



Metallic Elements Dissipation Avoided by Life cycle design for Steel

Deliverable 2.2

**Report of workshop on quantifiable effects of
tramp elements on materials.**

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Abstract

The present document described as the deliverable D2.2 report on “MEDALS workshop” held on November 14, 2024, focusing on ‘Tramp Elements in Metallurgy: Quantitative Evaluation and Impact Assessment’. This online event hosted by KTH, brought together leading experts and stakeholders to discuss the critical issues surrounding tramp elements in steel production. The workshop featured presentations from KTH staff, including an in-depth overview by KTH and a detailed session on alloy recovery led by Kobilde & Partners AB (KOB). In addition, practical insights into the management of tramp elements were shared by KTH, emphasizing innovative approaches to enhance metallurgical processes. This report encapsulates the discussions, presentations, and collaborative insights garnered during the workshop, aiming to align with the MEDALS project’s objectives to optimize recycling ratios and improve scrap sorting techniques in the metallurgy industry. The outcomes of this workshop are poised to influence future research directions and industry practices, promoting a deeper understanding of material properties and fostering advancements in recycling technologies.



1. Introduction

The workshop served as a dedicated platform to discuss the measurable impacts of tramp elements on materials, enhancing metallurgical processes, and supporting MEDALS project objectives with expert insights and collaborative discussions. There were three presentations in which different topics were addressed. The outline of the workshop was to understand and tackle the quantitative evaluation and impact assessment of tramp elements in metallurgy. Generally, elements in steels are considered as alloying elements if they are added purposely and as tramp elements if they are not added on purpose (depending on the steel grade) and whether they are removable or not by available methods. These elements enter the steel mostly through contaminated scrap, especially in the so-called end-of-life scrap in which different materials coexist.

1. Understanding Tramp Elements

Definition and Common Types: the workshop participants reviewed definitions and identified common tramp elements such as copper and tin, which are crucial to understand their source and impact.

Sources and Paths: Discussion focused on the various paths through which tramp elements enter steel recycling streams, highlighting the complexities involved in tracking and managing these elements from the source to the final product.

2. Impacts of Tramp Elements on Steel Recycling

Effect on Mechanical Properties: The ways in which tramp elements compromise the mechanical integrity of steel were examined, underscoring the importance of maintaining quality in recycled steel.

Economic and Environmental Impacts: The discussions extended to the economic ramifications and environmental considerations of tramp element contamination, emphasizing the need for sustainable practices in the steel recycling industry.

3. Current Techniques and Challenges in Quantitative Evaluation

Detection Difficulties: Participants articulated the challenges associated with detecting and quantifying tramp elements, noting the limitations of current technologies.

Technological Limitations: The current state of technology was critiqued, with a focus on the gaps that hinder effective measurement and separation of tramp elements.

4. Methods of Mitigation and Impact Assessment



Removal Techniques: Effective strategies for mitigating the presence of tramp elements were shared, including both established and novel approaches.

Case Studies: Successful case studies were presented as evidence of effective tramp element management.

Policy and Standards Evolution: it was discussed how industry standards and policies need to evolve to better manage tramp elements, enhancing regulatory frameworks to support these changes.

5. Pyrometallurgical Processes for Tramp Element Removal

Emerging Technologies: Exploration of the latest technological advances in pyrometallurgical processes aimed at removing tramp elements.

Development of Resilient Steel Grades: Strategies for developing steel grades that are resilient to the effects of tramp elements were discussed, highlighting the need for innovation in steel formulation.

The discussions among participants sought to answer critical questions regarding following:

- Existing Process Data: What process data is currently available on tramp elements and their separation from scrap and liquid steel?
- Effective Monitoring Metrics: Is there an existing metric that should be considered for effectively monitoring tramp elements?
- Standardization of Measurement: How can the measurement of these metrics be standardized to ensure consistency and comparability across different processes and facilities?
- Impact Assessment: How should the impact of tramp elements on steel's mechanical properties be assessed, and which metrics should be employed to quantify these impacts?



Table 1. List of workshop participants.

Participant	Organization
Björn Glaser	KTH
Mikael Ersson	KTH
Peter Samuelsson	KTH
Sudhanshu Kuthe	KTH
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Asier Artega	SID
Nora Egido Perez	SID
Beñat Elorrieta de la Torre	SID
Philipp Döhr	STE
Kristin Rudolf	STE
Norma Bargary	UL
Michael Vynnycky	UL
Prince Siddharth	UL
Teresa Gutierrez Seco	TECNALIA
Mikel Merchan Zubieta	TECNALIA
David Eguizabal	TECNALIA



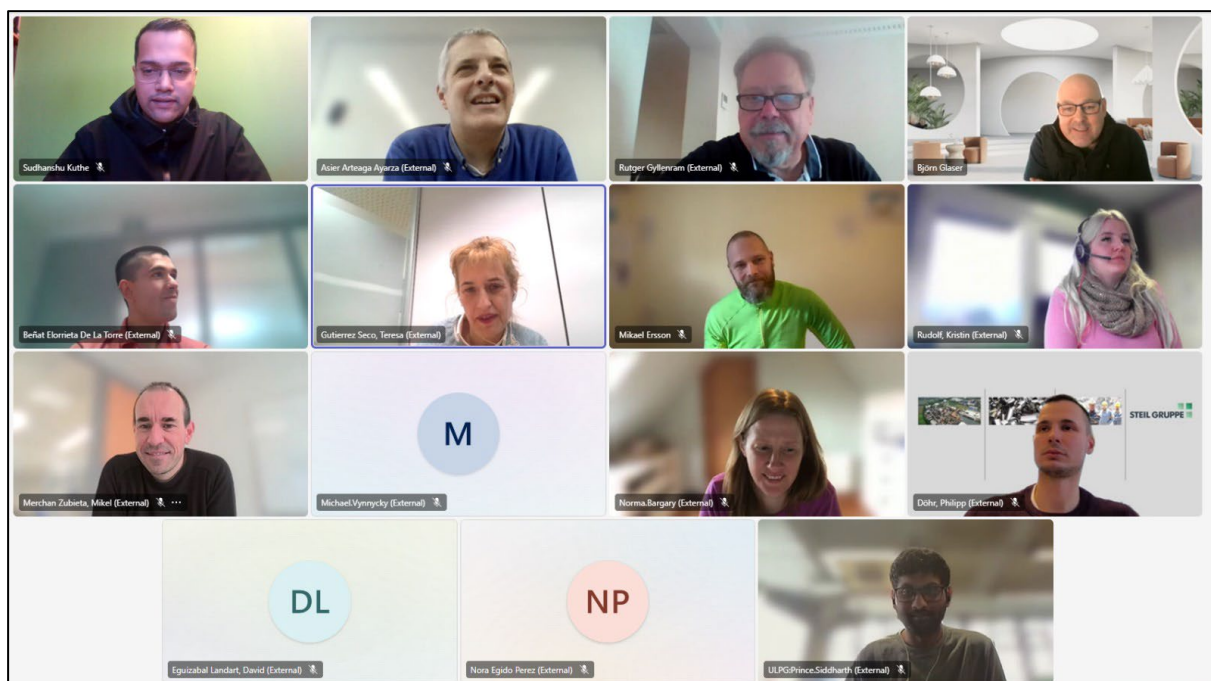


Figure 1. Participants in the MEDALS workshop organized on 14th November 2024.

2. Alloy Recovery

A presentation was given on "Alloy Recovery" during the MEDALS workshop by Rutger from KOB. This presentation introduced the concept of alloying, explaining that alloys typically consist of multiple elements, which enhance the properties of base metals. The complexity of modern products, which often contain several alloys, each tailored for specific functionalities was highlighted. The ubiquity and importance of alloying elements in industrial applications were explained, emphasizing the role of these elements in achieving desired mechanical and chemical properties in final products and the diversity of metals used in automotive manufacturing was discussed. The example showing the alloy recovery from the different parts of the car was described. (refer **Figure 2**). Various steel types and other metals, such as low alloy, high Mn, spring steel, and different classes of stainless steel, along with non-metals that contributed to the vehicle functionality and structure.

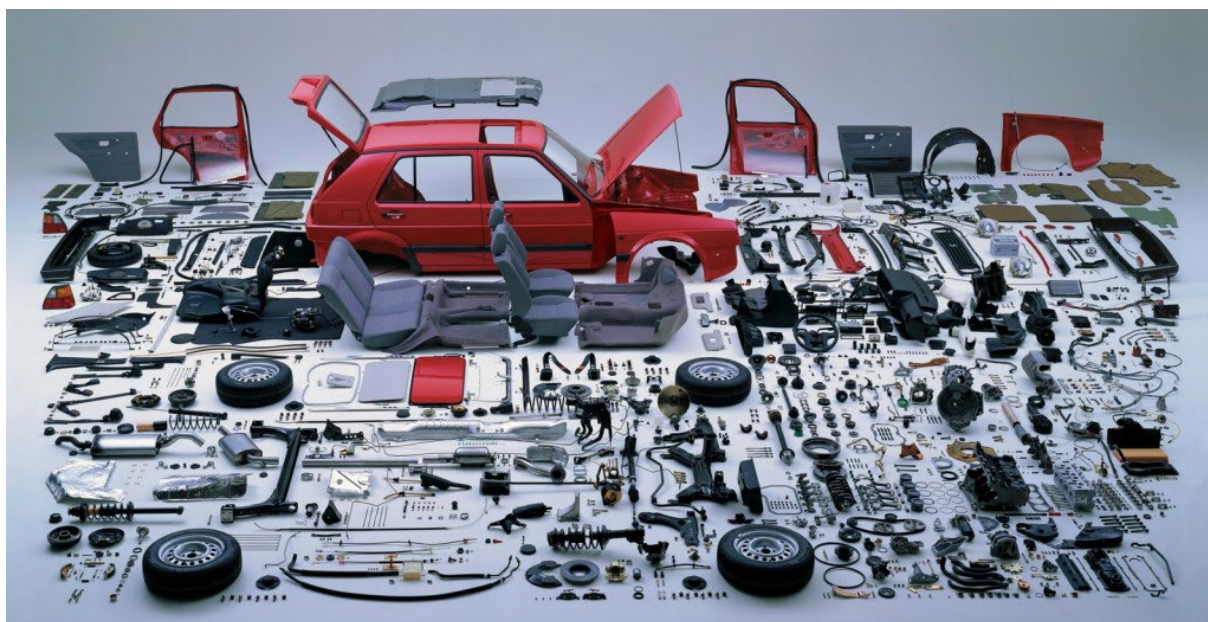


Figure 2. Alloy recovery from different parts of the car [1].

The importance of understanding each metal's role to optimize recycling processes, highlighting the presence of tramp elements like Cu, Pb and Sn could complicate recycling efforts. The microscopic aspects of metals, particularly the crystal structures and the occurrence of dislocations, affect material properties. Rutger explained how dislocations influence the mechanical properties of metals, including their strength, ductility, and hardness, which are crucial for their applications in various industries. A more detailed discussion on the processes involved in alloy fabrication was held, starting from ore handling and mining to more complex steps such as pyrometallurgy and hydrometallurgy. Each process's role in transforming raw ores into usable metals and alloys, emphasizing the energy-intensive nature of these processes and their environmental impacts was described. The primary production methods for converting ores into metals using examples like iron and copper production. Rutger used the Ellingham diagram to explain the thermodynamics of these reactions, showing how different metals are extracted

based on their thermodynamic behavior and stability in different conditions. Further discussion was held on examination of the environmental impacts of extracting and processing critical metals such as Ni and Mo. Significant energy requirements and greenhouse gas emissions are associated with these processes, advocating for more sustainable practices and technologies. The overview of how small additions of alloying elements can drastically alter steel's properties was given. The implications of these changes for industrial applications, focusing on the importance of tailored alloy formulations to meet specific engineering requirements was highlighted further. The solidification processes of iron and steel, detailed on how different cooling rates and chemical compositions lead to various microstructures, such as grey and white iron, which have distinct properties. The challenges of element dissipation throughout the steel production and recycling value chain were presented. Rutger highlighted the need for improved management practices to minimize losses and improve the efficiency of resource use in the industry. A critical look at the operational challenges in scrap sorting, emphasizing the diminishing attention to scrap quality as materials move further from meltshop to end-use applications. The major issues in maintaining material quality in recycling streams, particularly when processing was outsourced or occurs offsite was pointed out.

The participants discussed the complexities and challenges in alloy recovery and recycling. The important given here was on the necessity for a precise and known analysis of tramp elements in scrap materials. Understanding the specific tramp element content is essential for deploying effective separation and treatment techniques that enhance the purity of the recycled metal and comply with the stringent industry standards. The presentation connected directly on enhancing metallurgical processes through better management of tramp elements and clean scrap management. Low Tramp Elements stressed the importance of reducing tramp elements to enhance the quality of the metal recycling process. Techniques for reducing concentrations of these elements include advanced sorting and pre-treatment, which are crucial for maintaining the integrity and usability of recycled metals. Identifying and quantifying tramp elements are crucial for selecting the appropriate processing methods. This targeted approach helped in effectively removing or neutralizing these elements during recycling, thereby improving the overall quality of the processed metal. The effectiveness of magnetic separation technique (refer **Figure 3**) in isolating materials reduces the presence of unwanted tramp elements, ensuring a cleaner metal input for further processing. Cleaning of scrap is crucial to remove residues, oils, and other contaminants that could carry tramp elements into the recycling stream. This step is necessary for ensuring that the recycled metal meets quality standards and reduces the risk of introducing impurities during the melting phase. Robots equipped with sensors and advanced vision systems can identify and sort metals based on composition and color, significantly reducing human error and increasing the efficiency of removing tramp elements. This automated sorting helps in accurately segregating different types of metals and enhances the overall quality of the recycling output.





Figure 3. Recycling considering different steps of (a) magnetic or gravimetric separation, alongside (b) cleaning and (c) Robot sorting to enhance scrap metal quality by reducing tramp elements.

The described shredding system in **Figure 4** highlighted advanced mechanical processing techniques essential for further optimizing scrap refinement. The shredding system is used to break down waste materials into smaller fragments, facilitating the segregation of ferrous from non-ferrous materials. This separation is important for minimizing tramp element contamination and enhancing the purity of recycled metals.

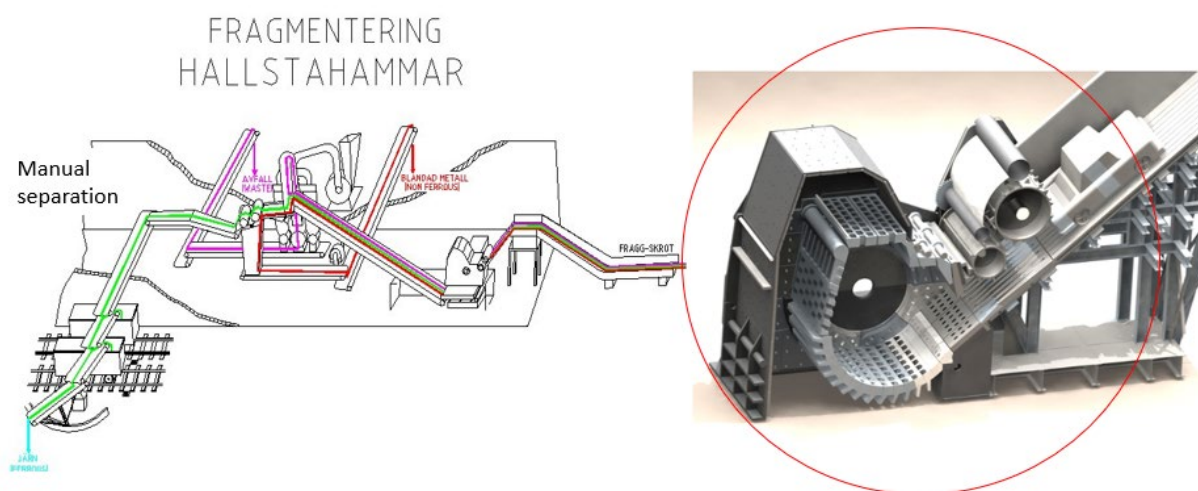


Figure 4. Advanced shredding facility to segregate ferrous and non-ferrous materials for further refinement [2].

2. Tramp Elements in Metallurgy

2.1 General

Elements that cannot be removed easily by current smelting processes are called “Tramp” elements. Tramp elements cause problems as impurities during hot working processes [3]. Cu, Sn, Pb, P, Cr, Ni and Mo are some of the tramp elements. Cr, Ni, Mo are used as alloying elements for some steel grades. During the workshop, the quantitative effects of Cu and Sn were mainly discussed.

- Copper (Cu) – Copper is the most common tramp element that can be present in scrap used for steelmaking. It can be difficult to detect Cu because of several reasons (non-magnetic, low concentrations, present in surface contamination). Cu in steel is fully undesired as it can cause strong surface damage on rolled bars, which can be boosted in presence of S or Ni.
- Tin (Sn) – Tin can have negative effects on the mechanical properties of steel. It makes the steel more brittle and reduces its ductility, making it more prone to cracking and failure under stress. It can also make it more difficult to work with and process, as it can cause the steel to become more prone to cracking and deformation during shaping and forming operations. Especially not desired in steels for offshore application.



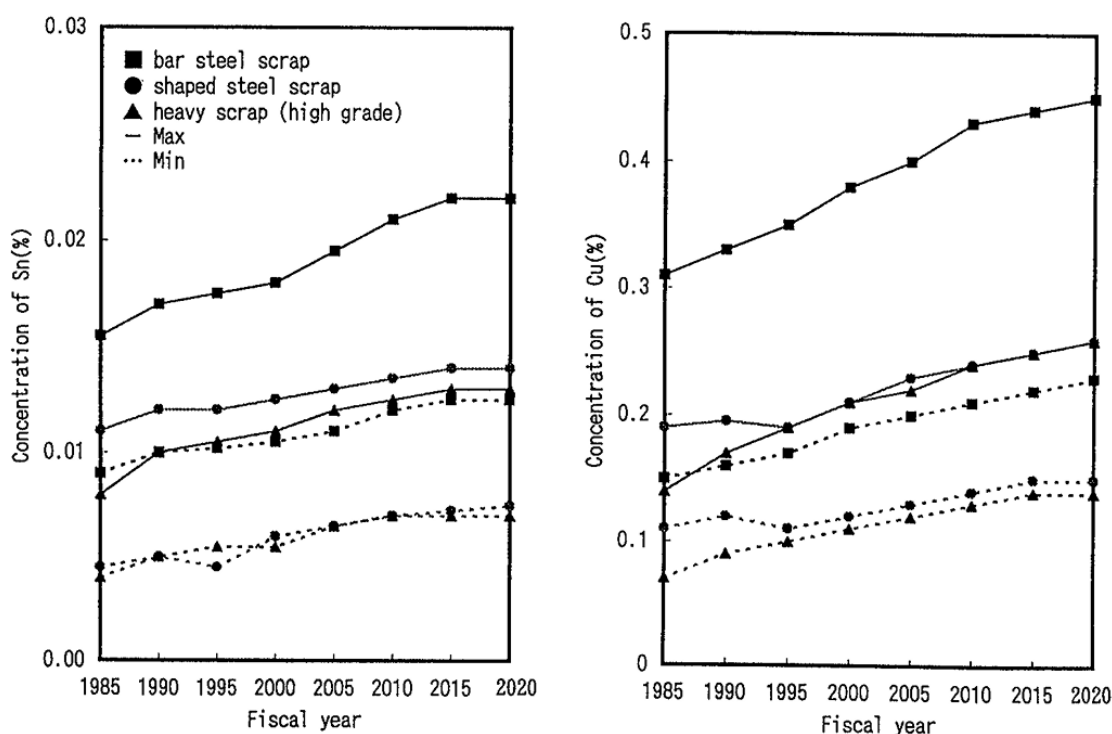


Figure 5. Content of tramp elements Tin and Copper over the years. This is not actual data but simulated data from publication [4].

The left graph in **Figure 5** describes the concentration of tin (Sn) in different types of steel scrap, bar steel scrap, shaped steel scrap, and high-grade heavy scrap. Over the years, there is a visible increase in tin concentrations across all categories, with the least increase in high-grade heavy scrap, suggesting somewhat better control of tramp elements in higher quality inputs. The maximum and minimum values indicated by dashed lines show a relatively tight range of fluctuation in tin content, which suggests a consistent presence that doesn't vary as widely between different scrap sources or over time. The right graph displays the trend in Cu concentrations, which shows a more pronounced increase compared to tin. This trend is especially notable in shredded and car scrap, which often contains a variety of metals including copper from electrical wiring and other components. The increase in copper is steeper and more consistent across the categories, indicating a broader systemic influx of this tramp element into the scrap supply over the decades. The max and min lines also depict a wider range of copper concentration, highlighting greater variability which can complicate recycling efforts and impact the quality of the final steel product. Since Cu has the highest economic value, market demand and content in steel scrap compared to Sn and Pb, it's the only one among the three to have a potential relevant economic gain in case of selling the retrieved percentage from an optimized sorting. Moreover, it is at



the top of the worst contaminants in steel scrap. For these reasons it is of primary importance to primarily focus on the Cu removal. Therefore, all the analysis is focused solely on Cu removal and recovery. **Table 2** shows the maximum residual contents of Cu, Ni, Mo, Cr, Sn and its quantities in different steelgrades.

Table 2. Maximum residual content in steelgrades (wt%) [3].

Element	IF Steel	DDQ	Drawing	Commercial	Structural	Fine Wire	Rebar
Cu	0.03	0.04	0.06	0.1	0.12	0.07	0.4
Ni	0.03	0.04	0.06	0.08	0.1	0.07	0.35
Mo	0.008	0.01	0.015	0.015	0.04	0.015	0.08
Cr	0.03	0.04	0.06	0.08	0.1	0.08	0.15
Sn	0.008	0.015	0.015	0.02	0.03	0.015	0.08
$\Sigma(\text{Cu}+\text{Ni}+\text{Mo}+\text{Cr}+\text{Sn})$	0.106	0.145	0.21	0.295	0.39	0.25	1.06

Steel scrap comes from different streams: home/prompt scrap, industrial and obsolete scrap. **Home scrap** includes leftovers from manufacturing processes, that are then reintroduced within the production processes by the plant in which it was manufactured. Since its composition is well-known, this scrap is recycled infinite times without affecting the material's performance. **Prompt scrap** is clean and new scrap that leaves its production plant since the facility itself doesn't have the machinery to process it. Prompt scrap is high-quality and high-value material; hence it's usually sold through pre-arranged contracts. **Obsolete scrap** (or **old scrap**) refers to post-consumer products that have achieved their end-of-life stage, so they're no longer useful as they are in any sort of way. Compared to prompt and home scrap, obsolete scrap requires much more caring since it's not ready as it is as secondary raw material, since it is often mixed with other materials, and it could be unclean, due to possible retained moisture, oil, food particles etc. In **Table 3**, the chemical composition of different scrap types is highlighted mainly after the melting. For Zinc (Zn), values in parentheses indicate content before melting.



Table 3. Chemical composition of scraps after melting (%) [4]

Category of Scrap	Cu	Sn	Ni	Cr	Zn*
Obsolete					
Shredded	0.23	0.052	0.069	0.123	0.05
Car Scrap	0.234	0.017	0.07	0.13	0.21
Heavy Scrap	0.05	0.128	0.032	0.061	0
Can Scrap	0.027	0.002	0.02	0.031	0.7
Process					
Factory Bundle	0.021	0.01	0.05	0.03	0.01
Home					
Steel	0.01	0.002	0.02	0.02	0.002

2.2. Impact of Tramp elements on steel properties

Tramp elements are difficult to remove through standard smelting processes. The quality of steel during recycling and subsequent manufacturing is therefore affected due to their presence. Specifically, Cu and Sn can cause surface hot shortness and negatively impact steel formability as their concentrations increase. Copper contamination often results from inadvertently incorporating copper materials during steel recovery from end-of-life products. Past study illustrated the historical integration of copper into steel scrap and potential increase in copper content if current mixing rates persist without improved separation techniques [5]. Similarly, elements like Ni and Cr, present as impurities in carbon steel, often come from the mixing of steels into carbon steel scrap during recovery without adequate separation by alloy type. These tramp elements fall into two categories: those unintentionally mixed as non-steel materials and those initially added as alloying elements that became impurities due to the lack of precision in sorting during recycling. Copper tends to segregate at the grain boundaries of austenite in steel. This segregation can lead to the formation of cracks that are filled with copper. The slide explains that these cracks often follow the austenite grain boundaries, weakening the steel's structural integrity. The presence of these copper-filled cracks is particularly detrimental as they can occur without the need for an externally applied load, indicating that the structural failures are due to the inherent properties of the steel influenced by copper (Refer **Figure 6**).



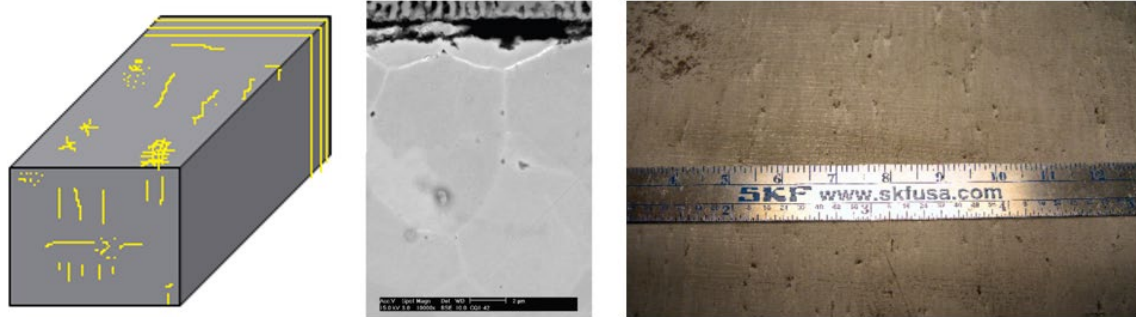


Figure 6. The presence of these copper-filled cracks is particularly detrimental as they can occur without the need for an externally applied load.

Depending on the steel grade, individual properties are desired which leads to different tolerable tramp element limits and it also means that elements which act as alloying element in certain steels can count as tramp elements in others. Copper can act as alloying or tramp element. While it is added purposely to weather resistant structural steels, it leads to various problems in others. Due to its superior solubility in austenite, copper heavily segregates during the formation of ferritic microstructure, resulting in enrichment at the grain boundaries which, in turn, leads to hot-shortness and to a higher tendency to surface cracks. Molybdenum is added to high-alloyed steels. It is known to decrease the critical cooling rate and thus increases the hardenability of carbon steels. On the other hand, steels with soft microstructures or certain hardness profiles like mild steels or rail steels allow only for low molybdenum contents. Tin has an even higher solubility in liquid steel than copper. It segregates heavily and exacerbates the hot shortness by large extent. While the combination of tin and copper at grain boundaries may lead to excessive hot-shortness, the addition of nickel can diminish this effect partly. Hot shortness is a tendency of steel to fracture in a brittle manner along grain boundaries when deformed at temperatures near the melting point. Hot shortness generates difficulty in hot-working operations.

2.3 Additional discussions

During the workshop, participants also shared their experiences and challenges related to specific tramp elements encountered in different stages of metal processing. Notably, SID and STE provided interesting perspectives on their observations on the impact of Sn and Cu as tramp elements. This also reflected the variability in industrial challenges depending on the facility and the source of scrap metal. SID highlighted that during EAF operations, Sn does not pose significant challenges; instead, Cu is the predominant concern. The presence of Cu in steel grades, particularly in higher concentrations, can lead to issues such as hot shortness, which affects the material's workability at high temperatures. The experiences at STE, as conveyed by Philipp, where tin occasionally exceeds the maximum bearable limits during scrap processing. Although Sn is generally less problematic at the steelmaking, its accumulation in the recycling loop can reach thresholds that jeopardize the integrity of steel, impacting properties like strength and malleability. These differing accounts for the necessity for a specific approach to managing tramp elements. The variability can be attributed to several factors, including the origin of scrap metal, the specific recycling and manufacturing processes employed, and regional market demands that dictate the composition of input materials.

Proposed Framework for Addressing Variability in Tramp Element Impact:

- 1. Enhanced Monitoring and Reporting Systems:** Implementing more robust monitoring systems that can track the concentration of tramp elements at various points in the recycling process would help facilities to adjust their input materials and processing parameters dynamically.
- 2. Customized Management Strategies:** Developing tailored strategies that account for the specific metallurgical challenges of each plant. For facilities like Sidenor, focusing on technologies and additives that mitigate the effects of copper may be prioritized, whereas for recyclers like Theo Steil, enhancing separation and purification techniques to reduce tin content might be more critical.
- 3. Collaborative Industry Standards:** Encouraging the establishment of flexible yet stringent industry standards that accommodate the diversity in operational contexts and the technical capabilities of different plants, promoting a more adaptive approach to quality control in metal production.



Addressing the discussion questions in the next section is critical in shaping the above proposed framework that aims to tackle the variability in tramp element impacts observed across different steel plants. Using innovative tools and methodologies, steel industry can enhance the ability to monitor and control these elements effectively. The rich discussions from the MEDALS workshop highlighted the need for a holistic approach that incorporates enhanced real-time data acquisition, the development of universally accepted metrics for tramp element concentration, and standardized procedures to ensure consistency across the industry. These elements are integral to the framework, facilitating the design of strategies that are not only tailored to specific industrial challenges but also aligned with global standards.

2.3. Discussion questions

1. What existing process data is available on tramp elements and the processes of separating tramp elements both from scrap and liquid steel?

The availability of process data on tramp elements varies widely across the metallurgical industry. Generally, data are available from studies focusing on the sources and types of tramp elements in scrap and liquid steel. These studies often outline the concentrations of common tramp elements such as copper, tin, and nickel. However, real-time data during smelting and processing is less comprehensive and often proprietary to specific steel plants. The discussion during the workshop highlighted the need for more detailed and accessible real-time monitoring systems that can provide data across the entire lifecycle of steel production and recycling. This data is crucial for optimizing separation processes and enhancing the quality control of steel products. In this aspect, **SID** as a steel plant can provide valuable real-time production data, offering insights into the concentrations and behavior of tramp elements during smelting and refining processes. This data is pivotal in identifying the specific challenges faced in minimizing tramp element contamination during steel production. **STE** can contribute by sharing data on the initial concentrations of tramp elements found in various scrap materials. This information is essential for tracking the origin and influx of tramp elements into the recycling stream, facilitating better sorting and preprocessing techniques. **TEC will work in developing the technology to recover these elements from the wastes.** **KTH** can explore innovative metallurgical techniques to remove or neutralize tramp elements more effectively. Their research helps in understanding the transformations of these elements



under different processing conditions, providing a scientific basis for developing more efficient removal strategies.

2. Is there any existing metric that should be considered for monitoring tramp elements effectively?

Currently, the metrics used to monitor tramp elements often involve chemical assays and spectral analysis to determine the composition of steel. However, these metrics are not standardized and can vary significantly between facilities and regions, depending on local regulations and industry standards. The workshop participants agreed that there is a need for accepted metrics that are sensitive, reliable, and capable of detecting low concentrations of tramp elements. However, developing such metrics would involve collaborative efforts from industry leaders, researchers, and regulatory bodies to ensure they are robust and applicable across different settings. In general, the target specifications of tramp elements before and after the processing and melting of scrap at both SID and STEs can play a fundamental role in understanding and developing novel metrics for monitoring tramp elements.

3. How can the measurement of this metric be standardized to ensure consistency and comparability across different processes and facilities?

Standardization of measurement metrics for tramp elements would require the development of agreed-upon methods and protocols that can be adopted globally. This standardization process could be facilitated by international standards organizations, such as ASTM or ISO, which would develop and disseminate guidelines based on rigorous testing and consensus from various stakeholders. These standards would need to cover aspects such as sampling methods, analytical techniques, and acceptable limits of tramp elements. Standardization would help ensuring that data on tramp elements is consistent, reliable, and comparable across different processes and facilities, thus facilitating global compliance and quality assurance.

4. How should the impact of tramp elements on steel's mechanical properties be assessed, and what metrics should be used to quantify these impacts?



Assessing the impact of tramp elements on the mechanical properties of steel requires a multifaceted approach. The workshop suggested using a combination of mechanical testing (such as tensile, hardness, and impact tests) and microstructural analysis (using techniques like scanning electron microscopy) to understand how tramp elements affect the steel's performance. Metrics such as changes in ductility, strength, toughness, and corrosion resistance could be quantified to evaluate the impact. Additionally, developing predictive models that can simulate the long-term effects of tramp elements under various environmental and operational conditions was seen as beneficial. These models would help in quantifying the impacts and could guide the development of more resistant steel grades. The MEDALS project partner UL started initial talks with SID on the same. Furthermore, initial discussions focus on aligning data-driven models with practical, industrial needs.



Conclusions

The discussions and insights gained during the MEDALS workshop highlighted the complexities and challenges posed by tramp elements like copper and tin in steel recycling. These elements significantly impact the mechanical properties of steel, with copper enhancing corrosion resistance but also potentially causing hot shortness when present in high concentrations, and tin increasing brittleness, particularly affecting the steel's weldability and structural integrity.

This rising trend in tramp elements within the scrap supply is driven by factors such as the increasing prevalence of electronics in consumer goods and automobiles, which introduces more complex material streams into recycling processes. Such trends necessitate the development of more sophisticated separation and purification technologies to maintain the quality of recycled steel. Addressing these challenges is not only critical for maintaining the structural integrity and usability of recycled steel but also for controlling production costs, as higher concentrations of tramp elements can lead to more intensive sorting and processing requirements as well as potential material losses.

Moreover, the environmental imperative to reduce waste and enhance the sustainability of steel recycling aligns with the need to manage tramp elements effectively. Lowering the concentrations of these elements is crucial for minimizing the environmental footprint of steel production and enhancing the material's recyclability. Discussions between the project partners during the MEDALS workshop highlighted the importance of a collaborative approach to tackle these challenges, involving contributions from various industry stakeholders to develop innovative solutions that are versatile and effective. Through the integration of advanced technology, updated regulatory frameworks, and shared industry best practices, the steel industry can make significant strides in enhancing the sustainability and efficiency of metallurgical processes. These efforts are crucial for advancing the MEDALS project's objectives, which aim to optimize recycling ratios and improve scrap sorting techniques, ultimately fostering a deeper understanding of material properties and pushing forward the boundaries of recycling technology.

Both copper and tin affect steel's mechanical properties in significant ways. Copper, while beneficial for corrosion resistance, can lead to issues like hot shortness when present in higher concentrations, especially when combined with other elements like sulfur. Tin can make steel more brittle, particularly



impacting its weldability and structural integrity. The rising trend in these tramp elements reflects the evolving composition of steel scrap, influenced by factors such as the increasing use of electronics in automobiles and other consumer goods. This makes the recycling process more complex and necessitates more advanced separation and purification technologies to maintain steel quality. Increased tramp elements can lead to higher costs in steel production, from more intensive sorting and processing requirements to potential losses in material due to quality issues. Environmentally, the need to achieve lower tramp element concentrations is aligned with reducing waste and improving the sustainability of steel as a recycled material. The complex nature of tramp element management also highlighted the importance of industry-wide collaboration and innovation in developing solutions that are both versatile and effective. Addressing these challenges through a combination of technology, regulation, and shared best practices is therefore essential for advancing the sustainability and efficiency of the metallurgical industry.



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