an aluminium alloy (3 wt.% Fe, 0.14 wt.% Si) is investigated by **in situ scanning transmission electron microscopy (STEM)**.

STEM uses a focused, high-energy electron beam (here 200 kV) that is scanned point by point across a very thin specimen; the **transmitted electrons are detected to form the image**. The specimen is mounted on a heated microchip inside the microscope. The chip area containing the **sample is rapidly heated into the melting range and then cooled back to room temperature at about 1 °C/s** while we observe the material (*in situ*).

We observe the **fully molten state, the nucleation of the primary phase ($\text{Al}_{13}\text{Fe}_4$), subsequent growth of this phase during further cooling, and finally solidification of the remaining matrix**. After returning to room temperature, we analyze the **re-solidified specimen using energy-dispersive X-ray spectroscopy (EDS)** and electron diffraction to determine its composition and phases.



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Research focus

- Al alloys
- Atom probe tomography
- Fast scanning calorimetry / Differential Scanning Calorimetry
- *In situ* transmission electron microscopy



Funded/Co-funded by the European Union (ERC, HETEROCIRCAL, 103124514). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council. Neither the European Union nor the granting authority can be held responsible for them.

6xxx-based sheet material:

Influence of increased secondary aluminum content on the formability

Introduction

In modern metallurgy, aluminum alloys with increased scrap content are of great importance due to reduced energy consumption during the production process. However, new variables are introduced in terms of deviated chemical compositions and hence resulting properties, which need to be assessed. In the automotive and aircraft industries, where high-quality requirements must be considered, performance comparable to conventional material is particularly crucial.

Concept & Methodology

Al-Si-Mg wrought alloys are optimized regarding formability through varying elements based on conventional sheet material compositions (figure 1). The **bottom-up approach** aims to determine trends and the behavior of alloys with high scrap content. The starting baseline for element contents is in accordance with typical industry alloying variants.

The **top-down approach** enables to identify beneficial composition areas to achieve good forming behavior of alloys despite an increased fraction of secondary aluminum. Here, alloying element contents are lowered starting from the industrial “worst-case” baseline composition.

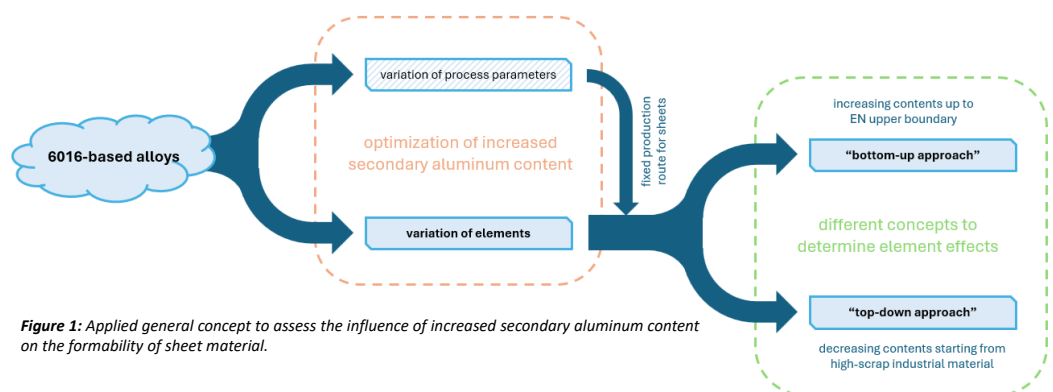


Figure 1: Applied general concept to assess the influence of increased secondary aluminum content on the formability of sheet material.

Workflow & Key aspects

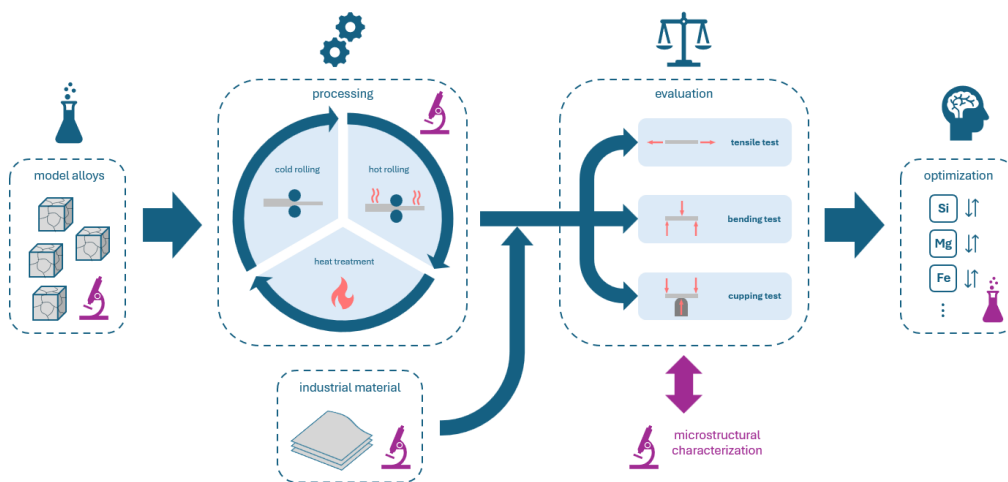


Figure 2: Detailed workflow for processing, evaluating and optimizing new 6016-based alloys to achieve comparable results to conventional material.

- What are the mechanisms behind formability?
- Which microstructural features are preferable and how can it be achieved?
- How can detrimental effects of elements be reduced/avoided?
- What are beneficial element ranges?
- Which alloying variants with good forming behavior can be established?



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Research focus:

- Formability of sheet material with increased secondary aluminum content



Bubble Formation in Liquid Metal Reactors

The Key to efficient Hydrogen Production through Methane Pyrolysis

The introduction of gases into liquid metals plays an important role in many metallurgical processes. Prominent examples include the treatment of aluminium or steel, where inert gases are injected into the liquid metal to remove dissolved gases or non metallic inclusions. [1, 2]

Research at the Chair of Nonferrous Metallurgy focuses on the use of a liquid metal bubble column reactor for the production of low-emission hydrogen and solid carbon. Figure 1 illustrates the methane pyrolysis process, in which methane is injected into a molten metal bath that acts as a heat transfer medium and a potential catalyst. The injected gas forms bubbles that rise through the melt while methane decomposes into hydrogen and solid carbon [3].

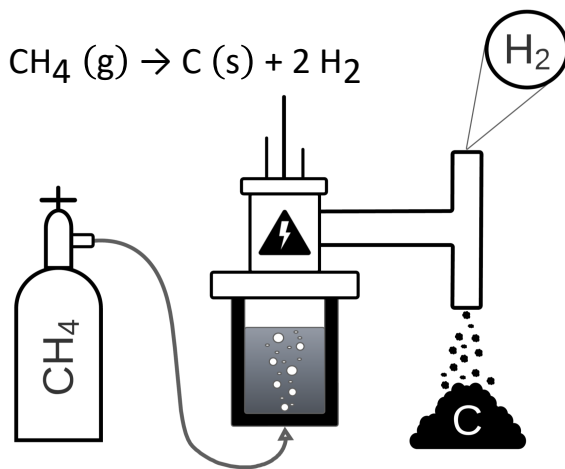


Figure 1: Schematic view of the methane pyrolysis process

Bubble size is a key parameter influencing reaction efficiency in liquid metal reactors. For a constant gas volume, smaller bubbles provide a larger interfacial area, improving heat transfer and increasing gas residence time, which enhances methane conversion [4].

Experiments using a porous nozzle tip instead of a conventional alumina lance, together with bubble size measurements in various liquids (molten tin, water, silicone oil), revealed the following (cf. Figure 2 and Figure 3):

- The usage of a porous plug reduced the bubble size, which lead to a **significant increase in methane conversion**
- Bubbles formed in tin are **smaller** than those in water and oil, which is attributed to the **difference in liquid properties**
- At higher flow rates, a **change in trend** is observed which suggests a **change in the gas-liquid flow dynamics**.

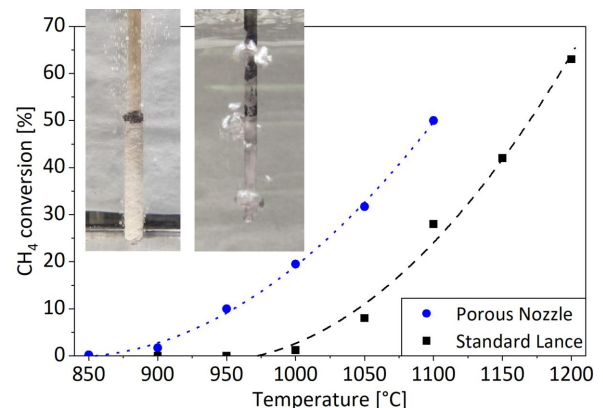


Figure 2: Comparison of standard lance and porous nozzle introduction of methane into liquid tin, $Q = 2 \text{ l/min}$

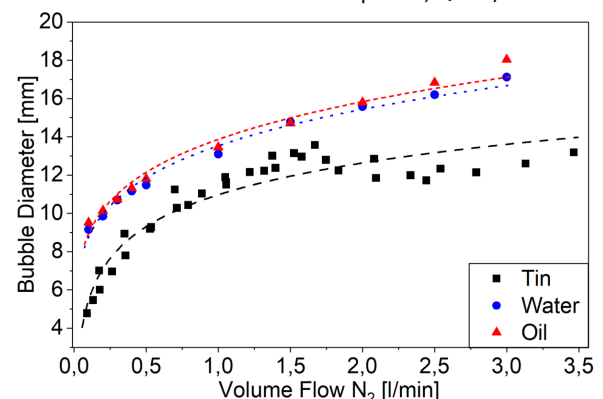


Figure 3: Comparison of the bubble size when injecting N_2 into liquid tin, water, and silicone oil



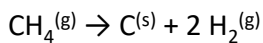
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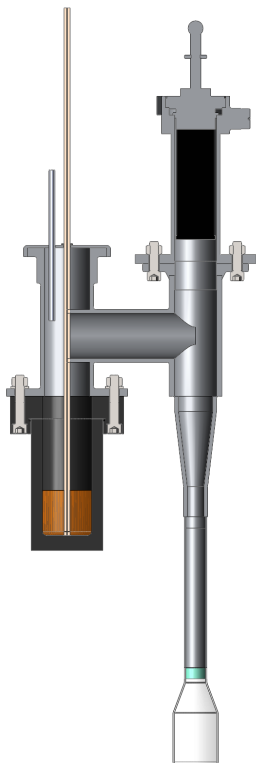
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Development of Laboratory-Scale Liquid Metal Reactors for Methane Pyrolysis

Methane pyrolysis offers a highly efficient pathway for hydrogen production with minimal energy input and zero direct CO₂ emissions. This process involves the thermal decomposition of CH₄ in the absence of oxygen at temperatures exceeding 1000 °C, yielding gaseous H₂ and solid carbon. The standard reaction enthalpy is 37 kJ/mol H₂ which is approximately one-seventh of the energy required for water electrolysis (286 kJ/mol H₂) [1].



Methane pyrolysis is investigated using three distinct liquid metal bubble column reactor (LMBCR) setups. All systems share a core design: Induction heating, gas injection via alumina lance, and integrated hot gas filtration.



The foundational LMBCR design, illustrated in Figure 1, established the core technical framework for the research conducted. This configuration served as the baseline for the iterative development of the subsequent optimized and scaled-up versions.

Technical specifications:

- **Reaction Vessel:**
Graphite crucible containing up to 0,25 dm³ melt with a max. bath depth of 10 cm
- **Gas injection:**
Methane throughput at 0,5 l_n/min
- **Research Focus:**
Alloy development and initial bubble size characterization

Figure 1: First laboratory setup and base design of the LMBCR [2]

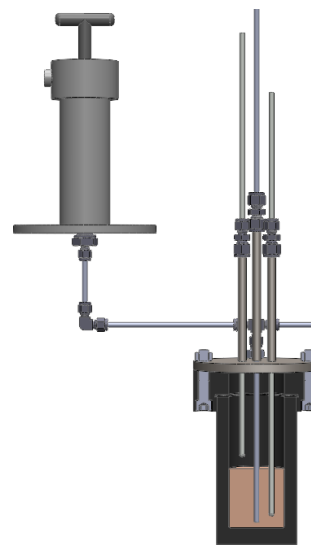


Figure 2: Optimized design of the first setup

The configuration shown in Figure 2 utilizes the same reaction vessel as the base setup but significantly reduces the headspace to minimize secondary gas-phase reactions.

Technical specifications:

- **Gas injection:**
Methane throughput at 0,25–1,0 l_n/min
- **Research Focus:**
Investigation of the liquid-phase reaction kinetics

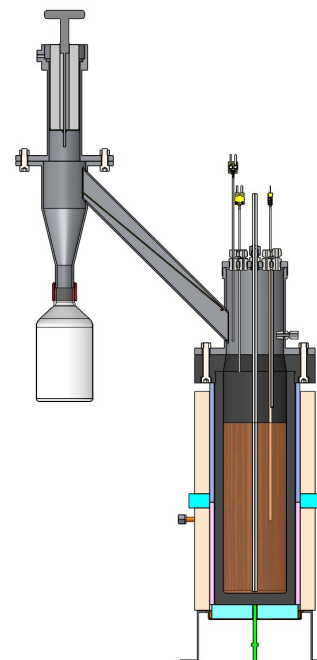


Figure 3: Scale-up of the first laboratory setup [3]

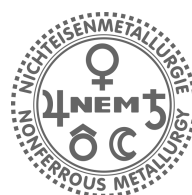
The scale-up configuration shown in Figure 3 features an expanded reaction volume and a modified reactor head. A tilted steel pipe design is implemented to reduce metallic contamination in the recovered carbon.

Technical specifications:

- **Reaction Vessel:**
Graphite crucible containing up to 3,3 dm³ melt with a max. bath depth of 35 cm
- **Gas injection:**
Methane throughput at 0,5–4,0 l_n/min
- **Research Focus:**
Process engineering, system design and gas mixtures



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Pyrolysis of Natural Gas

Methane Decomposition in the Presence of Ethane

Methane pyrolysis is a thermochemical process splitting methane into hydrogen and solid carbon in the absence of oxygen, offering a CO₂-neutral hydrogen route when operated efficiently. This poses a promising bridge technology toward low-emission hydrogen with a valuable co-product. [1]

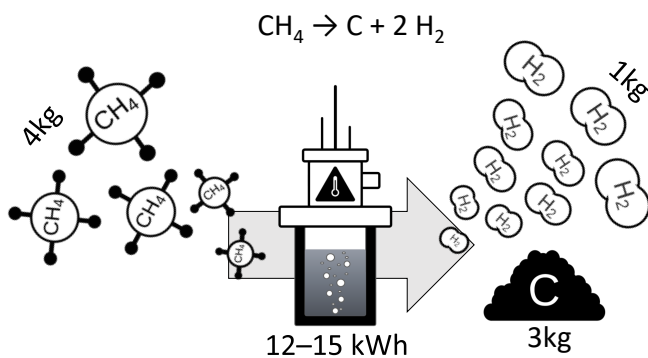


Figure 1: Schematic illustration of methane pyrolysis

Regarding the industrial realisation of the process, using a liquid metal reactor offers several advantages like improved heat transfer, catalytic decomposition and continuous carbon separation. Figure 2 displays a general overview of the reactor. In practice, natural gas (NG) will be used as feedstock. Whilst methane is the major component in NG, other species – especially hydrocarbons – are also present, as can be seen in Table 1: [1]

CH ₄	C ₂ H ₆	C ₃ H ₈	alkanes	CO ₂	N ₂	H ₂ O
70–98	1–10	0–5	0–3,5	0–1	0–15	0–5

Table 1: Typical ranges of components found in natural gas in mol.-% [2]

At the Chair of Nonferrous Metallurgy, the influence of these components on methane pyrolysis is investigated to ensure a smooth industrial realization.

In this work, C₂H₆ and its influence on methane conversion are prioritized. Experiments were carried out in a molten metal reactor filled with tin, where gas is introduced into the melt, bubbles rise and provide residence time for thermal cracking, and the product gas is analyzed via Fourier-Transform Infrared Spectroscopy to infer conversions. Experiments span 950–1150 °C at a flow rate of 2 NI/min, with ethane concentrations in the ranges found in NG.

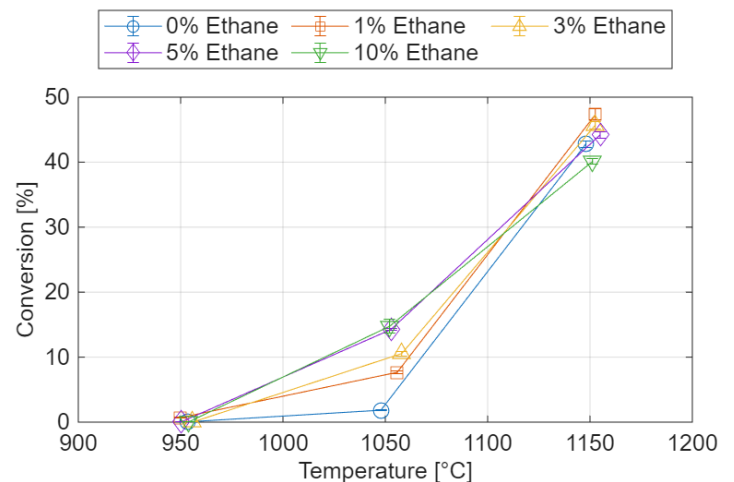
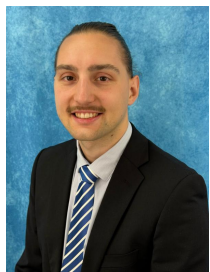


Figure 2: CH₄-conversion in pyrolysis of Methane-Ethane mixtures at different temperatures

Results are displayed in Figure 2:

- Ethane promotes methane conversion at intermediate temperatures around 1050 °C.
- As the temperature increases, this promotional effect diminishes, and the behavior of CH₄-C₂H₆ mixtures converges toward that of pure methane.

In conclusion, the ethane concentrations present in natural gas could increase methane decomposition at the start of the pyrolysis process, but seem to have an negligible impact at higher temperatures needed for a complete conversion to hydrogen.



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Sources:

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[2] Speight J. G.: Composition and properties: Natural Gas (2019): Elsevier, 99-148

Anode Materials for Aluminum-Based Batteries

Sustainable, High-Performance Al- Anodes

Al-based batteries offer a compelling safety and sustainability profile, but many studies rely on ultra-high-purity Al anodes that are expensive and non-scalable. Realistic anodes must perform under variable chemistry and processing histories.

We aim to move from “tolerance” to “design”: **process and surface modification** reduce interfacial resistance and accelerate stable cycling without requiring for ultra-pure aluminum.

Two Interface Levers: Oxide + Surface Structure

Plating/stripping is governed by the native Al_2O_3 film and the evolving interphase. Ways to reduce charge-transfer resistance and cycling overpotential are:

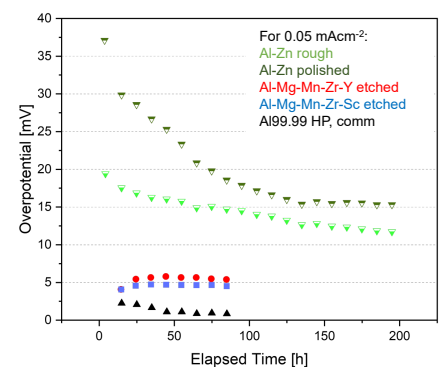
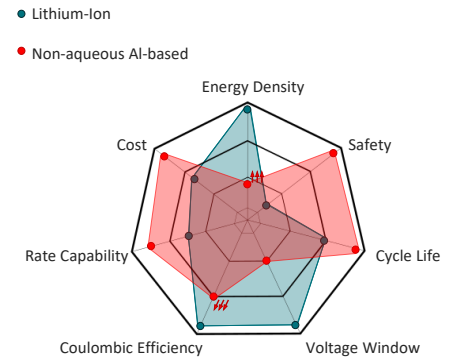
- Alloying to weaken oxide stability and create activation sites (e.g., Mg-rich regions / intermetallics).
- Surface modification (roughening, etching, aging) to increase active area and promote oxide disruption.

Novel Production Route + Electrochemical Validation

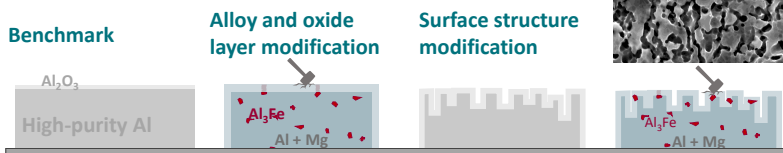
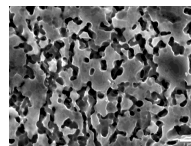
We produced foil anodes based on Al–Zn and Al–Mg concepts, including Al–Mg–Mn–Zr with minor Sc or Y additions. Cycling performance was evaluated as a function of surface roughness and tailored heat treatments that enable selective etching of Mg-rich regions.

Electrochemical performance assessed via impedance spectroscopy and galvanostatic stripping/plating:

- Al-Zn: rougher surfaces show lower initial charge-transfer resistance and lower overpotential.
- Al-Mg: etched surfaces → lower initial charge-transfer resistance, stable cycling, and fast stabilization (with a slightly higher overpotential)



Combined approach

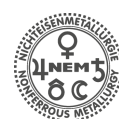


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Christian Doppler Laboratory for *Deformation-Precipitation Interactions in Aluminum Alloys*

Recycling Without Compromise

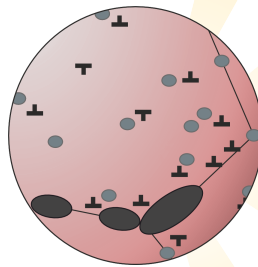
Increasing the share of **secondary Al** can cut energy demand significantly and particularly in Europe it is a **strategic and increasingly indispensable supply**. Yet scrap introduces **composition scatter** and **impurity accumulation**. The challenge is to tolerate this variability while still meeting strict requirements for **safety, durability, strength, and formability**.

Focus on formability in sheet material with high recycled Al-content

Microstructures' effect on corrosion and dynamic properties in high-strength Al-alloys

Sustainable, high performing anodes for Al-batteries: Alloy and process design

Advanced microstructure analysis: Orientation & phase mapping across scales

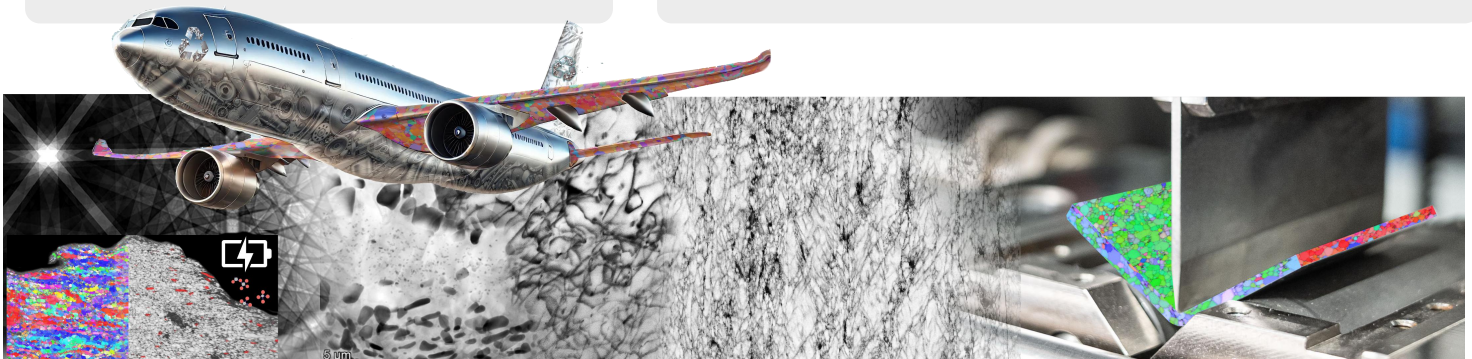


Residual Elements and Local Damage

Tramp elements affect intermetallic phases and precipitation states and alter dislocation behavior during deformation. This changes strain localization and damage initiation. The result: changes in sheet-critical performance – **formability and strength**, but also corrosion behavior.

From Microstructure Analysis to Robust Alloys & Processes

We systematically study compositional effects in **5xxx, 6xxx, 7xxx** and novel **crossover alloys**, combining alloy design with processing. Advanced multi-scale orientation-, phase and defect analysis of mechanically loaded material links local effects to the macroscopic response, delivering microstructure targets and robust process windows for recycled Al-sheet.



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Turning Old Cars into High-Performance Alloys

Direct Upcycling from Entire End-of-Life Vehicles

Motivation

Each year, 7–9 million metric tons of end-of-life vehicle (ELV) scrap are generated in the EU. Modern cars contain up to 26 different Aluminium alloys. Sorting all of it is technically impossible at scale.

Mixed scrap is downcycled into low-grade cast alloys. By 2030, over 6 Mt/year will become unrecyclable causing substantial economic costs.

Challenge:

No industrial-scale upcycling route existed until now.

Our Approach

One-step direct upcycling:

All Aluminium parts of a vehicle can be melted together without prior sorting. No dilution with primary material is required.

Three ELV types studied: EU car, US pickup truck, electric car.

Key Results

Record-breaking strength:

Tensile strength >400 MPa with >12 % elongation, even surpassing commercial automotive wrought alloys (5xxx and 6xxx series) can be reached.

Tramp elements as an asset:

Fe- and Si-rich intermetallic particles refine grain structure and enhance strain hardening now turning impurities into a mechanical advantage.

Accelerated precipitation:

Pre-straining before paint-baking drives diffusion to a million times faster, achieving a peak-aged microstructure in a 20 min cycle.

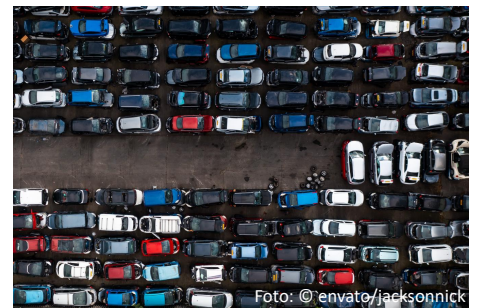
Key levers:

Grain refinement, heterostructure effects from intermetallic particles, accelerated precipitation strengthening.

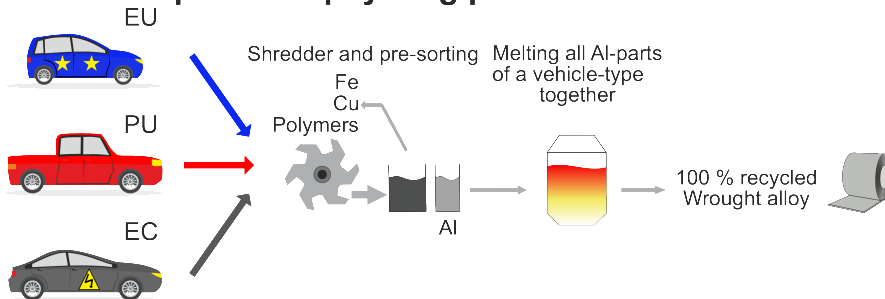
Conclusions

Our study presents the first industrially scalable process to directly upcycle mixed ELV Aluminium scrap into high-performance wrought alloys without sorting or primary material dilution.

The alloys can exceed the strength and ductility of current automotive standards and the process is robust across EU, US pickup and electric car scrap compositions. It can use standard direct chill casting compatible with existing industry, today's shredders (100+ vehicles/h) and recycling furnaces (50+ ELVs per charge) and is ready for immediate industrial deployment.



One-step direct upcycling process



Environmental & economic impact:

Could save up to 90 Mt CO₂/year. Immediately deployable to establishes a circular low-emission Aluminium recovery route.



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Reference:
DOI: 10.1038/s41467-026-69492-z | Nature Communications (2026)



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“Science of Dirty Alloys”: Fe-Intermetallics in Wrought Aluminium Alloys from Scraps

Motivation

- Aluminium is a key material for a sustainable future due to its low weight, corrosion resistance and wide range of applications. Recycling plays a crucial role, as it requires up to 95% less energy compared to primary production.
- However, modern scrap streams are becoming increasingly complex. With the decline of combustion engines, the demand for cast aluminium components such as engine blocks is decreasing, removing a major sink for recycled scrap.
- As a result, recycled aluminium with varying composition must increasingly be used in applications with higher performance requirements. This leads to challenges associated with impurities such as Fe, Si, or Cu, which form complex intermetallic phases (IMP), that strongly influence the mechanical properties. A detailed understanding of the microstructure is therefore essential for controlling and optimizing material performance.

SEM/EDS

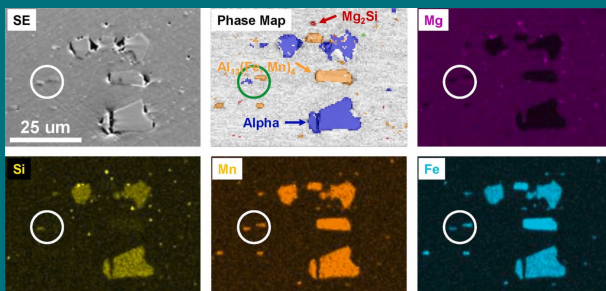


Fig. 1: SEM image and corresponding EDS elemental maps showing the morphology and composition of intermetallic particles in Al matrix [1].

PIP → EBSD

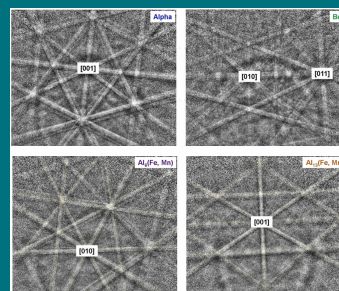


Fig. 2: Kikuchi patterns obtained by EBSD for different intermetallic phases [1].

FIB → TEM

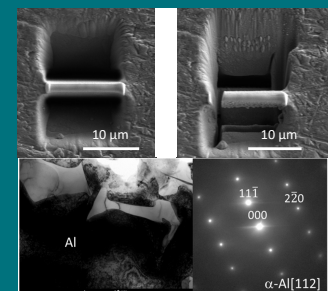


Fig. 3: FIB lamella extraction (own work) and TEM bright-field image with corresponding SAED pattern [2].

- As shown in Fig. 1, SEM combined with EDS provides rapid insight into morphology and elemental distribution of intermetallic particles. However, due to large interaction volume and overlapping compositions of matrix and IMP, purely composition-based identification is often insufficient to reliably distinguish between phases.
- To overcome these limitations, EBSD enables structure-based phase identification through analysis of Kikuchi patterns, see Fig. 2. As EBSD is a near surface technique (10-30 nm), highest quality of specimen preparation is required which can be achieved via Precision Ion Polishing (PIP) as final preparation step.
- Fig. 3 demonstrates Focused Ion Beam (FIB) sample preparation, which in contrast to conventional TEM preparation methods enables site-specific lamellae, allowing targeted TEM analysis of individual intermetallic particles at highest spatial resolution.

References:

- [1]: Adapted from Yu et al., Materials Today Communications 50 (2026) 114476, <https://doi.org/10.1016/j.mtcomm.2025.114476>, CC BY-NC 4.0.
[2]: Adapted from Jimenez et al., Metals 16 (2026) 34, <https://doi.org/10.3390/met16010034>, CC BY 4.0.



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My research focuses on a multimodal approach, to characterize intermetallic phases in Al alloys originating from scrap streams.

Understanding the influence of IMP on the microstructure and changing the composition and morphology as desired.



High-Throughput Approach for Assessing Cooling Rate Sensitivity of a Secondary Aluminum Alloy from EU Automotive Scrap

Introduction

Recycling leads to the accumulation of problematic elements like Fe, Si, Mg, Cu and Cr in the melt. Due to the low solubility limits of these elements, especially Fe, brittle intermetallic phases (IMPs) form. These IMPs are often considered detrimental to the mechanical properties [1]. However, it has been shown that correct processing can convert these harmful IMPs into beneficial forms in the final state. The cooling rate during casting is a key factor in determining the type, size and morphologies of the IMPs, which further affect the processability the final mechanical properties.

Workflow and Methodology

The alloy composition was calculated directly from the Al alloys used in a standard EU vehicle [2]. The schematic recycling scenario can be seen in Figure 1a). To investigate the effect of different cooling rates that occur during continuous casting, a special crucible with a controlled cooling rate gradient was designed. The ingot can then be further subjected to thermomechanical processing and heat treatment (Figure 1b). The samples were pre-aged (5h, 100°C), followed by naturally ageing for 14 days and finally paint-baked (20min, 180°C) for the mechanical testing.

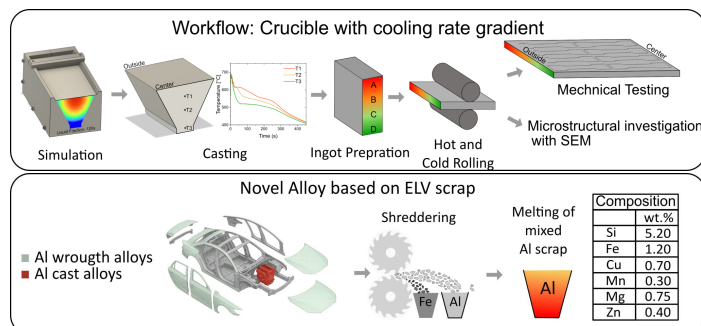


Figure 1: Workflow a) for direct aluminum recycling and b) for assessing the cooling rate sensitivity.

Results

As can be seen in Figure 2, slow cooling rates lead to coarse, blocky IMP, whereas faster cooling rates promotes the formation of fine Chinese script and needle-shaped morphologies, that are more easily fragmented in the rolling process. Figure 3 shows the technical stress-strain curves for the different positions along the cooling rate gradient, whereas the negative effect of coarse and blocky IMP on the mechanical properties, especially the ductility can be seen.

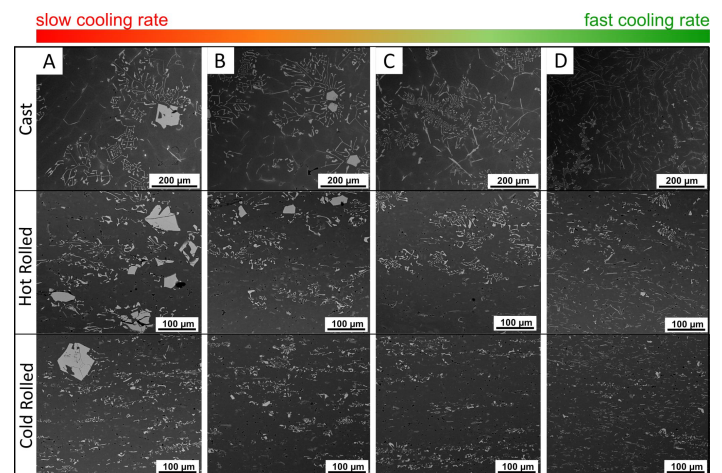


Figure 2: BSE-SEM images showing the Fe-rich IMPs of the as-cast, hot rolled, and cold rolled states at the positions A to D along the cooling rate gradient of the ingot.

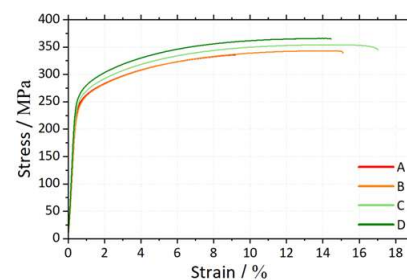


Figure 3: Engineering stress-strain diagram of the cold rolled and heat treated sheet at the positions A to D of the ingot.

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Focus:

- Secondary wrought aluminum alloys with high impurity content



Biometallurgical Recycling of Lithium-Ion Batteries

A comparative study on the bioleaching efficiencies of *Gluconobacter oxydans* and *Acidithiobacillus thiooxidans*

Biometallurgy is a metallurgical process that uses microorganisms to dissolve and recover metals from ores, concentrates or other residues. This method of processing solids is generally considered to be more environmentally friendly and cost effective but requires longer process times.

Introduction

Microbial leaching is based on the mechanisms of acidolysis, redoxolysis and complexolysis in various forms. For example, *At. thiooxidans* oxidizes elemental sulfur to sulfate ions in an acidic environment in an aerobic process that acidifies the medium. Iron-oxidizing strains such as *At. ferrooxidans* produce Fe^{3+} ions in iron-containing media, which in turn have an oxidizing effect on various minerals, converting metal ions to a soluble oxidation state. Other organisms have the ability to metabolize organic carbon to produce and release organic acid anhydrides. Figure 1 provides an overview of the different mechanisms of action.

Materials and Methods

The used Black Mass for leaching tests was obtained from an industrial lithium-ion battery recycling plant and underwent a mechanical and thermal pre-treatment process, including pyrolysis at 550 °C. For conducting bioleaching experiments two gram-negative bacteria, *Gluconobacter oxydans* (DSM 3504) and *Acidithiobacillus thiooxidans* (DSM 14887) were used. The cultivation was achieved under sterile conditions in their optimized culture media and temperature (*G. oxydans* NM 105; *A. thiooxidans* NM 35).

Results

The results of the two bioleaching approaches using *Gluconobacter oxydans* are presented in table 1. These findings demonstrate that high leaching efficiencies can be achieved through biological processing, particularly for lithium (>55%), cobalt (>81%), and manganese (>95%). In the indirect approach, the leaching efficiency for nickel is also noteworthy,

exceeding 54% without the addition of any redox agent. The leaching efficiencies for *Acidithiobacillus thiooxidans* are shown in table 1 and reveal similar values for the direct, indirect, and inorganic approaches. The low efficiencies highlight the necessity of employing a redox agent during the leaching step of black mass with H_2SO_4 .

Table 1: Schematic representation of biometallurgical leaching

Element	<i>Gluconobacter oxydans</i>				<i>Acidithiobacillus thiooxidans</i>				Technical leaching	
	Direct		Indirect		Direct		Indirect		H_2SO_4	
	LE (%)	σ (%)	LE (%)	σ (%)	LE (%)	σ (%)	LE (%)	σ (%)	LE (%)	σ (%)
Li	55.38	3.84	66.84	4.91	34.01	0.16	31.02	0.03	28.05	2.39
Ni	10.11	2.32	54.47	4.45	6.31	0.72	6.23	0.27	6.62	0.77
Co	22.17	3.38	80.87	4.36	12.04	1.36	15.82	2.18	15.28	1.58
Mn	63.14	2.25	94.77	5.95	35.59	4.12	23.43	3.17	22.03	3.46
Cu	3.87	1.05	14.59	1.56	34.98	0.54	36.18	0.41	36.11	1.72
Al	26.52	6.45	40.91	2.77	5.25	0.20	7.67	1.32	6.09	0.19

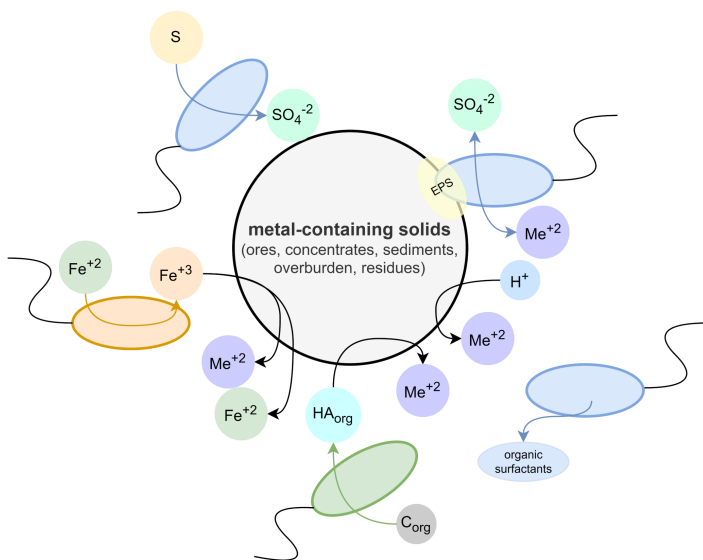


Figure 1: Schematic representation of biometallurgical leaching

Summary and Outlook

This study demonstrates the potential of bioleaching as a sustainable alternative to conventional hydrometallurgical processes for the recovery of valuable metals from lithium-ion battery black mass. Indirect bioleaching using *G. oxydans* yielded high extraction efficiencies for cobalt, manganese, nickel, and lithium by decoupling acid production from metal exposure,

thereby minimizing microbial inhibition. Notably, biologically produced sulfuric acid from *At. Thiooxidans* achieved leaching efficiencies comparable to those of industrial sulfuric acid for several elements, positioning it as a viable option without any performance losses in the hydrometallurgical recovery of LIBS.



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Development of sustainable recycling processes for cemented carbides

Introduction

- Cemented carbides (CC) consist of a hard carbide phase (e.g. tungsten carbide) embedded in a ductile metallic binder phase (typically cobalt), combining high hardness, wear resistance, and thermal stability.
- Due to their outstanding properties, cemented carbides are primarily used as cutting tools and wear-resistant components in metal processing, mining, and construction applications.
- In view of the increasing demand and the classification of tungsten and cobalt as critical raw materials in the EU, the recycling of cemented carbides represents an essential contribution to resource security and sustainability.
- Over the past two decades, extensive research on the recycling of cemented carbides has been conducted at the Chair of Nonferrous Metallurgy (see Fig. 1).
- Through the investigation of chemical, semi-direct, and direct recycling routes, significant contributions have been made to the development of sustainable strategies for cemented carbide recycling.
- For soft residues such as sludges and dusts, a chemical recycling process has been developed.
- Within the scope of semi-direct recycling, a binder leaching process has also been established, which is suitable for clean scrap that cannot be directly reused.
- Due to its potential as a more environmentally friendly direct recycling method, research at the Chair of Nonferrous Metallurgy has focused exclusively on the zinc process in recent years.

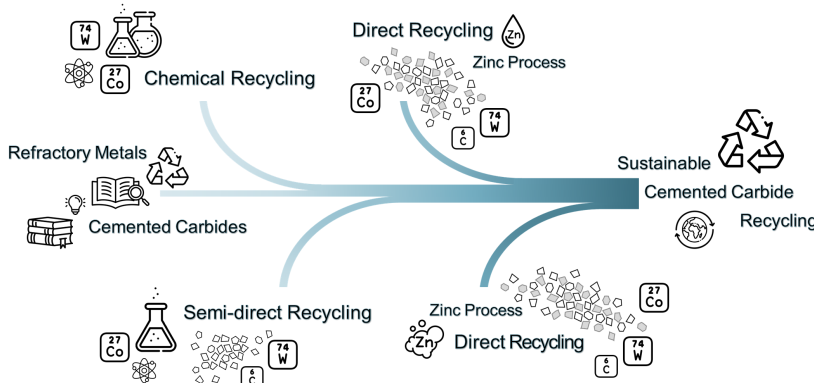


Figure 1: Illustration of two decades of research on cemented carbide recycling at the Chair of Nonferrous Metallurgy

Zinc Recycling Process for Cemented Carbides

- The zinc process is one of the most efficient methods for recycling EoL-CC-scrap, enabling recovery of the constituent materials without chemical transformation (see Fig. 2).
- Upon contact with liquid zinc, it diffuses into the composite and forms intermetallic Co-Zn phases. Their larger volume compared to the original binder leads to swelling and structural loosening.
- The incorporated zinc is then completely removed by vacuum distillation, leaving a porous cemented carbide sponge.
- This sponge can be mechanically comminuted into a recycled powder comparable in composition and quality to the original material, and directly reused for new cemented carbides.
- Current research focuses on the use of gaseous zinc as an advanced development of the zinc process.

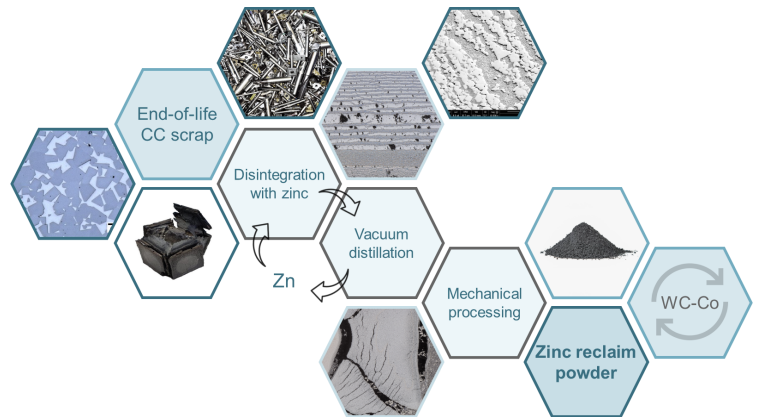


Figure 2: Schematic representation of the zinc process for direct cemented carbide recycling

Key Findings and Outlook

- Disintegration using gaseous zinc can achieve up to three times higher rates than conventional contact with liquid zinc.
- Nanoscale concentration variations within the formed Co-Zn phases highlight the complexity of the underlying mechanisms.
- Different cemented carbide grades show varying behavior in zinc diffusion and subsequent vacuum distillation, influenced by alloying with grain growth inhibitors.
- Material-specific treatment times enable significant energy savings in the recycling process.



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Impurity Fingerprints in Black Mass: Linking Feed Variability to Process Performance

Feed variability is the central challenge in Li-ion battery recycling

- Black mass composition varies with battery chemistry, origin, and pre-treatment
- Impurities introduce process instability and performance risks

Typical consequences:

- Yield loss
- Off-spec products
- Increased reagent consumption
- Operational and safety issues

Impurity fingerprints (see Fig. 1) translate **feed variability** into **predictable process behavior**.

Each black mass exhibits a characteristic impurity profile. This fingerprint defines:

- Operating windows
- Control limits
- Process robustness

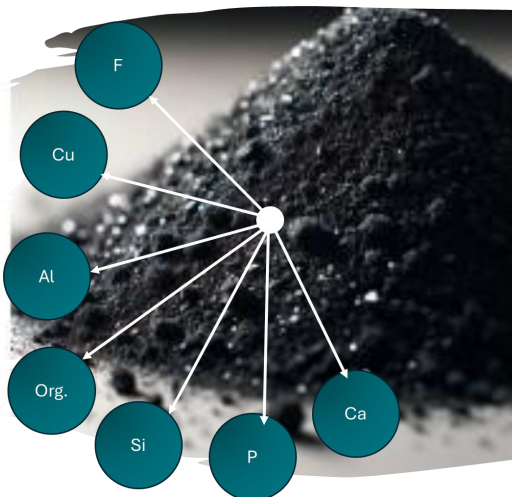


Figure 1: Impurity spectrum in typical black mass from Li-ion batteries

Impurity Landscape of Black Mass

Black mass combines valuable metals with a complex impurity spectrum.

Main impurity sources:

- **Current collectors:** Al, Cu
- **Electrolytes & binders:** F-, P-, S-containing species
- **Graphite & residues:** Fe, Na, Ca, Si, organics

Key aspect: Speciation matters

- Metallic, oxidic, halide, or organic forms
- Determines reactivity and downstream behavior

The speciation and concentration of impurities determine their interaction with individual process steps. These impurities influence multiple stages across the recycling flowsheet rather than acting in isolation. Their combined effects govern process response and ultimately define operational performance (see Fig. 2).

Linking Impurities to Process Performance

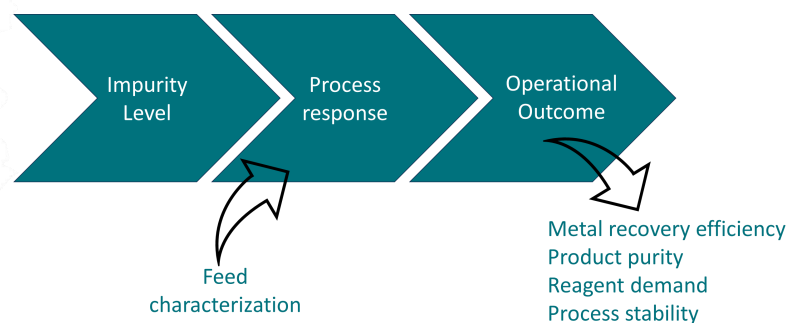


Figure 2: Impurity-driven process response as the link between feed composition and operational performance



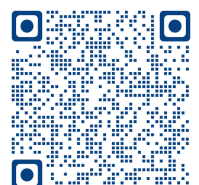
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Neutron Shielding in Deep Space: A Materials Selection Study

How can we protect humans during deep space exploration missions?

Description:

In space, astronauts are exposed to highly energetic particle radiation from galactic cosmic rays (GCR) and solar particle events (SPE) as shown in Figure 1. In addition to SPE and GCR, nuclear interactions between incoming ions and shielding materials generate secondary neutrons and gamma radiation, which contribute significantly to the overall radiation risk in space missions. This study focuses on material selection for radiation shielding, with emphasis on secondary neutron production caused by proton-induced spallation reactions.[1] Using radiation transport calculations based on the Monte Carlo method, the following processes are analyzed:

- Proton interactions with shielding materials
- Generation of secondary neutrons in the shielding material
- Neutron scattering and absorption

Shielding performance is evaluated in terms of the reduction of neutron flux between incident and transmitted radiation and displayed in Ashby maps (e.g. Figure 2) at standardized areal density of 15 g/cm² (Table 1). The metric does not account for biological effects, which depend on neutron energy.

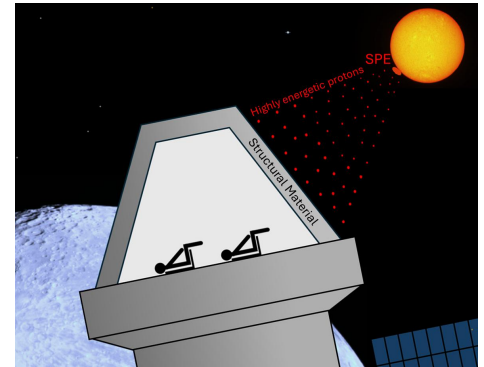


Figure 1: Schematic image of a spacecraft irradiated by highly energetic solar protons in deep space.

Key results:

Metal-polymer composites outperform conventional metals

Magnesium-based systems like composites, exhibit highest neutron shielding efficiency

Multilayer hybrids enable combined structural and shielding performance

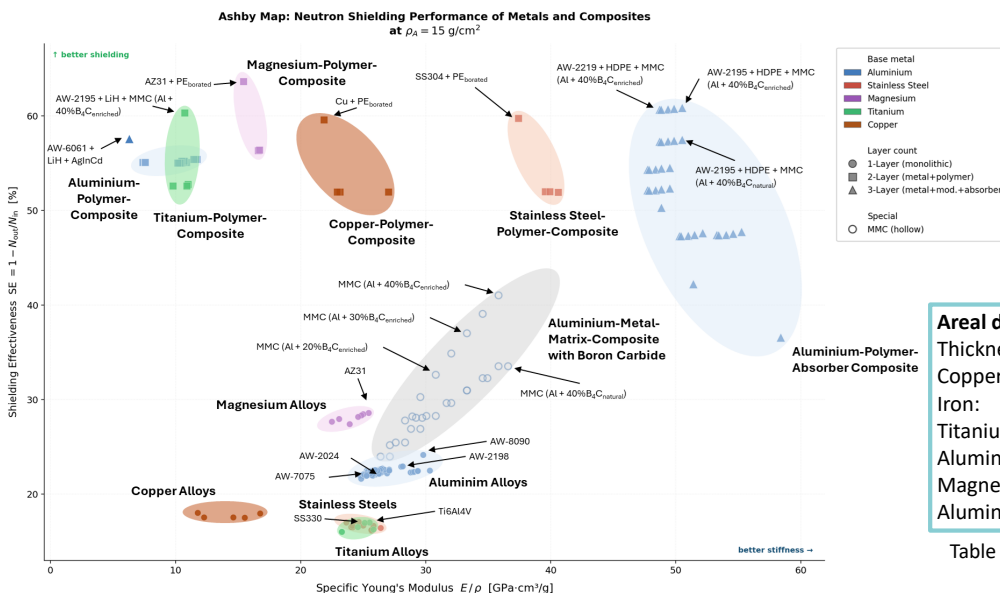


Figure 2: Ashby map for neutron shielding performance of different shielding materials with thickness 15g/cm² in respect to the specific Youngs Modulus

Areal density

Thickness equivalent for different materials:

Copper:	~1.7 cm
Iron:	~1.9 cm
Titanium:	~3.3 cm
Aluminium:	~5.6 cm
Magnesium:	~8.6 cm
Aluminium + Polyethylene composite:	~10.3 cm

Table 1: Thickness comparison at 15g/cm² areal density [2]



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References:

- [1] Tunes, M.A. (2026), *The Legacy and Future of Aluminum Alloys: Space Exploration and Extraterrestrial Settlement*. ACS Materials Au, 6(1), 1–27.
[2] MatWeb LLC. Material Property Data. Available at: <https://www.matweb.com>
Radiation Transport Code: MCNP6.3
Data Analysis and text refinement supported by ChatGPT 5.3 and Claude Sonnet 4.6

Abbreviations and definitions:

AW-2XXX: AlCu(Mg)	AW-8090: ALi2,5Cu1,5Mg1	MMC: Metal matrix composite
AW-6XXX: AlMgSi	SS3XX: FeCrNi	PE: Polyethylene (C2H4)n
AW-7XXX: AlZnMg(Cu)	AZXX: MgAlZn	HDPE: High-density polyethylene

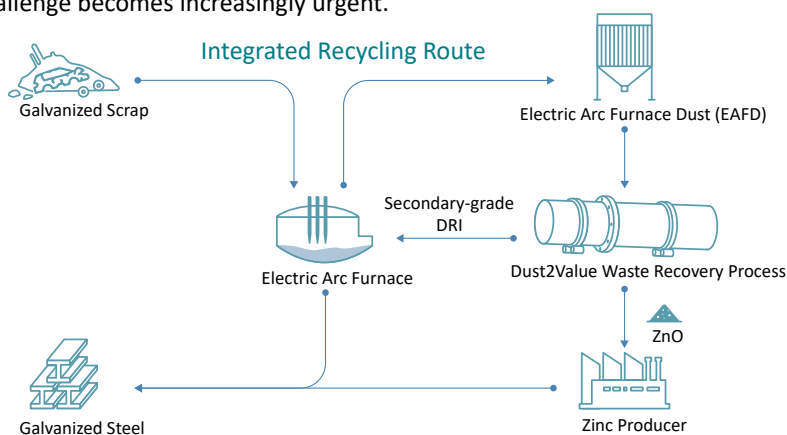
DUST2VALUE

Pioneering Steelmaking Waste Recycling

“Dust2Value develops hydrogen-based recycling of steelmaking dust to recover zinc and produce iron-rich DRI, eliminating direct CO₂ emissions and closing material loops.”

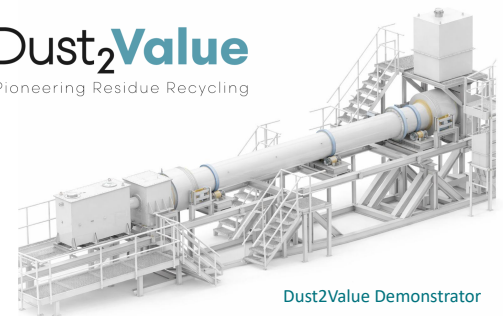
A transition towards cleaner production coordinated by the Chair of Nonferrous Metallurgy

Electric-arc furnaces generate fine dust containing valuable zinc and iron oxides. Currently classified as hazardous waste, this dust is predominantly treated via the carbon-intensive **Waelz process**, generating over **2 tons of CO₂ per ton of zinc recovered**. With the increasing use of galvanised scrap, addressing this environmental challenge becomes increasingly urgent.



Dust2Value replaces conventional carbon-intensive recycling methods with a hydrogen-based reduction process, thereby eliminating direct CO₂ emissions. The core innovation is the reoxidation of zinc with steam (H₂O) to **recover and reuse the hydrogen** consumed during reduction. Hydrogen allows the process to run at lower operating temperatures, which preserve the morphology and enhances reaction kinetics throughout the process and subsequently the resource efficiency and metal recovery. Treating Electric Arc Furnace Dust to recover zinc will be possible with a specific **hydrogen consumption of just 4 kg per ton of treated residue**.

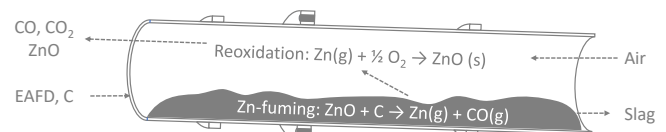
The secondary-grade DRI exhibits high metallization and low sulfur content, enabling its direct reuse in the EAF as secondary raw material. This closes the material loop and prevents approximately **300,000 tons of iron and 20,000 tons of zinc from ending up in landfills across Europe each year**.



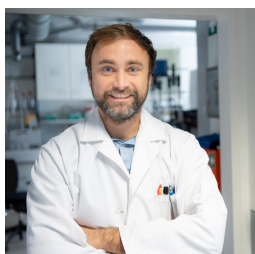
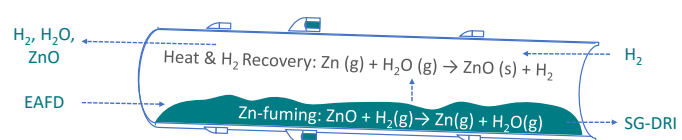
Dust2Value is a collaborative project funded by Horizon Europe (€4.6M), involving industry partners Befesa and Georgsmarienhütte, academic institutions Technical University Leoben (**Chair of Nonferrous Metallurgy, Chair of Ferrous Metallurgy, Research & Innovation Service**) and Politecnico Milano, as well as technology providers M.A.L. and Inspyro from five European countries.

The primary objective is demonstrating feasibility through a pilot plant capable of continuously processing **200 kg over 8 hours**, including integrated hydrogen regeneration and recirculation to minimize hydrogen consumption.

The State-of-the-Art Waelz Process



The Novel Dust2Value Process



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Further
information:



Coffee capsule recycling 'live' at Nespresso boutiques

Demonstration of the recovery of metallic aluminium from pre-processed coffee capsules directly in the Nespresso boutiques in Graz and Vienna

A team from the Chair of Nonferrous Metallurgy (NFM), in collaboration with Altstoff Recycling Austria AG (ARA) and Nespresso, held a 'live' demonstration on 17 and 18 March 2026 at the Nespresso boutiques in Graz and Vienna, showing how aluminium can be recovered from used coffee capsules. First, ARA illustrated how the processing of returned coffee capsules works. This mainly involves crushing, where the coffee grounds, the main component of a capsule, are separated from the aluminium fraction. In this context, it is important to collect the capsules separately and by type, as this allows the processing stage to be optimised for the input material ensuring the best possible product quality. The recovered coffee residues can subsequently be processed into organic fertiliser, oil binders or biogas. The aluminium capsules, now largely free of coffee, are further processed in the next stage via pyrolysis. This removes

any remaining organic residues that could adversely affect the subsequent melting process. Using an induction furnace, the NFM-team demonstrated how metallic Al is recovered from the pre-treated capsules and subsequently cast into coin blanks. Visitors were able to have these blanks stamped with a Nespresso, ARA or Montanuniversität logo and fitted with a magnet, before taking them home as souvenirs. As part of a research project, the Al recovered from the capsules is cast to small ingots weighing 100 grams, which serve as starting material for the subsequent rolling process. Here, foils with a final thickness of 0.1 mm are produced, which should further be used for the production of new aluminium capsules. The project is therefore a prime example of the circular engineering approach of the Montanuniversität, as it closes material cycles and avoids the use of primary raw materials.



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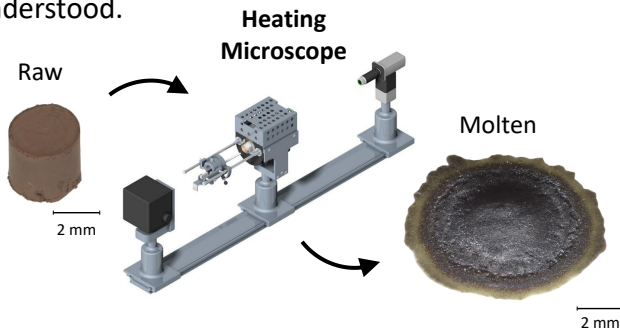


DUST2VALUE

Effect of Lime Addition on Zinc Extraction from EAF Dust in the Waelz Process

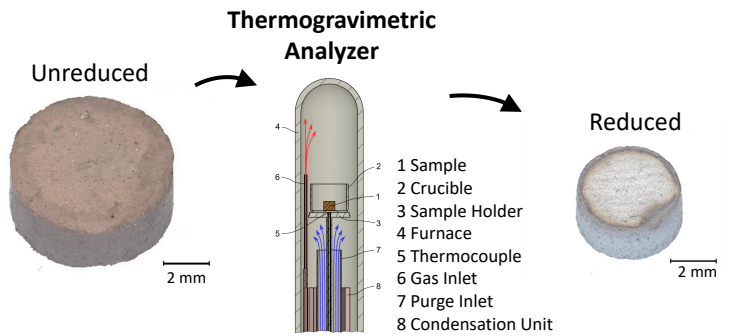
Introduction

Steel recycling in electric arc furnaces produces a hazardous by-product known as electric arc furnace dust (EAFD). This dust is typically treated in the Waelz process to recover zinc. However, its behavior during processing strongly depends on its chemical composition, as low-melting phases can lead to sticking and partial melting. Lime is therefore added to improve stability, but its influence on reaction behavior is not yet fully understood.



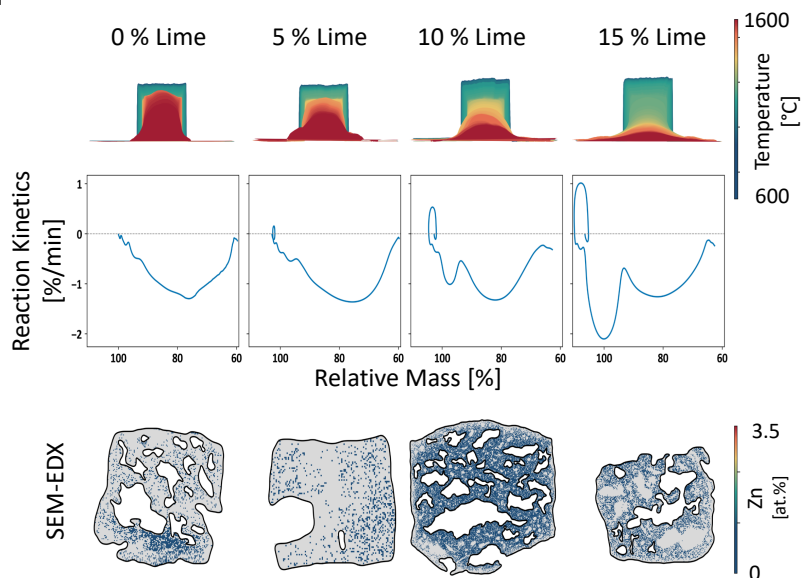
Conclusion

The effect of lime addition on zinc extraction from EAFD is strongly dependent on the dust composition. Moderate lime additions can improve extraction by delaying sintering, but this effect is not universal. While one material showed a clear optimum at 5 wt.% lime, others benefited differently or even showed reduced performance with increasing lime content. These results highlight that lime addition should be optimized for each specific dust rather than applied as a fixed parameter. A better understanding of composition, phase formation, and sintering behavior can improve zinc recovery and reduce losses to slag.



Experimental Procedure

Four EAFDs were blended with 0–15 wt.% lime and investigated under Waelz-like conditions. Reaction kinetics were analyzed using thermogravimetric analysis (TGA) by monitoring mass loss during a controlled temperature–gas program. The resulting samples were examined by SEM-EDX to study their internal structure and element distribution. In addition, sintering and



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