Contents

PREFACE xxi

**Advanced Installation Techniques and Equipment**

DEVELOPMENT OF AUTOMATIC REPAIR TECHNOLOGY BY CONTINUOUS AND QUICK MIXING TECHNOLOGY
Junichi Tsukuda, Hiroyuki Itoh, Youichi Furuta, Kazunori Seki, Seiji Hanagiri, Takayuki Uchida, Satoru Itoh, Seiji Asoh, and Sakae Nakai

DEVELOPMENT OF CONTINUOUS QUICK MIXING & REPAIRING TECHNOLOGY
Satoru Itoh, Seiji Hanagiri, Takayuki Uchida, Hironori Takeuchi, Hisashi Nakamura, Seiji Asoh, Hiroyuki Itoh, Youichi Furuta, Kazunori Seki, Junichi Tsukuda, and Sakae Nakai

THE NEXT GENERATION OF MONOLITHIC INSTALLATION TECHNOLOGY: CONTINUOUS MIXING OF LOW CEMENT CASTABLES FOR WET SHOTCRETING APPLICATIONS
Josh Pelletier, Charles Alt, Chris Parr, Jim Farrell, and Tripp Farrell

TAPHOLES REPAIR ON CSN'S BLAST FURNACE 3: CORE & CAST AND CORE & PLUG*

GUNNING ROBOTS FOR THE HOT REPAIR
Christian Wolf

**Advanced Testing of Refractories**

CHARACTERIZATION METHODS OF ZIRCONIA AND THE IMPACT OF STABILIZING AGENTS ON ITS FUNCTIONALITY
C. Bauer, B. Rollinger, G. Krumpel, O. Hoad, J. Pascual, and N. Rogers

CHARACTERIZATION OF THE MECHANICAL BEHAVIOR OF MAGNESIA SPINEL REFRACTORIES USING IMAGE CORRELATION
Y. Belrhiti, A. Germanneau, P. Doumalin, J.C. Dupré, O. Pop, M. Huger, and T. Chotard

TEMPERATURE DEPENDENT THERMO-MECHANICAL BEHAVIOR OF NOVEL ALUMINA BASED REFRACTORIES
A. Böhm, E. Skiera, C.G. Aneziris, S. Dudczig, and J. Malzbender

*NOTE: A bold title indicates that the paper was peer-reviewed.
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>THERMO-MECHANICAL CHARACTERISATION OF MAGNESIA-CARBON REFRACTORIES</td>
<td>53</td>
</tr>
<tr>
<td>BY MEANS OF WEDGE SPLITTING TEST UNDER CONTROLLED ATMOSPHERE AT</td>
<td></td>
</tr>
<tr>
<td>HIGH-TEMPERATURE</td>
<td></td>
</tr>
<tr>
<td>E. Brochen, C. Dannert, and P. Quirmbach</td>
<td></td>
</tr>
<tr>
<td>MATERIAL SPECIFIC PROPERTIES FOR THE EVALUATION OF THE THERMAL</td>
<td>59</td>
</tr>
<tr>
<td>STRESS RESISTANCE OF REFRACtORY PRODUCTS—COmpendium AND NEW</td>
<td></td>
</tr>
<tr>
<td>INVESTIGATION METHODS</td>
<td></td>
</tr>
<tr>
<td>E. Brochen and C. Dannert</td>
<td></td>
</tr>
<tr>
<td>MEASUREMENT OF THE VOLUME EXPANSION OF SIC REFRACtORIES INDUCED BY</td>
<td>65</td>
</tr>
<tr>
<td>MOLten SALT CORROSION</td>
<td></td>
</tr>
<tr>
<td>E. de Bilbao, P. Prigent, C. Mehdi-Souzani, M.L. Bouchetou, N.</td>
<td></td>
</tr>
<tr>
<td>Schmitt, J. Poirier, and E. Blond</td>
<td></td>
</tr>
<tr>
<td>BASIC UNDERSTANDING OF PHYSICAL PROPERTIES OF CARBON BONDED</td>
<td>69</td>
</tr>
<tr>
<td>REFRACtory COMPOSITES</td>
<td></td>
</tr>
<tr>
<td>D. Dupuy, M. Huger, T. Chotard, S. Zhu, D. DeBastiani, P. Guillo,</td>
<td></td>
</tr>
<tr>
<td>C. Dumazeau, and C. Peyratout</td>
<td></td>
</tr>
<tr>
<td>THERMAL SHOCK ON THE LOWER SLIDE GATE PLATE WHEN CLOSING: TEST</td>
<td>73</td>
</tr>
<tr>
<td>DEVELOPMENT AND POST MORTEM INVESTIGATIONS</td>
<td></td>
</tr>
<tr>
<td>Renaud Grasset-Bourdrel, Javier Pascual, and Christian Manhart</td>
<td></td>
</tr>
<tr>
<td>CORROSION OF CORUNDUM-MULLITE REFRACtORIES IN GASEOUS HCl/H2O</td>
<td>79</td>
</tr>
<tr>
<td>ATMOSPHERE AT ELEVATED TEMPERATURE</td>
<td></td>
</tr>
<tr>
<td>M.M. Jafari, M. Ghanbari, F. Golestanifard, and R. Naghizadeh</td>
<td></td>
</tr>
<tr>
<td>DEVELOPMENT OF A NEW SPALLING TEST METHOD FOR BOTTOM BLOWING</td>
<td>83</td>
</tr>
<tr>
<td>TUYERES FOR BOFS</td>
<td></td>
</tr>
<tr>
<td>M. Kakihara, H. Yoshioka, M. Hashimoto, and K. Inoue</td>
<td></td>
</tr>
<tr>
<td>REFRACtORY INDUSTRY SUFFERS FINANCIAL DAMAGES THROUGH IMPRECISE</td>
<td>89</td>
</tr>
<tr>
<td>TEST PROCEDURES FOR THE DETERMINATION OF THE CORESISTANCE OF</td>
<td></td>
</tr>
<tr>
<td>REFRACtORY MATERIALS—TIME TO REVIEW ISO 12676 AND ASTM C 288</td>
<td></td>
</tr>
<tr>
<td>Olaf Krause, Christian Dannert, and Lisa Redecker</td>
<td></td>
</tr>
<tr>
<td>CURRENT SITUATION AND DEVELOPMENT OF CHINESE STANDARDS ON</td>
<td>95</td>
</tr>
<tr>
<td>REFRACtORY PRODUCTS</td>
<td></td>
</tr>
<tr>
<td>Peng Xigao, Li Hongxia, and Wang Xiaoli</td>
<td></td>
</tr>
<tr>
<td>THE INFLUENCE OF IN-SITE FORMATION SPINEL ON THE FRACTURE ENERGY</td>
<td>101</td>
</tr>
<tr>
<td>OF ALUMINA-MAGNESIA REFRACtORY CASTABLES</td>
<td></td>
</tr>
<tr>
<td>Hongbin Qin, Hongxia Li, Jianhong Wang, Guoqi Liu, and Wengang Yang</td>
<td></td>
</tr>
<tr>
<td>HIGH TEMPERATURE CHARACTERISTICS OF REFRACtORY ZIRCONIA CRUCIBLES</td>
<td>107</td>
</tr>
<tr>
<td>USED FOR VACUUM INDUCTION MELTING</td>
<td></td>
</tr>
<tr>
<td>A. Quadling, L. Vandeperre, W.E. Lee, and P. Myers</td>
<td></td>
</tr>
<tr>
<td>CHARACTERIZATION OF MAGNESIA AND MAGNESIA-CHROMITE BRICKS BY THE</td>
<td>113</td>
</tr>
<tr>
<td>USE OF DIFFERENT DESTRUCTIVE AND NON DESTRUCTIVE TESTING METHODS</td>
<td></td>
</tr>
<tr>
<td>A. Ressler, C. Manhart, and R. Neuboeck</td>
<td></td>
</tr>
<tr>
<td>INFLUENCE OF PROCESS CONDITIONS ON THE CRYSTALLIZATION OF</td>
<td>119</td>
</tr>
<tr>
<td>CALCIUM SILICATES IN THE STIRRING AUTOCLAVE AND THEIR IMPACT ON</td>
<td></td>
</tr>
<tr>
<td>THERMAL STABILITY</td>
<td></td>
</tr>
<tr>
<td>Benjamin Schickle, Thorsten Tonnelesen, Rainer Telle, Ann Opsommer,</td>
<td></td>
</tr>
<tr>
<td>Oras Abdul-Kader</td>
<td></td>
</tr>
<tr>
<td>MICROSTRUCTURAL PROCESSES IN THE WAKE REGION OF THE CRACK IN</td>
<td>123</td>
</tr>
<tr>
<td>CASTABLES CONTAINING EUTECTIC AGGREGATES</td>
<td></td>
</tr>
<tr>
<td>Jonas Schnieder, Nicolas Traon, Thorsten Tonnelesen, and Rainer</td>
<td></td>
</tr>
<tr>
<td>Telle</td>
<td></td>
</tr>
<tr>
<td>IMPLEMENTATION OF A STANDARD TEST METHOD FOR ABRASION RESISTANCE</td>
<td>129</td>
</tr>
<tr>
<td>OF REFRACtORY MATERIALS FOR TESTING AT ELEVATED TEMPERATURES</td>
<td></td>
</tr>
<tr>
<td>Ralf Simmat, Christian Dannert, Olaf Krause, and Peter Quirmbach</td>
<td></td>
</tr>
</tbody>
</table>
INFLUENCE OF THE CABORES CONTENT ON THE STRENGTH OF CARBON BONDED ALUMINA OBTAINED BY MEANS OF SMALL PUNCH TEST
S. Soltysiak, M. Abendroth, and M. Kuna

INFLUENCE OF THE PORE SHAPE ON THE INTERNAL FRICTION OF REFRUCTORY CASTABLES
Nicolas Traon, Thorsten Tonnesen, Rainer Telle, Barbara Myszka, and Rafael Silva

CONTRIBUTION OF DIFFERENT BINDER SYSTEMS TO YOUNG’S MODULUS OF ELASTICITY OF CARBON-BONDED ALUMINA AT ELEVATED TEMPERATURES
J. Werner and C.G. Aneziris

INVESTIGATION ON RELIABILITY OF REFRUCTORIES VIA WEIBULL AND NORMAL DISTRIBUTION
Wenjie Yuan, Qingyou Zhu, Chengji Deng, and Hongxi Zhu

DRY-OUT SIMULATION OF CASTABLES CONTAINING CALCIUM ALUMINATE CEMENT UNDER HYDROTHERMAL CONDITIONS

Cement and Lime Refractories

DRIY AND WET GUNNING—TECHNICO-ECONOMIC REFRUCTORY CONCRETE CONCEPTS FOR HIGHLY LOADED CEMENT PLANTS
Kai Beimdiek and Hans-Jürgen Klischat

DEVELOPMENT OF AN ELECTROFUSED MgO-CaZrO₃ REFRUCTORY WITH ADDITION OF HERCYNITE FOR THE CEMENT INDUSTRY
G. Alan Castillo, Fabiola Dâvila, T. K. Das Roy, B. Krishnan, Ana-Maria Guzmán, and S. Shaji

HYBRID SPINELS TECHNOLOGY FOR BASIC BRICKS IN CHEMICALLY HIGHLY LOADED CEMENT ROTARY KILNS
G. Gelbmann, R. Krischanditz, and S. Joerg

THE EFFECT OF TiO₂ ON PROPERTIES AND MICROSTRUCTURE OF CHROME-FREE BASIC BRICK
S. Ghanbarnezhad, M. Bavand-Vandchali, A. Nemati, and R. Naghizadeh

THE PERFORMANCE OF HIGH QUALITY MAGNESIA RAW MATERIALS IN CEMENT APPLICATIONS
F. Goorman, J. Visser, M. Ruer, C.G. Aneziris, and J. Ulbricht

HIGHER THERMOCHEMICAL RESISTANCE BY INSTALLATION OF MAGNESIA FORSTERITE BRICKS
Hans-Jürgen Klischat and Holger Wirshing

THE PROCESS OF NEW PHASES FORMATION IN THE Al₂SiO₅-ZrSiO₄ REFRUCTORY MATERIAL DURING INDUSTRIAL TEST IN CEMENT KILN PREHEATER
Dominika Madej, Jacek Szcerba, and Krzysztof Dul

DEVELOPMENT OF MAGNESIA-SPINEL BRICK FOR TRANSITION ZONE IN CEMENT ROTARY KILNS UNDER THE VASTLY INCREASING USE OF WASTE
Makoto Ohno, Hitoshi Toda, Kozo Tokunaga, Yoshihki Tsuchiya, and Yoshio Mizuno

A NEW TYPE OF BASIC CASTABLE FOR THE CEMENT INDUSTRY
V. Wagner and P. Malkmus

MAGNESIA-SPINEL REFRUCTORIES FOR ROTARY KILN BURNING 60% ALTERNATIVE FUEL
Michał Sułkowski, Lucyna Obszyńska, and Cezarstw Golawski

INFLUENCE OF ANDALUSITE ADDITION AND PARTICLE SIZE ON PROPERTIES OF BAUXITE-SILICON CARBIDE BRICK
Jinxing Ding, Guotian Ye, Yaozheng Li, Lin Yuan, and Anping Fu
# Contents

**Developments in Basic Refractories**

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>STUDIES ON THE EFFECT OF NANO-CARBON IN MgO-C: A NEW GENERATION REFRACTORIES</td>
<td>227</td>
</tr>
<tr>
<td>M. Bag, R. Sarkar, A. S. Bal, R. P. Rana, S. Adak, and A. K. Chattopadhyay</td>
<td></td>
</tr>
<tr>
<td>REACTANT SIZE EFFECTS ON MgAl₂O₄ FORMATION EXPANSION</td>
<td>233</td>
</tr>
<tr>
<td>Flavia C. Duncan and Richard C. Bradt</td>
<td></td>
</tr>
<tr>
<td>MAGNESIA-CARBON BRICKS MADE IN EUROPE: CHALLENGES AND SOLUTIONS</td>
<td>239</td>
</tr>
<tr>
<td>G. Buchebner, A. Kronthaler, and W. Hammerer</td>
<td></td>
</tr>
<tr>
<td>MICROSTRUCTURAL AND PHYSICO-CHEMICAL EVOLUTION OF Al₂O₃ AND Fe₂O₃</td>
<td>245</td>
</tr>
<tr>
<td>C. Gómez Rodríguez, T. K. Das Roy, S. Shaji, G.A. Castillo Rodríguez, and L. García Quiñonez</td>
<td></td>
</tr>
<tr>
<td>EFFECTS OF Mg ADDITION ON PROPERTIES, PHASE COMPOSITION AND MICROSTRUCTURE OF Al₂O₃-C MATERIAL</td>
<td>251</td>
</tr>
<tr>
<td>Xinhong Liu, Zhiwang Niu, Enxia Xu, Xiaoyan Zhu, Long Feng</td>
<td></td>
</tr>
<tr>
<td>EFFECT OF MAGNESIA DISSOLUTION IN NON-STOICHIOMETRIC CHROMIUM-FREE COMPLEX SPINEL</td>
<td>257</td>
</tr>
<tr>
<td>Rahul Lodha, Carmen Oprea, Tom Troczynski, and George Oprea</td>
<td></td>
</tr>
<tr>
<td>SPINEL INVERSION AND LATTICE PARAMETERS IN CHROMIUM-FREE SPINEL SOLID SOLUTIONS</td>
<td>263</td>
</tr>
<tr>
<td>Rahul Lodha, George Oprea, and Tom Troczynski</td>
<td></td>
</tr>
<tr>
<td>DEVELOPMENT OF PLANAR AND CYLINDRICAL REFRACTORIES WITH GRADED MICROSTRUCTURE</td>
<td>267</td>
</tr>
<tr>
<td>Uwe Scheithauer, Tim Slawik, Kristin Haderek, Tassilo Moritz, and Alexander Michaelis</td>
<td></td>
</tr>
<tr>
<td>DEVELOPMENT OF MAGNESIA REFRACTORIES WITH HIGHER SLAKING RESISTANCE</td>
<td>273</td>
</tr>
<tr>
<td>Koichi Shimizu, Yoshitaka Sadatomi, Tsubasa Nakamichi, and Jyouki Yoshitomi</td>
<td></td>
</tr>
<tr>
<td>THERMAL CYCLING RESISTANT MgO BASED MONOLITHIC LININGS</td>
<td>279</td>
</tr>
<tr>
<td>C. Dromain, P. Malkmus, and J. Soudier</td>
<td></td>
</tr>
<tr>
<td>ALUMINATES INFLUENCE ON EVOLUTION OF THE THERMO-MECHANICAL PROPERTIES OF REFRACTORY MATERIALS FROM THE CaO-MgO-Al₂O₃-ZrO₂ SYSTEM</td>
<td>285</td>
</tr>
<tr>
<td>DEVELOPMENT OF MgO-C NANO-TECH REFRACTORIES OF 0 % GRAPHITE CONTENT (NANO-TECH REFRACTORIES-12)</td>
<td>291</td>
</tr>
<tr>
<td>Shinichi Tamura, Tsunemii Ochiai, Shigeyuki Takenaga, Osamu Matsuura, Hiroki Yasumitsu, and Masami Hirashima</td>
<td></td>
</tr>
<tr>
<td>MICROSTRUCTURE AND PROPERTIES OF POROUS ZrO₂ CERAMICS PREPARED BY FOAMING COMBINED WITH GELCASTING METHODS</td>
<td>297</td>
</tr>
<tr>
<td>Wang Gang, Han Jianshen, Yuan Bo, and Li Hongxia</td>
<td></td>
</tr>
<tr>
<td>METASTABILITY IN THE MgAl₂O₄-Al₂O₃ SYSTEM</td>
<td>303</td>
</tr>
<tr>
<td>Kelley R. Wilkerson, Jeffrey D. Smith, and James G. Hemrick</td>
<td></td>
</tr>
<tr>
<td>THE EFFECT OF RARE EARTH OXIDES ON THE STRUCTURE AND PROPERTIES OF MgO-CaO CERAMICS</td>
<td>309</td>
</tr>
<tr>
<td>Y. W. Yu and Y. X. Zhao</td>
<td></td>
</tr>
<tr>
<td>INFLUENCE OF SOLID SOLUTION FORMATION ON THE SOLID STATE SINTERING OF MgCr₂O₄</td>
<td>313</td>
</tr>
<tr>
<td>Hamidreza Zargar, George Oprea, and Tom Troczynski</td>
<td></td>
</tr>
</tbody>
</table>
Energy Savings Through Refractory Design

EVALUATION OF THERMAL CONDUCTIVITY OF REFRACTORY MONOLITHICS BY VARIOUS METHODS AND THE ISSUES THIS RAISES
Zena Carden, Andrew J. Brewster, Dr. David Bell, and Ian Whyman

EFFECT OF PARTICLE SIZE ON PROPERTIES OF NOVEL THERMAL INSULATION MATERIALS SYNTHESIZED BY MOLTEN SALT METHOD
Chengji Deng, Jun Ding, Xiaojun Zhang, Wenjie Yuan, and Hongxi Zhu

ROTARY KILNS—LINING DESIGN AND ENERGY SAVINGS
Niels I. Jacobsen and Leo F. Juhl

DEVELOPMENT OF A NEW CALCIUM SILICATE BOARD WITH SUPER INSULATING PROPERTIES
Volker Krasselt, Jürgen Rank, Ann Opsommer, and Xiao Wu

IMPROVEMENT OF THERMAL EFFICIENCY IN STEEL LADLES
Yong M. Lee, Sanjay Kumar, Jim Bradley, Lionel Rebouillat, and Norman Roy

ACHIEVEMENT OF THE REDUCING EROSION FOR THE INVESTIGATION OF TROUGH BOTTOM ANGLE IN THE SEMIPOOLING TYPE MAIN TROUGH
Hiroshi Fujiwara, Toshio Komatsu, Masaki Kajiwara, and Hideyuki Tasaki

ENERGY SAVING OF SLAB REHEATING FURNACES BY IMPROVEMENTS OF REFRACTORIES
Masaharu Sato, Takeuchi Tomohide, Kohno Kohji, and Shimpo Akihiro

NOVEL GENERATION OF KILN FURNITURE
U. Scheithauer, C. Freytag, K. Haderk, T. Moritz, M. Zins, and A. Michaelis

ENERGY SAVING IN WALKING BEAM FURNACES AT ARCELORMITTAL (BREMEN, GERMANY) BY A NEW CONCEPT FOR SKID PIPE INSULATION
Jens Heinlein, Heiko Siefkes, Michael Springer, Frank Hügel, Andreas Buhr, and Rainer Kockegey-Lorenz

ENERGY SAVINGS AND IMPROVEMENT OF PRODUCTIVITY IN CONTINUOUS REHEATING FURNACES
Patrick Tassot, Jörg Fernau, and Hugues Lemaistre

NANOPOROUS REFRACTORY INSULATING: SOLUTION OR ILLUSION?
Diogo O. Vivaldini, Vânia R. Salvini, Amadeu A.C. Mouroão, and Victor C. Pandolfelli

MATERIAL DESIGN FOR NEW INSULATING LINING CONCEPTS
Dale Zacherl, Dagmar Schmidtmeier, Rainer Kockegey-Lorenz, Andreas Buhr, Marion Schnabel, and Jerry Dutton

Global Education in Refractories

ENHANCING TECHNOLOGY TRANSFER CAPABILITIES—A GERMAN PERSPECTIVE
Anja Geigenmueller and Stefanie Lohmann

VISUALIZING THE INVISIBLE: HOW TO ATTRACT STUDENTS TO REFRACTORY ENGINEERING
Anja Geigenmueller

PROMOTING NATURAL SCIENCE AND ENGINEERING AT FREIBERG UNIVERSITY—SOME OUTSTANDING TOOLS AND RESULTS
Kathrin Haeussler

KOBLENZ UNIVERSITY OF APPLIED SCIENCE, DEPARTMENT OF MATERIALS ENGINEERING, GLASS AND CERAMICS PLAYING A KEY ROLE IN THE SCIENCE AND EDUCATION NETWORK FOR THE REFRACTORY INDUSTRY
Olaf Krause and Peter Quirmbach
INTEGRATING EDUCATION CONCEPTS—THE KOBLENZ REGION OFFERS A ONE-OF-A-KIND INFRASTRUCTURE TO IDENTIFY AND QUALIFY SPECIALISTS IN ORDER TO ENSURE RELIABLE AND CONTINUOUS PROVISION OF BEST-SKILLED EMPLOYEES TO THE REFRACTORY INDUSTRY
Peter Quirmbach and Olaf Krause

GRADUATE PROGRAMS IN REFRACTORY ENGINEERING: WHAT IS DULY NEEDED?
Michel Rigaud

Iron and Steel Making Refractories—Blast Furnace Troughs

DEVELOPMENT AND APPLICATION OF TAPHOLE MUD FOR 5800 M³ LARGE SCALE BLAST FURNACE
Ping-Kun Chen and Nan-Hsien Lin

HIGH PERFORMING Al₂O₃-SiC-C MONOLITHIC REFRACTORIES RELEASING NO HYDROGEN FOR BF CASTHOUSE APPLICATIONS
Nicolas Duvauchelle and Jérôme Soudier

INVENTION REACTION BONDED ALUMINA BRICKS FOR BF CERAMIC CUP
Yun-Cheol Hong, Soon-II Yoon, and Sang-Ahm Lee

INNOVATIVE GRAPHITIC CASTABLE UTILIZED AS BOTH A REPAIR AND REPLACEMENT MATERIAL FOR CARBONACEOUS REFRactory
Yuechu Ma, Dominic J. Loiacono, and Floris Van Laar

CHALLENGES TO IMPROVING THE ENVIRONMENTAL AND HEALTH SAFETY CHARACTERISTICS OF TAP HOLE CLAY
James W. Stendera, Ryan A. Hershey, and Glenn G. Biever

HOT STRENGTH IN RELATION WITH BINDING SYSTEM OF SiC AND Al₂O₃ BASED CASTABLES INCORPORATED WITH SILICON POWDERS AFTER NITRIDATION
Renhong Yu, Huifang Wang, and Ningsheng Zhou

Iron and Steel Making Refractories—BOF

PROPERTIES AND PERFORMANCE OF GUNNING AND PATCHING MATERIAL OF CONVERTER AT TATA STEEL
Goutam Ghosh, Amit Banerjee, Brijender Singh, Subir Biswas, and Atanu Ranjan Pal

IMPROVEMENT OF DURABILITY AND TAPPING TIME OF TAP HOLE SLEEVE BY COMPOSITION AND SHAPE CONTROL
Kye-sung Kim, In-kyoung Bae, Ji-eon Lee, and Kang-yong Lee

POST MORTEM ANALYSIS OF BOF TUYERES
S. K. Kubal, C. Pleydell-Pearce, J. R. Powson, and W. E. Lee

IMPROVEMENT OF BOF BOTTOM STIRRING AT RUUKKI, RAAHE STEEL WORKS
Heikki Pärkkä, Tuomas Meriläinen, Jukka Vatanen, Petri Tuominen, and Jaakko Kärjä

IMPROVEMENT OF THE REFRACTORY LINING CONCEPT AND OF THE INSTALLATION METHOD OF A BOF AT VOESTALPINE LINZ
Helge Jansen, Lutz Schade, Dr. Thomas Schemmel, and Reinhard Exenberger

Iron and Steel Making Refractories—Coke Ovens

PHYSICAL PROPERTIES OF USED BRICKS OF COKE OVENS
S. Hosohara, H. Matsunaga, and Y. Fushima
INFLUENCE OF THERMAL EXPANSION BEHAVIOR ON THE ADHESIVE STRENGTH OF SILICA MORTAR
Atsuya Kasai

EVALUATION OF COKE OVEN REGENERATOR CHECKERS AFTER 40 YEARS IN SERVICE
Silvia Camelli, M J Rimoldi, A Vázquez, and Dario Beltrán

DEVELOPMENT OF ZERO EXPANSION SILICA BRICKS FOR HOT REPAIR OF COKE OVEN
S. P. Das, S. Si, B. Prasad, J. K. Sahu, B. K. Panda, J. N. Trwari, and N. Sahoo

Iron and Steel Making Refractories—Continuous Casting

EFFECTS OF VISCOSITY AND SURFACE TENSION OF FREE FLUORINE FLUXES ON THE WEAR MECHANISMS OF Al₂O₃-C NOZZLE
E. Benavidez, M.V. Peirani, M. Ávalos, and E. Brandaleze

DEVELOPMENT OF ALUMINOUS NOZZLES REINFORCED WITH SIALON
Clenice Moreira Galinari and Paula Regina Dutra

PROPERTIES OF SELF-GLAZING Al₂O₃-C-REFRACTORIES INFLUENCED BY THE GRAPHITE CONTENT AND NANOSCALED ADDITIVES
Susann Ludwig, Vasileios Roungos, and Christos G. Aneziris

Iron and Steel Making Refractories—General

DEVELOPMENT OF NEW BASIC WORKING LINING FOR TERNIUM SIDERAR TUNDISHES
Silvia Camelli, Maria Lujan Dignani, and Marcelo Labadie

APPLICATION OF MULTI-HOLES STOPPER FOR MOLD LEVEL STABILITY
Sangbae Choi, Ikbae Lee, Domun Choi, Kwangchul Choi, Sangahn Lee, and Sik Sunwoo

NEW DEVELOPMENTS ON REFRACTORY HOLLOWWARE MATERIALS FOR INGOT CASTING
Roberto de Paula Rettore, Erwan Guéguen, and Gilbert Zieba

CHALLENGES OF BLAST FURNACE CASTHOUSE: FAILURE ANALYSIS OF MAIN RUNNER REFRATORY CASTABLE

NOVEL DRY MIX TECHNOLOGY FOR TUNDISH REFRATORY LINING

DEVELOPMENT OF ACTIVE AND REACTIVE CARBON-BONDED FILTERS FOR STEEL MELT FILTRATION
M. Emmel and C. G. Aneziris

IMPROVING MAINTENANCE AT DIRECT-REDUCTION PLANTS USING INFRARED THERMOGRAPHY
Y. J. Girón, E. J. Estrada, and D. Gutiérrez-Campos

APPLICATION AND DEVELOPMENT OF HBS IN CHINA
Fuchao Li, Jiantao Li, Hongqin Dong, and Gengchen Sun

EFFECTS OF CORDIERITE ADDITION ON THE PROPERTIES OF MULLITE-ANDALUSITE-CORDIERITE BRICKS
Fuchao Li, Jiantao Li, Hongqin Dong, Gengchen Sun, Guolu Zhou, and Shijian Gao

TAPE CASTING OF COARSE-GRAINED OXIDE POWDERS FOR THE MANUFACTURE OF ADVANCED REFRATORY MULTILAYER COMPOSITES
D. Jakobsen, I. Götschel, and A. Roosen
DIFFERENT FABRICATION ROUTES FOR CARBON-BONDED \( \text{Al}_2\text{O}_3-\text{C} \) AND THEIR INFLUENCE ON THE PHYSICAL AND MECHANICAL PROPERTIES
Yvonne Klemm, Horst Biermann, and Christos Aneziris

DEVELOPMENT OF A MONOLITHIC REFRACTORY USING SPENT REFRACTORIES
Ryo Otake, Hitoshi Sawada, Koji Nakanishi, and Ko Kobayashi

EFFECTS OF B\(_2\)C ADDITION ON THERMO-MECHANICAL PROPERTIES OF Al-Si INCORPORATED LOW CARBON \( \text{Al}_2\text{O}_3-\text{C} \) SLIDE PLATE MATERIALS
Xinhong Liu, Yanna Wang, and Xiangchong Zhong

OPTIMUM QUANTITY OF GAS BLOWN INTO THE BORE OF TUNDISH UPPER NOZZLE
A. Mizobe, J. Kurisu, K. Furukawa, T. Tsuduki, M. Yamamoto, T. Oouchi, and K. Oki

IMPROVEMENT OF THE DURABILITY ON SG PLATE FOR STEEL LADLE
Zenta Ohmaru, Keiichiro Akamine, Katsumi Morikawa, and Jyouki Yoshitomi

DEVELOPMENT OF A METHOD TO MEASURE TORPEDO LADLE BRICK THICKNESS USING A COMMERCIAL 3D LASER SCANNER
Ryo Otake, Norio Sakaguchi, Koji Nakanishi, Ko Kobayashi, and Toshiya Ozato

HOW DO STEELMAKERS PICK REFRACTORIES? A SUPPLIER’S PERSPECTIVE
Ian D. Prendergast

STEEL CLEANLINESS & SEQUENCE LENGTH IMPROVEMENT THROUGH TUNDISH CONFIGURATION & BLACK REFRACTORIES QUALITY OPTIMIZATION AND BY INTRODUCING THE CONCEPT OF MANAGEMENT
Asis Sarkar

BENCHMARKING OF CAS-OB REFRACTORY BELLS
S. Muthukumar and A. Kremer

REFRACTORY RESPONSE FOR PIG IRON REFINING WITH KR-PROCESS
Patrick Tassot, Jacky Wang, and Hugues Lemaistre

CHEMICAL WEAR OF \( \text{Al}_2\text{O}_3-\text{MgO}-\text{C} \) BRICKS BY AIR AND BASIC SLAGS
Leonardo Musante, Pablo G. Galliano, Elena Brandaleze, Vanesa Muñoz, and Analía G. Tomba Martinez

ANDALUSITE APPLIED IN EAF ROOF CASTABLES
Xiao-Yong Xiong, Zong-Sun Mu, Zhi-Jian Li, and Feng Hu

CALCIUM HEXALUMINATE DISTRIBUTION AND PROPERTIES OF CALCIUM ALUMINATE CEMENT BONDED CASTABLES WITH MAGNESIUM CHLORIDE ADDITION
Qingfeng Wang, Guotian Ye, Yajuan Wang, Chuanyin Zhang, Yunfei Zhang, and Aiping Hua

IMPROVEMENT OF REFRACTORY CASTABLES FOR KR DESULPHURIZATION IMPELLER
Shang-ru Yeh, Henry Chen, and Wei-tin Lin

STUDY ON LADLE PURGING PLUG WITH GRADIENT COMPOSITE STRUCTURE AND MATERIAL
Zhang Hui, Yu Tongshu, Yang Wengang, and Chen Lu

STRENGTHENING MECHANISM OF GRAPHENE OXIDE NANOSHEETS FOR \( \text{Al}_2\text{O}_3-\text{C} \) REFRACTORIES
Qinghu Wang, Yawei Li, Ming Luo, Shaobai Sang, Tianbin Zhu, and Lei Zhao

Iron and Steel Making Refractories—Ladles

TROUBLESHOOTING IN STEEL LADLES WITH REFRACTORY SOLUTIONS
S. Bharati, S. Bose, B. Singh, and A. R. Pal
EFFECT OF MICROPOROUS AGGREGATE ON LIGHTWEIGHT ALUMINA-MAGNESIA CASTABLE FOR LADLE

DEVELOPMENT OF ALTERNATIVE SOLUTIONS FOR IRON LADLE REFRACTORY LINING

INSULATION BOARD INVESTIGATION AND TRIALS IN 300 TONNE STEEL LADLES AT ARCELORMITTAL DOFASCO
Vanessa Mazzetti-Succi

STEEL LADLE LINING: A PROVEN TECHNIQUE TO ACHIEVE 3.0% PRODUCTIVITY IN TRANSPORTED VOLUME WHILE REDUCING REFRACTORY COST USING A SMART LINING
L.C. Simão, Paulo Osório R.C. Brant, and Robson A. Dettogne

ALUMINA-MAGNESIA-CARBON BRICKS FOR STEEL LADLE
Marcin Kiewski, Obezyńska Lucyna, and Sulkowski Michał

Iron and Steel Making Refractories—Magnesia-Carbon

IMPROVEMENT AND MAINTENANCE OF MgO-C BOTTOM-BLOWING TUYERE IN BOF CONVERTER FOR PROLONGING SERVICE LIFE
Li Lin, Peng Xiaoyan, Gao Fei, and Ding Hewei

INFLUENCE OF Zn ADDITION ON PROPERTIES OF METAL COMPOSITE LOW CARBON MgO-C REFRACTORIES
Chengliang Ma, Zhen Ren, Hua Ma, and Dongdong Meng

EFFECTS OF NANO BORON CARBIDE AS ADDITIVE FOR MgO-C FOR BOF
Carlos Pagliosa, Nestor Freire, Gabriel Cholodovskis, and Victor Carlos Pandolfelli

DEVELOPMENT OF Al2O3-MgAI2O4-C REFRACTORIES FOR STEEL LADLE: EFFECT OF MgO AND AI2O3 REACTIVITY
H. S. Tripathi and A. Ghosh

PROPERTIES OF MgO BASED REFRACTORIES WITH SYNTHETIC MgO-SiC-C POWDER
Yaowu Wei, Huawei Xu, Xinyan Li, Nan Li, Bing Wu, Luoxia Wang, and Lieying Ma

THE COMPREHENSIVE STUDIES OF MAGNESIA CARBON BRICK’S ANISOTROPY
Houliang Zhu, Hideo Asakura, Yasuo Mizota, Akira Yamaguchi, Zhongyang He, and Baikuan Liu

Iron and Steel Making Refractories—RH Snorkels

DEVELOPMENT OF DEGASSER SNORKEL REFRACTORIES AND THE EFFECT OF THE PROCESS PARAMETERS ON WEAR RATE
Y. Bi, I. A. Smith, and K. Andreev

THEORETICAL AND PRACTICAL TEMPERATURE GRADIENT OF THE REFRACTORY LINING OF THE RH SNORKEL
Z. Czapka, J. Szczesny, and W. Zelik

DEVELOPMENT OF HIGH-DURABILITY HOT REPAIR SPRAY AND NEW INSTALLATION METHOD FOR THE RH SNORKEL
Je-Ha Lee, Byung-Su, Kim, and Chang-Jung Um
Iron and Steel Making Refractories—Spinel Castables

EXPANSION UNDER CONSTRAINT AND ITS EFFECT ON HIGH-ALUMINA SPINEL-FORMING REFRUCTORY CASTABLES
M. A. L. Braulio, E. Y. Sako, and V.C. Pandolfelli

COMPARISON OF PROPERTIES AMONG SPINEL-CONTAINING CASTABLES FOR STEEL LADLE
Rak-Hee Kim, Seung-Jun Lee, Sung-Ryong Jung, and Seok-Keun Lee

THERMAL SHOCK RESISTANCE OF ALUMINA AND ALUMINA-RICH SPINEL REFRUCTORY COMPOSITIONS CONTAINING ALUMINUM TITANATE
K. Moritz, S. Dudczig, G. Aneziris, D. Hesky, D. Veres, and N. Gerlach

DEVELOPMENT OF CaO FREE ALUMINA-MAGNESIA PRECAST BLOCKS
Masafumi Nishimura, Shigefumi Nishida, and Makoto Namba

Iron and Steel Making Refractories—Submerged Entry Nozzles

MAIN MECHANISMS OF SEN SLAG BAND CORROSION AS OBSERVED BY POST MORTEM INVESTIGATIONS
H. Harmuth, V. Kircher, N. Kölbl, M. Antczak, and G. Xia

IMPROVEMENT OF THE THERMAL SHOCK RESISTANCE ON LOWER NOZZLE FOR TUNDISH AND LADLE
Kentaro Iwamoto, Hidetoshi Kamio, Katsumi Morikawa, and Jyouki Yoshitomi

CRITICAL EVALUATION AND OPTIMIZATION OF THE Li2O-ZrO2 AND Li2O-ZrO2-SiO2 SYSTEMS
Wan-Yi Kim and In-Ho Jung

EVALUATION METHODS OF THE CORROSION RESISTANCE OF ZrO2-C MATERIAL USED FOR SEN SLAG LINE
Koji Moriwaki, Kyohei Yamaguchi, and Masanori Ogata

STUDIES & OPTIMISATION OF VARIOUS TYPES OF ZIRCONIA TO MINIMISE CRACK PROPAGATION & IMPROVE CORROSION & EROSION RESISTANCE OF SLAG BAND OF SUBENTRY NOZZLE
Anupal Sen, B. Prasad, Dr. J.K. Sahu, and J. N. Tiwari

Modeling and Simulation of Refractories

THERMOMECHANICAL COMPUTATIONS OF REFRUCTORY LININGS ACCOUNTING FOR SWELLING INDUCED BY CHEMICAL REACTION
Tarek Merzouki, Eric Blond, Nicolas Schmitt, Emmanuel de Bilbao, and Alain Gasser

SIMULATION OF THE STEEL LADLE PREHEATING PROCESS
Magdalena Drózd-Ryś, Harald Harmuth, and Roman Rössier

MODELLING OF A COKE OVEN HEATING WALL COMBINING PERIODIC HOMOGENISATION AND SUBMODELLING
Nicolas Gallienne, Matthieu Landreau, Eric Blond, Alain Gasser, and Daniel Isler

INFLUENCE OF DIFFERENT MASONERY DESIGNS OF BOTTOM LININGS

MARANGONI CONVECTION AS A CONTRIBUTION TO REFRUCTORY CORROSION—CFD SIMULATION AND ANALYTICAL APPROACHES
S. Vollmann and H. Harmuth
TOWARDS EFFICIENT MODELING ON SLAG CORROSION OF LIGHTWEIGHT CORUNDUM SPINEL CASTABLE FOR LADLE 863
Ao Huang, Gu Huazhi, and Zou Yang

DISSOLUTION RATES OF SOLID OXIDES INTO MOLTEN SLAGS 869
Fuxiang Huang, Nobuhiro Merukka, Akira Ishikawa, Jiang Liu, and Shin-ya Kitamura

AN ANALYSIS OF REFRUCTORY CONCRETE DRYING AND A MECHANISM FOR EXPLOSIVE SPALLING 875
Greg Palmer, Juan Cobos, James Millard, Tony Howes, and Edison Ge

MODELING CRACKING IN REFRUCTORY MATERIALS DUE TO THERMAL CYCLING 881
A. A. Pandhar, P. V. Barr, D. Maijer, and S. Chiartano

THE LOAD-DISPLACEMENT CURVE OF STEADY CRACK PROPAGATION: AN INTERESTING SOURCE OF INFORMATION FOR PREDICTING THE THERMAL SHOCK DAMAGE OF REFRUCTORIES 887
Dan Yushin Miyaji, Caio Zuccolotto Ototugi, and José de Anchieta Rodrigues

ADEQUACY CHECK OF REFRUCTORY DESIGN BY FE MODELLING 893
Prasenjit Saha, Prasenjit Pal, Biswup Sarkar, and PP Lahiri

GEOMETRY DEPENDENT EFFECTIVE HEAT CONDUCTIVITY OF OPEN-CELL FOAMS BASED ON KELVIN CELL MODELS 897
J. Storm, M. Abendroth, and M. Kuna

THERMAL STRESS DISTRIBUTION IN STOPPER BY FINITE ELEMENT ANALYSIS 903
Yang Wengang, Liu Guoqi, Li Hongxia, Ma Tianfei, Qian Fan, and Yu Jianbin

Monolithics

EFFECT OF SODIUM IMPURITIES ON PHASE AND MICROSTRUCTURE EVOLUTION IN CALCIUM ALUMINATE CEMENT BONDED CASTABLES AT HIGH TEMPERATURES 911
J. Alex, L. Vandeperreau, B. Touzob, C. Parmb, and W. E. Lee

THE EFFECT OF AGING OF BLAST FURNACE TROUGH CASTABLES DUE TO STORAGE CONDITIONS ON PERFORMANCE IN SERVICE 917
Samuel Bonsall and William Gavrish

RHEOLOGICAL & DISPERSION BEHAVIOUR OF CALCINED ALUMINAS WITH DEFLOCCULANTS 923
E. Chabas, C. Ulrich, A. Lafaurie, E. Papin, and D. Dumont

PRESENT TREND OF PRE-CAST SHAPE AND REFRUCTORY CASTABLE USES IN VIZAG STEEL PLANT—CHALLENGES FACED AND SUCCESS STORIES 929
P. S. Paul and Atanu Datta

STUDY ON THE HYDRATION BEHAVIOR OF MgO POWDERS 935
Quanli Jia, Ran Wu, Tiezhu Ge, and Xiaogai Sun

MIXING OPTIMIZATION OF AN ALUMINA BASED LC-CASTABLE BY APPLYING VARIABLE POWER INPUTS 941
J. Kasper and O. Krause

SETTING AGENT EVALUATION OF NON-CEMENT REFRUCTORY CASTABLE 947
Aya Kusunoki, Kazuaki Haraguchi, and Yasuhiro Eguchi

RHEOLOGICAL BEHAVIOUR OF NEW ADDED VALUE REACTIVE ALUMINAS FOR REFRUCTORY APPLICATIONS 953
A. Lafaurie, E. Chabas, F. Murgalé, and C. Ulrich
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>METHODS TO ASSESS THE DRYING ABILITY OF REFRACTORY CASTABLES</td>
<td>959</td>
</tr>
<tr>
<td>Pierre Meunier and Peter Ermtraud</td>
<td></td>
</tr>
<tr>
<td>CEMENT FREE MgO CASTABLES: PART I: FLOW, SETTING AND SLAKING</td>
<td>965</td>
</tr>
<tr>
<td>Björn Myhre, Hong Peng, and Luo Ming</td>
<td></td>
</tr>
<tr>
<td>CEMENT FREE MgO CASTABLES PART II: STRENGTH AND EXPLOSION RESISTANCE</td>
<td>971</td>
</tr>
<tr>
<td>Björn Myhre, Hong Peng, and Luo Ming</td>
<td></td>
</tr>
<tr>
<td>NO-CEMENT ALUMINA—MAGNESIA CASTABLES</td>
<td>977</td>
</tr>
<tr>
<td>Yasuhiro Ohba, Hirohide Okuno, Nobuyuki Takeuchi, and Makoto Ishikawa</td>
<td></td>
</tr>
<tr>
<td>SYNTHESIS OF NANO MgO FROM NATURAL RAW MAGNESITE AND ITS APPLICATION IN HIGH ALUMINA CASTABLE PRODUCTS</td>
<td>983</td>
</tr>
<tr>
<td>P. R. Rauta, N. Sahoo, L. N. Padhi, and J. N. Tiwari</td>
<td></td>
</tr>
<tr>
<td>ADVANCED UNDERSTANDING ON IN SITU SPINEL FORMATION AND CORROSION PERFORMANCE OF SPINEL-CONTAINING REFRACTORY CASTABLES</td>
<td>989</td>
</tr>
<tr>
<td>Eric Y. Sako, Mariana A. L. Brauilo, and Victor C. Pandolfelli</td>
<td></td>
</tr>
<tr>
<td>CONTROL OF ALUMINA CEMENT PHASE BY PROCESS PARAMETERS</td>
<td>995</td>
</tr>
<tr>
<td>Saptarshi Sengupta, Tarun K. Roy, and N. Ramasubramanian</td>
<td></td>
</tr>
<tr>
<td>PRACTICAL EXPERIENCE OF TIME STABLE CALCIUM ALUMINATES IN LOW CEMENT CASTABLE APPLICATIONS</td>
<td>1001</td>
</tr>
<tr>
<td>F. Simonin, J. Mahiaoui, O. Pawlig, and M. Szepizdyn</td>
<td></td>
</tr>
<tr>
<td>TIME, ENERGY AND COST SAVING DURING MONOLITHIC REFRACTORY LINING INSTALLATION BY COMBINING QUICK DRY TECHNOLOGY AND GUNNING TECHNICS</td>
<td>1007</td>
</tr>
<tr>
<td>Patrick Malkmus, Pierre Meunier, and Jérôme Soudier</td>
<td></td>
</tr>
<tr>
<td>INFLUENCE OF MICRO SILICA ON MECHANICAL PROPERTIES OF BASIC CASTABLES</td>
<td>1013</td>
</tr>
<tr>
<td>J. Szczerba, R. Prorok, Z. Czapka, D. Madej, E. Śnieżek, and I. Jastrzębska</td>
<td></td>
</tr>
<tr>
<td>NEXT GENERATION ALUMINA BINDER FOR CEMENT-FREE CASTABLES</td>
<td>1019</td>
</tr>
<tr>
<td>V. A. Lifton, Ch. Tontrup, and T. von Rymon Lipinski</td>
<td></td>
</tr>
<tr>
<td>INFLUENCE OF BONDING METHODS ON PROPERTIES OF ALUMINA BASED CASTABLES WITHOUT MICRO SILICA ADDITION</td>
<td>1025</td>
</tr>
<tr>
<td>Zhanmin Wang, Shouye Wang, Zi Li, Xijing Cao, and Lihong Zhou</td>
<td></td>
</tr>
<tr>
<td>NOVEL CALCULUM MAGNESIUM ALUMINATE BONDED CASTABLES FOR STEEL AND FOUNDRY LADLES</td>
<td>1031</td>
</tr>
<tr>
<td>C. Wöhrmeyer, J.M. Auvray, B. Li, H. Fryda, M. Szepizdyn, D. Pörzgen, N. Li, and W. Yan</td>
<td></td>
</tr>
<tr>
<td>DEVELOPMENT OF LIGHTWEIGHT Al₂O₃-CaO-MgO CASTABLES USING MICROPOROUS CA₆-MA AGGREGATES</td>
<td>1037</td>
</tr>
<tr>
<td>Ningsheng Zhou, Weiwei Wang, and Yubao Bi</td>
<td></td>
</tr>
<tr>
<td>PROPERTIES IMPROVEMENT OF LIGHTWEIGHT Al₂O₃-SiO₂ CASTABLES BY ANDALUSITE ADDITION</td>
<td>1045</td>
</tr>
<tr>
<td>Ningsheng Zhou, Shuhe Hu, Hongran Wang, Xiaoyong Xiong, and Xinyu Liu</td>
<td></td>
</tr>
<tr>
<td>HIGH PERFORMANCE GUNNING MIX WITH CT10SG AS A PLASTICISER</td>
<td>1051</td>
</tr>
<tr>
<td>Dale Zacherl, Bin Long, Zhoufu Wang, and Andreas Buhr</td>
<td></td>
</tr>
<tr>
<td>CEMENT HYDRATION AND STRENGTH DEVELOPMENT—HOW CAN REPRODUCIBLE RESULTS BE ACHIEVED?—PART 1</td>
<td>1057</td>
</tr>
<tr>
<td>Dagmar Schmidtmeier, Andreas Buhr, Geert Wams, Stefan Kuiper, Sebastian Klaus, Dale Zacherl and Jerry Dutton</td>
<td></td>
</tr>
</tbody>
</table>
CEMENT HYDRATION AND STRENGTH DEVELOPMENT—HOW CAN REPRODUCIBLE RESULTS BE ACHIEVED?—PART 2
Dagmar Schmidtmeier, Andreas Buhr, Geert Wams, Stefan Kuiper, Sebastian Klaus, Dale Zacherl, and Jerry Dutton

Nonoxide Refractory Systems

WEAR OF GRAPHITE AND MICROPOROUS CARBON BY SYNTHETIC PGM MATTE
B. M. Thethwayo and A. M. Garbers-Craig

STRUCTURE EVOLUTION AND OXIDATION RESISTANCE OF PYROLYTIC CARBON DERIVED FROM Fe DOPED PHENOL RESIN
Boquan Zhu, Guoping Wei, Xiangcheng Li, Lieying Ma, and Ying Wei

NITRIDE BONDED SILICON CARBIDE REFRACTORIES: STRUCTURE VARIATIONS AND CORROSION RESISTANCE
Andrey Yurkov, Oxana Danilova, and Alexey Dovgal

Petrochemical

AVOID COSMETIC REPAIR OF REFRACTORY LINING IN CRITICAL EQUIPMENTS
Eissa S. Al-Zahrani and Manabendra Maity

ENGINEERED REFRACTORY CASTABLES WITH IMPROVED THERMAL SHOCK RESISTANCE
A. P. Luz, T. Santos Jr., J. Medeiros, and V. C. Pandolfelli

SINTERING ADDITIVE ROLE ON THE PERFORMANCE OF ADVANCED REFRACTORY CASTABLES
A. P. Luz, T. Santos Jr., J. Medeiros, and V. C. Pandolfelli

DETERIORATION OF REFRACTORY CERAMIC FIBRE LINING IN AN ETHYLENE CRACKING FURNACE—A CASE STUDY
Manabendra Maity, Eissa Al-Zahrani, Majed Al-Thomali, and Mohammed Abdul Kareem

THE COKE EFFECT ON THE FRACTURE ENERGY OF A REFRACTORY CASTABLE FOR THE PETROCHEMICAL INDUSTRY
Dan Yushin Miyaji, Caio Zuccolotto Otofúji, Marcelo Dezena Cabrelon, Jorivaldo Medeiros, and José de Anchieta Rodrigues

ROLE OF DESIGN AND APPLICATION ON REFRACTORY PERFORMANCE
Biswarup Sarkar, Prasenjit Pal, Prasenjit Saha, and PP Lahiri

POROUS CERAMICS IN THE Al2O3-Al(OH)₃ SYSTEM
Rafael Salomão, Adriane D. Souza, Leandro Fernandes, Luciola L. Sousa, and Vera L. Arantes

Raw Materials

ANDALUSITE, AN UNDER-UTILIZED REFRACTORY RAW MATERIAL WITH UNDEVELOPED HIGH POTENTIAL
W. H. McCracken and C. A. De Ferrari

STUDIES ON SINTERING BEHAVIOUR AND MICRO STRUCTURAL CHARACTERISTICS OF INDIAN MAGNESITE IN PRESENCE OF ADDITIVE
Manas Kamal Haldar

PHASE TRANSFORMATION IMPACT ON THE IRON DIFFUSION IN OLIVINE RAW MATERIAL REFRACTORY
R. Michel, M.R. Armmar, P. Simon, and J. Poirier
FLAKE GRAPHITE: SEEKING CHINESE INDEPENDENCE DAY
Simon Moores
1147

HYDROTALCITE (Mg$_6$Al$_2$(OH)$_{16}$(CO$_3$)$_4$H$_2$O): A POTENTIALLY USEFUL RAW MATERIAL FOR
REFRACTORIES
Rafael Salomão, Isadora M.M. Dias, and Cezar C. Arruda
1151

DEVELOPMENT AND APPLICATION OF BAUXITE-BASED HOMOGENIZED GROGS
Tiezhu Ge, Jiancheng An, and Shenrong Yang
1157

RAW MATERIALS FOR REFRACTORIES: THE EUROPEAN PERSPECTIVE
Astrid Volckaert
1163

EFFECTS OF PARTICLE SIZE AND IMPURITIES ON MULLITIZATION OF ANDALUSITE
Shuang Li, Guotian Ye, Yunfei Zhang, Yuan Zhang, Xiujuan Song, and Chuanyin Zhang
1167

EFFECT OF SYNTHESIZED FORSTERITE ADDITION ON PROPERTIES OF MgO BASED CASTABLES
Ningsheng Zhou, Lili Guo, Jiwei Li, and Kai Shi
1173

THERMAL STABILITY AND OXIDATION RESISTANCE OF Ca-α/β-SIALON POWDERS PREPARED BY
REACTION NITRIDATION METHOD
Haijun Zhang, Shuang Du, Yingnan Cao, Lilin Lu, and Shaowei Zhang
1179

THE INFLUENCE OF IRON IMPURITY ON THE PREPARATION OF MgAl$_2$O$_4$-SiC COMPOSITE
POUDERS FROM FORSTERITE, ALUMINA AND CARBON BLACK
Hongxi Zhu, Hongjuan Duan, Chengji Deng, and Wenjie Yuan
1185

EFFECT OF PRECURSOR MILLING TREATMENT AND ADDITIVES ON THE MORPHOLOGY OF
α-Al$_2$O$_3$ FROM COMMERCIAL γ-Al$_2$O$_3$
LingLing Zhu, Guotian Ye, QiaoHuan Cheng, and Ying Zhou
1191

Refractories for Chemical Processes

MECHANISMS OF WEAR REDUCTION IN HIGH CHROME OXIDE REFRACTORIES CONTAINING
PHOSPHATE ADDITIONS EXPOSED TO COAL SLAG
James P. Bennett, Brent W. Riggs, Kyei Sing Kwong, and Jinichiro Nakano
1199

CHEMICAL WEAR MECHANISMS OBSERVED IN BASIC BRICKS REMOVED FROM TWO
HIGH-CARBON FERROCHROME FURNACES
A.M. Garbers-Craig
1205

SPINEL-BASED REFRACTORIES FOR IMPROVED PERFORMANCE IN COAL GASIFICATION
ENVIROMENTS
James G. Hemrick, Beth Armstrong, Angela Rodrigues-Schroer, Dominick Colavito, Jeffrey D. Smith, and Kelley O'Hara
1211

INVESTIGATION OF Y$_2$O$_3$-STABILIZED ZIRCONIA RAMMING MIX AFTER SERVICE
IN CARBON BLACK REACTOR
Vladimir V. Primachenko, Valeriy V. Martynenko, Irina G. Shuilik, Elena B. Protsak, Natalya G. Pryvalova, Vladimir I. Ivanovskiy, and Gennadiy V. Babich
1217

STUDY ON EROSION MECHANISM OF Cr$_2$O$_3$-Al$_2$O$_3$-ZrO$_2$ BRICKS FOR COAL-WATER SLURRY
PRESSURIZED GASIFIER
Youqi Li, Changming Ke, Yucui Zhang, Yanfeng Zhang, Jizeng Zhao, and Guotian Ye
1223

EFFECTS OF ZIRCONIA ON THE THERMAL SHOCK RESISTANCE OF HIGH CHROME REFRACTORIES
FOR COAL SLURRY GASIFIER
Youqi Li, Changming Ke, Song Gao, Yanfeng Zhang, Jizeng Zhao, and Guotian Ye
1229
Refractories for Glass

UNDERSTANDING MICROSTRUCTURE/PROPERTIES RELATIONSHIPS RELATED TO THE THERMOMECHANICAL BEHAVIOUR OF HIGH ZIRCONIA REFRACTORIES
C. Patapy, F. Gouraud, M. Huger, R. Guinebretière, and T. Chotard

NEW MATERIALS AND IMPROVEMENTS FOR THE GLASS INDUSTRY
Silvio Cassavia Frasson, Marcelo Adriano Fernandes Guerra, Vladnilson Peter de Souza Ramos, Sergio Murillo Justus,
and Eric Y. Sako

RESEARCH OF REFRACTORIES AFTER 88 MONTHS CAMPAIGN IN THE E-GLASS FIBER PRODUCTION FURNACE LINING
Vladimir V. Primachenko, Valeriy V. Martynenko, Pavlo P. Kryvoruchko, Yuliya E. Mishnyova, Natalya G. Pryvalova,
Eleonora L. Kariakina, and Olena I. Synyukova

Refractories for Nonferrous Metallurgy

DEVELOPMENT OF HIGH PERFORMANCE ALUMINA-CHROME-ZIRCONIA BRICK FOR MULTIPLE APPLICATION

PROCESSING AND CHARACTERIZATION OF MgAl_2O_4—CALCIUM ALUMINATE REFRACTORIES BY REACTION SINTERING OF ALUMINA-DOLomite

MOLten ALUMINUM LONG-DISTANCE TRANSPORTATION: A REfractory ISSUE!
M. A. L. Braulio, D. R. Oliveira, J. Gallo, and V.C. Pandolfelli

phosphatE BONDED MONOLITHIC REfractory MATERIALS WITH IMPROVED MEchaniCAL AND CHEmICAL RESISTANCE FOR APPLICATIONS IN THE ALUMInum INDUSTRy
J. Decker

DEVELOPMENT AND APPLICATION OF IMPROVED SHOTCTRETE REfractory FOR ALUMINUM ROTARY FURNACE APPLICATION
James G. Hemrick, Angela Rodrigues-Schroer, Dominick Colavito, Jeffrey D. Smith, and Kelley O'Hara

ADVANCES IN NO CEMENT COLLOIDAL SILICA BONDED MONOLITHIC REfractorIES FOR ALUMINUM AND MAGNESIUM APPLICATIONS
M. W. Anderson, L.A. Hrenak, and D. A. Snyder

CHROMiUM-FREE COMPLEX SPiNEL BONDeD BASIC CASTABLES
Rahul Lodha, Hamidreza Zargar, Tom Troczynski, and George Oprea

CHROMIUM-FREE SPiNEL BONDeD CASTABLES VERSUS REBONDED FUSED GRAIN BASIC BRICKS
George Oprea, Hamidreza Zargar, Carmen Oprea, Rahul Lodha, Tom Troczynski, and Dominic Verhelst

CALCIUM ZIRCONATE REfractorIES FOR TiTANIUM MELTs
S. Schafföner, B. Rotmann, H. Berek, B. Friedrich, and C.G. Aneziris

INFLUENCE OF CORROSIVE ATTACK BY AMg_5 ON THE HOT ABRASION RESISTANCE OF REfractory MATERIALS FOR THE USE IN THE SECONDARY ALUMINUM INDUSTRy
Ralf Simmat and Christian Dannert

FUNCTIONAL COATINGS ON ALUMINA FOAM CERAMICS FOR ALUMINUM FILTRATION
C. Voigt and C. G. Aneziris
NANOSTRUCTURED SELF-FLOW REFRAC'TORY CASTABLE TO LONG-LIFE MELT ALUMINUM CONTACT LINING
F. L. Ziegler, F. A. de O. Valenzuela, F. Ziegler Nt. and F. Ziegler

Refractories for Waste to Energy Processing and Power

IMPROVEMENT TO Al₂O₃-Cr₂O₃ BRICKS FOR WASTE MELTING FURNACES
Hisanori Hoshizuki, Hiroyuki Tanida, Satoshi Ota, Yasutaka Yoshimi, and Yoshiki Tsuchiya

IMPROVED PHYSICAL PROPERTIES OF Al₂O₃-SiO₂ BRICKS USING SOL IMPREGNATION
G. Monsberger and K. Santowski

RECENT LINING CONCEPTS FOR THERMAL TREATMENT OF HAZARDOUS WASTES
D. Schweez and J. Sperber

VAPOUR PHASE AND MELT CORROSION OF REFRAC'TORY CASTABLES IN BIOMASS GASIFICATION AND INCINERATION PROCESSES
Thorsten Tönnies and Rainer Telle

Safety, Environmental Issues, and Recycling

IS THERE A VIABLE ALTERNATIVE TO REFRAC'TORY CERAMIC FIBERS?
Chris Johnson and Steve Chernack

AN ATTEMPT TOWARDS THE DEVELOPMENT AND SUCCESSFUL USE OF ECO FRIENDLY BASIC REFRAC'TORY PRODUCT
Prasunjit Sengupta, Nitesh Gupta, Sandip Mondial, and Santanu Mondial,

THE ISSUE OF USE OF BASIC REFRAC'TORY SCRAP
Kielski Andrzej, Obszynska Lucyna, Sułkowski Michał, Wyszomirski Piotr, and Blumenfeld Philippe

ANALYSIS OF CHEMICAL VALENCE OF CHROMIUM IN Cr₂O₃-CONTAINING REFRAC'TORIES USED IN DIFFERENT HIGH-TEMPERATURE FURNACES
Chencen Yao, Guotian Ye, Yuandong Mu, Xiujuan Song, and Juan Ma

AUTHOR INDEX
This proceedings contains 231 manuscripts that were submitted and approved for the 13th biennial worldwide refractories congress recognized as the Unified International Technical Conference on Refractories (UNITECR), held September 10-13, 2013 in Victoria, British Columbia, Canada.

UNITECR has become the premier worldwide congress on refractories and is the most prominent international technical conference on refractories. This was the first time the conference was held in Canada. UNITECR 2013 was organized by current and previous members of the North American Executive Board of UNITECR comprised of Tom Vert, Rob Crolius, Jeff Smith, Dana Goski, Nancy Bunt, and Mike Alexander with the assistance of The American Ceramic Society (ACerS). The organizers want to thank you to Mark Stett, Lou Trostel, Jr. and Charlie Semler for their continuing support, providing both historical details of previous UNITECR meetings and offering new suggestions to continually advance the meeting to benefit attendees, authors and industry.

Two new communication opportunities were created for authors this UNITECR. Authors were provided the option to have manuscripts peer reviewed, a new approach for UNITECR that was implemented in the expectation to further elevate the quality of the congress and proceedings. Fifty manuscripts were peer reviewed and are identified in the table of contents with a bold title. The second new opportunity was to include a poster session. Over 30 authors presented their poster during this special session.

The editors want to thank the 34 symposia organizers listed in the table on the following page, the authors for their contributions, the manuscript reviewers and the publication staff at ACerS.

We were pleased that the congress advanced the understanding of refractory technology and promoted international exchanges in research, education and industrial practice. The editors envision that this proceedings volume will serve as a useful resource for research in a field which has limited global publications.

DR. DANA G. GOSKI
UNITECR 2013 Technical Program Chair

DR. JEFFREY D. SMITH
Chairman, North American UNITECR Executive Committee
<table>
<thead>
<tr>
<th>Topic</th>
<th>Authors</th>
<th>Countries/Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Testing of Refractories</td>
<td>Len Krietz, Plibrico Company LLC, USA</td>
<td>Nigel Longshaw, Ceram, UK</td>
</tr>
<tr>
<td>Advanced Installation Techniques &amp; Equipment</td>
<td>Jim Stendera, Vesuvius, USA</td>
<td>Hirohide Okuno, Taiko Refractories, Japan</td>
</tr>
<tr>
<td>Monolithic Refractories</td>
<td>Dale Zacherl, Almatis, USA</td>
<td>Goutam Bhattacharya, Kerneos, India</td>
</tr>
<tr>
<td>Iron &amp; Steel Making Refractories</td>
<td>Mike Alexander, Riverside Refractories, USA</td>
<td>Patrick Tassot, Calderys, Germany</td>
</tr>
<tr>
<td>Raw Material Developments &amp; Global Raw Material Issues</td>
<td>Shane Bower, Christy Minerals, USA</td>
<td>Phil Edwards, Imerys, France</td>
</tr>
<tr>
<td>Refractories for Glass</td>
<td>Dr. M.D. Patil, Corning, Inc., USA</td>
<td>Adam Willsey, Kopp Glass, USA</td>
</tr>
<tr>
<td>Cement &amp; Lime Refractories</td>
<td>Fielding Cloer, Spar Refractories, USA</td>
<td>Dr. Swapan Das, Central Glass &amp; Ceramic Research Institute, India</td>
</tr>
<tr>
<td>Modeling and Simulation of Refractories</td>
<td>Dr. Bill Headrick, MORCO, USA</td>
<td>Prof. Harald Harmuth, Montanuniversität Leoben, Austria</td>
</tr>
<tr>
<td>Petrochemical</td>
<td>Don McIntyre, ANH, USA</td>
<td>Ken Moody, Refractory System Solutions, USA</td>
</tr>
<tr>
<td>Refractory for Waste to Energy Processing &amp; Power</td>
<td>Ben Markel, Resco, USA</td>
<td>Dr. Andy Wynn, Morgan Engineered Materials, China</td>
</tr>
<tr>
<td>Energy Savings through Refractory Design</td>
<td>Dr. James Hemrick, Oak Ridge National Laboratory, USA</td>
<td>Dr. Valeriy Martynenko, The Ukrainian Research Institute of Refractories, Ukraine</td>
</tr>
<tr>
<td>Nonoxide Refractory Systems</td>
<td>Dave Derwin, Superior Graphite, USA</td>
<td>Marcus Vinicius Moraes, Magliano, Morgan, Brazil</td>
</tr>
<tr>
<td>Refractories for Chemical Processes</td>
<td>Dr. James Bennett, NETL, USA</td>
<td>Matthias Rath, Rath, Austria</td>
</tr>
<tr>
<td>Developments in Basic Refractories</td>
<td>Dominick Colavito, Minerals Tech, USA</td>
<td>Prof. Andrie Garbers-Craig, University of Pretoria, South Africa</td>
</tr>
<tr>
<td>Global Education in Refractories</td>
<td>Dr. George Oprea, University of British Columbia, Canada</td>
<td>Prof. Yawei Li, Wuhan University of Science and Technology, China</td>
</tr>
<tr>
<td>Refractories for Nonferrous Metallurgy</td>
<td>Rick Volk, United Refractories, USA</td>
<td>Angela Rodrigues-Schroer, Wahl Refractories, USA</td>
</tr>
<tr>
<td>Safety, Environmental Issues &amp; Recycling Solutions for Refractories</td>
<td>Jason Canon, Christy Refractories, USA</td>
<td>Dr. Leonardo Curimbaba Ferreira, US Electrofused Minerals/Electroabrasives LLC</td>
</tr>
</tbody>
</table>
Advanced Installation Techniques
and Equipment
DEVELOPMENT OF AUTOMATIC REPAIR TECHNOLOGY BY CONTINUOUS AND QUICK MIXING TECHNOLOGY

Junichi Tsukuda*, Hiroyuki Itoh, Youichi Furuta, Kazunori Seki
Krosaki Harima Corporation, Japan
Seiji Hanagiri, Takayuki Uchida, Satoru Itoh, Seiji Asoh,
Nippon Steel & Sumitomo Metal Corporation, Japan
Sakae Nakai
NS engineering Corporation, Japan

ABSTRACT

In conventional wet-gunning it is not easy to decrease the amount of water in the gunning mix because the mix has to be pressurized and transported smoothly through hoses. An excessive amount of water in the mix often results in a poor durability of the body of gunned material. The newly developed method, Continuous Quick Mixing & Repairing Technology (QMS), does not require the gunning mix to be transported through hoses and therefore, the amount of water can be decreased. As a result the installed body, obtained by means of the QMS method, has a more excellent quality when compared to the wet-gunning method. Furthermore the cleaning job after the gunning repair is as easy and simple as that after dry-gunning. This paper describes the development of QMS and the improved durability of the gunned material.

1 PREFACE

The conventional gunning application of refractory materials has been performed in various ladles and furnaces and classified as dry-gunning and wet-gunning. The former is easier and simpler from the point of view of application, but a much greater amount of water is required in the gunning mix, which often results in poor durability of the gunned material body. The latter is effective to obtain a relatively dense gunned body, but gunning work is not simple due to the preliminary mixing and to the cleaning of equipment after work. Continuous Quick Mixing & Repairing Technology (QMS as the abbreviation of Quick Mixing Shot) is introduced in this paper. It provides both a simpler and easier gunning method equivalent to that in conventional dry-gunning and a more excellent quality of the gunned body which results in better durability than that obtained in conventional wet-gunning.

2 FEATURES OF THE GUNNING EQUIPMENT

2-1 Conventional gunning methods

Fig. 1 shows the typical conventional gunning methods: dry-gunning and wet-gunning. In dry-gunning dry refractory material is conveyed by air flow and gunning water is added at the tip of the nozzle to produce slurry which is subsequently applied.
In wet-gunning the material is mixed first with water to produce slurry which is pressurized and conveyed through hoses and mixed with binder at the tip of the nozzle in order to solidify the gunned body.

2-2 Features and advantages of the QMS method

1) The system of the QMS method

Fig. 2 shows the system of the QMS method, which consists of a material feeder, a water pump, a binder pump and the Continuous Quick Mixing & Repairing device. Refractory material is conveyed by air flow and water is sprayed, as fine mist, into it just before the device. Next the mix of material and water is kneaded in the mixing chamber to obtain an excellent kneading effect.

After kneading, the gunning mix is flung to the targeted repair spot by a rotating projection disk. In the QMS method, the material after having been mixed with water is not conveyed through hoses. Therefore, the amount of water can be reduced considerably.

2) The Continuous Quick Mixing device

Fig. 3 shows the vertical section of the Continuous Quick Mixing device. In the fixed outer casing the inner rotor is installed and rotates with 800 rpm. The upper half of the rotor has many dispersion blades on its cylindrical surface, while the lower half is conical and has many kneading pins on its conical surface. The blades and pins are positioned along the spiral line on the rotor surface. The outer rotor, which covers the conical surface of the inner rotor, rotates with 150 rpm. Dry material is sprayed with water and fed horizontally close to the top of the outer casing. After having been mixed by the dispersion blades in the upper half of the inner rotor, the mix descends to the lower half and forms there the relatively dense retention layer due to the centrifugal force generated by the rotation of the outer rotor. As shown in Fig. 4, the retention layer is scratched by many kneading pins on the inner rotor. When scratched, the retention layer of the mix is subjected to shearing, compression and tensile forces and deformed and kneaded sufficiently. The scratching does not occur at the same height but on the different levels of each kneading pin, due to the spiral positioning of the kneading pins. The kneaded mix is gradually pushed downward along the inner
surface of the outer rotor to the projection disk.

![Image](image1)

Fig. 3. Mechanical structure of the continuous quick mixing device

Dry material Mist injection Dispersion blades (800rpm) Kneading pins Inner rotor (800rpm) Projection disk

![Image](image2)

Fig. 4. Principle of kneading

The kneaded mix is conveyed and gunned to the targeted repair spot not by means of conventional compressed air but by centrifugal flinging force. As shown in Fig. 5, the gunning device consists of 1) the projection disk positioned at the lower exit of the outer rotor, 2) the belt wound around the disk (with one opening area) to drive it and 3) the reflector to direct and rectify the mix flow toward the spot of application. The adhesion of the kneaded mix on the targeted repair spot can be optimized by adjusting appropriately both the velocity of the mix flow and the thickness of the gunned material body.

![Image](image3)

Fig. 5. Plane view of the gunning device and isometric view of the projection disc

3 EVALUATION OF THE MIXING EFFECT

To evaluate the mixing effect, the QMS was compared with a common desk-top mixer in mixing for three minutes. After adding a specified amount of water, the material was mixed for three minutes with the continuous quick mixer and also with the desk-top mixer and the viscosity of the mixed material was measured in each case. The kneading ratio is defined as the value determined by dividing the viscosity of the material mixed by the QMS device with that mixed by the desk-top mixer. As shown in Fig. 6, the QMS device showed 89% of kneading ratio under the mixing condition of a 15 mm gap between the kneading pins and the outer rotor. In general, the faster rotation of the inner rotor results in a better kneading ratio because it is guessed that both the shearing and the compressing force applied on the material increase as the rotation of the inner
rotor becomes faster. With the smaller gap of 10 mm, the kneading ratio of 93% was obtained because of a similar reason. Fig. 7 shows the distance of the gap between the kneading pins and the outer rotor.

Fig. 6. Influence of the gap between the kneading pins and the outer rotor and the rotation of the inner rotor on the kneading ratio

Fig. 7. Gap between the kneading pin and the outer rotor

4 FEATURES OF THE REFRACTORY MATERIALS FOR QMS

To obtain excellent durability of the applied material in hot service, the refractory materials for QMS have been developed pursuing the targets:
1) the application of a small amount of water and
2) a tight adhesion on the targeted spot.

Fig. 8 shows the quality map of the materials applied with the QMS method among various application methods of monolithic refractories. Table I shows typical properties of the material for the QMS in comparison with the material for conventional wet-gunning.

Fig. 8. The quality map in the obtained apparent porosity comparing various application methods of monolithic refractory materials

Table I. Typical properties of materials applied in QMS and wet-gunning

<table>
<thead>
<tr>
<th>Installation method</th>
<th>QMS</th>
<th>Wet-gunning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition/%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>MgO</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Apparent porosity/%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>110°C x 24h</td>
<td>21.4</td>
<td>23.4</td>
</tr>
<tr>
<td>1500°C x 3h</td>
<td>26.0</td>
<td>28.6</td>
</tr>
<tr>
<td>Bulk density/g/cm³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>110°C x 24h</td>
<td>2.93</td>
<td>2.87</td>
</tr>
<tr>
<td>1500°C x 3h</td>
<td>2.74</td>
<td>2.68</td>
</tr>
<tr>
<td>Modulus of rupture/MPa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>110°C x 24h</td>
<td>5.1</td>
<td>3.6</td>
</tr>
<tr>
<td>1500°C x 3h</td>
<td>25.0</td>
<td>18.6</td>
</tr>
<tr>
<td>Permanent linear change/%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500°C x 3h</td>
<td>+1.36</td>
<td>+0.53</td>
</tr>
<tr>
<td>1500°C x 12h</td>
<td>+1.38</td>
<td>+0.35</td>
</tr>
<tr>
<td>Amount of water/mass%</td>
<td>7.7</td>
<td>8.8</td>
</tr>
</tbody>
</table>

There is generally a tight connection between the amount of water applied and the density of the gunned material. During application,