6th Freiberg Refractories Forum

The Freiberg Refractories Forum 2015 was organized on 8–9 December 2015 in Freiberg/DE by the Institute of Ceramics, Glass and Construction Materials (IKGB) at Freiberg University of Mining and Technology in cooperation with the DFG (German Research Foundation) to present the results of the second research period of the DFG-project „Refractories Initiative for the Reduction of Emissions – SPP 1418" (FIRE – Feuerfestinitiative zur Reduzierung von Emissionen). Invited were especially the members of the DGM (German Association of Materials Science), the DKG (German Ceramic Society) and MORE (Meeting of Refractory Experts Freiberg Regd.) to be able to present these comprehensive results to the industry and experts of applied research. Before the technical sessions, the 11th Annual Meeting of MORE (Fig. 1) was held to up-date the members on the activities of the association in the current year. The highlight of this meeting was the Theodor Haase Award 2015 (see textbox).

Introduction

Prof. Dr C.G. Aneziris (Freiberg University of Mining and Technology/DE) welcomed over 100 guests to the 6th Freiberg Refractories Forum and reviewed the main activities of the institute. He explained that topic of the forum in 2015 is focused on the SPP 1418 research programme, which was started in 2009. Researchers from twelve German universities and research institutions have joined the Priority Programme, established to develop novel refractory materials and components. The interdisciplinary collaboration between these members enhanced the creation of fundamental knowledge about innovative refractories.

It was funded by the German Research Foundation (DFG) from 2009 to 2015 in recognition of the importance of refractory materials. The Dean of the Freiberg University of Mining and Technology, Prof. Dr Klaus-Dieter Barbknecht, welcomed the attendees and also reviewed the history of the university, which had celebrated its 250th anniversary just two weeks previously.

He mentioned that refractory research had been started much earlier as Georgius Agricola (1494–1555), known as "the father of mineralogy", was born at Glauchau in Saxony nearby. His chief historical work, the "Dominatores Saxonici a prima origine ad hanc aetatem", was published at Freiberg. He stated that Germany has to protect its leading role in research to maintain German industry's good position on a global scale.

Technical outline of SPP 1418

General approach

The programme concentrated on interdisciplinary research for carbon containing refractories. These materials exhibit an excellent thermal shock resistance which explains their importance in steel production. On the one hand, the activities focused on the optimization of the properties of these refractories as well as on the more efficient use of raw materials and resources.

On the other hand, the project aimed at reducing the carbon content in the refractories because of the high carbon dioxide emissions especially during the production process. This is important because of the increasing requirements for sustainability and reduction of environmentally relevant emissions in industrial processes.

Material scientists, physicists, process engineers, information scientists and others cooperated in Germany in four project areas, namely Materials, Processes, Modelling and Testing Technology accompanied by the Development of a Refractory Research Roadmap.

Better thermal shock resistance at lower carbon content

The research groups in the project area "Materials" followed different approaches towards innovations in this field of research. Prof. Michael Scheffler and his co-workers at the Otto-von-Guericke University of Magdeburg/DE investigated the synthesis

Fig. 1 Prof. Dr habil. C. G. Aneziris (IKGB) presenting the activities of MORE to the attendees of the annual meeting before the conference

Fig. 2 Prof. Dr Klaus-Dieter Barbknecht giving the welcome address

of a two-phase material of alumina and mullite via sol-gel processes. Varying the process parameters permitted the generation of specific alumina/mullite gradients, which resulted in better thermal shock resistance.

An alternative way to produce carbon-free refractories with improved thermal shock resistance was explored by Prof. Christos G. Aneziris at TU Bergakademie Freiberg. His group concentrated on ceramics based on alumina with additions of titania and zirconia, so-called AZT ceramics. In these materials, a secondary phase is formed during the synthesizing step. Under thermal shock, they undergo phase transformations accompanied by volume changes. Hence, they act as "spring elements" and improve the material's thermal shock resistance. This was confirmed by wedge splitting tests in the research group led by Dr Rolf-W. Steinbrech and Dr Jürgen Malzbender at Forschungszentrum Jülich/DE. Based on these results, a transfer project with the industrial partner Deutsche Edelstahlwerke GmbH / DEwas started in the second funding period.

Two more subprojects concentrated on carbon-free materials with improved thermal shock properties. Prof. Thomas A. Bier from TU Bergakademie Freiberg focussed on the optimization of spinel-forming castables based on the generation of microcracks owing to oxidic additives and reduced porosity in the material. Prof. Rainer Telle from RWTH Aachen/DE investigated the use of eutectic aggregates in refractories. These materials exhibit a special melting behaviour and a particular microstructure that increases the fracture energy of the refractory and, hence, improves its thermal shock behaviour.

Besides research in the field of carbon-free refractories, the reduction of the carbon content in comparison to conventional carbon-bonded refractories was also of interest. The group of Prof. Christos G. Aneziris studied the reduction of the carbon content with regard to conservation of the required thermal shock properties. The use of nano-scaled additives resulted in better bonding between carbon matrix and coarse-grained material. These new refractories contain about 1/3 less carbon while the remaining strength after thermal shock was even better than that of conventional carbon-bonded refractories. The investigation of the effects of such additives and of the different refractory components was accompanied by Prof. Heike Emmerich from University of Bayreuth by means of microstructure modelling and simulation.

Innovative testing procedures for refractory materials

Several projects concentrated on the further development of testing procedures for high temperature materials for improving the characterisation of conventional and innovative refractories. The group of Prof. Veselin Michailov from BTU Cottbus/DE used a plasma test stand to apply a thermal shock load to materials. The investigations in combination with finite element analysis resulted in information on critical stresses and failure criteria for the refractories.

Prof. Horst Biermann, TU Bergakademie Freiberg, and his group focused on the specific area of thermo-cyclic loads, especially of carbon-bonded refractories. After conceptually designing an appropriate testing device, they investigated specifically the relation between carbon content, graphite content, porosity and coarse grain fraction with regard to thermal and thermo-mechanical properties of the refractories.

Prof. Rainer Telle, RWTH Aachen, and his co-workers investigated the subcritical damage of the microstructure of refractories under repeated thermal shocks. They concentrated on the use of resonant frequency-attenuation analysis and improved this testing methodology.

The scientists within the Priority Programme 1418 were able to use a novel testing device. During the first funding period a metal casting simulator was planned and constructed which permits material tests in a small-scale casting process under real conditions.

It allows the specific investigation of interactions between metal melt, refractory material, slag and particles which were specifically introduced into the system to simulate impurities.

Innovative shaping technologies for high-temperature materials

New approaches in the shaping of refractories were investigated particularly with regard to the application of multilayer technology to refractories. The groups of

Theodor Haase Award 2015

To commemorate Theodor Haase and his commitment to education in silicate research, since 2008 MORE has presented this award to students who have delivered exceptional master theses addressing refractory and high-temperature applications. In 2015, at the MORE annual meeting, Prof. Aneziris honoured Marcel Bastian from the University of Koblenz, WesterWaldCampus Höhr-Grenzhausen for his work "Investigations on the Mechanisms and Reaction Kinetics of the Oxidation of Nitride-Bonded SiC in Water Vapour Atmospheres at Temperatures between 900–1000 °C".

Fig. 3 Prof. C. G. Aneziris (r.) awarded Marcel Bastian (University Koblenz/DE)

Prof. Alexander Michaelis, Fraunhofer Institute for Ceramic Technologies and Systems IKTS in Dresden/DE, and Prof. Andreas Roosen, Friedrich-Alexander-University of Erlangen-Nuremberg/DE, used tape casting in the field of refractory ceramics. The stacking of these tapes followed by a winding process allowed the manufacture of multilayered composites. The combination of different tape types yielded specific microstructures and structural gradients for adjusting particular high-temperature properties.

A similar technique was investigated by Prof. Peter Greil and his co-workers, also from Friedrich-Alexander-University of Erlangen-Nuremberg. They adapted the paper making technology by replacing pulp fibres with high-temperature-resistant ceramic fibres. The resulting fibroid structures had a positive effect on the thermal shock behaviour of the material.

Additionally, the integration of semi-conductive parts into the system was investigated which can be potentially used as sensors in the on-line control of a refractory component. A multilayer set-up of these components was realized and the macroscopic structure specifically adjusted.

The position of the single layers in the multilayer components was optimized in collaboration with other subprojects. Prof. Meinhard Kuna, TU Bergakademie Freiberg, simulated with his co-workers different layer structures with regard to their internal stresses caused by the production process and under application conditions.

Prof. Andreas Ricoeur, Universtity of Kassel/DE, and his group used multi-scale modelling for describing microstructural properties in cell models. The groups used novel numerical tools in their work. The results were used for optimizing the structure of the multilayer components.

The group of Prof. Wolfgang Kollenberg from the University of Applied Sciences Bonn-Rhein-Sieg/DE focussed on baseline investigations to use additive manufacturing in the field of high-temperature materials. This method is beneficial to form specific microstructures in a component in order to increase its thermal shock resistance.

Dr Guido Falk, University of Saarbrücken/DE, investigated an alternative shaping technology. Refractories with a cellular carbon matrix were manufactured, which had a minimized carbon content while maintaining appropriate thermo-mechanical properties. The work was accompanied with extensive numerical calculations.

Modelling

The sub-projects presented so far have shown how numerical and experimental methods can be advantageously combined. Furthermore, the group headed by Prof. Dimosthenis Trimis, Prof. Subhashis Ray, Dr Felix Ballani and Prof. Karl-Gerald van den Boogaart from TU Bergakademie Freiberg and Karlsruhe Institute of Technology/DE investigated the effective thermal conductivity of novel refractory materials depending on their specific microstructure.

Fig. 4 Auditorium at "Alte Mensa" in Freiberg/DE

Research roadmap

The development of a research roadmap for the field of refractories is an instrument for the strategic research planning and promotion. Prof. Anja Geigenmüller, TU Ilmenau/DE, and her co-workers applied this method for the first time to the refractory industry. The first step was the identification of requirements of the industry and strategic propositions in the field of refractories. Then, the approaches of the different stake holders to reach these aims were derived. This investigation used tools such as expert surveys and the analysis of scientific publications in the field of refractories with regard to content and quantity.

Summary

The Freiberg Refractory Forum has again shown that it provides a reliable platform for enhanced dialogue between industry partners and research institutions on a wide scale. This dialogue contributes in a significant way both to the translation of research findings into industrial applications and to the identification of new research projects. The next edition of this impressive meeting of experts involved in the refractory sector will be organized again in Freiberg on 14–15 December 2016 with invited speakers from Iran and Turkey. KS

Remark from the editor:
The findings of the second period of SSP 1418 (2012–2015) will be published in the paper section of refractories WORLDFORUM ***8*** *(2016) [2] and in J. Ceram. Sci. Tech.* **6** *(2016) [3].*
The results of the first period (2009–2011) have already been published in refractories WORLDFORUM ***4*** *(2012) [1] 85–186.*