SFB 920

Multifunktionale Filter für die Metallschmelzefiltration – ein Beitrag zu Zero Defect Materials

NEWSLETTER

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DFG Deutsche Forschungsgemeinschaft

TECHNISCHE UNIVERSITÄT BERGAKADEMIE FREIBERG
Die Ressourcenuniversität. Seit 1765.

DEAR READERS,

The Collaborative Research Center CRC 920 “Multi-Functional Filters for Metal Melt Filtration - A Contribution towards Zero Defect Materials” is entering the third program period. Ultimately, the CRC 920 reaches out for a model-based investigation and development of functionalized filter materials with various filter chemistry and filter surface properties, employing innovative processes and methods for saving energy resources and protecting the environment.

As before, research activities of the CRC 920 will span disciplines and national borders. In this vein, a recently founded international research lab, jointly organized with Wuhan University of Science and Technology WUST, will be of great importance.

The new issue of our newsletter keeps you informed about recent publications, patents, research results and further information about the CRC 920. Further information is provided at http://tu-freiberg.de/forschung/sfb920.

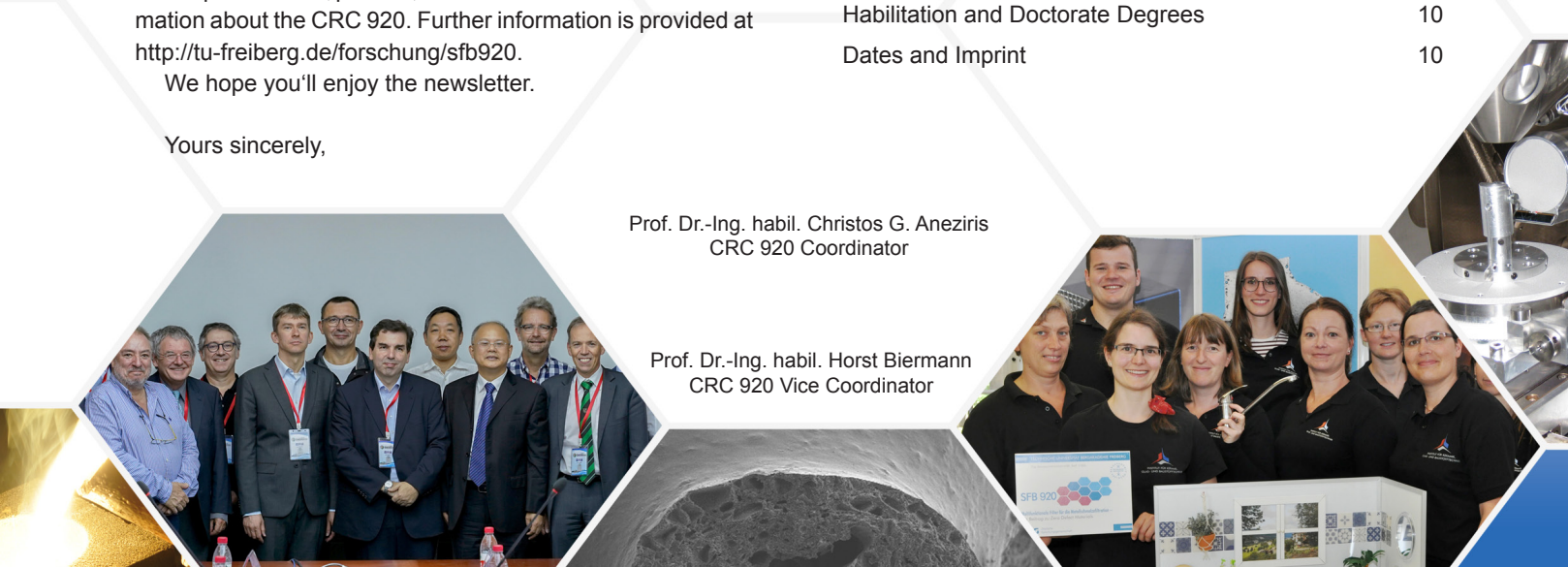
We hope you‘ll enjoy the newsletter.

Yours sincerely,

Prof. Dr.-Ing. habil. Christos G. Aneziris
CRC 920 Coordinator

Prof. Dr.-Ing. habil. Horst Biermann
CRC 920 Vice Coordinator

CONTENT



ENTERING THE THIRD PROGRAMM PERIOD: SAVING RESOURCES THROUGH INNOVATIVE METHODS AND PROCESSES

The Collaborative Research Center CRC 920 "Multi-Functional Filters for Metal Melt Filtration - A Contribution towards Zero Defect Materials" aims at the model-based investigation and development of functionalized filter materials with various filter chemistry and filter surface properties. In particular, researchers focus on the design of novel combined cleaning filter systems. In addition to a sophisticated research infrastructure, collaborations with partners across disciplines and nations turn out as drivers of the CRC's successful work.

The CRC 920 is following its vision of novel filter materials as well as a model-based filter design of the macro and micro structure, inspired by filtration technology. Among others, the third program period is dedicated to a combined **process of inclusion flotation** in such a way, that within seconds Al_2O_3 inclusions can be nearly completely removed from steel melt. **Novel, eco-friendly binders** for carbon-bonded filter bodies and a **generative hybrid flame spraying process** advance the idea of a model-based filter development. Employing robot-assisted flame spraying technology, 3D-printed, water-soluble water-sugar-plastic kernels will be transformed into active filter components.

Moreover, research focuses on the removal of fine inclusions ranging between 50 and 500 nm with different chemical compositions and crystal systems. To this end, meta-stable phases, nanofunctionalized carbon-containing filter surfaces, carbon-containing nano tubes or graphene oxid will be utilized. For instance, with regard to metal recycling, researchers strive to be the first who find a way to reduce up to 60 % of deleterious iron from aluminum scrap.

Delivering on these promises requires sophisticated research methods and instruments. The equipment the CRC will be employing includes a **high-temperature atomic force microscope**, a **high-temperature confocal laser scanning microscope**, a **specific sessile drop heating microscope, 3D micro-tomography**, and an **atmospherically controlled steel casting simulator**. Additionally, simulation and modeling are of utmost importance for a deeper understanding of active and reactive effects of novel filter structures. Likewise, quantum-mechanical calculations, flow simulations during metal melt filtration, phase-field modeling of in situ layer generation, thermodynamic modeling of materials and interfaces as well as continuum-mechanical and damage-mechanical modeling provide essential contributions to the CRC's research aims during the third program period.

From the very beginning, research activities of the CRC 920 have embraced **contributions from various academic disciplines as well as from partners and institutions around the world**, in order to benefit from an intensive dialogue and exchange of ideas, approaches, and solutions. In this vein, a recently founded **International Research Lab, launched jointly by TU Bergakademie Freiberg and Wuhan University of Science and Technology (WUST)**, will be of great importance to materials research in general and research activities of the CRC 920 in particular. In October, **the president of WUST, Prof. Hongwei NI, inaugurated the International Research Lab**, in the presence of scientists from several countries and institutions.

Activities of the International Research Lab center on a **joint research and development of high-temperature materials.** The International Research Lab aims at enabling an open, impartial scientific exchange between universities and industry, in order to jointly respond to challenges of developing novel high-temperature materials.

Photo: The President of the Wuhan University of Science and Technology (WUST), Prof. Hongwei NI (9th from right), the Director of The State Key Laboratory of Refractories and Metallurgy, Prof. Yawei LI (4th from left), Prof. Christos G. Aneziris (10th from left) as well as other European and Chinese partners of the joint International Research Lab (Photo: WUST, China).

Several highly reputed scientists from Europe, China and the US as well as the CRC's coordinator, Prof. Christos G. Aneziris joined the International Research Lab. In a keynote presentation at **Wuhan Annual Symposium on Refractories at Wuhan University** on October 11th, Prof. Christos G. Aneziris gave a speech on his research. Furthermore, young scientists involved in the Institute of Ceramics, Glass and Construction Materials as well as in the CRC 920 (namely, Dr. Patrick Gehre, Dr. Enrico Storti, Dr. Claudia Voigt, Tony Wetzig, and Lisa Freitag) presented their research projects and results on the generation and functionalization of filters and refractory materials.

Photo (from left to right): Dr. Claudia Voigt, Tony Wetzig, Dr. Junfeng Chen, Lisa Freitag, Dr. Enrico Storti (Photo: WUST, China).

For 15 years, TU Bergakademie and Wuhan University of Science and Technology (WUST) have been research partners in the field of high-temperature materials. From now on, this new network of scientists from all over the world promises new research endeavors at the highest level. ■

MORE NEWS

Scholars of the Collaborative Research Center CRC 920 attended several international academic conferences in order to give insights into their research projects and recent research results. In September, both Collaborative Research Centers at TU Bergakademie Freiberg – CRC 920 and CRC 799 "TRIP Matrix Composite" – shared a booth at **DGM MaterialsWeek in Dresden**. Attendees took the opportunity to illustrate approaches and applications of their developments to stakeholders from several industries. In four presentations, researchers introduced to the audience aims, perspectives and recent research results the CRC 920 has gained so far.

Moreover, members of CRC 920 were invited for presentations at the **62nd International Colloquium on Refractories in Aachen** and at the **16th UNITECR in Yokohama/Japan**. Both conferences enhance intensive dialogue and exchange between research and industry and, hence, are among the most important platforms for research and knowledge transfer on refractory materials. ■

CONFERENCES AND PRESENTATIONS

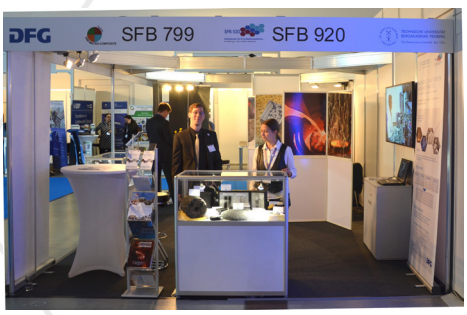


Photo: Joint appearance of both Collaborative Researrch Centers - CRC 920 and CRC 799 - at DGM MaterialsWeek in Dresden.

For the third program period, **Dipl.-Ing. Benjamin Bock** (Institute of Ceramic, Glass and Construction Materials) and **M. Sc. Lisa Ditscherlein** (Institute of Mechanical Process Engineering and Mineral Processing) have been elected as **representative** and **deputy representative** of the CRC's doctoral students.

In November 2017, Dipl.-Ing. Benjamin Bock joined subproject A01. In his research, he deals with the development of novel filter materials and filter systems for metal melt filtration. In his doctoral dissertation, Benjamin Bock explores unconventional technologies for generating filter structures for steel melt filtration.

M. Sc. Lisa Ditscherlein joined the CRC team in July 2015. Since then, she has been contributing to subproject B01. In her research, she focuses on particle-particle or particle-substrate interactions. She employs a high-temperature atomic force microscope, in order to determine realistic indicators for procedural applications.

As doctoral students' representative, Benjamin Bock will be joining the general assembly as well as the CRC board as a consulting member. Thus, he will be playing an active role in the general management of activities and the further development of the CRC. ■

DOCTORAL STUDENTS' REPRESENTATIVES

Photo (from left to right): Benjamin Bock and Lisa Ditscherlein have been elected as the new representatives of the CRC's doctoral students.

Shortly before summer holidays, students from the **Freiberg Primary School "Carl Böhme"** visited the Ceramic Departments at the Institute of Ceramic, Glass and Construction Materials at TU Bergakademie Freiberg. Members of the CRC staff introduced their audience to the **variety and to production technologies of ceramic products and components**. The young researchers were invited to learn more about casting molding and procedures to test for instance the strength of ceramic components.

On invitation from the Dresden Secondary School "Heinrich Pestalozzi", CRC research assistants gave insights into the fascinating world of materials and opportunities for exciting and diversified studies of materials science and technology. Furthermore, they gave reports about their professional careers and their research within the CRC 920. ■

JUNIOR RESEARCHERS

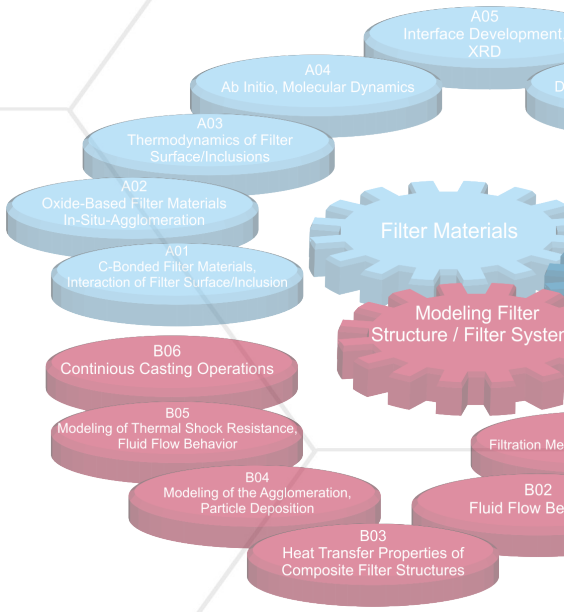
Photo: A team of CRC researchers introduced high-school students to the fascinating world of ceramic materials and components.

WORKING GROUPS' REPORT

Research teams in the CRC 920 are connected in four working groups, thus ensuring targeted activities, close collaborations between subprojects, and intensive exchanges between all researchers involved. Young scientists are taking responsibility for coordinating these working groups - a measure the CRC has taken to support young scientists already in early career stages to promote their capabilities to work independently as well as in teams and to strengthen their management skills.

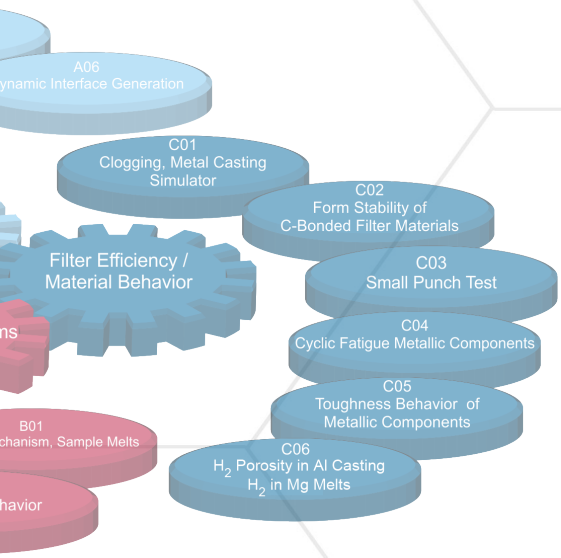
Working Group 1: "Metal melt/inclusions, active/reactive filter material, boundary surface design" (Coordination: Dr.-Ing. Claudia Voigt)

- Design of filters and ingot casting components (sprue, pipe bricks) for industrial steel casting experiments at Deutsche Edelstahlwerke (T04),
- Filtration trials with carbon bonded alumina filters and the aluminum alloy AlSi7Mg under industrial conditions (A02),
- Determination of mechanical properties and residual carbon content of Al_2O_3-C filters using environmentally friendly binders (A01),
- Investigation of reactive interactions of Al_2O_3-C filter materials with secondary alloys based on aluminum-silicon in sessile drop experiments and small scale crucible experiments (A07 in cooperation with A02 and C06),
- Reconstruction of the Kikuchi-Sphere for an enhanced identification of the pseudo-symmetric phases and for the microstructural interpretation of pattern super positions measured by electron back scattering diffraction (EBSD) (A05 in cooperation with A07),
- Phase relation investigation in the ternary Al_2O_3-TiO_2-SiO_2 system with an emphasis on the solid-state reaction; thermodynamic assessment of the binary TiO_2-SiO_2 system (A03),
- Theoretical investigation of selected tannins, e.g. gallic acid, using standard density functional theory (DFT) and FLO-SIC, including the simulation of solvation effects (A04),
- Synthesis of MgAlON to be used as a coating material for ceramic foam filters for metal melt filtration; investigation of the kinetics of the reaction using varying staring compositions containing Al_2O_3, AlN and MgO as well as thermodynamic calculations (C06 in cooperation with A05),
- Investigations of the interaction of potentially reactive filter materials with model alloys based on aluminum-silicon with the aim of removing borides from aluminum melts (C06 in cooperation with S03),
- Development of a new stable slurry based on CA2 with carbon to be used for the coating of carbon-bonded alumina filters (A01),
- Investigation of topography, adhesion force and filtration efficiency of new 3D printed filters (B01),
- Development of a MatLAB based routine to calculate van der Waals forces on rough surfaces by using AFM scans of real particle/filter surfaces (B01),
- Modification of the steel casting simulator for combined cleaning system trials consisting of metal melt treatment in the melting crucible, casting through filters with modified surfaces and solidification of the melt in the tundish (C01),
- Preparation of of substrates with different chemical composition and wetting tests for the investigation of the copper extraction of steel (C01).



Working Group 2: "Modelling and designing of the filter geometry" (Coordination: Dipl.-Ing. Eric Werzner)

- CT-based analysis of the separation of particles and agglomerates in 3D-printed structures and foam filters, including investigation of the spatial distribution along the strut perimeter (B01, A01, B02, B05, S02),
- Determination of hydrogen diffusion in aluminum melt by means of high temperature sorption measurements as well as optimization and error analysis of the experimental determination of the radiation properties with the external integrating sphere (B03),
- Conceptual design of a 2D/3D temperature measurement in molten steel during the flow through the filters, taking into account the reusability of the thermocouples (B03, S03),
- Identification and comparison of inter-atomic potentials of different origins for atomistic simulations of sintering of alumina and calculation of Hamaker functions between two half spaces with up to two coatings per side (B04),
- Development of a hybrid material model to describe the inelastic deformation of foams using neural networks, which are trained with numerical simulations, and successful application for two-dimensional structures (B05),
- Development of a continuum-mechanical theory extended by chemo-mechanical coupling, which accounts for diffusion processes and chemical reactions within a multi-phase multi-component system, aiming to model the in-situ layer formation observed in steel melt filtration with carbon-bonded alumina filters (B05),
- Construction of an experiment for the investigation of the bubble/inclusion interaction in the metal melt (B06, B04, B01),
- Numerical analysis of influencing factors of the reactive cleaning approach on the cleanness of the metal melt (B06).



Working Group 4: "Mechanical properties, metallic materials, critical inclusions" (Coordination: Dr.-Ing. Sebastian Henschel)

- Electrolytic extraction and TEM investigations on thin lamellae produced by focused ion beam of non-metallic inclusions contained in 42CrMo4 out of three batches: Carbon-bonded alumina filters without coating, with a coating containing nano particles (carbon nano tubes and alumina nano sheets) and with a flame-sprayed alumina coating; comparison of the generated results with these from automated scanning electron microscopy (ASPEX) (C04),
- Analysis of non-metallic inclusions that result in damage under tensile load, i.e. void nucleation/growth/coalescence and cleavage fracture. In contrast to fatigue loading, plate-like alumina inclusions did not show a damaging effect during tensile loading (C05),
- Investigations on the effect of temperature/time profile during oxidation and deoxidation of 42CrMo4 on the formation of plate-like Al_2O_3 inclusions by means of ultrasonic fatigue testing technique, monotonic tensile testing, fractography, automated scanning electron microscopy (ASPEX) and electrolytic extraction; comparison with batches filtered with coated and uncoated filter systems (C01, C04, C05),
- Analysis of microstructure and fatigue life of AlSi9Cu3 after melt conditioning and hot-isostatic pressing by means of scanning electron microscopy, micro-computer tomography and ultrasonic fatigue testing technique (S03, C04),
- Determination of the relationship between the radius of the plastic zone and the characteristic features of fatigue fracture surfaces with the characteristic areas FGA ("fine-grained area"), smooth area and fisheye by use of scanning electron microscopy and investigations on lamellae produced by focused ion beam (C04),
- Design and test of a set-up for fracture mechanics loading. With this device, a superposition of mode I (symmetrical crack opening) and mode II (in-plane shear) is possible. The crack tip loading is analyzed by means of strain gauges and digital image correlation. Acoustic emissions were measured in order to characterize damage processes before final fracture (C05),
- Study on the effect of the spatial distribution of non-metallic inclusions on those non-metallic inclusions, which are found at metallographic sections and on fracture surfaces (C05).

Working Group 3: "Thermomechanical properties of the filter material and structures" (Coordination: Dipl.-Ing. Alexander Malik)

- Further development of carbon-bonded alumina materials with environment-friendly binders as well as mechanical tests at high temperatures up to 1,500 °C (C02),
- Constructive development of the load device of the High Temperature-B3B test setup to 1,500 °C (C03),
- Design and adjustment of the testing rig for the Brazilian Disc (BD) test with the help of a parametrized numerical model. The stress state and stress triaxiality will be evaluated to determine the ideal specimen geometry. (C03),
- Coordination of the specimen production for the BD test between subprojects A01, A02 in cooperation with C03,
- Development of an effective material law for foam structures to design ceramic filters. Required data for the filter material are provided by the subprojects A01, A02 and C01 (B05),
- Strength evaluation of the immersed filter in comparison to the experimental data from subproject T04 (B05),
- Mechanical, numerical and physical characterization of Al_2O_3-C foam filters produced by distinct routes (A01, T01, B05, S01).

IMPACT OF MICROSTRUCTURAL DEFECTS ON HIGH-TEMPERATURE PHASE TRANSITIONS IN γ-AL_2O_3

Author: Martin Rudolph
(Subproject A05)

Subproject A05 investigates the interface and phase formation in active and reactive ceramic filters during the melt filtration process. Particular issues are the studies of thermal stability and transformation mechanisms of metastable phases, which are constituents of the functional coatings or form during the filtration process.

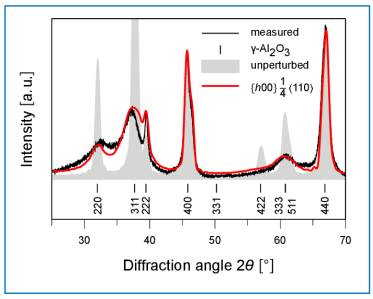


Fig. 1: Comparison of measured and calculated XRD patterns of γ-Al_2O_3.

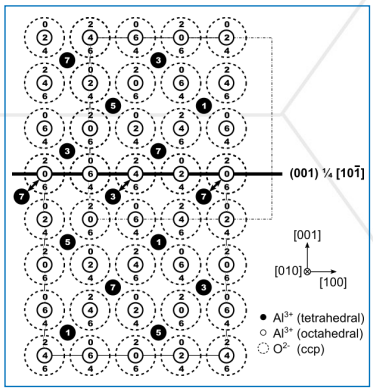


Fig. 2: Schematic representation of the APBs (001) ¼ [101] in γ-Al_2O_3. The y-values are given in multiples of 1/8 *a*, where *a* is the size of the depicted cubic unit cell (square) of γ-Al_2O_3. The bidirectional arrows mark unfavorable coordinated cations.

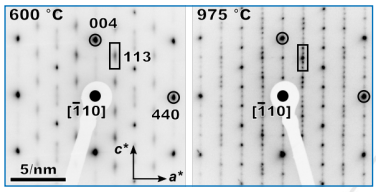


Fig. 3: SAED patterns of γ-Al_2O_3 heat-treated in air for 20 h.

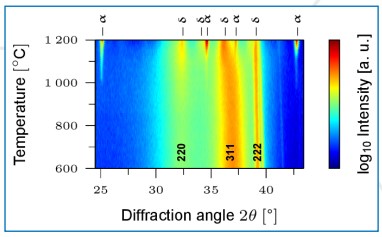


Fig. 4: HTXRD pattern of γ-Al_2O_3 that was originally heat-treated in air for 20 h at 600 °C.

One of the most important metastable phases is γ-Al_2O_3, which is not only a constituent of active filter coatings [1] but also forms at the interface between the metallic melt and the functionalized filter [2, 3] and can be found as endogenous inclusions in the metallic melt [4]. At elevated temperatures, γ-Al_2O_3 transforms into the thermodynamically stable α-Al_2O_3 (corundum) by a sequence of metastable phases [5]:

$$\gamma\text{-}Al_2O_3 \rightarrow \delta\text{-}Al_2O_3 \rightarrow \theta\text{-}Al_2O_3 \rightarrow \alpha\text{-}Al_2O_3$$

A delay of this transition in coatings and reaction layers favors a homo epitaxial growth of the endogenous inclusions at the filter surface. However, the targeted stabilization of γ-Al_2O_3 to higher temperatures requires an understanding and a detailed description of the structural changes accompanying the transition process.

All investigated metastable Al_2O_3 phases were synthesized from a hydroxide precursor (boehmite). The subsequent crystal structure and microstructure analyses were carried out ex-situ with the aid of X-ray and selected area electron diffraction (XRD and SAED). The phase transition process was tracked in-situ by means of high-temperature X-ray diffraction (HTXRD).

The comparison of measured and calculated XRD (Fig. 1) and SAED patterns revealed that γ-Al_2O_3 possesses a defective spinel structure [6]. The predominant microstructural defects are antiphase boundaries (APBs) of the type {*h*00} ¼ ‹110›. Near these APBs, energetically unfavorably coordinated aluminum cations (Fig. 2) occupying octahedral positions are replaced by vacancies. These vacancies preserve also the Al_2O_3 stoichiometry within the defective spinel structure. In other words, the APBs (and the presence of the cation vacancies) are a prerequisite for the existence of the γ-Al_2O_3 phase.

Furthermore, the APBs induce atomic displacements in the crystal lattice, which conserve the positions of approximately cubic close packed oxygen ions, but seriously distort the aluminum sublattice. Thus, the reflections like 222, 004, 440, which are dominated by the scattering on the well-ordered oxygen sublattice, remain narrow, whereas the reflections, which stem from the aluminum sublattice, exhibit a strong anisotropic (hkl-dependent) broadening (Fig. 3, left).

With increasing temperature and cation mobility, the formation of sharp superstructure reflections [7] is observed that is accompanied by a decay of the diffuse scattering (Fig. 3, right) as expected for an increasingly periodic rearrangement of the APBs and for a formation of a superstructure. The in situ HTXRD measurements (Fig. 4) revealed that these structural changes are continuous.

At temperatures above 1,000 °C, the formation of α-Al_2O_3 starts. It is assumed that the formation of this phase, which involves the rearrangement of oxygen sublattice, is restricted to local regions, where the periodic order of APBs is already pronounced.

Thus, the thermal stabilization of metastable γ-Al_2O_3 can only be accomplished by hindering the periodic rearrangement of APBs, e.g., through the incorporation of alternative point defects via doping. ■

[1] Gehre, P., Schmidt, A., Dudczig, S., Hubálková, J., Aneziris, C. G., Child, N., Delaney, I., Rancoule, G., DeBastiani, D.: Interaction of slip- and flame-spray coated carbon-bonded alumina filters with steel melts, Journal of the American Ceramic Society, 101 [7] (2018), 3222-3233.
[2] Dudczig, S., Aneziris, C. G., Emmel, M., Schmidt, G., Hubálková, J., Berek, H.: Characterization of carbon-bonded alumina filters with active or reactive coatings in a steel casting simulator, Ceramics International, 40 (2014), 16727-16742.
[3] Salomon, A., Zienert, T., Voigt, C., Dopita, M., Fabrichnaya, O., Aneziris, C. G., Rafaja, D.: Formation of different alumina phases and magnesium aluminate spinel during contact of molten AlSi7Mg0.6 alloy with mullite and amorphous silica, Corrosion Science, 114 (2017), 79-87.
[4] Wasai, K., Mukai, K., Miyanaga, A.: Observation of Inclusion in Aluminum Deoxidized Iron, ISIJ International, 42 (2002), 459-473.
[5] Euzen, P., Raybaud, P., Krokidis, X., Toulhoat, H., Le Loarer, J.-L., Jolivet, J.-P., Froidefond, C.: Handbook of Porous Solids, 3 (2002), 1591-1677.
[6] Rudolph, M., Motylenko, M., Rafaja, D.: Structure model of γ-Al_2O_3 based on planar defects, Journal of Applied Crystallography IUCrJ, 6 (2019), 116-127.
[7] Rudolph, M., Salomon, A., Schmidt, A., Motylenko, M., Zienert, T., Stöcker, H., Himcinschi, C., Amirkhanyan, L., Kortus, J., Aneziris, C. G., Rafaja, D.: Thermally Induced Formation of Transition Aluminas from Boehmite, Advanced Engineering Materials, 19 [9] (2017), 1700141.

CARBON-BONDED ALUMINA FILTERS FOR CONTINOUS STEEL CASTING

Subproject T01 investigates reactive filter systems developed within the CRC 920 for steel melt filtration regarding their industrial-scale applicability. Up-scaling of special cylindrical geometries and the comprehensive lab-scale evaluation enabled the successful application of reactive carbon-bonded alumina filters in the tundish of an industrial continuous casting plant.

Author: Tony Wetzig
(Subproject T01)

Sheet steel for packaging and deep-drawing applications have high purity requirements regarding the content of non-metallic inclusions. With the motivation for weight reduction, energy and material savings, the steelmaking process has been steadily improved in order to reliably produce even extremely thin-walled steel products. Inevitably, the limits for the tolerable inclusion size get further reduced. However, the established methods in secondary metallurgy, slag technology, flow control and tundish design are limited regarding the removal of micro inclusions. This is partly due to the low buoyancy of the smallest inclusions. Steel melt filtration offers a promising alternative in this situation. While filtration is common in foundry technology, the technique has not yet become standard in the continuous casting of steel. Long casting times, corrosion and high processing volumes drastically reduce the maximum service life of integrated foam filter systems. To address this challenge, a new filtration approach was tested. Thereby, the filter is submerged into the tundish from above by piercing the slag layer during the ladle change. This process allows for the exchange of the filter systems without interrupting the underlying casting process. As a prototype geometry, cylinders with a diameter and a height of 200 mm were selected. In addition to the centric hole for attachment, optional eight additional channels for flow control and simplified manufacturing were implemented.

The development of the filters showed that a high-solids initial coating based on impregnation-centrifuging technology provides good base strength and high open porosity. Compared to empirical values from previous laboratory tests, however, the initial coating does not meet the mechanical requirements. Secondary dip coatings to increase the strength and final spray coating to improve fracture behavior were used as a compromise with minimal porosity loss. A carbon-bonded alumina filter, which was manufactured accordingly and coked at 800 °C, was successfully impinged with molten 42CrMo4 steel in a steel casting simulator at 1,650 °C under laboratory conditions. The filter survived the test without corrosion, erosion or thermal shock damage [1].

In industrial tests, the filter was attached to an isostatically pressed carbon-bonded mounting shaft and immersed for 45 minutes at over 1,550 °C in molten ultra-low carbon steel. Filters with eight additional macro channels broke in the outer ring structure and require a geometry adjustment regarding reinforcement of the intermediate webs. Solid cylinder filters survived the test and essentially showed two filtration mechanisms. The entire filter was coated with Al_2O_3-rich dense layers with a thickness of several 100 µm. These structures were comparable to in-situ formed layers of lab-scale steel casting simulator tests as a result of carbothermal reactions (reactive filtration effect). Furthermore, macroscopic inclusion clusters formed by the direct deposition and agglomeration of floating inclusions (active filtration effect) were found at the bottom of the filter. By means of scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD) investigations, slag and filter material were clearly distinguished from attached inclusion clusters. After these first successful feasibility studies, the authors aim for optimization of the filter geometry and industrial-scale steel purity analyzes [2]. ■

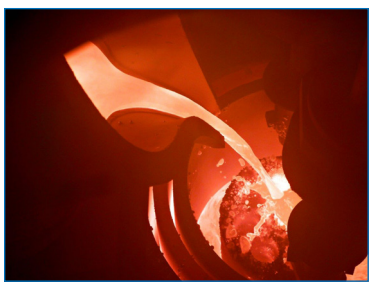


Fig. 1: Carbon-bonded alumina filter in lab-scale steel casting simulator test.

Fig. 2: Carbon-bonded alumina filter after application in industrial-scale continuous steel casting.

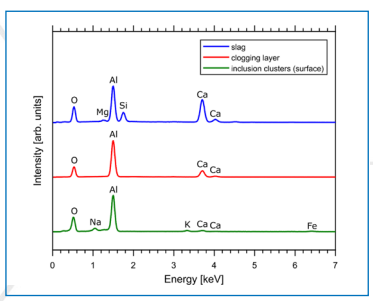


Fig. 3: EDS spectra of slag, clogging layers and inclusion clusters observed on a filter tested in an industrial continuous casting tundish.

[1] Wetzig, T., Luchini, B., Dudczig, S., Hubálková, J., Aneziris, C. G.: Development and testing of carbon-bonded alumina foam filters for continuous casting of steel, Ceramics International, 44 (2018), 18143–18155
[2] Wetzig, T., Baaske, A., Karrasch, S., Brachhold, N., Rudolph, M., Aneziris, C. G.: Application of exchangeable carbon-bonded alumina foam filters in an industrial tundish for the continuous casting of steel, Ceramics International, 44 (2018), 23024–23034.

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CURRENT PUBLICATIONS (JUNE - NOVEMBER 2019)

Further information about the 50+ publications that have been generated since the start of the third program period as well as about the currently 16 patents and patent applications are available at http://tu-freiberg.de/forschung/sfb920.

Projectarea A - Filter materials

Subproject A01

Aneziris, C. G., Gehre, P., Wetzig, T., Storti, E., Dudczig, S., Hubálková, J. (2019): Ceramics in Active and Reactive Metal Melt Filtration Approaches, Principles and Applications, Annual Symposium on Refractories, Wuhan, China, October 9-11, plenary lecture.

Bock, B., Schmidt. A., Dudczig, S., Schmidt, G., Sniezek, E., Aneziris, C. G., Szczerba, J. (2019): Spinel forming systems (Fe-/Mg-/Mn-Al-O) as functional filter coatings for improve steel melt filtration, Proceedings of the 62th International Colloquium on Refractories 2019 – Supplier Industries enabling REFRACTORIES, September 25-29, Aachen, pp. 107-110, ISBN 978-3-9815813-5-5.

Gehre, P. (2019): Cold and Flame sprayed Filter Coatings for Steel Filtration, Annual Symposium on Refractories, Wuhan, China, October 9-11, oral presentation.

Herdering, A., Hubálková, J., Abendroth, M., Gehre, P., Aneziris, C. G. (2019): Additive Manufactured Polymer Foams as Templates for Customized Ceramic Foams – Comparison of SLS and FFF Techniques, Interceram, Vol. 68, Iss. 4, pp. 30-37.

Luchini, B., Storti, E., Wetzig, T., Settgast, C., Abendroth, M., Hubálková, J., Pandolfelli, V. C., Aneziris, C. G. (2019): Mechanical and physical characterization of Al_2O_3-C foam filters produced by distinct processing routes: The role of the strut morphology, UNITECR 2019, 13.-16.10.2019, Yokohama, Japan, in: Proceedings UNITECR 2019, pp. 784-787, paper ID 16-C-11.

Schmidt, A., Fruhstorfer, J., Dudczig, S., Schmidt, G., Hubálková, J., Voigt, C., Aneziris, C. G. (2019): Interactions between carbon-bonded alumina filters and molten steel: Impact of a titania-doped filter coating, Advanced Engineering Materials, 1900647 (1-10), DOI 10.1002/adem.201900647.

Storti, E. (2019): High surface filter coatings based on nanoscaled additions or fiberlike structures, Annual Symposium on Refractories, Wuhan, China, October 9-11, oral presentation.

Storti, E., Himcinschi, C., Kortus, J., Aneziris, C. G. (2019): Synthesis and characterization of calcium zirconate nanofibers produced by electrospinning, Journal of the European Ceramic Society, Vol. 39, Iss. 16, pp. 5338-5344, DOI 10.1016/j.jeurceramsoc.2019.08.007.

Storti, E., Jankovsky, O., Sedmidubsky, D., Dudczig, S., Aneziris, C. G. (2019): Filter coatings based on combination of nanomaterials for steel melt filtration, Advanced Engineering Materials, 1900457 (1-8), DOI 10.1016/adem.201900457.

Storti, E., Aneziris, C. G. (2019): Nano-functionalized ceramic foam filters: effect of carbon-based nanomaterials on wettability, XVI Conference of the European Ceramic Society, ECerS 2019, June 16-20, Torino, Italy, oral presentation ID 157.

Subproject A02

Voigt, C. (2019): Filters system approaches for aluminum metallurgy, Annual Symposium on Refractories, Wuhan, China, October 9-11, oral presentation.

Voigt, C., Hubálková, J., Giesche, H., Aneziris, C. G. (2019): Characterization of carbon bonded alumina by mercury intrusion and extrusion porosimetry for steel applications, UNITECR 2019, October 13-16, Yokohama, Japan, in: Proceedings UNITECR 2019, pp. 593-596, paper ID 15-E-14.

Subproject A03

Fabrichnaya, O., Ilatovskaia, M. (2019): Ceramic filters: thermodynamic modelling of Al_2O_3 based systems, 48th CALPHAD Conference, 02.-07.06.2019, Singapore, poster ID P87.

Ilatovskaia, M., Fabrichnaya, O. (2019): Heat capacity of Al_2MnO_4 and thermodynamic assessment of the Al_2O_3-MnO system, 48th CALPHAD Conference, July 2-7, Singapore, oral presentation ID O41.

Ilatovskaia, M., Bärthel, F., Fabrichnaya, O. (2019): Phase relations in the Al_2O_3-TiO_2-SiO_2 system, CEEC-TAC5 & Medicta 2019, August 27-30, Roma, Italy, oral prsentation ID OP3.09.

Ilatovskaia, M., Bärthel, F., Fabrichnaya, O. (2019): The Al_2O_3-TiO_2-SiO_2 system: experiments and thermodynamic calculations, EUROMAT 2019, September 1-6, Stockholm, Sweden, oral presentation ID 15690.

Subproject A05

Rudolph, M., Salomon, A., Rafaja, D. (2019): In situ study of high-temperature induced reactions between molten aluminum alloys and ceramic filters, DGM WerkstoffWoche 2019, September 18-20, Dresden, oral presentation ID 94, 18.09.

Subproject A07

Becker, H. (2019): Robust indexing of phase with related layered crystal structures, AK-Treffen Mikrostrukturcharakterisierung im REM, Fh IMWS Halle, May 27, oral presentation.

Becker, H., Fankhänel, B., Stelter, M., Leineweber, A. (2019): Interaction of Fe-containing, secondary Al-Si alloy with oxide and carbon-containing ceramics for Fe removal, EUROMAT 2019, September 1-6, Stockholm, Sweden, oral presentation ID 14154.

Becker, H., Irmer, D., Leineweber, A. (2019): Formation a α_c intermetallic particles in Fe- and Mn-containing Al-Si casting alloys during solidification with different cooling rates. Proceedings Intermetallics 2019; Eds. M. Heilmaier, M. Krüger, S. Mayer, M. Palm, F. Stein; Conventus Congressmanagement & Marketing GmbH, Jena, Germany, ISBN 978-3-948023-07-2, pp. 132-133.

Project area B - Modeling of filter structures/ filter systems

Subproject B01

Ditscherlein, L., Knüpfer, P., Peuker, U. A. (2019): The influence of nanobubbles on the interaction forces between alumina particles and ceramic foam filters, Powder Technology, DOI 10.1016/j.powtec.2019.08.077.

Hoppach, D., Werzner, E., Demuth, C., Löwer, E., Lehmann, H., Ditscherlein, L., Ditscherlein, R., Peuker, U.A., Ray, S. (2019): Experimental Investigations of the Depth Filtration Inside Open-cell Foam Filters Supported by High-Resolution CT Scanning and Pore-Scale Numerical Simulations, Advanced Engineering Materials, 1900761 (1-13), DOI 10.1002/adem.201900761.

Subproject B04

Roy, S., Prakash, A., Sandfeld, S. (2019): A comparsion of interatomic potentials for atomistic simulations of sintering of alumina, 29th International Workshop on Computational Mechanics of Materials (IWCMM29), September 15-18, Dubrovnik/Croatia, oral presentation.

Subproject B05

Settgast, C., Hütter, G., Abendroth, M., Kuna. M. (2019): A Hybrid Approach to Describe the Elastic-Plastic Deformation Behaviour of Porous Media Including Damage Effects, 6th International Conference on Material Modelling (ICMM6), June 26-28, Lund/Sweden, oral presentation.

Subproject B06

Asad, A., Schwarze, R., Aneziris, C. G. (2019): Numerical Investigation of the Filtration Influenced by Micro-Scale CO-Bubbles in Steel Melt, Advanced Engineering Materials, 1900591 (1-7), DOI 10.1002/adem.201900591.

Project area C - Filter performance, materials properties

Subproject C01

Wei, X., Chebykin, D., Volkova, O. (2019): Investigted surface tension of liquid pure iron, nickel and copper with sessile drop technology, Asian Thermophysical Properties Conference - ATPC 2019, June 2-6, Xi'an, China, poster P34.

Subproject C02

Ranglack-Klemm, Y., Storti, E., Biermann, H., Aneziris, C. G. (2019): Influence of carbon nanotubes-based coatings on the high temperature compression strength of Al_2O_3-C foam filter structures, Advanced Engineering Materials, 1900423 (1-7), DOI 10.1002/adem.201900423.

Subproject C04

Seleznev, M., Biermann, H., Weidner, A. (2019): Quantitative characterization of fracture zones in 42CrMo4 steel with plate-like alumina inclusions after very high cycle fatigue, EUOROMAT 2019, 01.-05.09.2019, Stockholm/Sweden, oral presentation ID 18915.

Seleznev, M., Henschel, S., Storti, E., Aneziris, C. G., Krüger, L., Weidner, A., Biermann, H. (2019): Effect of filter functional coating on detrimental non-metallic inclusions in 42CrMo4 steel and its resulting mechanical properties, Advanced Engineering Materials, 1900540 (1-11), DOI 10.1002/adem.201900540.

Subproject C06

Schramm, A., Bock, B., Schmidt, A., Zienert, T., Ditze, A., Scharf, C., Aneziris, C. G. (2019): Grenzflächenreaktionen beschichteter, kohlenstoffgebundener Alumina-Filter mit einer AZ91-Magnesiumschmelze, DGM WerkstoffWoche 2019, Dresden, September 18-20, oral presentation ID 152, 19.02.

Schramm, A., Bock, B., Schmidt, A., Zienert, T., Ditze, A., Scharf, C, Aneziris, C. G. (2019): Investigation of interface reactions of differently coated carbon-bonded alumina filters with an AZ91 magnesium alloy melt, Proceedings of the 62th International Colloquium on Refractories 2019 – Supplier Industries enabling REFRACTORIES, 25.-26.09.2019, Aachen, pp. 111-112, ISBN 978-3-9815813-5-5.

Schramm, A., Voigt, C., Hubálková, J., Aneziris, C. G., Scharf, C. (2019): Influence of the manufacturing technique on the macro- and microstructure of reticulated carbon-bonded alumina foams, Advanced Engineering Materials, 1900457 (1-11), DOI 10.1002/adem.201900457.

Transfer projects

Transfer project T01

Neumann, S., Asad, A., Kasper, T., Schwarze, R. (2019): Numerical simulation of metal melt flow in a one-strand tundish regarding active filtration and reactive cleaning, Metallurgical and Materials Transactions B, Vol. 50, Iss. 5, pp. 2334-2342, DOI 10.1007/s11663-019-01637-6.

Neumann, S., Asad, A., Schwarze, R. (2019): Numerical Investigation of the Filtration Influenced by Micro-Scale CO-Bubbles in Steel Melt, Advanced Engineering Materials, 2019, 1900658 (1-11), DOI 10.1002/adem.201900658.

Wetzig, T., Luchini, B., Dudczig, S., Hubálková, J., Aneziris, C. G., Baaske, A., Karrasch, S. (2019): Exchangeable Carbon-bonded Alumina Foam Filters for Continuous Casting of Steel, UNITECR 2019, 13.-16.10.2019, Yokohama, Japan, in: Proceedings UNITECR 2019, pp. 788-791, paper ID 16-C-12.

Wetzig, T., Schmidt, A., Dudczig, S., Schmidt, G., Brachhold, N., Aneziris, C. G. (2019): Carbon-bonded alumina spaghetti filters by alginate-based robo gel casting, Advanced Engineering Materials, 1900657 (1-11), DOI 10.1002/adem.201900657.

Transfer project T04

Fruhstorfer, J., Hubálková, J., Leißner, T., Peuker, U., Aneziris, C. G. (2019): Corrosion of carbon free and bonded refractories for application in steel ingot casting: An approach for improving steel quality, Materials Science Forum, Vol. 959, pp. 166-176, DOI 10.4028/www.scientific.net/MSF.959.166.

Wetzig, T. (2019): Spaghetti filters for metal melt filtration, Annual Symposium on Refractories, Wuhan, China, October 9-11, oral presentation.

Complementary projects

Aneziris, C. G., Fischer, U. (2019): Aktiver und reaktiver Filterkosmos: Erforschung von ressourcen- und energieeffizienten Technologien im Bereich der Metallurgie auf Basis von multifunktionalen Filtersystemen für die Metallschmelzefiltration, in: Schriften zum Zentrum für effiziente Hochtemperatur-Stoffwandlung (ZeHS) an der Technischen Universität Bergakademie Freiberg, Hrsg.: Meyer, D. C., Lemser, T., Zentrum für effiziente Hochtemperatur-Stoffwandlung an der Technischen Universität Freiberg, Heft 2, pp. 56-79, ISSN 2513-1192.

Fischer, U., Aneziris, C. G. (2019): Multifunktionale Filtersysteme - Beiträge zur Schonung von Ressourcen, DGM WerkstoffWoche 2019, September 18-20, Dresden, oral presentation ID 137, 19.01.

Patents and patent applications

Subproject A01

Ceramic metal melt filter, patent no.: 10 2018 201 577.5, patent granted: 2019-10-29.

Subproject A02

Ceramic filters for alumina melt filtration and process of their manufacturing, patent no. PCT 10 2017 20196 964, patent granted: 2019-06-25.

Subproject B01

Ceramic metal melt filters and process for filtrating a metal melt, patent no. 10 2019 117 513.5, patent registration: 2019-06-28.

EXCELLENT!

For his master thesis on “Formation of Fe-containing α_c phase particles during solidification in secondary Al–Si casting alloys and their characterization“, Daniel Irmer, student at TU Bergakademie Freiberg, received the **“Best Presentation Award“**. The prize has been awarded at the **26th International Students‘ Day of Metallurgy ISDM** in Wels/Austria.

Photo: Daniel Irmer, TU Bergakademie Freiberg, (second from left.), other awardees and organizers of the 26th International Students‘ Day of Metallurgy in Wels/Austria.

Daniel Irmer‘s work has been embedded in research activities of the CRC 920. His work demonstrates how students are involved in basic research even in early stages of their development. **Dr.-Ing. Hanka Becker and Prof. Dr. Andreas Leineweber (subproject A07)** both served as supervisors for this thesis. ■

HABILITATION AND DOCTORATE DEGREES

In June 2019, **PD Dr.-Ing. habil. Anja Weidner**, who is responsible for two CRC subprojects (C04, T02), successfully completed her state doctorate (habilitation) at the Faculty of Materials Science and Materials Technology at TU Bergakademie Freiberg. The habilitation committee, chaired by Prof. Dr. David Rafaja, assigned to her both the habilitation degree as well as the "venia legendi" (teaching approval) for the subject of materials science and materials technology.

Her habilitation thesis on **"Strain localizations and time sequence of deformation processes in high-alloy CrMnNi TRIP/TWIP steels - Achievements of complementary in situ characterization techniques"** originates from her research in the Collaborative Research Center CRC 799 "TRIP Matrix Composite" .

Besides her work on high-alloy steels and steel-ceramic composites, in CRC 920 Dr.-Ing. habil. Anja Weidner investigates, among others, the impact of non-metallic inclusions on the fatigue life of steel and aluminium alloys. This research inspired her academic presentation on "Mechanical properties of ultrafine grained TRIP steels" as well as her public lecture on "Nanoindentation measurements for identifying local hardness parameters of individual metallographic constituents."

Photo: PD Dr.-Ing. habil. Anja Weidner.

Moreover, several doctoral students successfully finished their dissertation projects. **Dr.-Ing. Johannes Solarek** presented his outstanding work on "Mechanical behavior of carbon-bonded refractory materials up to 1,500 °C". In his dissertation, Johannes solarek introduces methods for tensile tests and fracture-mechanical tests and thus provides mechanical parameters for two sorts of refractory materials in a continuum ranging from room temperature up to 1,500 °C.

Dr.-Ing. Bruno Luchini received his doctoral degree for his excellent dissertation on "Processing and properties of bulk and cellular carbon-bonded refractory materials".

Dr.-Ing. Christoph Settgast focused in his research on fracture-mechanical processes and a macroscopic characterization of opencell ceramic foams. To this end, he included numerical simulations in order to assess the bulk materials behavior. His dissertation thesis is entitled "Numeric analyses of fracture strength and inelastic deformations of open-cell ceramic foams." ■

Photo (from left to right): Prof. H. Biermann, Prof. C. G. Aneziris, Prof. T. Bier, Dr.-Ing. B. Luchini, Prof. B. Kiefer, Dr.-Ing. S. Sinnema.

CONFERENCES AND CALLS FOR PAPERS

10. Freiberg Refractory Forum: 11.12.2019, Freiberg.

Keramik 2020: 95. DKG Annual Meeting 2020, March 15-18, 2020, Forschungszentrum Jülich, http://www.2020.dkg.de/.

CIMTEC 2020: 15th International Ceramics Congress, June 15-19, 2020, Montecatini Terme/Italy, http://2020.cimtec-congress.org/.

CellMAT2020: 6th Cellular Materials, October 7-9, 2020, Erlangen, https://cellmat2020.dgm.de.

IMPRESSUM

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PHOTOS
TU Bergakademie Freiberg, CRC 920 "Multi-Functional Filters for Metal Melt Filtration - A Contribution towards Zero Defect Materials"; Detlev Müller; Wuhan University of Science and Technology (WUST).

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SFB 920
Multifunktionale Filter für die Metallschmelzefiltration – ein Beitrag zu Zero Defect Materials