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Refractories, Composites and Recyclates: Approaches for Sustainability and Strategic Sovereignty

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Abstract. The challenges of today´s world such as scarcity of energy and resources, turbulent political situation as well as environmental aspects demand for a re-thinking in view of strategical sovereignty in Europe. There is an urgent need to strike new pathways, towards recycling and upcycling as well as towards development of new advanced materials and technologies enabling to respond quickly to changing environments. The presented paper depicts selected approaches to address such challenges in the field of high temperature materials. Recent examples include novel concepts for electrification of the ceramic, cement and metal processing industries using new developed electrodes based on refractory composite materials and/or using hybrid heating systems such as microwave plasma torch, concepts for non-premixed combustion of ammonia in porous inert media additive manufactured from composite ceramic materials as well as innovative concepts for recycling and upcycling of carbon bonded refractory materials.

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The Role of Additives in Developing an Efficient High Performance Castables Resistant to Explosive Spalling under High Temperatures

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Abstract. CAC is a kind of special high-performance inorganic cements and usually used in the monolithic refractory materials as a hydraulic binder due to its high reactivity, high early strength, setting at low temperatures, short setting time, high refractoriness and good resistance to chemical attack. The high-temperature resistance of CAC is above 1580°C. The cement anhydrous phases (CA, CA_2 and $C_{12}A_7$; C = CaO, A=Al_2O_3) can produce a variety of hydration products of the C-A-H-type (H = H_2O). Different compounds including thermodynamically metastable CAH_{10} (< 10-15°C), C_2AH_8, C_4AH_{13-19} (between 15 and 30°C), and thermodynamically stable C_3AH_6 (> 30°C) hydrates, and aluminum hydroxide (AH_3 or $Al(OH)_3$ phase) can be formed. Density and crystal shape influence the further explosive spalling resistance of monolithics. CAH_{10} (1720 kg/m^3 density) has tiny hexagonal prisms shapes at the early stages of hydration, C_2AH_8 (1950 kg/m^3 density) forms the hexagonal large plates, whereas the C_3AH_6 hydrate (2520 kg/m^3 density) has a cubic structure (Table 1). Generally, monolithics cured at temperature below 10°C tend to explode during their first heating, due to the CAH_{10} hydrate having the highest content of combined water and close compact microstructure. Nevertheless, the type of hydrates formed and their conversion process can be directly connected with the calcium aluminate cement type, time, temperature, water availability, additives and water vapour pressure.

TABLE 1. Density of CAC hydrates[1]

Phase	Density (kg/m^3)	Combined water (%)
CAH_{10}	1720	53
C_2AH_8	1750	40
C_3AH_6	2520	28
AH_3	2400	35

It is well known that the mechanical strength and further spalling resistance of monolithics under conditions of rapid heating are closely related to the hydration degree, the hydrate type and the microstructure evolution during the cement hardening process. Therefore, the hydration behavior of CAC is a key factor of affecting these properties of monolithics. Hence, the main aim of this work is to investigate the effect of different additives on early hydration of CAC. The effect of additives on the explosive spalling resistance of castables heat-treated from room temperature to 600°C will be also discussed.

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1. "Development of innovative refractory castables and technology for the production of precast shapes based on these castables" No. POIR.01.01.01-00-0864/18-00,
2. “Development of the technology of high-performance, cement-free refractory castables for industry” No. POIR.01.01.01-00-1645/20-00, co-financed by the European Union through the European Regional Development Fund from the Smart Growth Operational Program 2014-2020.

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Statistical Analysis of Selected Mixtures of Alkali-activated Materials Exposed to Thermal Stress

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Abstract. Alkali-activated materials have come to the forefront of interest of construction experts in recent decades. It is a composite material, an alternative to concrete, where the binder component can be, instead of ecologically disadvantageous cement, a by-product (with pozzolanic or latently hydraulic properties) of some industrial processes. The work is focused on the statistical analysis of the compressive strength of alkali-activated materials exposed to temperature stress, where the first part contains three mixtures of alkali-activated composites that were subjected to frost resistance tests, and the second part follows the functional dependence of the compressive strength of given mixtures of alkali-activated systems on exposure to high temperatures with by choosing the optimal statistical model.

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Refractory Recycling: A Contribution for Raw Materials, Energy and Climate Efficiency in High-Temperature Processes (GRK 2802)

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Abstract. Every year, approximately 28 million tons of used refractories are generated worldwide. The majority of the consumed refractories are primarily used for foreign applications, such as aggregates for road construction (downcycling) or deposited in landfills. The recycling of such materials played a rather subordinate role until now. For ecological reasons and due to the risen landfill costs, an increased research potential to deal with the application of refractory recyclates was identified in the last few years. The objective of the Research Training Group GRK 2802 is to research and develop new sophisticated recycling options for used refractories. Within the scope of the Research Training Group, fundamental knowledge should be developed, allowing both the recycling (re-utilization in similar high-temperature materials) and the upcycling (material upgrading) of refractories in metallurgical processes.

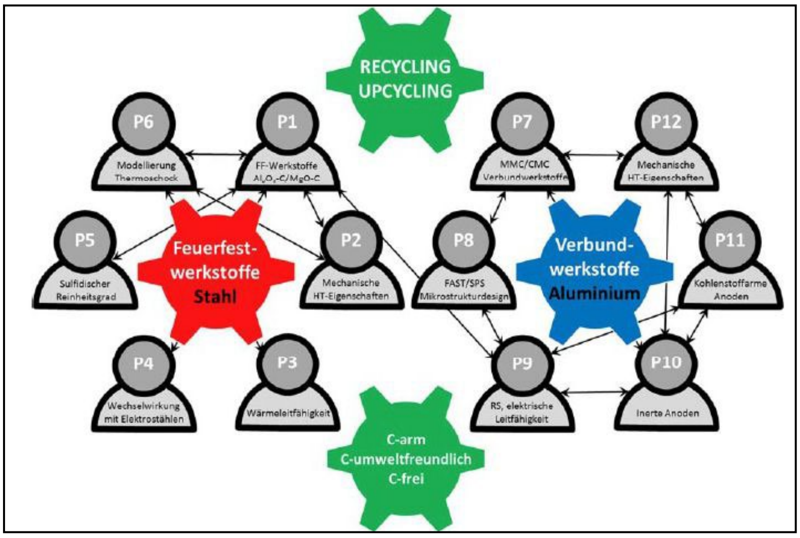

FIGURE 1. Scheme of the interconnectivity of the projects.

The main objectives of the GRK 2802 are an interdisciplinary and structured training of PhD students in the fields of recycling and upcycling of refractories as well as the research and development of a new generation of coarse-grained high-temperature materials based on refractory recyclates with particular functional properties for high-temperature processes in the metallurgy (figure 1).

This will be applied to 2 core ideas:

1. Core idea I: Recycling - Novel refractories based on refractory recyclates and environmentally friendly binders (resin-free, pitch-free) with an application as lining material for steel ladles
2. Core idea II: Upcycling - Novel composites based on refractory recyclates with an application as electrode material for aluminium fused-salt electrolysis

The interdisciplinary team of the Research Training Group GRK 2802 comprises 12 PhD students, 1 Mercator Fellow, 12 Principal Investigators and several Associated Members. The training and qualification programme of the Research Training Group GRK 2802 is being developed and organised by a scientific coordinator. The administrative coordinator is responsible for the fund management and accounting.

The presentation will provide insights into the technical motivation of this long-term project and will give an overview of the results of each subproject of the past one and a half years.

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Slurry Infiltrated Fiber Castable

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Abstract. Slurry infiltrated fiber castable is type of composite material utilizing steel fiber in refractory castable matrix. The amount of steel fiber addition to fiber reinforced refractory castable is usually between 0.5 to 3 % of castable. In slurry infiltrated fiber castable it is possible to add the amount of steel fibers up to 25 % of castable. The main advantage of high steel fiber addition is enormous increase of modulus of rupture. For this reason, influence of amount of steel fibers to the modulus of rupture, cold crushing strength of castable were studied. There were also tested two types of steel fibers and influence of thermal treatment temperature. The results show the massive improvement of mechanical properties as the amount of steel fibers rise.

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Calibration and Application of DEM Modelling in the Development of 3D Printing Processes for Silicate Materials

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Abstract. While 3D printing of ceramic materials is not as established as polymer printing or metal additive manufacturing, it holds significant promise for the future. The current challenge lies in refining the design and process technology of 3D printing equipment specifically tailored for silicate materials, as well as advancing the development of new silicate compounds suitable for 3D printing. This crucially involves tackling the processing and flow characteristics of the visco-elastic material (clay suspension). The mixture may exhibit widely varying properties during homogenization, transport, and extrusion of the silicate material from the nozzle, influenced by factors like particle size or fluctuating water content. In recent years, Discrete Element Method (DEM) modelling has gained popularity in the design of bulk material conveying and storage systems. While not conventionally used for particulate materials, this method, employing interparticle bonding, can be applied in the process of 3D printing of silicate materials. The primary objective is to calibrate the properties of a material and validate its behaviour within technological processes, ensuring that the resulting simulations provide as much information as possible. This work proposes general calibration procedures for employing DEM modelling in 3D printing of silicate materials, aiming to enhance understanding and optimize the printing process for these innovative materials.

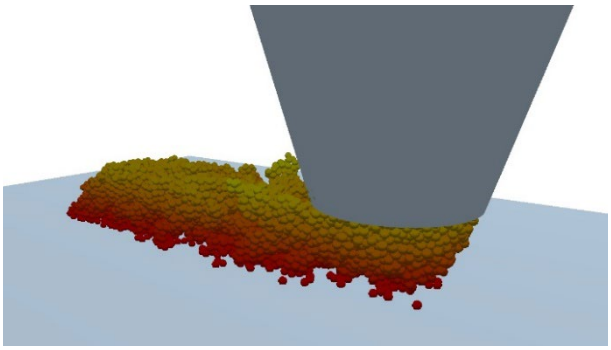

FIGURE 1. Simulation of 3D printing process of silicate materials via Discrete Element Method.

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Shaped Insulating Refractories Based on Rice Husk Ashes Functionalized with a Flame-Sprayed Alumina Coating for Steel Ingot Casting

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Abstract. Traditional refractory materials used in steel ingot casting, particularly those containing free silica, often interact with the steel melt, leading to the formation of non-metallic inclusions. While acceptable for lower grade steel products, higher-grade steel necessitates superior cleanliness. Within this study, a new refractory insulating material derived from renewable resources, specifically rice husk ash (RHA), is investigated for its usage in high-temperature applications. Leveraging the high thermal insulation of RHA, this material may significantly improve the heat and energy balance during ingot casting. However, achieving chemical inertia against the steel melt requires a functionalized ceramic coating applied via flame spraying.

The refractoriness, oxidation resistance, phase evolution and thermal expansion of four different grades of RHA materials and phase evolution and thermal expansion of flame-sprayed alumina coatings are studied. Moreover, the feasibility of applying flame-spray coatings on RHA substrate materials is investigated, assessing layer bonding via pull-off tests.

The refractoriness of the RHA materials increased with increasing silica content, showing sufficient refractoriness up to 1600 °C for SiO_2 > 94 wt%. Immersion tests with composite materials made from RHA substrate and flame-sprayed alumina coating were successfully performed in a steel casting simulator. No deformation of the substrate material nor spalling of the flame-sprayed alumina coating was observed despite an immersion without preheating.

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Utilization of Sol Gel Technology in Refractory Castables Manufacturing

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Abstract. The utilization of the sol-gel method as an alternative binder to the standard hydraulic bond has been at the forefront of refractory materials research for past several years. There are already a number of products on the market that apply the principle of binding using colloidal solutions, most often silica based, but there are also alumina or mullite based colloidal solutions.

We most often encounter the use of sol-gel binding in refractory castables applied by shotcreting, or in prefabricated shapes, less so in lightweight insulating materials or hydraulically pressed materials (dense and lightweight).

In collaboration with the Faculty of Chemistry of the Brno University of Technology, refractory materials using sol-gel binding were developed as part of a project subsidised by Czech Technology Agency. Specifically, it was a dense refractory castable shape, a lightweight refractory castable shape, and a shotcrete mixture.The paper describes experiences with the sol-gel method, not only in the specific project, but also in refractory production in general.

Keywords. refractory castables; sol gel method; precast shapes; dense refractory products; insulation refractory products; shotcreting

Organic Admixtures in 3D Printed Fired Ceramics and their Effect on the Porosity and Permeability of the Material Applied for Interior Elements that Increase Air Humidity

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Abstract. This project delves into the exploration of enhancing indoor humidity through the use of 3D-printed fired ceramic objects, crafted with a robotic arm (UR10/UR5) and an LDM extruder. The primary research objectives extend beyond the application of interior elements solely for increasing indoor humidity; it also encompasses considerations for plant cultivation. The research is distinctly focused on two key realms: 1) materiality, and 2) design and shape tectonics, both intricately intertwined with the chosen technology, namely 3D printing of ceramics. The refinement of shape and material is informed by data derived from meticulous observations, measurements, and experimental endeavors.
Materiality, the initial focal point, delves into the porosity and absorbency of the chosen ceramic material.[1] Incorporating organic additives, which dissipate during the firing process, influences the material's open and closed porosity.[2] Various waste fibrous materials, distinguished by different width-to-length ratios, serve as organic additives. Assessments explore the impact of these materials on water absorption, buoyancy, and the subsequent release of water into the environment. Compatibility with 3D printing is concurrently investigated, considering factors such as viscosity and immediate stability.[3]
The second realm of interest concentrates on the tectonics and design of the objects, aligning with the unique possibilities and requisites of 3D printing technology. This technology enables the production of articulated shapes, with larger surface areas potentially facilitating greater evaporation of water into the surrounding air.[4] Three distinct shapes, varying in complexity, are scrutinized.
Objects, constructed from diverse material mixtures, undergo placement in controlled indoor environments for subsequent measurement and comparison of humidity and temperature levels. Preliminary findings establish a direct correlation between material porosity and water absorption, demonstrating the material's efficacy in releasing water into the environment.

FIGURE 1. 3D printed ceramics with additives.

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Measurement and Modeling of Elastic Properties and Thermal Conductivity of Silica Refractories

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Abstract. Silica refractories are traditional shaped refractory materials with well-established niches of application (e.g. coke ovens and roof constructions of glass melters). Based on a classical application in the iron and steel industry (hot blast stoves), a more recent application of silica refractories concerns advanced high-temperature thermal energy storage aggregate systems. For this application the mechanical and thermophysical properties of silica bricks must be thoroughly known. Despite the compositional and microstructural simplicity of silica refractories, it is well known that the temperature dependence of elastic properties is highly complex. In particular, when the temperature dependence of Young's modulus, as measured via the temperature-dependent impulse excitation technique (IET), exhibits elastic anomalies at relatively low temperature (around 200 °C) that are related to the phase transitions of the low-temperature phases of tridymite and cristobalite[1], an overall increase of Young's modulus during heating and a significant hysteresis in heating-cooling cycles.[2-7] Depending on the maximum temperature achieved, the IET curves may or may not indicate damage accumulation after cooling down to room temperature. In this contribution, we study the temperature dependence of Young's modulus for repeated heating-cooling cycles with different maximum temperatures. It is shown that only for sufficiently high maximum temperatures damage accumulation can be avoided. The new concept of differential IET (DIET) curves is used to represent the results in a form that makes phase transitions and microstructural changes more easily discernible. On the basis of analytical predictions and numerical calculations on computer-generated model microstructures (proxies) it is shown how the elastic constants of silica refractories at room temperature can be predicted and how the changes in elastic properties during heating and cooling can be explained by changes in the phase composition and microstructure of silica refractories. The second part of this contribution is focused on the thermal conductivity of silica refractories. Also, in this case measurements using a transient plane source (TPS) technique are compared to analytical and numerical predictions.

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Research of the Sintering Process of no Cement Refractory Concretes with Dead Burned Magnesia Filler

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Abstract. Sol-gel refractory concretes have many advantages compared to ordinary cement concretes. One of the main factors limiting the use of these concretes is their low resistance to basic slags. This is mostly due to the impossibility of using magnesite raw materials resistant to basic slags, due to the fact that MgO causes almost instantaneous coagulation of the gel. A possible solution to this problem could be the reproduction of a recipe that does not contain finely ground magnesium oxide, but only large grains. To continue research in this direction, it is important to understand how the interaction between concrete components occurs during its sintering. This work presents the results of the study of the interaction of pure oxides ground to a powder state, as well as the interaction of the binder with the filler during heating to a temperature of 1400 °C.

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Utilization of MgO-C Refractory Recyclate in New Generation of Composites

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Abstract. This contribution deals with utilization of MgO-C-based recyclate in two types of composites. The first application wass focused on reuse of the MgO-C recyclate as a raw material for MgO-C bulk samples, partially replacing fresh raw materials such as pure MgO and graphite. This experiment also included implementation of environment-friendly binder based on lactose and tannin instead of pitch- or resin-based binder. The objective was the investigation of their influence on the resulting physical and mechanical properties. The binder system showed reliable binding properties, although the recyclate-containing MgO–C exhibited higher porosity, slightly lower density, and lower strength compared to the reference batches without recyclates.

The second approach dealt with utilization of MgO-C-based recyclate as a supplementary alternative filler material in construction composites replacing the ordinarily used silica sand filler. Furthermore, the matrix used in this experiment was based on magnesium oxychloride cement (MOC), an eco-friendly alternative to the commonly used Portland cement. To reach the best possible material properties, two different size fractions were applied in various ratios, completely replacing quartz sand. A comprehensive analysis of all composite material samples was conducted utilizing various analytical techniques, XRD, SEM, EDS or STA-MS. Mechanical properties such as compressive strength, flexural strength, and Young's modulus of elasticity were evaluated.

Together, these two approaches show a broad application potential of end-of-life MgO-C refractories, which would otherwise end up landfilled.

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Technical Aspects for Durable Fiber Modules Linings

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Abstract. Reheating Furnaces requiring stable insulation systems for temperatures in range of 1200°C to 1350°C. Next to temperatures these furnaces struggle with pollutions from the steel which are degradation the fiber chemistry over time. Next to the high temperatures and pollution there is also the cycling element as the furnaces open after heating period of 16-24 hours whilst furnace is at temperatures. A part of standard design of modules Vulcor supplies special futures modules for higher working temperature and/or better chemical resistance like monolithic Solibloc (1300°C), high density Solibloc PRO (1300°C) as well as PCW/RCF hybrid SoliStack HY (1430°C) which have found wide acceptance on the market Whan of important reason of customers' approval is controlled shrinkage over time when furnaces are operating over 1250°C. In this paper we will explain why.

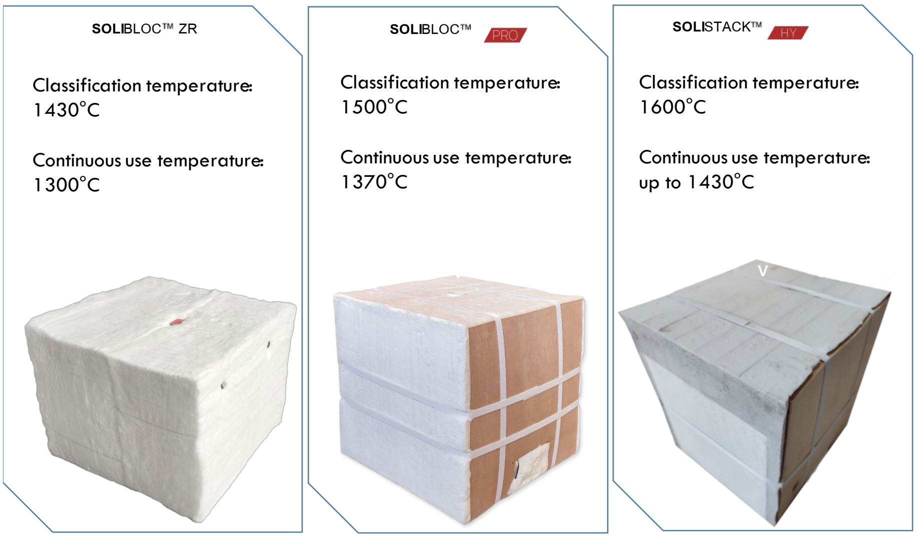


FIGURE 1. Vulcor special futures modules

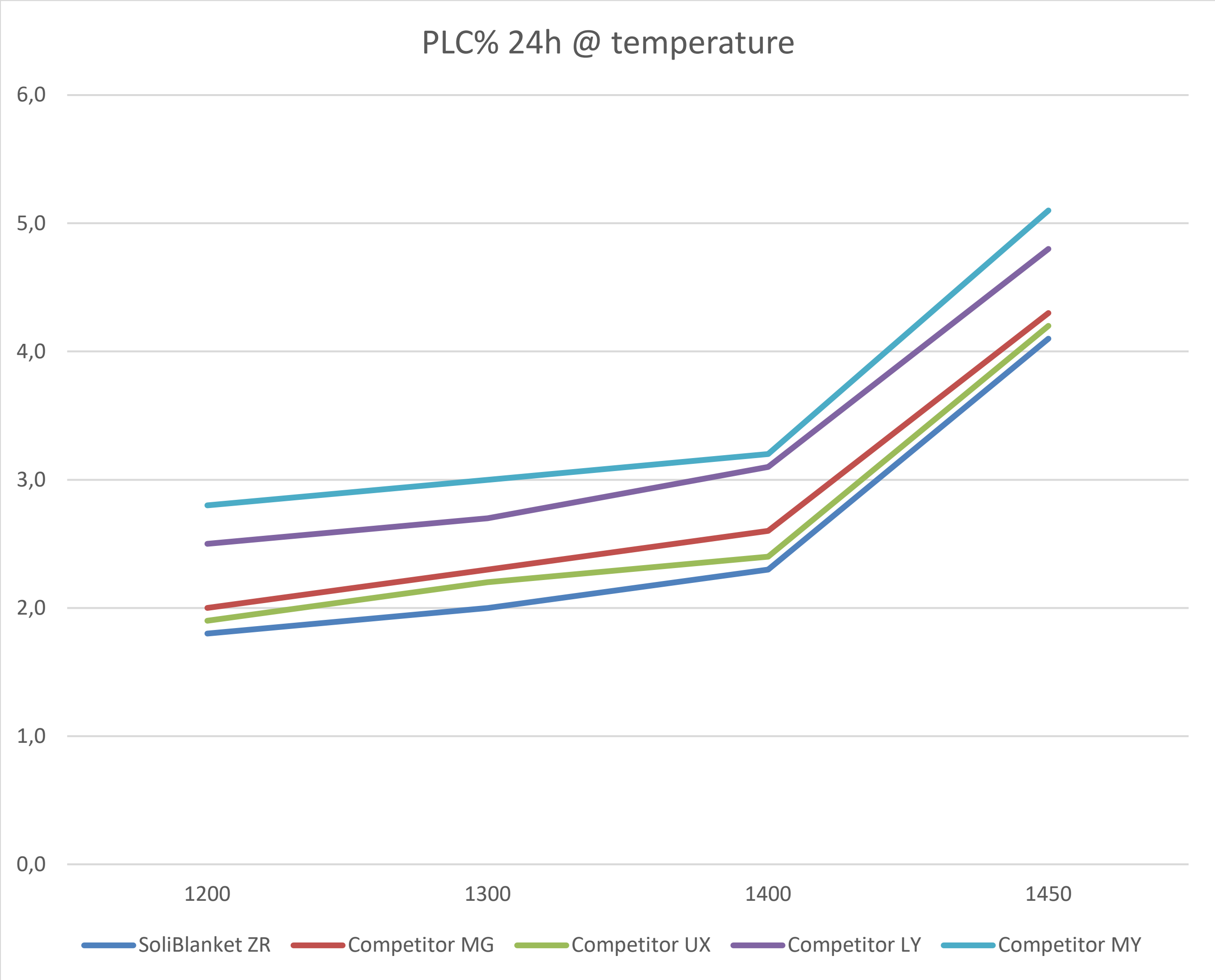


FIGURE 2. Comparative shrinkage testing RCF1430

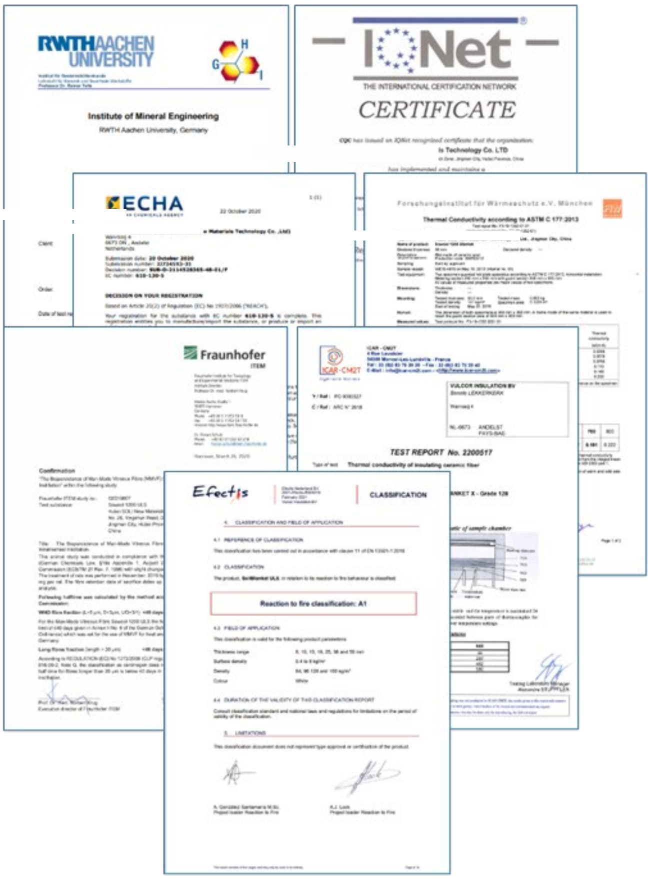
TABLE 1. Comparative shrinkage testing RCF1430

°C / %	SoliBlanket ZR	Competitor MG	Competitor UX	Competitor LY
1200	1,8	2,0	1,9	2,5
1300	2,0	2,3	2,2	2,7
1400	2,3	2,6	2,4	3,1
1450	4,1	4,3	4,2	4,8

ACKNOWLEDGMENTS

Properties given validated by external testing like RWTH Aachen. As we can depend on our superior, Generation III, fiber technology we can be assured that every bit of testing we do, typically results in the expected properties. Our factory is ISO 9001 certified and has an extensive laboratory validating the product properties of each batch before dispatching the product to the customer. This ensures that whatever you are receiving, will meet expectations.

We are one of an exclusive group of suppliers which have completed REACH registration and for that reason comply with the European regulations. Our low bio persistence fibers (ULS) meet the requirements specified under NOTE Q of European Regulation 1272/2008 and have been fully tested by Fraunhofer.



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From Design to Commissioning – The Lower Part Lining of Alu Furnaces Made of Large-scale Prefabs

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Abstract. Lining designer, producer of refractories, installation worker and device operator - each of these people has a different perspective on things, different experience, and faces different problems in his work. Nevertheless, only their close cooperation can create an innovative solution that pushes the boundaries of technical practice. The presented paper was also created through the cooperation of the designer, manufacturer and installation company. It maps the emergence of a solution for the lower part lining of melting and holding furnaces, the basis of which are pre-dried large-scale castable prefabs. The paper describes the entire process from the first sketches to commissioning, including the differences in the point of looking at things of individual participants and the main problems they are facing in the individual phases of the project.

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Ahead of Time: Providing a Full Cycle of Material Recycling from Demolition to Circular Products

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Abstract. Heading towards a greener future, companies are forced to improve their carbon footprint and environmental indicators. SEBOREF Minerals, active in demolition of industrial furnaces and REF Minerals, a dedicated recycling company, help the glass, fiber glass, cement and lime manufacturing industry, as well as the refractory and ceramic industry to save money and being sustainable, by taking care of demolished waste and providing circular products to substitute primary raw materials.

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Properties of 3D Printed Ceramic

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Abstract. Additive technologies are now a common part of production process in many industries. In Czech Republic, ceramic 3D print is not a standard technology for industrial production. The current experience in 3D ceramic printing is based primarily on testing the technology in laboratory conditions.3D printing is an additive process of creating three-dimensional objects based on digital data. The printer can work on different principles depending on the print material and final product. The custom-made set of 3D printer is supplemented by necessary devices. The device is built on an open-source RepRap architecture. The experiments compare the resulting properties of ceramic samples which were prepared by pressing, casting and 3D printing method. By joining two workplace Department of Thermal Engineering and Department of Robotics is aim better mechatronic system and innovation of existing printer. The aim of is to print both complicated and simple shapes which are commonly produced in engineering industry. Tested different type of ceramic mixtures and evaluation final ceramic properties.

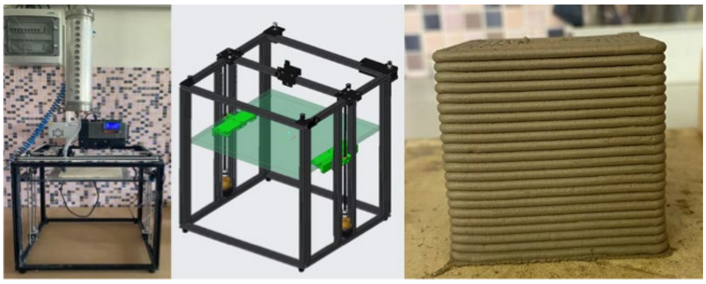

FIGURE 1. The existing printer before reconstruction

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Ceramic Glazes by Recycling Waste

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Abstract. The study deals with the preparation of waste glazes for ceramics. The main goal of the experiment is to use waste products from the metallurgical industry, e.g. slag, construction industry (bricks, consrete etc.), fly ash, ash after biomass combustion, waste glass and prepare pigments, which are then mixed with other commercial glazes. The second way is prepard mixtures with combiation of different waste withou commercial glazes. These glazes applied to the ceramic body. The aim is thus to replace natural resources or eliminate the synthetic preparation of expensive glazes. To set the firing conditions so that the surface of glazes are without the defects.

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Reducing Brucite Formation and Cracking in Magnesia Castables: The Impact of Microsilica and Drying Agent

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Abstract. Magnesia-based castables have long been problematic due to in-situ crack formation during the curing and drying of samples, attributed to the formation of magnesia hydroxide, commonly referred to as brucite ($Mg(OH)_2$). This study investigates the use of microsilica, along with a specialty product called SioxX®-Mag and a unique polymorphic fiber called EMSIL-DRY®™, in a magnesia castable to enhance its anti-hydration properties and drying behavior. Evaluation methods such as X-ray diffraction (XRD) and scanning electron microscopy (SEM) micrographs were also used to assess the anti-hydration mechanism of magnesia in the castable. Additionally, an industrial-scale thermobalance (Macro-TGA) was utilized to understand the drying behavior of magnesia-based castables and to design a proper heating profile for large industrial-scale samples. The results demonstrate that the inclusion of the specialty drying agent EMSIL-DRY™, combined with an optimized heating profile, facilitates faster water release during the early stage of dry-out and reduces the water/steam available for brucite formation during the heat-up process. Using this approach, perfect 600 kg blocks of MgO castable were produced with no cracking during dry-out. The results also show that the combination of microsilica and SioxX®-Mag functions as an efficient anti-hydration agent, and that efficient water removal using this unique fiber during dry-out is necessary to reduce brucite formation by lowering the water vapor pressure inside the refractory body. These findings provide valuable insights into the formulation and processing of magnesia castables for efficient and reliable use in the steel-making process. The study offers valuable information for refractory manufacturers and steel producers to improve the quality and durability of magnesia castables used in their operations.

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The Benefits of Using an Advanced Materials for Producion of Spherical Impact Pad in Tundish

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Abstract. The primary objectives of our materials research were to develop a material that can withstand long-term exposure to the dynamic environment of liquid steel without deforming the surfaces that control the flow of prefabricated components, particularly those used in the steel inflow area of the tundish. We aimed to create a mixture for producing prefabricated components with the lowest possible energy consumption and carbon footprint. To achieve these goal, we abandoned the idea of producing prefabricated components using LCC and ULCC concrete due to their clear drawbacks, especially regarding points 1 and 2. Instead, we focused our research on preparing cement-free mixtures using a binder created through the sol-gel method. These mixtures demonstrated good resistance to corrosion caused by casted steel.

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Investigation of the Influence of Selected Additives on Non-Wetting Effect and Corrosion of Cementless High-Alumina Refractory Castable with Sol-gel Bond for Use in the Production of Primary and Secondary Aluminum

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Abstract. In the current practice of aluminum production, whether primary or secondary, overgrowing of the melting space of aluminum furnaces and simultaneous degradation of refractory lining formed by aluminosilicates are frequent problems. The classic manifestation is the formation of a corundum mushroom in the area of contact of the aluminum melt level with a refractory lining and a free atmosphere, and at the same time corrosive degradation of the refractory lining under the aluminum one. These phenomena in both cases are caused by the presence of SiO_2 in refractories, its reaction with other components present in refractory systems with its subsequent decomposition and the formation of Al_2O_3 with the formation of growths, or corrosion of lining under the aluminum melt. To suppress these phenomena, non-wetting additives such as $BaSO_4$, CaF_2 or AlF_3 are used. The subject of our paper is to investigate the influence of these additives in cementless refractory concrete mixtures using silicate and silicate-aluminate sol-gel binding method.

Key words. non-wetting agent; sol-gel; castable; corundum; growth; erosion; molten alumina

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Data-Based Carbon Footprint and Roadmap Towards Net Zero of Imerys Specialty Minerals for Refractories

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Abstract. Since sustainable product offerings are key for achieving national, EU and global CO_2 reduction targets, it all starts with a data-based evaluation of the current CO_2-footprint of existing products and their production processes including the energy input, in order to create the base line for the reduction targets. This needs to be done through transparent and scientifically proofed and internationally recognized calculation methods to create comparable data that allow purchasers and product developers making decisions. This paper will explain in detail the boundaries for the quantification of the CO_2 equivalents of Imerys specialty minerals for refractories. Here we can build on our long-lasting experience with the eco-profiling of calcium aluminates and environmental product declarations. [1] The analysis leads to product-specific scientific data-based CO_2 equivalents[2] that allow a transparent calculation of the footprint of refractory products formulated with it. This paper will concentrate on some Imerys specialty minerals and highlight the impact of different contributors, including the energy sources, on their carbon footprint. A process flow chart for the manufacturing of chamotte is exemplary shown in Fig. 1. It details the different steps from clay extraction in the mines to the final calcined product ready for shipment to customers. At each step the environmental impact needs to be evaluated in detail. Thanks to its effort to turn to low-emission energy supply, Imerys is capable of reducing its footprint significantly. By providing more sustainable solutions it fulfills its purpose to contribute to the decarbonization of the refractory value chain. Furthermore, an outlook will be given on potential routes to achieve the mid- and long-term targets towards net zero CO_2 emission.

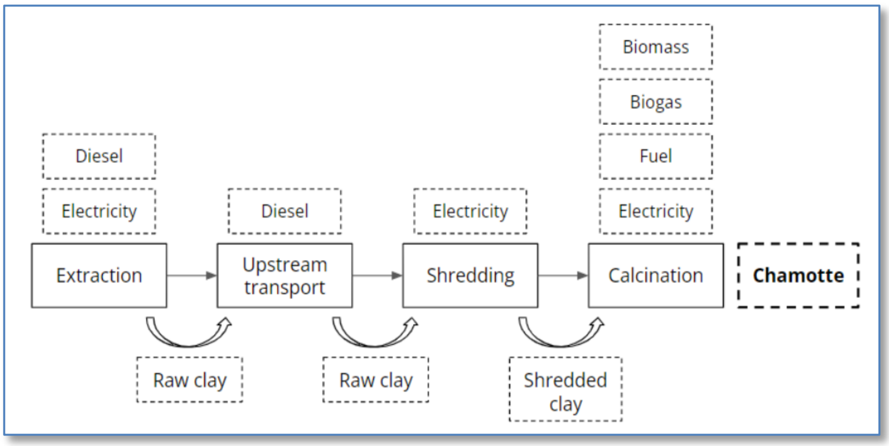

FIGURE 1. Imerys chamotte manufacturing process

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Silicon Carbide Ceramics for Ultra-High Temperature Applications

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Abstract. Freeze-granulated silicon carbide powder was densified to the full density without any sintering aids by rapid hot-pressing at temperatures from 1850 °C to 1900 °C. This densification temperature is at least 150-200 °C lower compared to the up to now known solid state sintered silicon carbide powders. This way prepared material has a high thermal conductivity of almost 200 W/mK. Static and dynamic oxidation resistance of this way prepared ceramics is excellent. The static oxidation (parabolic rate constant) at 1450 °C for 204 h was 4.9×10-5 mg^2/cm^{4}h, which is almost negligible in comparison to the parabolic rate constant 7.0×10^{-5} mg^2/cm^{4}h of the LPS sintered SiC materials. In the dynamic regime the ceramics sustained 1900 °C for 60 s without substantial damage, weight loss was only 0.2 %. When the oxidation was prolonged to 300 s the damage was visible but still not crucial, weigh loss was 1.6 %. It seems that this material is really suitable for ultra-high-temperature applications.

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Coating of the Ceramic Cores

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Abstract. A ceramic core is a tool for making cavities and holes in the Investment Casting technique. The core surface has an important impact on the surface quality of the casting. Controlled interactions between the ceramics and the molten metal of the casting are one of the monitored properties of the cores. The thin surface layer of carefully chosen stable oxides minimizes interactions. A core coating moves up the core use for demanding applications.

Modelling and Measurement of Elastic Properties and Thermal Conductivity of Porous High-Alumina Refractories

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Abstract. High-alumina refractories based on mullite and / or sillimanite are traditional shaped refractory materials with many well-established applications, and their porous varieties are ideally suited for high-temperature thermal insulation purposes. Therefore they are potential candidates for the insulation of advanced high-temperature thermal energy storage aggregate systems. For this application the mechanical and thermophysical properties of porous high-alumina refractories must be thoroughly known. In this contribution we build on the extensive detail knowledge available for mullite[1] and mullite-based ceramics, including partially sintered and porous mullite-based ceramics[2,3] and mullite-based ceramic foams[4,5] and apply this knowledge to commercial mullite- and sillimanite-based high-alumina refractories with high porosity and hierarchical microstructure. In particular, based on the phase composition (determined via XRD) and the microstructure (determined via X-ray computed microtomography) the effective properties (elastic properties and thermal conductivity) are predicted analytically (via micromechanical bounds and model relations)[6,7] and numerically (on the basis of binarized digital microstructures) and compared with experimentally measured values. Experimental measurements of elastic properties have been performed via the impulse excitation technique (IET) and ultrasound wave propagation[8,9], while the thermal conductivity has been determined from the thermal diffusivity measured via a transient plane source (TPS) technique. The correlation of relative Young's modulus and thermal is compared with a simple cross-property relation, and the temperature dependence of Young's modulus, as measured via the IET, is compared with previous results for alumina-containing mullite ceramics[2,3].

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Use of Recycled Raw Materials for the Production of Refractories

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Abstract. The use of recycled raw materials for the production of refractory materials is nothing new for producers. Every producer tries to process their own scrap from the production of bricks, both raw and fired, for the production of new products. Also, the economic motivation of reducing production costs has always contributed to the fact that producers looked for ways to replace original raw materials with recycled ones, which in most cases are cheaper. However, there was no need to report the amount of recycled materials processed anywhere. The current economic and political situation and the drive for sustainability have increased the potential of using recycled materials as a technical, economic and especially ecological challenge. Producers of refractory materials are trying to increase the "Recycling rate" in order to reduce the CO2 carbon footprint of their products.

When we talk about recycled raw materials, most often there is an effort to process already used refractory materials from demolished linings, from various industrial applications. However, these materials must be thoroughly cleaned and sorted, then there is a wide possibility of their use, especially in the production of new bricks and shapes. There is a certain limitation in the use of these materials for the production of, for example, high-quality plasticized refractory castables of the LCC type; ULCC and NCC, where we need to achieve the required rheological properties to guarantee the parameters of these refractory castables. Recycled raw materials can also be by-products or secondary raw materials from other or related industries. We also use some of these recycles because they can be used to achieve advantageous properties in the manufactured materials.

The article highlights various types of recycled raw materials, used linings, but also fragments from the ceramic industry, by-products from metallurgy and presents their use for various materials produced at the RHIM in Velké Opatovice.

Keywords. Recycled raw materials; by-products; secondary raw materials; refractory materials; linings; shapes and bricks; plasticized refractory castables

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Rapid Determination of the Thermal Conductivity Coefficient of Insulating Materials

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Abstract. Currently, there is intensive development in the field of renewable energy sources, especially photovoltaics, whose share is growing by tens of percent on an annual average. These trends will cause dramatic changes in the energy sector, and one of the ways to address this situation is high-temperature heat storage. The aim of this research was to find materials suitable for high-temperature technologies in energy industry. Attention was paid to two directions: insulation materials for high-temperature applications and storage materials. The article describes the original methodology for quickly determining the thermal conductivity coefficient and the application of this method to a series of samples. From the results obtained, it is clear that the most suitable in terms of maintaining the largest thermal content (sensible heat, enthalpy) appears to be the use of insulation with a minimum value of the thermal conductivity coefficient and at the same time, the lowest value of the temperature conductivity coefficient, which ensures slower temperature equalization between the reservoir and the insulation, because the primary goal is to maintain the thermal potential of the reservoir at a usable value. The article also shows that there are possible material modifications to improve both insulating and mechanical properties of materials.

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Influence of the Ca-content of MgO-based Resin Free Tundish Working Linings on the Population of Non-metallic Inclusions in a Steel Melt

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Abstract. State-of-the-art magnesia-based dry vibrateable tundish linings are predominantly bonded by resin. However, besides high energy consumption, the pyrolysis of the resin-containing lining during the tundish heat-up process generates hazardous gases and carbon residues, resulting in an unwanted carbon pick by molten steel after the finished ladle treatment. For water-based or spray-coated tundish linings, similar energy consumption can be anticipated since the remaining water of the hydraulic bonding need to be removed during the heat-up process to avoid damage of the lining by released steam or H_2 dissolution by the steel melt. In contrast, their exist binders with a cold or low-temperature bonding behavior such as sol/gel, acid-base, or thermally (low temperature) activated systems. Hence, the aim of this study was to combine acid-based with thermally activated binders to develop new resin-free tundish linings. Ca-containing chemicals/hydrates as well as organic acids were used to promote the thermally activated acid/base bonding reaction. Their influence on the physical and mechanical properties such as density and compressive strength of the lining was investigated. Additionally, utilizing a unique steel casting simulator, the influence of newly developed lining compositions on the steel quality was tested and analyzed. Results showed that the reaction time is strongly dependent from the solubility of the acids. The influence on the inclusion population in molten steel as well as the elemental composition of the steel was evaluated. Newly developed compositions showed no significant influence on the steel cleanliness, only a minor change in the population could be detected.