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

NEWSLETTER 24 (1/2023)

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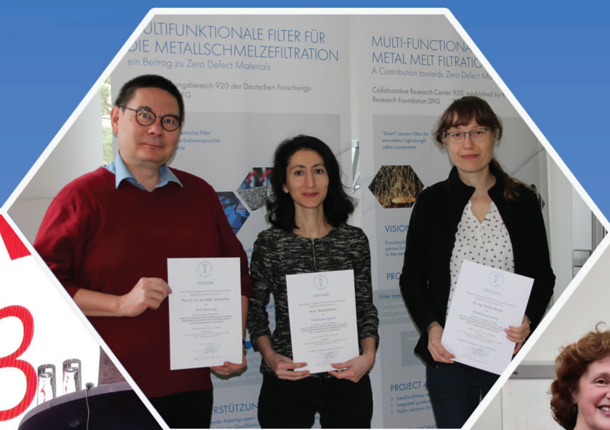



DEAR READERS,

the Collaborative Research Center 920 "Multi-Functional Filters for Metal Melt Filtration - a Contribution towards Zero Defect Materials" will be terminated on June 30, 2023 after 12 years of intensive research work. During this time, the scientists have successfully developed novel smart filter materials and filter systems with functionalized filter surfaces based on active and reactive coatings and in combination with tailored functional cavities to significantly increase the purity of metal melts. The vision of lighter, zero-defect and thus reliable materials based on e.g. steel, iron, aluminum and magnesium with superior properties for use in safety and lightweight structures is thus within reach.

International activities, recent research results and other news are presented in this last issue of our newsletter. Further information will be provided on our homepage at http://tu-freiberg.de/forschung/sfb920.

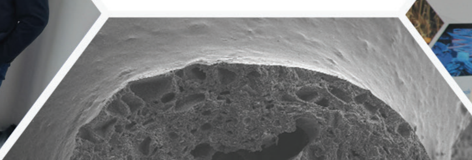
We hope you will enjoy the newsletter!

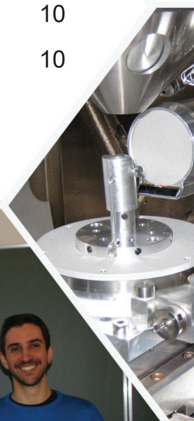
Yours sincerely,

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

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

CONTENT



12 YEARS TOP-LEVEL RESEARCH ALONG THE PROCESS CHAIN OF METAL MELT FILTRATION

The Collaborative Research Center 920 "Multifunctional Filters for Metal Melt Filtration - a Contribution to Zero Defect Materials" will be terminated after 12 years of intensive research. The interdisciplinary cooperation and the permanent exchange of information and results between the scientists led to the successful development and the use of smart filter materials and filter systems with functionalized filter surfaces for the purification of molten metals and thus to a significant reduction of non-metallic inclusions in the metal matrix.

The safety of road and railway vehicles as well as aircrafts requires highly stressable components made of steel, iron, aluminum and magnesium. During the production process, contaminations can occur in the metal melt, which lead to defects in the form of inclusions. Reducing or removing these inclusions is difficult or sometimes impossible. The CRC 920 focussed on **research into a new generation of metal qualities - also during recycling - via melt filtration with superior mechanical properties** for use in light-weight structures and high-demand construction materials.

The aim of the CRC is an enormous reduction of non-metallic inclusions in the metal matrix by the use of smart filter materials as well as filter systems with functionalized filter surfaces. Especially in the last four years, the focus has been on a **new generation of combined refining filter systems**. The metal melt comes first in contact with the **reactive carbon-bonded filters**, which in the case of steel, for example, generate CO gas bubbles in the melt as well as activate gas bubbles on the surface of the inclusions. As a result, a kind of flotation of the inclusions towards the slag on the surface of the melt takes place. Further, the high reactivity as well as the gas bubbles contribute to the agglomeration of the fine inclusions to big clusters. These clusters flow due to buoyancy forces to the surface of the melt or are filtrated on the surface of **active filters**, which do not form gas bubbles but provide on their functionalized surfaces the same chemistry as the inclusions for a sufficient adhesion and, as a result, for a sufficient filtration of the inclusions. The modeling activities focus mainly on the contributions of the gas bubbles and on the reactive layers that form in situ on the surface of the reactive filters. In addition, codes for the thermomechanical and functional properties of the filters were generated for **3D printing of filter structures**, which are then end-shaped and produced, for instance, with the aid of a **robot-assisted flame spraying technique.**

Photo: Filter components and structures for metal melt filtration, project area A.

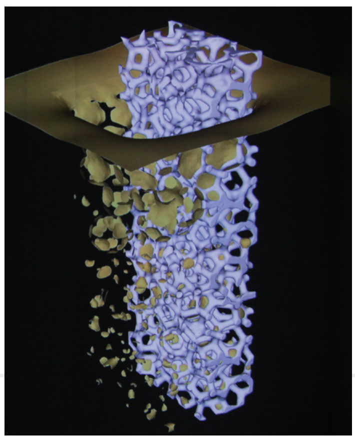


Fig.: Visualization of the model of gas bubbles, project area B.

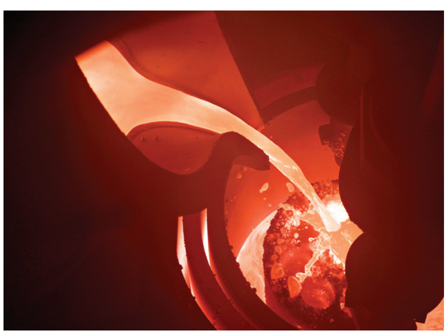


Photo: Testing of filter systems in the steel casting simulator, project area C.

The Collaboraive Research Center 920 was funded by the German Research Foundation (DFG) in three funding periods from 2011 to 2023 at Technische Universität Bergakademie Freiberg and was successfully completed after 12 years of intensive research work. A total of 19 scientific projects with more than 70 funded scientists from various disciplines contribute to closing the entire process chain of metal melt filtration **"from material to component"** and to transfer the results of materials research in CRC 920 into component innovations. The conversion of material-based innovations into industrial applications was investigated in further 8 transfer projects.

We would like to thank all participating professors, researchers and technicians, doctoral students and administrative staff, as well as the numerous students for their excellent cooperation, personal commitment and engagement. For the future we wish you all the best, happiness and always the best health! ■

SFB 920

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MORE NEWS

INTERNATIONAL EXCHANGE

From December 2022 to April 2023, **Dipl.-Ing. Xingwen Wei** completed a research stay at the **Wuhan University of Science and Technology (WUST)** in China. WUST has about 30,000 students and is one of the most renowned universities in China.

Mr. Wei thus followed an invitation to the Faculty of Materials and Metallurgy, Department of Metallurgical Engineering of Prof. Guojun Ma. At WUST in Wuhan, he carried out part of the work for subproject C01, which deals, among other things, with decopperization of steel scrap using functional filter coatings.

Using in-situ Confocal High-Temperature Laser Scanning Mocroscopy (CLSM), Mr. Wei was able to investigate the formation of copper selenides on oxide particles (e.g., Al_2O_3) in alloys containing iron and copper. By adding selenium and using aluminum-rich secondary slags, more copper can be selectively bound in steel melts containing scrap and later removed by metal melt filtration. ■

Photo: Dipl.-Ing. Xingwen Wei (2nd from left), Prof. Guojun Ma (4th from left) from WUST China.

EXCELLENT

The **publication award of the CRC 920** was presented five times to young researchers to honor their excellent publications by Prof. Christos G. Aneziris, speaker of the CRC 920.

The award was given to **Dipl.-Ing. Xingwen Wei (TP C01)** together with **Dr.-Ing. Enrico Storti** and **Dr.-Ing. Steffen Dudczig (both TP C01)** for their publication "The interaction of carbon-bonded ceramics with Armco iron". On the other hand, **Dr.-Ing. Ruben Wagner (TP C04)** was honored together with **Dr.-Ing. Enrico Storti, Dr.-Ing. Steffen Dudczig (both TP C01), Dr.-Ing. Lisa Ditscherlein (TP B01)** and **Dipl.-Ing. Christina Schröder (TP A01)** for the publication "Nanoindentation of alumina and multiphase inclusions in 42CrMo4 steel".

In addition, **Dipl.-Ing. Mariia Ilatovskaia (TP A03)** could be awarded for her contribution "Critical assessment and thermodynamic modeling of the Al-Mn-O system" and togehter with **Dr.-Ing. Hanka Becker (TP A07)** for "The η-Al_5Fe_2 phase in the Al–Fe system: the issue with the sublattice model". For their publication "β-$Al_{4.5}FeSi$: Hierarchical crystal and defect structure: Reconciling experimental and theoretical evidence including the influence of Al vs. Si ordering on the crystal structure" **Dr.-Ing. Hanka Becker (TP A07)** and **M.Sc. Nebahat Bulut (MGK)** were also granted the publication award of the CRC 920.

The publication award of the Collaborative Research Center 920 targets at doctoral students involved in the CRC 920 or young scientists who work in a scientific subproject of the CRC 920 and was presented at a doctoral colloquium of the CRC. ■

Photos: Awardees of the CRC 920 Publication Award; top (from left) Dr. E. Storti, Dr. S. Dudczig, Dr. R. Wagner, Dr. L. Ditscherlein, Dipl.-Ing. C. Schröder; below (from left) Dr. H. Becker, PD Dr. O. Fabrichnaya, M.Sc. M. Ilatovskaia.

JUNIOR RESEARCHERS

For the **Campus Day**, about **40 pupils** experienced and discovered the world of ceramic materials, their different manufacturing processes and applications at the Institute of Ceramics, Refractories and Composite Materials in January 2023.

During various demonstrations on a 3D printer, the flame spraying robot or the steel casting simulator, the students were able to learn how to produce porous ceramic structures using different additive manufacturing techniques, how to functionalize their surfaces as well as how ceramic filters for metal melt filtration work in use.

In carrying out the practicals and experiments on ceramics, the reserch assistants of the CRC 920 were able to actively pass on their knowledge and experience of their research work and arouse the students' enthusiasm and curiosity for the field of ceramic materials. ■

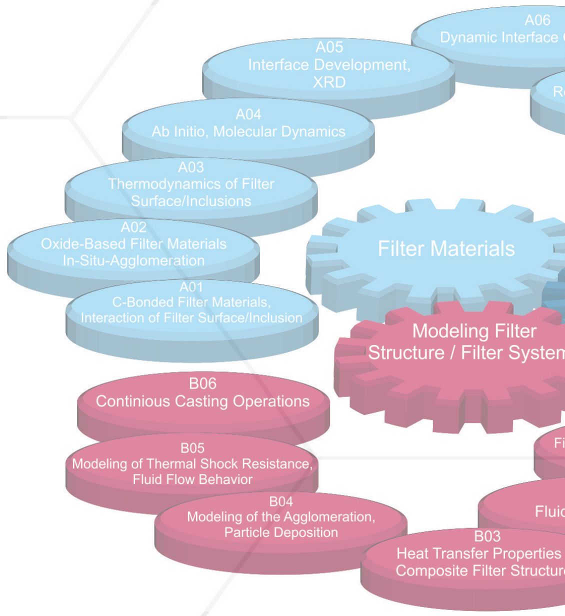
Photo: Dr.-Ing. Nora Franke (2nd from left) explains the use of ceramic filters for metal melt filtration to the Campus Day participants.

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.

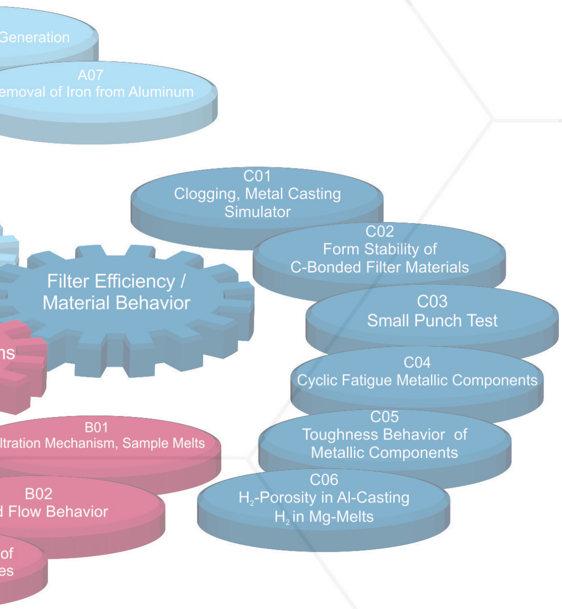
Working Group 1: „Metal melt/inclusions, active/reactive filter material, boundary surface design" (Coordination: Dr.-Ing. Hanka Becker)

- Development of a new transfer project to improve the purity of lead alloys by active and reactive filtration (A01),
- Investigation by EBSD of flame sprayed Al_2O_3 coating on carbon-bonded Al_2O_3 filter after casting of steel (A01) ,
- Al_2O_3 sample manufacturing for subproject A07 as reference for interaction tests with Al-Si melts (A02),
- Study of the ternary MgO-TiO_2-SiO_2 system is completed (A03),
- Work on the code and manuscript related to the software package "PyRamanGUI", which is used for the analysis, visualization, and organization of Raman data (A04),
- Determination and analysis of transition states during catechin pyrolysis, applying the CI-NEB method (A04),
- Electron microscopy and HTXRD study of orientation relationships between TiO_2 substrates with different orientations and corundum epitaxial layers (Al_2O_3) (A05),
- Additional experiments with the mass spectrometer: Recording of a baseline using an empty graphite tool without powder for the determination of the typical concentration and composition of the residual gases unaffected by the sample; experiments with $FeAl_2O_4$ to detect the CO/CO_2 creation (A06),
- Influence of 3d-transition metal elements in Fe-containing Al-Si-melts on the formation of intermetallic phases (A07),
- Realization of a casting series under near-industrial conditions to investigate the influence of larger melt quantities (AlSi7Mg) on the reactivity of spodumene-containing filter materials (C06),
- Characterization of interfaces and AZ91 sample cross-sections after laboratory-scale, gravity-cast filtration tests using Al_2O_3-C foams coated in MgAlON, Al_2O_3 or $MgAl_2O_4$ (C06),
- Co-firing tests with varying atmosphere of unsintered Al_2O_3 casting hoppers for steel ingot casting (air, outside) with carbon-bonded inner coating (pretcoke bed, inside) at 1600 °C (T09).



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

- Mechanical, numerical and physical characterization of Al_2O_3-C foam filters produced by distinct routes (A01, T01, B05, S01),
- Implementation of the modified, analytical Ehlers plasticity model for analyzing foam structures (B05),
- Comparison of full micromorphic and micropolar theory for application to foams (B05)
- Strength evaluation of the immersed filter in comparison to the experimental data from transfer project T04 (B05),
- Thermomechanical tests on Al_2O_3-C foam filters based on the lactose-tannin binder system (C02),
- Thermomechanical tests on slip-cast Al_2O_3-C compact bars based on lactose-tannin binder system (C02),
- Application of the Brazilian disc test for obtaining the Weibull strength distribution of various types of filter materials(C03),
- Obtaning the biaxial flexural strength of novel filter materials using ball-on-three-ball test. (C03).



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

- Evaluation of adhesion force measurements of alumina and polysterene particles at elevated temperatures to investigate sintering effects (B01),
- Determination of viscous and inertial permeabilities for a study concerning the effect of surface roughness on pressure drop in ceramic foam filters (B02),
- Measurement of the effective thermal conductivity of different ceramic filters with the Hot Disk method: Investigation of further influencing parameters such as sample/sensor size, contacting, anisotropy, coating of filters (B03),
- Investigation of the oxide layer formation of molten aluminum and its effect on hydrogen absorption using the high temperature magnetic suspension balance (B03),
- Development of a capillary force model for particle-bubble-interactions for the calculation of non-equilibrium contact angles from CP-AFM measurements (B04),
- Investigation of mechanical properties of agglomerates of alumina particles on the mesoscale by discrete element method (DEM) and experimental validation (B04),
- Analysis of size effects on mechanical properties of filter structures utilizing micromorphic theory (B05),
- Implementation of a suitable element formulation for inf-sup problems with high stiffness contrast of the considered phases into the phase-field model (B05),
- Carrying out and evaluating experiments to determine the three-dimensional flow field around an air bubble during its ascent in water and reconstruction of the bubble geometry as an ellipsoid based on three different camera views (B06),
- Comparative visualization of flow conditions in 84 different filter geometries based on in-situ compressed simulation results using the LITE-QA ParaView Plugin (S02).

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

- EBSD investigation of flame-sprayed alumina coating on carbon-bonded alumina filter after casting of steel (C01),
- Evaluation of inclusion analyses via light optical microscopy with respect to fatigue strength considering clusters of inclusions within the inclusion size distribution (C04, S01),
- Analysis of precipitation of MnS in 42CrMo4 during austenitic and ferritic solidification (C04, C01),
- Advanced analysis of the influence of particle density (ASPEX analysis), i.e., non-metallic inclusions in the steel 42CrMo4 for different variants of active and reactive filters, on the threshold value for fatigue crack growth and further relevant influencing factors (C04),
- Powder metallurgical production of a reference material using hybrid sintering technology; investigation of the effect of non-metallic inclusions with intentionally added alumina particles (C05),
- Investigation of the effect of non-metallic inclusion characteristics on crack tip blunting using test material from combined filtration tests (C05, C01),
- Conducting various experiments to determine hydrogen removal from aluminum melts using multifunctional spodumene-containing ceramic foam filters in sand casting (S03),
- Design, simulation, and evaluation of a casting geometry for the generation of dross in a magnesium-treated cast iron melt with oxygen addition in sand mold casting (T07).

PHASE-FIELD MODELING OF CHEMICALLY REACTIVE MULTI-COMPONENT AND MULTI-PHASE SYSTEMS

Author: Dr.-Ing. Andreas Seupel
(Subproject B05)

In subproject B05, modeling approaches are investigated for the simulation of layer formation processes that occur on the filter material during steel melt filtration. Phase interfaces are described using the phase-field method within the framework of a multiphysics continuum model. By numerically solving the coupled field equations using the finite element method (FEM), the spatial and temporal evolution of microstructures can be simulated.

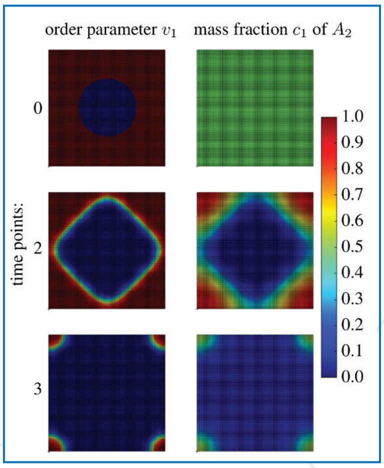


Fig. 1: Spatial and temporal evolution of the phases (left) and mass fraction of chemical component A_2 (right). The time points correspond to the labeled states in Fig. 2.

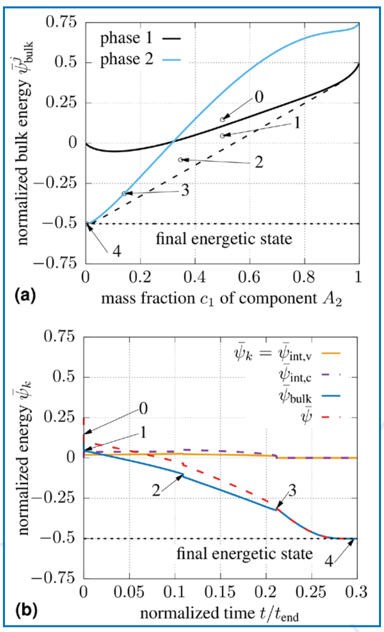


Fig. 2: Energetic state of the two-component/two-phase system under consideration: (a) Normalized bulk energy of component A_2 in the two aggregate states (phases). (b) Time evolution of the energy fractions (bulk-bulk energy, int-contributions to the interfacial energy).

The cleaning effect of carbon-bonded alumina (Al_2O_3-C) filters is due to reactive processes that occur between the chemical components of the filter and the molten steel. The fundamental aspect here is the dissolution of the primary alumina in the melt accompanied by the formation of gaseous carbon monoxide and the subsequent precipitation of a secondary layer of alumina, which terminates the reaction process.

The starting point for the modeling is a description within the framework of continuum mechanics based on a theory of mixture. This allows the description of transport processes (diffusion), the chemical reaction and the distinction of different aggregate states of the participating chemical components. The last aspect is addressed by the introduction of so-called order parameters in the model, which can be understood here as volume fractions of the aggregate states of the mixture of components at a material point under consideration. The chemical components are represented with the help of their respective mass fraction at the material point. The relevant balance equations and material laws were derived considering thermodynamic restrictions, whereby the influence of phase boundaries is taken into account by additional gradient terms of the order parameters and mass fractions in the selected state potential [1].

This corresponds to a phase-field approach, where phase separation processes can be accounted for. For the simulation of particular problems, a numerical solution procedure based on FEM was developed and implemented as software. For the verification of the numerical treatment, an example of a reactive system consisting of two components (molecule A_2 and atom A) and two phases was utilized, where the decomposition of the molecule into the atomic form was assumed as the chemical reaction [1].

The starting point of the simulation was a homogeneous spatial distribution of the two chemical components, see Fig. 1 (state 0 rhs), with the components in different states (droplet v_1=0 in the center Fig. 1, state 0, lhs). The energy landscape of the system sketched in Fig. 2a shows that the given initial state 0 is energetically unfavorable. The microstructure will evolve to minimize the energy. Through the assumed equilibrium reaction, at best global energetic minimum can be reached (state 4). This occurs via intermediate steps in which initially energy-driven separation processes occur due to diffusion of the substances, see Fig. 1 (state 2, rhs), i.e., as shown, the chemical components are no longer homogeneously present in the entire area.

The simulated time course of the energetic state is shown in Fig. 2b, where the fractions of the interfacial energies are also indicated. In state 2, the initially coherent interface breaks down into individual areas. In the final state, there is again a spatially homogeneously distributed mixture of substances in only one state of aggregation, but with a new composition. The simulated energetic final state in Fig. 2b agrees with the expectations due to the given state potential. The verified model can thus be used for the complex simulation of the layer formation processes. ■

[1] Seupel, A., Roth, S., Kiefer, B.: Phase-field modeling of chemically reactive multi-component and multi-phase systems, Proceedings in Applied Mathematics & Mechanics 22 (2023) 1, pp. E202200154. DOI: 10.1002/pamm.202200154.

APPLICATION OF CERAMIC FIBERS OF THE PURIFICATION OF ALUMINUM MELTS

The transfer project T05 investigates the influence of ceramic fibers on the cleaning of aluminum melts in industrial aluminum casting processes. The material quality of cast aluminum products is reduced in case of insufficient cleaning of the melt from non-metallic inclusions. The removal of inclusions is realized by the use of foam ceramic depth filters.

Author: M.Sc. Jan Nicklas
(Transfer project T05)

The size of the filter pores is crucial for the separation of inclusions, but the pore size cannot be arbitrarily reduced, as small pore sizes increase the pressure drop [1]. In sand mold casting, this can lead to solidification of the Al melt in the filters.

The application of ceramic fibers has great potential to increase the separation efficiency (Fig. 1) of smallest impurities (2 to 20 µm) [2], while maintaining a low-pressure drop [3] (Fig. 2). The concept has been investigated under real conditions in Al sand mold casting as well as in the room temperature model system (RT-system) of the CRC 920, which combines the analogy of the poor wetting properties of non-metallic inclusions by the aluminum melt and hydrophobized Al_2O_3 particles by water in the RT-system [1, 2].

The ceramic fibers can be added according to the concept of precoat filtration, or they can be introduced into the casting system in the form of encapsulated filters [3, 4] in place of a conventional ceramic foam filter. For encapsulated filters, the ceramic fibers are placed in the functional cavity between two ceramic filters. The Al_2O_3 fibers with a length of 15 to 20 mm are long enough to not pass through the pores of 10 ppi or 30 ppi filters. [3].

In the semi-technical filtration plant that is used for experiments with the RT-system (Fig. 3), it was shown that both the precoat filtration and the application of encapsulated filters increased the separation efficiency by 16.8 % and 92.9 % respectively compared to conventional filters [3]. Even a small added fiber mass supports the separation of the smallest impurities (Fig. 4). This is caused by a combination of a sieve-like-effect and an increased adhesive force caused by the high mass-specific surface area of the fibers. The local filtration efficiency (Fig. 1) is proportional to the added fiber mass [3]. The best results in terms of separation efficiency in the RT-system were obtained with the encapsulated filters [3].

These results from the RT-system are consistent with the increased strength characteristics of specimens produced from industriell casts with an AlSi10Mg alloy using encapsulated filters. Compared to the use of conventional 10 ppi filters, a significant increase in the tensile strength characteristics can be achieved by using the encapsulated filters with 0.03 to 0.06 g Al_2O_3 fibers. Increase of the the added fiber mass, as previously observed in the RT-system, leads to an increase in the separation efficiency, and a corresponding tensile strength. For example, encapsulated filters with 0.06 g Al_2O_3 fibers can increase the tensile strength to 272.2 MPa compared to 261.3 MPa when using a conventional 10 ppi filter.

The encapsulated filters with ceramic fibers, tested for the first time under industrial conditions, offer a simple and cost-effective method to improve the quality of small casting products, making a transfer of the concept to large-scale casting processes conceivable. ■

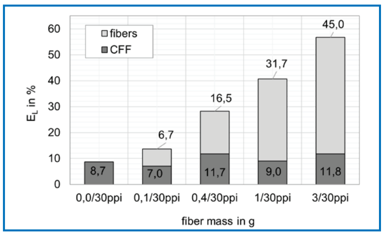


Fig. 1: Local filtration efficiency E_L of fibers placed on a 30 ppi support filter. The approach velocity is 3.2 cm/s. The increase in fiber mass leads to an increase in filtration efficiency [3].

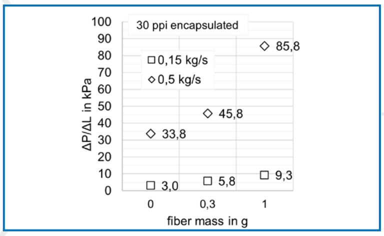


Fig. 2: Pressure drop in the RT-system when using encapsulated 30 ppi filters as a function of the fiber mass for two mass flows of 0.15 kg/s and 0.5 kg/s model melt [3].

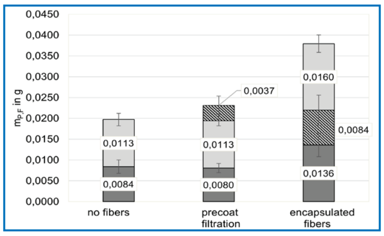


Fig. 3: Local deposited mass of Al_2O_3 inclusion particles in the RT-system for the addition of the fibers by precoat filtration or as encapsulated filters, compared to filtration with a conventional 30 ppi filter [3].

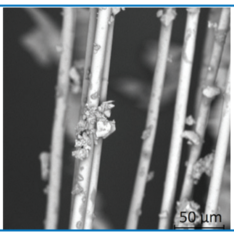


Fig. 4: SEM analysis of particle deposition on fibers with a diameter of 10 to 12 µm in the RT-system [3].

[1] Hoppach, D.: Abscheideeffizienz keramischer Tiefenfilter in einem Raumtemperatur-Modellsystem zur Charakterisierung der Aluminiumschmelzefiltration, Dissertation, Technische Universität Bergakademie Freiberg, 06.05.2022.
[2] Hoppach, D., Werzner, E., Demuth, C., Löwer, E., Lehmann, H., Ditscherlein, L., Ditscherlein, R., Peuker, U.A., Ray, S.: Experimental Investigations of Depth Filtration Inside Open-Cell Foam Filters Supported by High-Resolution Computed Tomography Scanning and Pore-Scale Numerical Simulations, Advanced Engineering Materials, 22 [2] (2020), 1900761 (1-13). DOI: 10.1002/adem.201900761.
[3] Hoppach, D., Peuker, U.A.: Using ceramic fibres for enhancing filtration efficiency in al-melts based on a room-temperature model system, FILTECH 2022 Conference, Köln, 08.-10.03.2022, oral presentation, paper no. P609.
[4] Hoppach, D. Peuker, U.A.: „Keramische Metallschmelze-Filter für die Filtration von Aluminiumschmelzen", german patent DE 10 2018 126 326, 2021.

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TU Bergakademie Freiberg

THE INTERACTION OF CARBON-BONDED CERAMICS WITH ARMCO IRON

Author: Dipl.-Ing. Xingwen Wei
(Subproject C01)

The subproject C01 investigated the possible reactions between carbon-bonded ceramics and liquid Armco iron, three types of carbon (10 wt% C) bonded ceramics Al_2O_3 rich spinel (C-AR78), MgO rich spinel (C-MR66), and $CaO{\cdot}6Al_2O_3$ (C-CA6) were put into contact with liquid Armco iron at 1625 °C by using the sessile drop method.

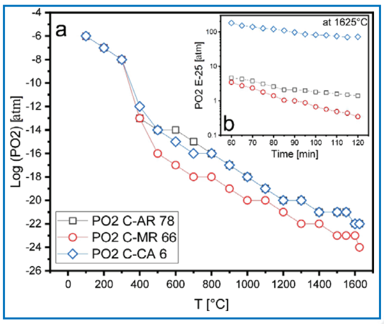

Fig. 1: Measured oxygen partial pressures p_{O_2}. a. Oxygen partial pressure as a function of temperature from room temperature up to 1625 °C; b. Oxygen partial pressure as a function of time (60 to 120 min) at 1625 °C.

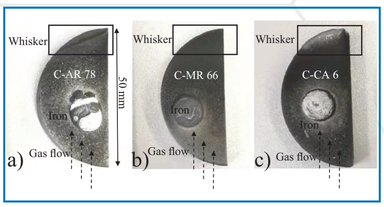

Fig. 2: Carbon-bonded substrates after interaction with molten iron. a. C-AR78; b. C-MR66; c. C-CA6.

During the experimental process, the oxygen partial pressure (p_{O_2}) inside the heating microscope was monitored by a high-temperature zirconia oxygen detector installed at the gas outlet. Fig. 1 shows the measured value of the p_{O_2} for all three experiments (C-AR78, C-MR66, and C-CA6 substrate) from room temperature (25 °C) up to the experimental temperature (1625 °C). The variations of p_{O_2}) and the final values were similar in the C-AR78 and the C-CA6 cases (p_{O_2} = 10-22 atm at 1625 °C for both substrates). A lower oxygen content (p_{O_2} =10-24 atm at 1625 °C) was detected in the C-MR66 substrate case. Based on the previous study [1] in the same heating microscope, the p_{O_2} value was 10 to 21 atm when using pure Al_2O_3 as substrate material at 1600 °C. Thereby, with a carbon-bonded Al_2O_3 substrate, the final oxygen partial pressure was lower (p_{O_2} =10-23 atm) at 1625 °C. Wei et al. [1] assumed that the lower p_{O_2} value in the case of carbon-bonded Al_2O_3 substrate was caused by oxidation of the released metallic aluminum (gas) and aluminum-bearing substances [1].

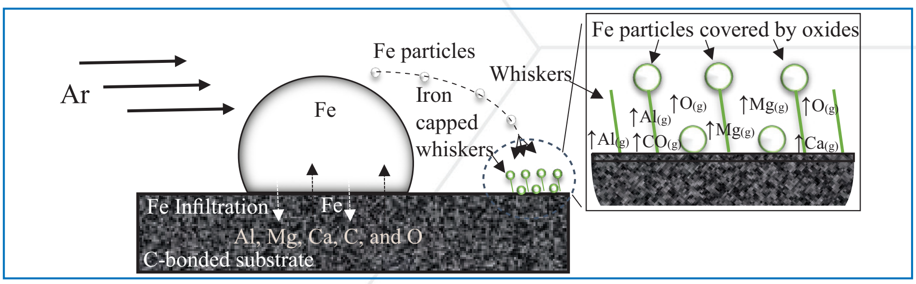

Fig. 3: Illustration of interaction mechanism.

After the contact experiments, the surfaces of the carbon-bonded substrates were found strongly modified as shown in Fig. 2. Phenomena such as decarburization, formation of whiskers, and oxide layer formation on the iron sample were observed.

As illustrated in Fig. 3, elements such as Mg, Al (including the gas phases AlO and Al_2O), and Ca partly evaporate into the atmosphere and partly dissolve in the liquid iron. However, due to the low degree of Mg and Ca solubility in the liquid iron it is enriched mainly by Al. The formation of $MgAl_2O_4$ or $CaO{\cdot}2Al_2O_3$ at the iron surface was considered due to the reaction of the Mg or Ca present in the gas phase with oxygen and Al in Fe liquid. Moreover, before the iron droplet was completely covered by such layers, some liquid iron particles were transferred to the surface of the substrates through the momentum of the gas flow. Once the iron particles reached the substrate, they started to pick up carbon and the elements (mostly Al and O, and a small percent of Mg or Ca), subsequently generating whiskers with iron capping. The proposed mechanism for the oxide layer and whiskers formation is shown in Eq. (1) and (2).

$$\text{(1)}\ MgAl_2O_4 / Al_2O_3 + MgO \xrightarrow{C,\ Fe} Mg, Al + CO \xrightarrow{Fe,\ O} MgAl_2O_4 \text{ oxide layers/ } MgAl_2O_4 \text{ whiskers}$$

$$\text{(2)}\ CaO{\cdot}6Al_2O_3 \xrightarrow{C,\ Fe} Ca, Al + CO \xrightarrow{Fe,\ O} CaO{\cdot}2Al_2O_3 \text{ oxide layers/ } Al_2O_3 \text{ whiskers}$$

In addition, the calculated stability of oxides in our previous investigation [2] explains the various p_{O_2} values detected with the different ceramic substrates. Firstly, MgO shows the lowest stability among the considered oxide phases, which indicates that more Mg would be released by the MgO reduction. CaO, on the other hand, shows the highest stability. Therefore, according to the calculations, for reduction reaction of ceramic materials should change as following C-MR66 > C-AR78 > C-CA6 which is in good agreement with the measured p_{O_2} results. Moreover, with increasing contact time, decarburization of the substrates would continue, hence more oxides would decompose into the atmosphere and more oxygen would be then consumed leading to the lower p_{O_2} values observed. Moreover, in the case of the C-CA6 substrate, the detected oxide whiskers were Al_2O_3, higher stability of CaO against reduction in the C-CA6 substrate [3]. ■

[1] X. Wei, A. Yehorov, E. Storti, S. Dudczig, O. Fabrichnaya, C.G. Aneziris, O. Volkova: Phenomenon of Whiskers Formation in Al_2O_3-C Refractories, Advanced Engineering Materials (2021), 2100718. https://doi.org/10.1002/adem.202100718.
[2] X. Wei, S. Dudczig, E. Storti, M. Ilatovskaia, R. Endo, C.G. Aneziris, O. Volkova: Interaction of molten Armco iron with various ceramic substrates at 1600 °C, Journal of the European Ceramic Society, 42 (2022), 2535–2544. https://doi.org/10.1016/j.jeurceramsoc.2022.01.011.
[3] X. Wei, E. Storti, S. Dudczig, A. Yehorov, O. Fabrichnaya, C.G. Aneziris, O. Volkova: The interaction of carbon-bonded ceramics with Armco iron, Journal of the European Ceramic Society, 42 (2022), 4676–4685. https://doi.org/10.1016/j.jeurceramsoc.2022.04.058.

CURRENT PUBLICATIONS
(November 2022 - June 2023)

Further information about the 170 publications that have been generated since the start of the third program period as well as about the currently 21 patents and patent applications are available at https://tu-freiberg.de/forschung/sfb920

Projectarea A - Filter materials

Subproject A03

Ilatovskaia, M., Becker, H., Fabrichnaya, O., Leineweber, A. (2023): The η-Al_5Fe_2 phase in the Al–Fe system: the issue with the sublattice model, Journal of Alloys and Compounds, Vol. 936, March 5, 2023, pp. 168361, DOI 10.1016/j.jallcom.2022.168361.

Ilatovskaia, M., Fabrichnaya, O.: Thermodynamic assessment of the MgO-TiO_2-SiO_2 system, 37th Annual MSIT Meeting, Schloß Ringberg, Kreuth, March 12-17, 2023, oral presentation.

Subproject A04

Kraus, J., Kortus, J. (2023): Investigating the thermodynamics and kinetics of catechin pyrolysis for environmentally friendly binders, ACS Omega, Vol 8, Iss. 4, April 11, 2023, pp. 12603-13478, DOI 10.1021/acsomega.2c07756.

Kraus, J., Kortus, J.: Investigating the thermodynamics and kinetics of catechin pyrolysis for environmentally friendly binders, Verhandlungen der Deutschen Physikalischen Gesellschaft, DPG Spring Meeting 2023, March 27-31, 2023, Dresden, poster.

Brehm, S., Himcinschi, C., Kraus, J., Kortus, J.: PyRamanGUI: An open-source multi-purpose tool to analyze Raman spectra, Verhandlungen der Deutschen Physikalischen Gesellschaft, DPG Spring Meeting 2023, March 27-31, 2023, Dresden, poster.

Subproject A06

Salomon, A.: SPS/FAST for the synthesis of $MnAl_2O_4$ and for the recycling of MgO-C complemented by mass spectrometry, 22th Meeting of the Expert Group Field Assist Sintering Technique / Spark Plasma Sintering, FAST / SPS, Dresden, April 4, 2023, oral presentation.

Subproject A07

Becker, H., Hielscher, R., Leineweber, A.: Habit plane determination based on 2D-EBSD data including use of orientation relationships, EMAS 2023 - 17th European Workshop on modern developments and applications in microbeam analysis, Krakow, Poland, May 7-11, 2023, poster.

Projectarea B - Modelling of filter structures/ filter systems

Subproject B01

Daus, S., Peuker, U.A.: Deep learning enhanced algorithm for in-line characterization of particle size and shape in depth filtration processes, FILTECH 2023, Cologne, February 14-16, 2023, oral presentation.

Subproject B03

Heisig, L.-M., Wulf, R., Fieback, T.M. (2023): Investigation and Optimization of the Hot Disk Method for Thermal Conductivity Measurements up to 750 °C, International Journal of Thermophysics, Vol. 44, 2023, pp. 82 (1-21), DOI 10.1007/s10765-023-03190-6.

Subproject B04

Nicklas, J., Peuker, U.A.: Wechselwirkung schlecht benetzbarer Partikel mit gekrümmten Gas-Flüssig Grenzflächen, Prozessnet, Jahrestreffen DECHEMA, March 9-10, 2023, Frankfurt, oral presentation.

Subproject B05

Seupel, A., Roth, S., Kiefer, B. (2023): Phase-field modeling of chemically reactive multi-component and multi-phase systems, Proceedings in Applied Mathematics and Mechanics - PAMM, Vol. 22, Iss. 1, 2023, e202200154 (1-6), DOI 10.1002/pamm.202200154.

Seupel, A., Roth, S., Kiefer, B.: A fully coupled chemo-mechanical phase-field model for reactive multi-component/multi-phase systems, 93th Annual Meeting of the International Association of Applied Mathematics and Mechanics - GAMM, Dresden, May 30 - June 2, 2023, oral presentation.

Projectarea C - Filter performance, materials properties

Subproject C01

Storti, E., Jiríčková, A., Dudczig, S., Hubálková, J., Aneziris, C.G.: Alumina castables with addition of fibers produced by electrospinning, 15th International Ceramics Congress - CIMTEC 2022, Perugia, Italy, June 20-24, 2022, oral presentation.

Zhao, W., He, S., Wei, X., Du, Y., Tang, G., Zhang, Y., Dai, G., Gao, K., Volkova, O. (2023): Quantitative relationships between cellular structure parameters and the elastic modulus of aluminum foam, Materials Science and Engineering A, Vol. 868, 14 March 2023, 144713, DOI 10.1016/j.msea.2023.144713.

Liu, K., Cheng, S., Wei, X., Li, J., Feng, Y., Volkova, O. (2023): Refinement mechanism and optimization for compact strip production process, Materials Science and Technology, accepted: 27.02.2023, pp. 1-12, DOI 10.1080/02670836.2023.2187150.

Subproject C02

Wu, X., Weidner, A.; Aneziris, C.G., Biermann, H. (2022): High-temperature mechanical behavior of compact carbon-bonded alumina based on a pitch-free lactose-tannin binder system, Ceramics International, Vo. 49, Iss. 8, April 15, 2023, pp. 13140-13149, DOI 10.1016/j.ceramint.2022.12.192.

Subproject C03

Takht Firouzeh, S., Abendroth, M., Kiefer, B. (2022): Application of Miniaturized Brazilian Disc Tests for the Determination of High-Temperature Strength of Ceramic Filter Materials, Procedia Structural Integrity, Vol. 42, 2022, pp. 1069-1073, DOI 10.1016/j.prostr.2022.12.135.

Takht Firouzeh, S., Abendroth, M., Kiefer, B.: Employing Miniaturized Test Methods to Determine High-temperature Strength of Carbon-bonded Alumina, 93. Annual Meeting of the InternationalAssociation of Applied Mathematics and Mecha nics - GAMM, Dresden, May 30 - Juni 2, 2023, oral presentation.

Subproject C04

Schmiedel, A., Weidner, A., Biermann, H.: Very-high cycle fatigue lives of high-temperature materials tested by ultrasonic fatigue, TMS 2023, San Digo, USA, March 19-23, 2023, oral presentation.

Wagner, R., Lehnert, R., Storti, E., Ditscherlein, L., Schröder, C., Dudczig, S., Peuker, U.A., Volkova, O., Aneziris, C.G., Biermann, H., Weidner, A.: Nanaoidentation od alumina and multiphase inclusions in 4CrMo4 steel, TMS 2023, San Digo, USA, March 19-23, 2023, poster.

Weidner, A.: Very high cycle fatigue art at RT and elevated temperatures on additively manufactured materials, 21. International Colloquium on Mechanical Fatigue of Metals - ICMFM, Brno, Czech Republik, 22.-24. Mai 2023, keynote lecture.

Subproject C05

Koch, K., Henschel, S., Krüger, L. (2022): Effect of the impact pulse on the dynamic fracture toughness behavior of high-strength steel and nodular cast iron, Procedia Structural Integrity, Vol. 42, 2022, pp. 506-512, DOI 10.1016/j.prostr.2022.12.064.

Henschel, S., Krüger, L. (2022): One-Step Dynamic Calibration of Strain Measurement in a Split Hopkins Pressure Bar, Procedia Structural Integrity, Vol. 42, 2022, pp. 110-117, DOI 10.1016/j.prostr.2022.12.064.

Koch, K., Wagner, R., Dudczig, S., Henschel, S., Weidner, A., Biermann, H., Aneziris C.G., Krüger, L.: Effect of non-metallic inclusions on the fracture toughness of 42CrMo4 steel in the ductile-brittle transition range, 15th International Conference on Fracture - ICF15, June 11-16, 2023, Atlanta, USA, oral presentation.

Transfer projects

Transfer project T03

Schoß, J.P., Schramm, E., Schönherr, P., Mrowka, N.-M., Schumann, H., Becker, H., Keßler, A., Szucki, M., Wolf, G. (2023): Investigation of the formation of iron-rich intermetallic phases in Al-Si alloys via thermal analysis cooling curves, including a real-time detection for filtration process, Advanced Engineering Materials, 2023, 202201576 (1-20), DOI 10.1002/adem.202201576.

Transfer project T04

Wetzig, T., Schöttler, L., Schwarz, M., Aneziris, C.G.: Development of filter starter tubes for industrieal continous casting of steel, 98th DKG Annual Meeting - CERAMICS 2023, March 27-30, 2023, Jena, oral presentation.

Aneziris, C.G., Wetzig, T., Storti, E., Hubálková, J., Gehre, P.: Carbon Bonded Foam Structures – Applications as high temperature reactive filters in combined refining filter-systems for improved steel cleanliness, 15th International Ceramics Congress - CIMTEC 2022, Perugia, Italy, June 20-24, 2022, invited lecture.

DFG Deutsche Forschungsgemeinschaft

TU Bergakademie Freiberg

GRADUATION IN CRC 920

The fracture mechanics characterization of flame-sprayed Al_2O_3 materials, which are used as base filter materials or as functional layers on the surface of filters for metal melt filtration, was the subject of the doctoral thesis entitled **"On the Fracture Mechanics of Flame-Sprayed Ceramic Structures for Functional Application"** by **Dr.-Ing. Marc Neumann,** a doctoral student in the MGK Research Training Group of the CRC 920, which he successfully completed in January 2023.

Photo (from left): PD Dr. A. Weidner, Dr. R. Wagner, Prof. H. Biermann.

In addition, **Dr.-Ing. Ruben Wagner**, a doctoral student in subproject C04 of CRC 920, successfully defended his dissertation entitled **"Investigation of non-metallic inclusions in 42CrMo4 steel after metal melt filtration"** in May 2023. The investigation results of the inclusion analysis allow an assessment of the effect of metal melt filtration as well as the expected mechanical properties of the steel under different stress scenarios and thus on the design of long-life components. ■

MEETINGS AND CONFERENCES

The **German Ceramic Society (DKG)** elected **Prof. Dr. Christos G. Aneziris**, head of the Institute for Ceramics, Refractories and Composite Materials and speaker of the CRC 920, as its new president for the next two years at its general meeting in Jena in March 2023.

Photo: Prof. C. G. Aneziris after being elected President of the German Ceramic Society (DKG).

According to its own information, the DKG is the ceramic society with the largest membership in Europe and one of the oldest professional associations worldwide. The society provides a forum for technical and scientific issues relating to ceramics. It maintains a network between users, the manufacturing industry, research, science and teaching. The main topics of the DKG are research and development, education and training, organization and implementation of events as well as the support of ceramic art and culture.

Under the topic **"3D-Refractories"**, the **13th Freiberg Refractory Forum** was held in December 2022 as a hybrid event with around 110 participants from science and industry. The presentations included a report by **Prof. Thomas Graule** of **EMPA**, Duebendorf, Switzerland, on the application of the selective laser sintering in the preparation of porous oxide ceramics. **Dr. Christoph Wöhrmyer** from **IMERYS MURG GmbH** in Oberhausen, Germany, gave an overview of the requirements for raw materials for the production of ceramics and construction by 3D printing processes. Water-based feedstock materials for the additive manufacturing of oxide ceramics were discussed by **Dr. Andrea Zocca** from **BAM** in Berlin. **M.Sc. Serhii Yaroshevskyi** from **IKFVW** at **TU Bergakademie Freiberg** presented recent research results on the development of 3D printing filaments for the production of tailor-made refractory products. After the lecture event, the participants were able to take a guided tour of the "Center for Efficient High Temperature Processes and Material Conversion (ZeHS)" to learn more about the new research infrastructure at the TU Bergakademie Freiberg. ■

CONFERENCES AND CALLS FOR PAPERS

ICF 2023: 15th International Conference on Fracture, June 11-16, 2023, Atlanta, USA, https://icf15.gatech.edu/.

ECerS 2023: XVIII Conference of the European Ceramic Society, July 02-06, 2023, Lyon, France, https://www.ecers2023.org/.

UNITECR 2023: The Unified Technical Conference on Refractories, 18th Biennial Worldwide Congress on Refractories, September 26-29, 2023, Frankfurt on the Main, https://unitecr2023.org/.

13th Freiberg Refractory forum: December 13, 2023, TU Bergakademie Freiberg.

IMPRESSUM

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PHOTOS
TU Bergakademie Freiberg, CRC 920 “Multi-Funktional Filters for Metal Melt Filtration - A Contribution towards Zero Defect Materials“, Detlev Müller.

ISSUE: No. 24, Issue 01/2023
(Two issues per year)

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