Studies within the flag ship program “Materials Chain”

Introduction

The UA Ruhr flagship program Materials Chain has launched two major studies with the aim to pursue two objectives: Firstly, to provide a comprehensive evaluation of the strengths and possibly existing weaknesses of the Materials Chain. Secondly, to thematically sharpen the research focus of the UA Ruhr flagship program and to generate new ideas for joint research proposals.

Bibliometric study: strengths and weaknesses of the Material Chain

A profound bibliometric study was commissioned by the Forschungszentrum Jülich to answer two important questions for the UA Ruhr flagship program “where does the Materials Chain currently position itself?” and “how does it has to align itself thematically in the future?”. For this purpose, publications of the Materials Chain members within the last five years, which were listed in the two large literature databases „Scopus“ and „Web of Science” (WoS) were analyzed, based on two evaluation criteria. The papers were first assessed concerning their scientific excellence as well as the scientific perception of the Material Chain members within the international science community. Secondly, topics and networks in which the Materials Chain is involved were scrutinized. The bibliometric study provided a detailed overview of all journals including publications from the Materials Chain. By evaluating their impact factors, the study has impressively demonstrated that the majority of contributions was published in renowned, peer reviewed journals of great scientific importance. It was also determined that Material Chain members have comprehensively contributed to the international research in the fields of materials science and production engineering, so far publishing more than 7.500 journal articles between 2011 and 2015. Based on the citation indices and the so-called "J-factor," the study concluded that the scientific perception of the Material Chain in the international science community can be deemed “very good” or even as "exceeding the expectations". This enables the Materials Chain to compete against prestigious and long-established research associations and universities, such as the RWTH Aachen University. A content analysis of the publications revealed all relevant research competencies and thematic clusters in which the Material Chain members are involved. It was demonstrated that the Material Chain members covered a broad thematic scope and worked highly interdisciplinary. The interdisciplinary field covered comprises of different research areas such as nanotechnology, scale-bridging simulation, materials synthesis, and production technology, in which the Materials Chain also occupies a leading position both nationally as well as internationally.

Trend study: profile sharpening of the Materials Chain

A trend study was carried out by the VDI Technologiezentrum together with the Forschungszentrum Jülich to answer another important question: “how does the Materials Chain has to align itself thematically in the future?” This study, which has been completed in the meantime, aimed to identify and assess major future trends in the field of material sciences and engineering, which are most relevant for the development of the UA Ruhr flagship program Materials Chain within the next 10 to 15 years. On the one hand, these envisaged megatrends will play an important role in science and industry (R&D), economy, and society providing a distinct potential to decidedly change life in future. On the other hand, they have to be consistent with key topics of major work- or funding programs by the government (such as the German Federal Government's high-tech strategy or Horizon 2020) and should match the research competencies of the Material Chain members as good as possible. In order to initiate novel future joint research projects, scientifically applicable topics were derived from these megatrends. Another objective of the study was to clarify whether the Materials Chain members bring all necessary resources and expertise together to study complex and highly interdisciplinary research topics comprehensively and completely.

The trend study consisted of two modules. In the first module, a bibliometric and project-related analysis was performed. At the beginning, a specific search strategy for the database Web of Science was developed to both identify and evaluate relevant "subject categories" in the material sciences. Simultaneously, interesting topics for the Materials Chain were analyzed in various other sources, such as conference programs, foresight-studies, and secondary literature. In the subsequent bibliometric indication, topics from WoS review articles, related to material sciences, were clustered in buzzword lists and visualized by means of bubble charts. To validate these results, a random sample of 500 publications from the WoS was taken and scrutinized. The overlap of topics from all preceding steps was transferred to a “longlist” of 100 topics. Representative scientific keywords were then defined for each topic according to the pareto-principle and subjected to search queries of the WoS. Afterwards, these keywords and the connected topics were analyzed, on the one hand, regarding their match with the previously ascertained “Subject Categories“ and, on the other hand, concerning their conformity with the Materials Chain. Based on the number of publications and the characteristics of each topic (e.g. niche topic or popular topic), a ranking was established. Additionally, the topics were compared to ongoing, coordinated DFG projects and it was checked whether the three UA Ruhr Universities are involved. As a result, nine topics, which, based on various indicators, proved to be particularly interesting for the Materials Chain, were suggested by the VDI / FZ Jülich and discussed in a workshop together with the Materials Chain members. Six priority topics were selected and partly enhanced concerning some thematic aspects by the Materials Chain members: (1) Surfaces and Interfaces (incl. Nano), (2) Nano-2-Giga: Steel and its production, concrete and cement, (3) Circular value creation and resource efficiency, (4) Materials research for the production of the future, (5) Quantification and prediction in materials design, (6) Materials for novel electronics.

Based on these six priority topics a profound “correlation of the current state of development in materials science” was performed. In analogy to the first module, representative scientific keywords were first defined and subjected to (a more comprehensive bibliometric analysis than in the first module) by means of a detailed search query in the WoS. A random sample of 500 publications from the WoS was taken and once more scrutinized to assess the conformity between the six priority topics and the Materials Chain by clarifying, whether and in how far the Materials Chain publications could be matched with the respective keywords. The results were evaluated using different indicators (such as the publication number and the citation rate) as well as their ranking (such as the TOP-30 institutions

in Germany, the TOP-5 institutions in the world, and the TOP-20 publications). Beside the bibliometric examinations, a comprehensive technical content-related analysis was carried out for the six priority topics in order to assess their future potentials. Within this context, two perspectives were considered: (1) a top-down approach, which focusses on the future-oriented nature of the six priority topics regarding technological megatrends and global challenges. (2) a bottom-up approach, which proves the future-oriented nature of the six priority topics in the context of large, coordinated projects and superior strategic work programs of the government and the EU with future prospective. The six priority topics were evaluated from the viewpoint of both the bibliometric and the technical content-related analysis, regarding their future viability and conformity with the Materials Chain in the light of various indicators. The results were presented and discussed together with some Materials Chain members at a creative workshop. Another goal of the creative workshop was to combine technological megatrends and major societal challenges with potential key activities of the Materials Chain in order to identify the long-term as well as sustainable social relevance of the Materials Chain initiative. Within this context, the "production of the future" and "circular value creation" were perceived as important trend topics.

In a final step, German leading institutions and their position according to their absolute publication numbers and impacts (i.e. the number of citations and the citation rate) were identified for each of the six priority topics and compared to the Materials Chain, which was considered an independent institution in Germany. Additionally, the conformity between the individual topics and the key activities of the Materials Chain were determined. Both indicators (ranking and conformity) were evaluated on the basis of the publications of the Materials Chain. It has to be noted that the Materials Chain's publications generally comprises all publications of the three UA Ruhr universities, publications by the affiliated/cooperating institutes (e.g. Max-Planck, Fraunhofer, Leibnitz), as well as joint publications between these institutions. To indicate a participation of the UA Ruhr universities in these publications and, furthermore, the cooperation within the Materials Chain, all publications that involved at least one or two of the three UA Ruhr Universities, were highlighted.

Regarding the evaluation of all indicators, the bibliometric and technical content-orientated analysis finally led to the conclusion that topic 3 of the six priority topics, namely "circular value creation and resource efficiency" features the highest potential for an appropriate future topic (or even the lighthouse project) for the Materials Chain. Measured by the number of international publications, Germany ranks fourth in terms of the research on this topic in the WoS. With regard to the number of publications and quotations, the Karlsruhe Institute of Technology is at the top (64 publications, 328 citations), the TU Dortmund University ranks second (49 publications, 363 citations), and the RWTH Aachen is ranked third (48 Publications, 321 citations). By comparison, the Materials Chain is ranked 11th, the Ruhr-University Bochum 14th (15 publications, 83 citations) and the University of Duisburg-Essen 27th (9 publications, 11 citations).

Despite the fact that this topic is already popular, the present number of publications in this field is neither generally (absolute) nor compared to all other priority topics (relatively) large. The many areas / facets of this topic and the good conformity with the key activities / competences of the Materials Chain offer great potentials for intense research within the flag ship program. In this context, and due to the overall manageable number of publications, there is a good chance for the Materials Chain to achieve a top national and international position with relatively little effort.

With regard to the big national and international funding programs (such as Horizon 2020), the topic "circular value creation and resource efficiency" has a high priority on the political agenda of the EU. There is also a separate virtual focus area called "circular economy" as well as many corresponding

funding opportunities. The topic is connected to many global challenges (such as sustainability, environmental protection, and sustainable production) and technological megatrends (such as robotic, artificial intelligence, industry 4.0, and digitization). The reference to the technological megatrends is largely characterized by the fact that they can be used to realize the circular value creation. A particularly close connection exists with the megatrend themes of "energy and resource conservation" and "climate protection".

The priority topic “circular value creation and resource efficiency” can offer a future perspective for the whole Ruhr region: the vision is to establish modern and interconnected circular value networks in this area, analogous to the traditional *mining complex* [1]. There is also a cross-reference to the second priority topic “Nano-2-Giga: Steel and its production, concrete, and cement” because steel features an excellent material efficiency and thus high recycling rates. In addition, steel production has a long tradition in the Ruhr area. Building on these traditions as well as the experiences and expertise gained over many decades, novel and innovative value creation circuits / networks can be established within the framework of this topic. From the scientific point of view, the Materials Chain plays a key role by providing the fundamentals for resource-efficient production processes and materials, as well as by developing sustainable solutions for recycling cycles.

In a certain way, key aspects of almost all six analyzed priority topics could be integrated into the recommended priority topic 3. This concerns in particular aspects of priority topic 2 "steel, concrete & cement", of priority topic 4 "materials research for the production of the future," and priority topic 5 "quantification and prediction in materials design". The latter generally has a high relevance in science and industry. The evaluation of the large, coordinated DFG programs has shown that the interplay between "quantification" through experiments / measurements and "predictions" by means of simulation / modeling can be regarded as universal methods for the synthesis, design, and production of materials. Due to its popularity and complexity, however, priority topic 5 needs to be refocused according to the key activities of the Materials Chain to obtain the necessary contextual emphasis for the Materials Chain. Priority topic 1 “surfaces and interfaces (incl. nano)" also shows various interconnections with the recommended priority topic 3 (e.g. by processes such as refining / renewing / repairing components by means of surface coating or surface finishing).

In addition to the high scientific relevance of priority topic 5 (which was proven by the study), the good integrability of all other priority topics, as well as the good conformity with the key activities of the Materials Chain, the creative workshop further concluded that aspects like "sustainability and resource savings" and "production and engineering", which are closely related to priority topic 5, have to be prioritized. Priority topic 5 also features close relationships to almost all technological megatrends. Furthermore, the megatrend topics can act as so-called “enablers” for the implementation of the “circular value creation and resource efficiency” (such as robotic, artificial intelligence, industry 4.0, and digitization). From this viewpoint, priority topic 5 can be realized and promoted as very modern and forward-looking.

The fact that the number of publications for this promising topic is relatively low shows that it is not very much developed or that it has not received much attention in scientific literature yet. On the one hand, this gives the Materials Chain plenty of room for the thematic design. On the other hand, it

[1] **Mining complex:** the coal mining and steel industries in the Ruhr region have created many more and new ancillary processes / industrial sites (such as coking plants, gas treatment, district heating) and by-products (such as gas, chemical products, tar, fertilizer).

provides the Materials Chain with good opportunities to position itself adequately for the future and to achieve a high visibility in the international scientific community.

Finally, in a more general view, the slogan of the Materials Chain "from atom to component" implies that actual products are important for this flagship program. At the same time, the production and material sciences also play a predominant role, because these research disciplines are fundamentally required to realize any product and therefore make the process chain complete. For this reason, the recommended priority topic 3 "circular value creation and resource efficiency" also appears to be ideal for the Materials Chain.

Beside this main topic, which is appropriate as superordinate future topic for the Materials Chain for a collaborate within the next 10 to 15 years, there is another minor topic, which is also very promising and interesting for the Materials Chain, namely “microorganisms on technical surfaces and interfaces”. As part of the priority topic 1, this sub-topic has a distinct "out-of-the-box" character. It is directly driven by various technological megatrends. Since exponential advances in genome sequencing have generated improved analysis methods and with metagenomics as a breakthrough technology in the field of microbiology, this has already led to a boom in research in the field of the microbiome within the human intestinal flora. In addition, the “CRISPR-Cas9” method can turn into a breakthrough technology in the gene modification of microorganisms. This motivates to form a new research field, which investigates “the role of microorganisms on technical surface and interfaces” and thereby supports the development of novel and innovative applications, such as catalytic biofilms, microbial fuel cells, or self-healing concrete. The fundamental study of the interaction of microorganism populations (not only in the form of biofilms) with technical surfaces and interfaces (or more generally: substrates) as well as the necessity to find suitable designs for their combination implies many very interesting, yet still unanswered scientific questions. Microorganisms can have both a positive (e.g. decomposition of pollutants) as well as highly harmful effect (e.g. environmental damages, health hazards). Therefore, the investigation of interactions between surfaces, interfaces, materials, and microorganisms as well as the processes involved, their optimization and the possibilities of their control are of particular interest. It is expected that this topic, which synergistically combines biotechnology with material sciences, will increasingly attract more interest within the next years. A major advantage for the Materials Chain is that a corresponding scientific institution, the "Biofilm Centre" at the University of Duisburg-Essen, is already active in this field. Funding opportunities may be found, for instance, in the work program “FET - FETPROACT-01-2018” with the key topics "artificial organs, tissues, cells and sub-cellular structures" and “living technologies".

Besides the analysis, the trend study also reveals some aspects that need to be improved and provides some suggestions, how to put this into practice. The amount of joined Materials Chain publications between the different institutions of the Materials Chain averaged to only about 4.5 % for the six priority topics. This shows that the scientific collaboration of the Materials Chain members needs to be intensified and promoted. Another important criterion is the definition of a uniform affiliation for the publications such as “UA Ruhr, Materials Chain”, in order to assign the publications more clearly to the flag ship program. Publications of the Materials Chain or the three UA Ruhr universities often do not reach the necessary high impact. Consequently, journals with higher impact factors should be favoured for future publications. International partners are of high value in science. Studies have shown that the impact of international collaborative publications is many times higher when compared to publications with only national partners. More international partners, who are big players in the corresponding topic, should therefore be involved in the research work and publications of the Materials Chain.