Fraunhofer flagship project »ORCHESTER«: Digital ecosystem for a resilient and sustainable supply of functionally reliable materials

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1. Introduction

The interdisciplinary Fraunhofer flagship project »ORCHESTER«, scheduled to run for four years (2024-2027), addresses the challenges of the circular economy and security of supply, in particular with functionally reliable materials for the energy transition along the entire value chain.

2. Global challenges and regulatory requirements drive the need for sustainable and resilient materials

The European Critical Raw Material Act (CRMA) [1] is setting political framework conditions for a multitude of raw materials: by 2030, 10% are to be extracted in the EU, the further processing rate is to increase to 40% percent, the recycling rate to 15%, and a maximum of 65% of imports are to be sourced from just one country. Consequently, the objective is to move towards a circular economy, and to substitute critical elements [2].

Additionally, geopolitical and social crises lead to major uncertainties in industry and society due to disruptive material supply flows. Of particular importance is the implementation of the energy transition. The EU aims to achieve greenhouse gas neutrality by 2050 [3], which is dependent on a secure supply of raw materials and at the same time has a massive impact on material flows.

However, the reliable supply situation over the last decades has contributed to the value chains becoming increasingly optimized, specialized, and globalized. The result is an enormous variety of materials with closely defined process routes. As unexpected events such as the pandemic and the war in Ukraine have shown, the high degree of optimization and specialization makes value chains more susceptible to disruption. Even minor disruptions in the supply of materials lead to immense economic, ecological, and social consequences - in the event of bottlenecks, substitution solutions must be found quickly. However, the associated process routes currently come up against rigid and over-regulated standards and methods for the development and release of products and processes.

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3. Three demonstrators in the context of the energy transition

The challenges described are particularly significant for metal and magnetic materials with critical elements and widespread use. This applies to classic construction materials as well as light metal alloys and ultra-modern specialized functional materials, which are represented in this project by steel, aluminium and magnetic materials. We focus on material specification, recycling and criticality as well as a strong reference to the energy transition, thereby addressing the largest industrial sectors and future markets.

Figure 1: Three components in the context of energy transition used as demonstrators in this project.

4. Building a digital ecosystem to map the value chain

Recycled materials play a crucial role in material supply but can compromise the functional safety of components due to chemical contamination. Ensuring a sustainable and resilient supply of functionally reliable materials requires the entire value chain to be digitally and physically networked. Current market technologies do not yet support this level of integration.

Scientific and technological advancements indicate that a secure material supply for value chains can only be achieved through interdisciplinary concepts applied holistically. This involves raw material extraction and processing, metallurgy, process technology, materials science, mechanics, production technology, and recycling. It necessitates a comprehensive understanding of how chemical elements and compounds enter and interact within the cycle.

Thus, ensuring safe material supply demands rapid evaluation of process and functional safety, resilience, and sustainability within a digital ecosystem. To this end, we integrate experimental, simulation-based, process, sensor, and digital technologies into such an ecosystem. Additionally, tools such as high-throughput screening, sensor data, process simulations, and knowledge graphs for linking material and process data with models and expert knowledge will be utilized.

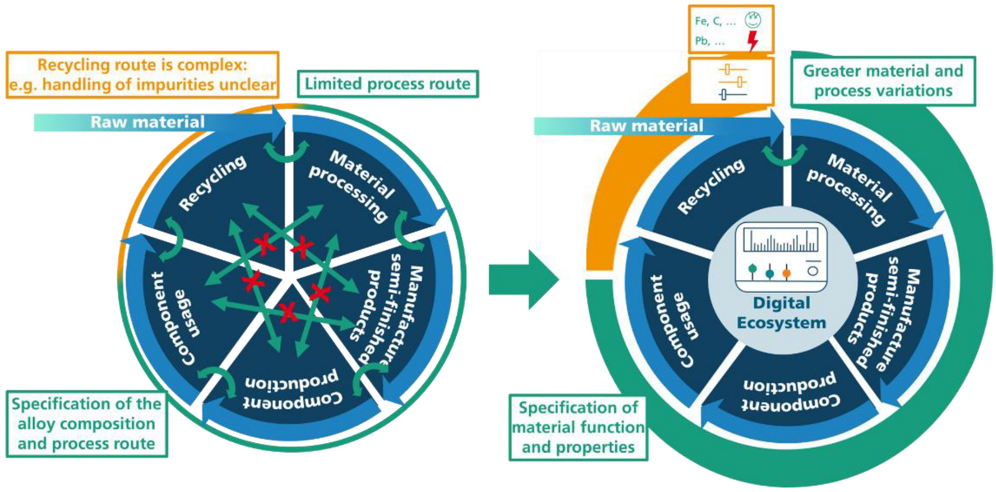

Figure 2: Representation of the value chain with the "state of the art" depicted on the left and vision of this project shown on the right.

5. Creating new opportunities with customized digital products

ORCHESTER will provide customers with a holistic offering to secure the supply of materials for resilient and sustainable value chains. The digital ecosystem to be created will provide integrated functional safety assessment solutions and recommendations for action based on a digital knowledge base. The solution approach is based on the digitalization and networking of information along the value chain. To this end, technical challenges in dealing with fluctuating material compositions in recycling routes, fast and efficient alloy variation, the integration of material flow models and computer-aided methods for predicting multifunctional material properties (e.g. mechanical, corrosive, producible and sustainable) must be solved.

6. Creating added value and measurable improvements

This project aims to show that a paradigm shift in material specification and the associated approval processes increases the selection of usable materials at least fivefold, increases the proportion of recycling in process routes by at least 50 % through methods for dealing with impurities in secondary metals. Moreover, the proportion of rare earths from primary production should be reduced by at least 25 %, and, in all demonstrators, the increase in resilience by more than 30 % is proven by a stress test.

Our targeted recommendations for action give the industry room for maneuver and evaluation options with regard to material supply and criticality as early as the development phase, proactively improving security of supply. In shortage and crisis situations, ORCHESTER will open up rapid response options for finding alternative materials and maintaining production via alternative routes or semi-finished products. This results in greater security of supply by reducing the proportion of critical alloying elements and by increasing the use of sustainable materials with a high proportion of secondary materials.

7. Conclusions

By driving technological advancements, the overarching goal of this project is to moderate the interplay between industry, associations, politics and research in the supply of functionally safe materials for the energy transition. In particular, we aspire a paradigm shift in material specification away from a definition based on material composition towards a function-based specification that enables faster substitution of critical materials and thus a more resilient material supply.

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8. References

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