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Refractories Applications and News

TRI THE REFRACTORIES INSTITUTE

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The American Ceramic Society www.ceramics.org

Technology Bimonthly for the Global Refractories Industries

In This Issue...

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From the Editor . . .

Jeffrey D. Smith, Editor, *jsmith@mst.edu*

Jeffrey D. Smith

This issue is arriving to you a few weeks later than normal. There are a number of reasons for this and I felt obliged to share them with you.

First and certainly foremost is that this is the first issue to go out since the retirement of Mary Lee. Anyone who has ever participated in anything related to *RAN* is aware that she and she alone kept everything on schedule. I was the one most guilty of procrastinating; eventually she learned how early to make my deadlines so that I could procrastinate my standard amount before completing my tasks. What a difficult person I must be to work with. She is certainly missed.

The second reason relates to Todd Sander doing most of the layout in this issue. Todd has worked with me for many years and has helped out on *RAN* during nearly all that time. He has done much of the behind-the-scenes things that improve the readability of the journal; re-making many of the figures and tables that have been included in manuscripts over the years. Everyone has a learning curve and Todd has once again shown that his is far steeper than most. He will continue to elevate *RAN* in subsequent issues.

The third reason relates to the fact that I am very seldom in Rolla these days. I have been on research leave all summer and will continue to be until the end of the calender year. Such leaves are less and less common and I couldn't pass up the opportunity it provided. Most of my time is spent working on a phase equilibria textbook that I hope will be useful not only to university students but also to technical people throughout many industries.

The last reason for the publication date may be obvious when looking at the content in this issue. I chose of couple of quality manuscripts that were originally published decades ago and added them to a prospective provided by Ruth Engel. I didn't choose these two manuscripts because they were somehow particularly relevant, I chose them out of necessity. In tough times like these, we not only tighten our financial belts, we stay close to our respective core missions. I don't know many companies whose core mission includes publishing technical content. It has always been universities that continue to publish come rain or shine. Unfortunately the universities that currently support refractory related industries are few and far between so the amount of technical content, although consistent, is relatively small.

This issue of technical content has loomed in the background for some time. With UNITECR, Conference of Metallurgist and conferences in Europe and south-east Asia, refractory technical content is spread very thin. The Refractory Ceramics Division of ACerS is looking into ways to help on this issue and I hope to announce some new features that will begin to appear in *RAN*; features that will help us to provide additional technical content that will help you be successful.

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About the Cover: An image of Almatis AR-78 Spinel grain in the -3 to +6 mesh size range, roughly 3 to 5 mm in average diameter. Please note that the image has been modified for the cover and that the grain is snow-white in appearence.

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"*Refractories Applications and News*" founded by Robert E. Moore in 1996 at MS&T.
Editorial offices at Missouri S&T
Materials Science and Engineering Department, 223 McNutt Hall, 1870 Miner Circle Drive, Rolla, MO 65409-0330
Phone: (573) 341-6561 Fax: (573) 341-6934 Website: www.ranews.info

Editor, Jeffrey D. Smith	jsmith@mst.edu	Phone: (573) 341-4447
Assistant Editor/Webmaster, Todd Sander	rannews@mst.edu	Phone: (573) 341-6561
RAN Advisor, Mariano Velez (MO-SCI Corporation)	mvelez83@alum.mit.edu	Phone: (573) 341-6561
Contributing Editor, Charles E. Semler (Semler Materials Services)	CESemler@aol.com	Phone: (480) 895-9830

Lou Trostel, Councilor, Refractories Ceramics Division, ACerS
Rob Crolius, President, TRI

Corresponding Editors:

Esteban Aglietti, (CETMIC, Buenos Aires, AR)
E-mail: eaglietti@cetmic.unlp.edu.ar
Carmen Baudin, (Institute for Ceramics and Glass, Madrid, Spain)
E-mail: cbaudin@icv.csic.es
Richard C. Bradt, (University of Alabama)
E-mail: rcbradt@coe.eng.ua.edu
Elena Brandaleze, (Universidad Tecnológica Nacional, San Nicolás, Argentina)
E-mail: ebrandaleze@frsn.utn.edu.ar
Geraldo E. Gonçalves, (Magnesita, Brazil)
E-mail: ggoncalves@magnesita.com.br
Delia Gutierrez-Campos, (Universidad Simon Bolivar, VE)
E-mail: dgutierr@usb.ve
Bill Lee, (Imperial College London)
E-mail: w.e.lee@imperial.ac.uk
Jose L. Mendoza-Bedolla, (Technical Consultant, Saltillo, MX)
E-mail: jlmendozab@prodigy.net.mx
Li Nan, (Wuhan University of Science and Technology, P.R. China)
E-mail: linan@mail.wust.edu.cn
George Oprea, (University of British Columbia, CA)
E-mail: oprea@interchange.ubc.ca
Victor C. Pandolfelli, (UFSCar, Brazil)
E-mail: vicpando@power.ufscar.br
Michel A. Rigaud, (Ècole Polytechnique, Montreal, CA)
E-mail: michel.rigaud@polymtl.ca
Analía G. Tomba Martinez, (INTEMA, Mar del Plata, AR)
E-mail: agtomba@fi.mdp.edu.ar
Raul Topolevsky, (Siderar, Buenos Aires, AR)
E-mail: yaptky@siderar.com

Subscription is free upon request in the U.S. only.

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2010 REFRACTORIES RELATED MEETINGS

September 6-10, **The 25th International Mineral Processing Congress 2010 (IMPC)**, Brisbane Convention Ctr., Australia; IMPC 2010 Event Management – The AusIMM, Tel: +61 3 9658 6123, Fax: +61 3 9662 3662, impc2010@ausimm.com.au, www.impc210.org, PO Box 660, Carlton South, Victoria 3053, Australia.

September 8-9, **Colloqium on Refractories**, Aachen, Germany.

October 3-6, **COM 2010-Conference of Metallurgists, 5th International Symposium on Advances in Refractories,** Vancouver, BC, Canada, George Oprea: oprea@interchange.ubc.ca, www.metsoc.org.

October 3-6, **The Michel Rigaud International Symposium on Advances in Refractories for Metallurgical Industries V** (in conjunction with Conference of Metallurgists-COM2010), Vancouver, British Columbia, Canada.

October 17-21, **Materials Science & Technology 2010 Conference and Exhibition - MS&T '10 combined with the ACerS 112th Annual Meeting,** George R. Brown Convention Center, Houston, TX.

Nov. 14-18, **3rd International Congress on Ceramics**, Osaka International Convention Center, Osaka, Japan.

December 6-9, **35th ALAFAR Congress**, Lima, Peru.

Ads must be received by October 1st for publication in the November/December 2010 issue. Ads received after the 15st will be placed in the next issue.

News from The Refractories Institute

www.refractoriesinstitute.org/

The Refractories Institute, P.O. Box 8439, 325 Maple Avenue, Pittsburgh, PA 15218

Rob Crolius

INDUSTRY NEWS

2010 TRI Elections: Board, Executive Committee, Officers

In April, the Active Membership of The Refractories Institute elected the following member company representatives to serve two year terms on the Institute Board of Directors:

Board Member	TRI Member Company
Timothy Albertson	Wahl Refractories
William K. Brown	Resco Products
Abel Carriquiry	Refractarios Peruanos
Louis S. Goltermann, III	Alsey Refractories
David A. Gregory	Magnesita
Dell C. Hadden	Thermal Ceramics
Dennis A. Hageman, Sr.	Missouri Refractories
Guenter Karhut	ANH Refractories
William P. Kelly	Unifrax Corporation
R. David Lane	Clayburn Industrial Group
Daniel W. Lease	Whetstone Technology
Lee Morris	Riverside Refractories
Stephen J. Nock	The Nock and Son Company
Frank R. O'Brien	Christy Refractories Company
Michael K. Pierce	C-E Minerals
Leslie M. Power	Almatis
Jonathan R. Tabor	Allied Mineral Products
William Wilkins	Minteq International

In addition, at the June Board of Directors meeting held in Napa, California, the following Board members were elected to the TRI Executive Committee and the officer positions as indicated:

Board Member	Elected Executive Position
David A. Gregory	TRI Chairman
Stephen J. Nock	TRI Vice Chairman
Louis S. Goltermann, III	TRI Treasurer
Daniel W. Lease	Immediate Past Chairman
Guenter Karhut	Executive Committee Member
Jonathan R. Tabor	Executive Committee Member

TRI 2009 SAFETY AWARDS

Three TRI member companies were recognized at the Institute Spring Membership Meeting for outstanding safety records in 2009. Chairman's Awards are given to those Active members that have achieved the best overall safety records among the TRI membership.

Chairman's Safety Awards Recipients

THE NOCK AND SON COMPANY

MINTEQ INTERNATIONAL

UNIFRAX CORPORATION.

In addition to Chairman's Awards, TRI also recognizes TRI member refractory plants that have operated for a calendar year without a lost-time accident or illness. A total of ***THIRTY*** plants were recognized for their achievements in 2009.

Chairman's Awards for Plants with Zero Lost-Time

ALLIED MINERAL PRODUCTS: Brownsville, Texas

ANH REFRACTORIES: A.P. Green: Middletown, Pennsylvania; Minerva, Ohio; Pryor, Oklahoma; Harbison-Walker: Fairfield, Alabama; Fulton, Missouri; North American Refractories: West Mifflin, Pennsylvania

CHRISTY REFRACTORIES COMPANY: St. Louis, Missouri

MAGNESITA REFRACTORIES: Engineered Ceramics-York, Pennsylvania; Quarry and Process Plant-York, Pennsylvania

MINTEQ INTERNATIONAL: Baton Rouge, Louisiana; Bryan, Ohio; Dover, Ohio; Old Bridge, New Jersey; Portage, Indiana; Slippery Rock, Pennsylvania

MISSOURI REFRACTORIES COMPANY: Pevely, Missouri

THE NOCK AND SON COMPANY: Oak Hill, Ohio

RESCO PRODUCTS: Santa Fe Springs, California; Hillsborough, North Carolina; Cedar Heights Clay-Oak Hill, Ohio; Refco-Wellston, Ohio

RIVERSIDE REFRACTORIES CANADA: Nanticoke, Ontario

THERMAL CERAMICS: Canon City, Colorado; Elkhart, Indiana; Girard, Illinois; Burlington, Ontario

UNIFRAX CORPORATION: Tonawanda, New York

WHETSTONE TECHNOLOGY: Cabot, Pennsylvania

WHITACRE GREER COMPANY: Alliance, Ohio

FIBERCON INTERNATIONAL PARKINSONS GOLF OUTING A RECORD BREAKER

The recent golf outing sponsored by TRI Associate Member Fibercon International on behalf of the Parkinson Foundation of Western Pennsylvania netted over $43,000 and was the biggest fundraiser ever for the organization. Refractory related companies that played golf included Riverside, Universal Specialties, Calucem, CE-Minerals, The Nock and Son Company, Washington Mills, ANH, Mt Savage, and of course Fibercon. In addition, Resco Products, Kerneos and Possehl Erzkontor sponsored tees. Now an established tradition, the second annual Fibercon event is scheduled for June 27th, 2011, at the Butler (PA) Country Club. Hold the date!

LEGISLATIVE

Bonus Depreciation: NAM Urges Congress to Restore Investment Incentive

The important issue of bonus depreciation is gaining traction on Capitol Hill. A temporary 50-percent bonus depreciation provision was included in both the 2008 and the 2009 economic stimulus laws. Bonus depreciation simply allows a company to accelerate the amount of depreciation taken in the year purchased by permitting businesses to immediately deduct 50 percent of the cost of new machinery, equipment and other essential capital investments. The provision expired in 2009, but the business community is seeking a one year extension for 2010. As the nation recovers from the economic downturn, an extension will help boost sales for manufacturers of these products and contribute to job creation and overall economic growth.

The House Small Business Committee held a hearing July 14 on bonus depreciation and its impact on small business.

On June 21, Senate Finance Committee Chairman Max Baucus (D-MT) and Ranking Member Charles Grassley (R-IA) introduced legislation (S. 3513) to extend bonus depreciation for companies of all sizes for one year through 2010. The bipartisan bill is designed to stimulate business investment and help create jobs. While this stand-alone legislation will not move on its own in the Senate, Chairman Baucus has offered a substitute amendment to the Small Business Lending (and Tax) bill (H.R. 5297), which would extend retroactively bonus depreciation through 2010. This legislation is currently pending on the Senate floor with possible action to occur as early as this month. The House passed H.R. 5297 earlier this year, but it did not include an extension of bonus depreciation.

Cap and Trade Scaling Back, but Issues Remain

Senators John Kerry (D-MA) and Joseph Leiberman (I-CT) are working to scale back their draft global climate change legislation in hopes of finding enough support to pass something. The revised bill is expected to focus only on utilities and will eliminate the proposed control scheme for other major industries.

Of continuing concern to refractories producers and other major industries are current efforts in Congress to encourage and coerce utilities into switching from coal to natural gas. Many are concerned that if the government promotes or mandates natural gas for such a huge sector as the power industry, it will have an inflationary impact on the price of natural gas for other industrial users who cannot necessarily burn other fuels.

REGULATORY

Challenge to EPA Regulations Relating to Green House Gases

The National Association of Manufacturers (NAM) and 16 other business associations have filed four petitions for review in the U.S. Court of Appeals for the D.C. Circuit, challenging EPA regulations from 1978, 1980 and 2002 that are now part of the EPA's effort to regulate green house gases (GHG) from stationary sources of emissions. No one anticipated that these previously issued rules would now be used to mandate GHG permit requirements, but that is the interpretation the EPA has adopted. The NAM also filed an administrative petition for reconsideration with the EPA on the same rules. The NAM’s lawsuits and the administrative petition challenge each of the four older rules to the extent that the EPA considers them to allow the regulation of pollutants such as GHGs that are not subject to a National Ambient Air Quality Standard (NAAQS).

OSHA Getting Tougher

The Occupational Safety and Health Administration (OSHA) is getting tougher. On June 18, its new Severe Violators Enforcement Program went into effect with the goal of clamping down on habitual OSHA scofflaws. Also, the agency has recently revised how it assesses penalties as outlined in its Administrative Penalties Bulletin. For more info both issues, go to www.osha.gov and scroll down to the box marked “Top Links”.

On a collateral issue, OSHA appears now to be cross-referencing violations among multiple employer work sites and plants and increasing penalties for violations which have been previously cited in other sites of the same employer.

CHANGES IN RAW MATERIALS–HISTORY REPEATS ITSELF

Ruth Engel, Refractories Consultant, 121 Olde Farm Rd., Oxford, OH 45056
ruthengel@refractoryexpert.com

Ruth Engel

INTRODUCTION

Availability and cost of raw materials have always been a major driving force in the changes that have taken place in the manufacture of routinely used refractories. Concurrently, the users of refractories keep implementing process changes leading to ever more demanding environments, which can only be satisfied by continuously improving refractory properties. These issues, together with environmental concerns, have pushed refractory development and reliability into new realms and stressed the raw material side to produce new, cheaper and easily available materials that can be used to fulfill all of these requirements.

Alumina silica refractories have changed over time because of all of the above. In this article, I will be concentrating on the effect that raw material changes had on physical properties. In particular, I will follow the changes that occurred in fired alumina silica brick. Although the data and events presented took place many years ago they are applicable to today's conditions as the difficult raw material's market forces the manufacturer to continuously reformulate their product in order to maintain expected properties and utilize what is available at a reasonable price. It also highlights the user's problem of determining when a change has taken place, which could affect the life of the installation.

BACKGROUND

Professor Brosnan stated that "With the advent of phase equilibrium diagrams after about 1920, the modern era of alumina-silica brick began. At that point, scientific principles guided the development of fireclay brick rather than trial and error" [1]. The manufacturing progression went from fireclay to ever-higher alumina bearing brick. Alumina silica refractory brick consumption peaked in the late 1970s to early 80s. Their use has decreased since as the result of many variables: advances in castable technology, development of alumina-magnesia-silica brick, processes requiring other refractory chemistries, etc.

In the United States, the cheap availability of high purity fireclays was reflected in brick properties, which were comparable to higher alumina refractories, made in other parts of the world. In particular, super duty brick (45% Al_2O_3), was once the standard product used in many applications. Little thought was given to either the provenance of the clay or the expected physical properties of the brick as many companies manufactured similar products. With the advent of steel ladle metallurgy, which led to longer contact times and increasing metal temperature, the use of fireclay brick was discontinued and more refractory types of alumina brick, 50% then 70% and now 85% with or without magnesia additions using high purity bauxites and fused aluminas, have taken their place.

Table 1 shows the continuously higher refractoriness of the brick as a function of their increasing alumina content [2]. Another consequence of the increase in refractoriness is that the PCE (Pyrometric Cone Equivalent) test is no longer carried out and the lower temperature Hot Modulus of Rupture or Hot Load are no longer important because the expected use temperature is considerably higher. Table 1 also shows how high temperature strength increases with the higher alumina levels and this was one of the reasons for greatly improved steel ladle life [2].

RAW MATERIAL CHANGES

In the late 1980s and early 1990s a major change to the alumina silica raw material provenance took place because the easily mined US deposits were exhausted, Guyana's mine was flooded and newly developed Chinese bauxite mines provided cheap and plentiful material. Consequently, they started to be used. Prior to this time, most bauxite came from Guyana which produced very high purity bauxite and many high quality deposits could be found in the southeast United States. These latter deposits were generally known as the source of SEUS grain.

Table 2 shows the chemistry and physical properties of several 70% alumina brick [2-4]. When available, the year the testing is included. Note that although this table was originally published as reflecting properties of 70% Al_2O_3 brick, today, the Early Chinese Bauxite-1988, would not be considered part of this group. The impetus for this work was an unexpected high wear rate of brick in steel ladle applications, leading to an unexplained dramatic decrease in life.

Of the commonly reported properties: the brick chemistry is quite consistent, with some variability shown in the TiO_2 level, the bulk density similar between products, but the apparent porosity shows some variation. The differences between the products become apparent when looking at the high temperature test results. The steel ladle problem was eventually traced back to a decrease in hot properties as shown by the lower hot modulus of rupture (ASTM C583) and poorer hot load (ASTM C16) values. This change could be summarized by "the outstanding product of the late 1970s has shown a distinct drop in properties at high temperature… Raw material substitutions have diminished the high temperature properties…" [3]. As these were fired brick, the number of standard tests available for determining properties is extensive. In addition, at the time of this problem many producers of refractories, as well as their users, had substantial laboratories where testing could be carried out easily and quickly. As a result, the problem could be addressed in a timely fashion. For comparison, data for a currently produced brick was added. Note its physical properties are in the same range as those produced using the Guyanese bauxite and that minimal hot properties are provided.

DISCUSSION

Today this problem has only historical significance because, after undergoing a learning curve, the refractory manufacturers were able to produce brick with good high temperature properties using Chinese bauxites.

What we can take away from this experience is that room temperature tests may not adequately differentiate between same category products. This can lead to problems when the user is not aware of the possible ramifications a new raw material could have on the product and consequently expect properties, in actuality service life, which are not met.

Many new types of refractories have been developed since these studies were undertaken: considerable brick quantity is no longer fired but resin bonded, many alumina brick are made out of fused product and many refractories are of basic composition. These choices have not decreased the difficulty in securing a steady and reliable supply of raw materials at a reasonable cost. In today's economy, this is again a major challenge to the producer's ability to deliver a consistent product. Their refractory knowledge and ingenuity has allowed for the continuing production of reliable materials, even though at times changes have to be made to accommodate the market. It is important that these changes be communicated to the user in such a way that the possible implications are understood.

Each refractory application requires a unique set of properties for it to be successful. Selecting refractories which optimize these values while minimizing their cost will lead to a best overall practice. To achieve this, knowledge of as many pertinent parameters as possible and close cooperation between all parties is needed.

If you have comments about this column or suggestions for future topics please visit me at www.refractoryexpert.com and I will try to address them.

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1. Refractories Handbook, Charles Schacht ed., p. 81, 2004.
2. R. Engel, R. Marr, E. Pretorius, "Refractory/Slag Systems for Ladles and Secondary Refining Processes", Keeping Current Series, I&SM, 1996.
3. B. Baker, R. Shultz, "The Importance of High Temperature Properties in Refractory Material Selection", Fall Meeting of the Refractories Division of the Am. Cer. Soc., Oct. 1989.
4. Internet: 70% alumina brick, data sheet, 2010.

RAN

Table 1. Comparison of Chemistry and Properties of Steel Ladle Brick

	Bloating Ladle Brick	50% Al_2O_3 Volume Stable Brick	70% Al_2O_3 Volume Stable Brick
SiO_2	67.2	45.4	25.2
Al_2O_3	26.1	49.5	70.6
TiO_2	1.3	2.2	2.9
Fe_2O_3	2.0	1.5	1.0
CaO	0.2	0.2	0.05
MgO	0.4	0.4	0.1
K_2O+Na_2O	2.7	0.7	0.1
PCE	20-33	>34	37-38
Bulk Density (g/m^3)	2.28	2.44	2.53
Apparent Porosity (%)	13.0	13.0	17.0
Cold Crushing Strength (kPa)	53,500	52,800	45,800
Hot MoR (kPa)			
@ 955°C (1750°F)	3,000	15,100	12,000
@ 1095°C (2000°F)	3,500	19,300	12,200
@ 1260°C (2300°F)	1,500	16,700	8,400
@ 1480°C (2700°F)	0	140	2,600
Linear Expansion (%)			
@ 540°C (1000°F)	0.35	0.26	0.24
@ 1095°C (2000°F)	0.35	0.58	0.60
@ 1315°C (2400°F)	3.85	0.73	0.76
@ 1450°C (2640°F)	NA	NA	NA
Permanent Linear Change (%)			
Schedule E (1290°C)	+10 to +16	-	-
Schedule C (1600°C)	NA	+1.3	-0.4 to +1.0

Table 2. Comparison of Chemistry and Properties of Fired 70% Alumina Brick

Raw Materials	Guyana Bauxite -1977	Early Chinese Bauxite-1988	50% Chinese 50% SEUS	All Chinese Bauxite-1994	All SEUS Grain	Chinese Bauxite-2010
Al_2O_3	71.8	76.3	69.6	72.0	68.2	69.9
SiO_2	22.9	16.8	22.4	23.0	27.0	24.1
TiO_2	2.9	3.6	2.9	2.9	2.9	3.2
Fe_2O_3	1.5	1.3	1.7	1.4	1.6	1.5
CaO	0.2	0.1	0.1	0.2	0.1	0.2
MgO	0.2	0.2	0.4	0.2	0.2	0.2
K_2O+Na_2O	0.5	0.8	0.6	0.4	0.2	0.9
P_2O_5			2.8			
Total % auxiliary oxides	5.3	6.0	5.7	5.1	5.0	6.0
Bulk Density (g/cm^3)	2.57	2.63	2.66	2.63	2.57	2.59
Apparent Porosity (%)	20.2	21.1	17.1	19.0	14.5-18.0	18.5
Hot MoR (kPa)						
@ 1260°C (2300°F)	7000	6850	5109	4800	9584	
@ 1480°C (2700°F)	2100	1700	3048	1620	3054	
Hot Load (%)						
@ 1450°C (2640°F)	-1.5	-0.4	-0.7	-	-1.1	
@ 1510°C (2750°F)	-	-	-	-3.1	-	
@ 1650°C (3000°F)	-11.0	-22.0	-17.6	-	-7.7	
Permanent Linear Change (%)						
@ 1600°C (2910°F)	+4.0	+6.0	+4.6	+2.4	+2.0	+4.1

Editorial from the Assistant...

by Todd Sander, *RAN* Assitant Editor

I'd like this opportunity to publically and personally thank Mary Lee, *RAN* Assistant Editor Retired, for her years of service to the publication. I have learned recently first hand the job she made seem effortless from the perspective of the observer is not what it appeared to be. Although, as with all professions, it is characteristic to the title that the observer thinks to themselves that they too can do what they do.

We all may have seen a home improvement show and been inflated with confidence and ignorance and the desire to accomplish the same in our own home. It is only later that we discover what appeared simple in the hands and care of a pro evolves into a litany of never-ending trips to the home center and countless additional hours of unanticipated toil, labor, and expense. Although the amateur may yield a functional product and take pride in its birth at his hand, it is usually lacking the fit and finish a true professional imparts. It is with this perspective I hope you judge our product, *RAN*, in this period of transition.

As our senior editor iterated, I further implore that you, the reader, consider contributing to the publication in any way you may feel compelled. Although advertising and donations are what makes this publication both possible and free to the reader; it is its content that we hope the readership both enjoys and can appreciate from. In that regard, I urge readers to seriously consider submitting copy to *RAN* for publication. You may think you might not have anything appropriate to submit; however, copy can be of any type and can range widely.

Examples of copy include but are not limited to:

- Comprehensive research submitted to *RAT* (Refractory Applications *Transactions*) for peer review
- Other research, observations, or experiences; failures to prove hypthesis are often the most valuable yet unpublished works and requires the most courage of author to forward. Success and improvement is easy to report.
- Student research from a simple summary/abstract to something more extended. (A great way for students in the industry to forward their name and work prior to seeking employment!)
- A retiree's retrospective on their careers and the industry, how it was then and is now, how they see the future.
- An opinion piece on anything related to our industry, as short as a paragraph or as long as you require to opine.
- Open letters to raw material suppliers, refractory producers, refractory users, regulatory officials, academia, etc.
- Reader mail, "I enjoyed the article...in particular...but...however...in our experience...well done...its 2 not 3...etc." We don't have to use your real or full name if you desire.

I formally challenge each of our **corresponding editors** acknowledged on page 2 to contribute at least one article a year of any type to *RAN*; I will not exclude myself from the contest.

As an engineer, I would be happy to assist and work with anyone on their submission from editing, to preparation of tables or charts, to rendering figures and diagrams. I look forward to working both with and for you in the coming issues.

I can be reached at rannews@mst.edu or 573.341.6561

A CLASSIFIED REVIEW OF REFRACTORY SLAG TESTS*

By Harold E. Simpson, Battelle Memorial Institute, Columbus, Ohio

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NOTE: Because of the desire for brevity and conciseness, detailed descriptions of apparatus and methods are omitted; however, references to the literature are included and further details may be obtained therin. Ferguson has given a splendid review of the literature on laboratory slag tests for refractories [1]. A similar, yet amplified, classification used by the above author has been adopted in this paper and is believed to include all types of tests. In order to avoid duplication, only those references to the work done subsequent to the above article are given.

ABSTRACT

The literature on refractory slag tests is reviewed. The various methods are divided into eight different classifications and references to the literature are given.

INTRODUCTION

A considerable amount of time and money has been expended in the attempt to develop a satisfactory test that will evaluate the ability of refractories to resist slag action. A survey of the literature discloses the wide variety of tests studied.

MEASUREMENT OF SLAG PENETRATION

Miehr, Kratzert, and Immke amplified the penetration test by taking measurements on the specimen before and after slagging to include (1) the slag solubility number and (2) the slag penetration number [2]. A cylindrical hole was made in the surface of the brick and 50 grams of slag were placed in the hole. The test piece was heated to 100°C above the fusion point of the slag; usually 1200 to 1400°C. The temperature was maintained for one hour. A section was cut through the brick and the progress of solution and penetration noted.

Salmang investigated the action of acid, basic, and neutral synthetic slags on refractory materials [3]. The powdered synthetic slags were placed in crucibles and heated to various temperatures for various lengths of time. After heating, the crucibles were broken in two and the conditions of the slag, penetration or attack on the bonding material of the crucible, and the penetration and attach of the body of the crucible were determined. The results of these studies using twenty-six slags were compared.

This work continued by Salmang and Schick who found that the order of corrosion of pure oxides on fireclay crucibles was as follows: PbO, FeO, MnO, CaO, Fe_2O_3, K_2O, Mn_2O_3 [4]. Mixtures of the oxides had less influence than the pure oxides.

Miksch and Salmang extended the work to the action of simple and complex slags on magnesite crucibles [5]. Singly, K_2O, Na_2O, PbO, FeO, B_2O_3 do so strongly. A corroding action was shown only by binary or ternary slags which contained P_2O_5, B_2O_3, SiO_2, or, to a less extent, Al_2O_3 in excess. The attack of ternary slags is less than binary. Smaller amounts of FeO and CaO in ternary slags cause stronger attack than do larger amounts (the effect of CaO is greater), while the reverse is true with MnO. That magnesite is less easily slagged than in fire clay is explained by the assumption that it loses its strongly basic characteristic at these temperatures.

Salmang and Schick, in investigating the corrosive power of various synthetic slags, found that oxides of the MO type (M = metal) react as bases, while those of the type M_2O_3 react as acids [6]. The latter oxides do not attack fire clay and check the attack of bases. In silicate fusions Fe_2O_3 is stable up to 1580°C, while Mn_2O_3 decomposes at 1500°C. The alkali oxides behave as weak acids at these high temperatures, while the alkali-earth oxides act as strong bases. P_2O_5 checks the attack of bases and when present in large amounts in the slag the excess attacks strongly.

Hebestreit measured the penetration of a high lime blast-furnace slag and a high iron slag by means of a planimeter [7]. The refractories used varied over a wide range in Al_2O_3 and SiO_2 content. The slags were pressed into drilled holes made in the brick samples and then fired to 1460°C. The cores from the drilled holes were used for porosity test pieces. The author correlates slag action with the large and small pore space in the refractory. A method for determining the porosity due merely to the large pore spaces and that due to both large and fine pore space is given.

Budnikoff placed powdered slag or glass in cavities made in testing samples [8]. Graphite electrodes were attached to the cavities and the electric current for heating could be regulated so as to maintain the required temperature. This arrangement for testing the stability of the refractories to the action of slag was believed to correspond more exactly with prevailing industrial conditions.

Salmang and Hebestreit later used crucibles of 70: 30 mixture of fired and unfired kaolin containing either 0.2 or 4% flux and had a porosity of ±24 vol %. FeO, as a slag, strongly attacked each type of crucible at 1500°C [9]. The action was greatest in the presence of 4% Na_2O or TiO_2. Refractories with 2 or 4% flux were attacked by the various slag only slightly more than those containing none. Tests on commercial brick showed that the action of blast furnace or open-hearth slag is not directly dependent on porosity. Brick of the same chemical composition and porosity are attacked to the same extent only when the microstructure is the same.

Hyslop and Biggs, in order to maintain a uniform temperature, rotated a crucible built up of four standard-sized firebrick cemented together [10]. The brick were set on end on a 12- by 12- by 4-inch block giving a crucible 6 by 6 by 4 ½ inches internal dimensions. This crucible is mounted through the bottom of an oil-furnace. After receiving a definite heat treatment, a synthetic slag is filled in two charges and the test continued for several hours, or until slag penetrates a joint. The crucible is broken when cold and the test brick removed for examination. One of the results given showed two brick of similar chemical composition but varying greatly in texture. The fine textured material showed deeper penetration.

Salmang and Kaltenbach measured the extent of attack with a standard fireclay crucible on the lower 10 millimeters of the crucible in square centimeters of cross-section after sawing the crucible in two [11]. A formula is developed showing the relation between attack in square centimeters and percent bases and acids of the slag. It is pointed out that the oxides retain acid or basic character as to their corrosive action in the molten iron silicate slags. Basic character is exhibited by (in order of decreasing strength) CaO, Cu_2O, PbO, BaO, FeO, NiO, and SnO; acid character by Al_2O_3, Fe_2O_3, Sb_2O_5, SiO_2, Ni_2O_3, ZnO, SnO_2, and Cr_2O_3 (in order of increasing acid strength). Generally, R_2O and RO oxides (excepting A and the alkali metals) promote corrosion; R_2O_3, RO_2, and R_2O_5 tend to prevent it. The corrosion at 1410°C is about 50% higher than 1320°C, indicating a 50% increase dissociation of the slags to the oxides.

THE EFFECT OF ASH ON THE FUSION POINT OF THE REFRACTORY

Nefedieva and Pacukov prepared (3:1, 1:1, 1:3) mixtures of refractory and ash, both sintered and heated in a current of oxygen [12]. The results showed in all cases, except one, a rapid decrease of fusion point to a 25% ash content, after which the decrease was more gradual and regular.

QUANTITATIVE MEASURE OF THE BRICK DISSOLVED OR OTHERWISE REMOVED DURING A DEFINITE HEAT TREATMENT IN CONTACT WITH THE SLAG

Very little work has apparently been done by this method.

Hyslop, Gumm, and Biggs [13], using a method similar to Coad-Pryor [14] and Rosehain [15], studied the effect of corrosion and erosion phenomena on the macrostructure of refractories. Disintegration depends upon two factors, viz, (a) the density of the solute-rich layer relative to the solvent, and (b) the size of the particles.

If a light upward-flowing layer is formed, the material with large particles is more rapidly broken up than that containing small particles. The reverse holds if a dense downward-flowing layer is formed, the finer the particles the more rapid being the corrosion. In the lead glass, refractory with the larger grog was more corroded than that with the finer, but in a soda-lime glass, the finer material was the more attacked. Hence, fine grog is recommended with lead glass and greater coarse grog with soda-lime glasses.

Nefedieva and Pacukov [16] amplified the following method of Nesbitt and Bell1 [7] to give quantitative results: A brick sample was weighed and measured and the size of the hollow in one of its sides was determined by means of a volumeter, using pure sand. Its porosity was also determined. The hollow was then filled with ash and slag and the brick with the hollow upward was heated for a known period at a known temperature. After being cooled, weighed, and placed with hollow downward on a fire-resisting crucible to allow any molten ash which might escape to collect in the crucible, it was placed in an oven and kept for the same length of time at the same temperature. After cooling, it was again weighed and measured and from the measurements of the hollow the degree to which the brick was attacked by the given ash sample could be determined.

The authors also include the following physico-chemical processes occurring between the hot slag and refractory materials: (1) penetration of the slag into the pores of the material, in which case the porosity of the refractory and the viscosity of the slag are most important factors; (2) change in the microstructure of the refractories, the fundamental factors of the stage being the temperature of the layer of the material saturated with the slag and the microstructure of the former; (3) destruction of the softened material layer by the molten slag. In this case the quantity of the slag and the temperature are of primary importance.

QUANTITATIVE MEASURE OF THE BRICK DISSOLVED OR OTHERWISE REMOVED DURING A DEFINITE CHEMICAL TREATMENT

Bowmaker developed a quantitative test for testing the durability of glass tank blocks [18]. A definite sized cube (1 by ½ by ½ inch) was weighed and subjected to the action of a solution containing 3 parts hydrofluoric acid and 2 parts sulphuric acid for 3 hours in a closed leaden vessel provided with a cooled cover. The loss in weight of the test piece served as a measure of the resistance to solubility of the tank block.

Partridge and Biggs [19] used the acid corrosion of Bowmaker [20] to include many different types of glass-house refractories as well as pot-clay mixtures. Glass corrosion tests were also made on the pot-clay mixtures by a crucible and comparison method.

Miehr, with Koch and Kratzert [21] used a similar method with slight variations. They placed an added importance on a solubility figure of the mullite-free portion of the refractory in addition to the solubility factor and resistance factor of Bowmaker. The possibility of standardization is remote in view of the diverse nature of the demands made upon tank blocks.

QUALITATIVE OR QUANTITATIVE ESTIMATION OF THE EFFECTS OF IMPACT OF POWDERED AND MOLTEN SLAG ON THE HOT FACE OF THE REFRACTORY

Hush [22] has applied this method to a rotating cylindrical gas-fired furnace, the test brick making up the walls of the furnace. Powdered slag is fed at a uniform rate through the burner at the top of the furnace and impinges with the blast on the vertical faces of the standard-sized test brick. A record of the volume of the brick before and after the run, expressed in cubic centimeters loss per square centimeter of exposed face, is an indication of the slagging effect upon the brick. Various temperatures and different furnace atmospheres may be used in the test. The test is believed to duplicate service conditions and may be used as a means of comparing the relative resistance of different types of refractories.

Schaefer [23] used a furnace in which three or four standard blocks were heated by gas to 1600°C in one hour. The slag was poured through the top of the kiln at a speed of 500 grams in 40 minutes. Schaefer emphasized the importance of volatile ingredients entering the pores of the refractory in the vapor state.

Stromberg [24] described a laboratory test furnace using a fuel oil burner and a powdered coal burner to introduce the slag. Thirty standard 2 ½ by 4 1/2- by 9-inch brick were built into a test panel and inserted in the wall of the furnace. Forty pounds of ash were fed into the furnace per hour for 48 hours at a temperature of 1350 to 1450°C. The slagging effect was estimated by the amount of brick eroded away, slag penetration, and comparison with the standard brick.

Schaefer and Baumhauer [25] continued the method of sidewise blowing of slag dust on a vertical brick at high temperatures. He tested magnesite and silica brick. Various quantities of slag penetration versus layer depth in millimeters are given as a measure of the degree of scorification. The quantity, thickness, density, and chemical composition of slag layers are also given.

Hyslop and Biggs [26], in attempting to develop a quantitative durability slag test, rotated a refractory test piece (9 by 1.5 by 1.5 cm.) in a silit (perhaps SiC) rod furnace. At the requisite temperature flux was charged over the rotating refractory b means of a water-cooled spoon. The time taken for the flux to sever the test piece was taken as a direct measure of the durability of the refractory under the conditions of test.

ESTIMATE THE CHANGE IN CHEMICAL COMPOSITION OF THE SLAG OR OF THE BRICK AFTER A DEFINITE PERIOD OF INTERACTION

Mellor [27] showed by difference in analysis of the fuel ash and the flue-dust slag that this might offer a possible means of determining slag action Dale [28] has stated, however, that the main experimental difficulty in effecting such a procedure is the problem of finding a containing vessel inert toward slag action.

Wilson [29] studied the effect of ammonium chloride on firebrick and silica brick. Weighed chips were placed in the furnace and subjected to ammonium chloride gas at various temperatures and time intervals. The results of analyses of representative samples before and after treatment were as follows: At temperatures between 700° and 1200°C, ammonium chloride removes iron and alumina from fire clay, or iron, alumina, and lime from silica brick. Silica brick should have a greater resistance to salty coal in coke ovens than firebrick.

Firth, et al., [30] investigated the corrosion of fire-clay pots or crucibles by molten glasses. The melted glass was then analyzed for the alumina and iron oxide increase over the calculated composition. This increase in alumina and iron oxide was taken as a result of the corrosion of the pot.

Hustin [31], in analyzing brick before being installed in a forge reheating installation and after eight days of severe corrosion, found the SiO_2:Al_2O_3 ratio decreased considerably. After the first eight days, corrosion appeared to decrease. Hustin states, "It is reasonable to assume that after the solution of fusible silicates and free silica the exposed portion of the brick becomes richer in alumina which acts as a protective surface against rapid attach."

Dale [3] also found by chemical analysis that the silica-alumina ratio in a slag formed by interaction of iron scale with 70% silica fire brick in a billet reheating furnace is greater than the same ratio in the original brick itself. This again shows preferential solution of SiO_2 by iron oxide under reducing conditions with a consequent concentration of the more resistant alumina on the exposed surface.

A RECORD OF THE PROGRESSIVE ALTERATION IN THE TEMPERATURE GRADIENT THROUGH A WALL, ONE FACE OF WHICH IS EXPOSED TO THE SOLVENT ACTION OF A CORROSIVE MELT

An investigation of corrosion effects under actual working conditions was made by the Glass Research Association [33]. Thermocouples were mounted to the walls of a glass tank at different depths and locations, a continuous record of variation in the temperature gradient through the walls during several months' service. As a result, it was possible to draw up contour diagrams, illustrating clearly the velocity of wall-corrosion and erosion in different parts of this special type of furnace.

Sherman [34] used a similar method in studying the temperature gradient produced in boiler refractories, but tests were conducted only over a few days' duration and were not conducted to final failure of refractory.

Data of this type are of extreme industrial value in suggesting change of furnace design, temperature control, the use of special refractories, of cooling devices, and of different types of fuel.

MICROSCOPIC EXAMINATION OF THE INTERFACE OF REFRACTORY AND SLAG AFTER A DEFINITE HEAT TREATMENT

With constant improvement and broadening of microscopic technique the microscope has found ready application in the study of the corrosion and erosion of refractories.

Insley [35] studied the corrosion of refractories in glassmelting furnaces by means of thin sections of the interface of refractory and glass from industrial installations. Clay refractories below the glass line show a narrow white intermediate zone of mullite crystals between refractory and glass. The mullite crystals are embedded in a glassy matrix. Adjacent to the contact zone, but within the soda-lime glass, there is frequently found a small layer of hexagonal plates of corundum (Al_2O_3), from which Insley deduces the relative insolubility of corundum in the soda-lime glasses. The glassy matrix of the refractory is apparently attacked first, giving a highly viscous glass from which corundum is precipitated after certain alumina content is attained. Corundum is therefore believed to be less soluble in these basic fluxes than the aluminum silicate. Therefore, alumina refractories should offer greater resistance to attack.

McDowell and Lee [36] made petrographic examinations of used and slagged boiler refractories and found that the principal phases present in the cooled slag were (1) plagioclase feldspar, (2) magnetite or hematite, (3) mullite with iron oxide in solid solution, and (4) glass. The interface between refractory and slag consists principally of mullite which, surrounded by the slag, has grown from fine needles to larger ones in the refractory. In high-alumina refractories where diaspore is present the stained interface is much thicker and grains of corundum are formed. Mullite is prominent on the outer surface but becomes mixed with corundum plates as the refractory is approached.

McVay and Hursh [37 examined petrographically samples of refractories subjected to the rotary furnace test [38]. Fireclay brick resist slag penetration because of the formation of a dense nonporous layer back of the slag contact caused by vitrification of the refractory. If there is a large amount of glass present, the grog particles are more easily eroded and removed.

Diaspore brick are much more deeply penetrated by the slag, since on account of their high temperature of fusion they are still quite porous at furnace temperatures. After the pores are filled with the slag, further penetration is retarded.

Klinefelter and Rexford [39] have developed a method wherein slag contained in refractory crucibles is quenched after receiving a definite heat treatment. By studying petrographic thin sections prepared from these quenched samples of slag and refractory, the authors concluded that to obtain a relatively low corrosive slag, conditions should be such that the slag solution is well saturated at all times with solid phases formed from constituents of the slag only. This involved the determination of three temperature ranges: (1) the lower temperature range where slag is saturated with solid phase originating from its own components; (2) a critical temperature range, where most of the crystalline phases from the slag components have come into solution and the slag is mostly liquid; and (3) the upper temperature range, where the temperature is high enough to permit the brick components to unite with those of the slag to cause supersaturation and recrystallization of a solid phase.

The temperature should be kept below the critical range, as immediately above it severe corrosion of the refractory can be expected.

It is obvious from the above review that a wide variety of factors are contributory in the slagging of refractories. All or a part are instrumental in effecting failure and some are more important than others under certain conditions.

None of the laboratory slag tests so far developed appears to be able to take into consideration all the factors involved and properly weigh them. If large units are used, careful and accurate control is hard to maintain, considerable time is consumed, large amounts of material are used, and considerable expense involved. If small units are used, the composition of the slag may change during the test with diminished chemical activity and, furthermore, no account is taken of erosion.

In the evolution of satisfactory laboratory tests, penetration was looked upon at first as being of maximum importance. The need of differentiation between penetration and solution or chemical attack was soon noted. The cone fusion method was the next step, but this method obviously ignored penetration and erosion effects. The trend of developments has all very definitely been toward a better definition of the chemical relations involved between slag and refractory. A test which would show chemical attack as well as penetration would obviously have the greatest value. A study of thin sections of slag and refractory with the polarizing microscope offers considerable promise in tracing the progress of attack of refractory by slag. Progress in the technique will be watched with interest in the near future.

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REACTION TEMPERATURE BETWEEN VARIOUS TYPES OF REFRACTORY BRICK[1]

Raymond E. Birch, Research Department, Harbison-Walker Refratories Co., Pittsburgh, PA

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INTRODUCTION

Best known of the reactions between different types of refractories is that which occurs between silica brick and magnesite brick and which, in the basic open hearth furnace, has in general led to their separation by a neutral course of chrome refractories. In certain other furnaces, however, it is now common practice to use magnesite and silica refractories side by side at fairly high operating temperatures. As a matter of fact, a sizeable minority of the steel plants has not found it necessary to separate these two refractories in the open hearth.

In view of these diverse practices, it is evident that the decision as to whether two different types of refractories need be separated in a furnace structure is a matter of engineering judgment. The purpose of this bulletin is to provide in a single source, data giving the temperatures at which the principal types of refractories react with each other, and a general idea of the extent to which these reactions may be damaging to the refractories.

METHOD OF TESTING

Brick or half-brick of each of seven different types of refractories were allowed to rest on top of samples of each of the other six refractory types. The samples were then heated to the following temperatures in a laboratory furnace: 1400, 1500, 1600 and 1700°C. So that the heat treatment would not be cumulative, new samples were used to each temperature.

After their withdrawal from the furnace, the samples were examined to observe which pairs of refractories had reacted with each other, and to determine the nature and severity of the reactions at each temperature.

The firings to 1400, 1500, and 1600°C were accomplished in a gas-fired furnace; the heating rate was 110°C per hour to 1200°C, with a further rise of to°C per hour until the holding temperature was reached. The furnace was maintained for five hours at the maximum or holding temperature. This heating rate gave a total firing time of approximately 20 hours for the 1400°C test, 22 hours for the 1500°C test and 24 hours for the 1600°C test. The standard pyrometric cones down in these firings were 15, 23, and 30 respectively.

The 1700°C firings were accomplished in a coal-fired furnace. The total time of heating was about 13 hours, including a holding period which did not exceed one hour. Standard cone 32 went down in this firing. This furnace gave rather poor temperature distribution, and for this reason 1700°C maximum temperature observed, (by optical pyrometer sighted on the furnace wall) is not to be taken as a precise measurement of the temperature of the test specimens.

DESCRIPTION OF REFRACTORIES

The refractories tested included the more important commercial types. Their approximate chemical analyses are given in **Table 1** and other pertinent information is detailed in the following paragraphs.

The silica refractories were lime-bonded brick of Pennsylvania manufacture.

Table I
Approximate Chemical Analysis of Refractories

Chemical Analysis	Silica	High Heat Duty Fireclay	High Alumina (70% Al_2O_3)	Chrome	Magnesite (Low Iron)	Magnesite (Regular)	Forsterite
SiO_2	95.9	52.9	22.7	5.0	2.0	3.5	31.7
$Al_2O_3 + TiO_2$	1.0	42.7	74.5	29.5	0.7	1.0	1.1
Fe_2O_3	1.0	2.3	1.8	13.3*	2.1	6.0	6.4*
CaO	2.0	0.3	0.1	---	1.7	3.7	2.8
MgO	0.1	0.4	0.3	17.8	93.5	85.7	57.2
Cr_2O_3	---	---	---	32.7	---	---	0.1
Totals	100.0	98.6	99.4	98.3	100.0	99.9	99.3

* In these cases, iron oxide is reported at FeO

The fireclay brick were manufactured in Pennsylvania and were of the High Heat Duty class.

The high alumina brick were typical of the best 70 per cent alumina refractory made in Missouri from calcined diaspore. For the sake of brevity, this brick is referred to in later paragraphs merely as "high alumina," but it should be remembered that the conclusions apply strictly to the 70 per cent alumina class.

The chrome brick were made from Camaguey (Cuban) ore.

The "low iron" magnesite brick, representing one of the more recent developments in basic refractories, contain much less iron oxide and lower silicate impurities than the "regular" magnesite brick.

The forsterite brick is a newcomer to the commercial field. Its principal constituent is the mineral forsterite ($2MgO{\cdot}SiO_2$), whose melting point is 1910°C (3490°F).

DATA

The results to the extent that they are reducible to "data," are given in **Table 2**, which shows the temperatures at which the various pairs of refractories reacted with each other. Other observations of interest are given below under headings identified with the various refractory types.

The use of **Table 2** is illustrated by the following example: To find the reaction temperature of silica brick with other refractories, one merely chooses the column headed "Silica," and reads the data under that heading; it will be seen that silica was first observed to react with the fireclay brick at 1500°C, but that the reaction was not damaging, even at 1700°C; with the high alumina brick, silica did not react until 1600°C; etc.

In the use of these data, the reader should keep in mind the limitations of the test methods as indicated below, and in the footnote which constitutes a part of **Table 2**.

DISCUSSION OF TEST METHOD

When this study was undertaken, it appeared that there were several factors peculiar to the test method which might influence the results, and other factors not recognized at the start, later became apparent. The severity of the reaction at high temperatures between certain pairs of refractories depends on which one is on the top. This was actually observed to be of some importance only in the case of forsterite-silica. When forsterite was the top brick, the reaction was slight at 1700°C, but the reversed position gave considerably more reaction. Inspection of the silica brick sample indicated that at this high temperature the lime bond, then in the form of a siliceous melt, had become sufficiently fluid to drain, by gravity, to the lower face of the silica brick, where it could react with the forsterite. This should not in the least be surprising, since it is commonly recognized that the lime silicate in a silica brick may even move through the brick counter to the force of gravity when the brick are used in an open-hearth roof. Such a migration being possible with these very viscous lime silicates, it follows that a similar movement may occur, at least as readily, with the probably more fluid ferro-magnesian silicates which form the bond in chrome and magnesite brick.

As in all reaction studies, the time factor influenced the results. In the present study, this is particularly true of the data given for inception of reaction. The heating time in the present test, however, was comparatively long, as laboratory tests go, and those reactions which can be checked with the work of other investigators show that our figures are the lowest reported [1].

In general the data as viewed with the background of available experience appear reasonable, although it was somewhat surprising that there was no evidence of a damaging reaction between silica and fireclay or high alumina brick. In the manufacture of silica brick, careful testing of the ganisters is carried out to eliminate all rock which is high in alumina, since the refractoriness of the brick is lowered to a marked degree by this impurity. The safest interpretation of

Table II

Reaction Temperatures (°C) Between Various Refractory Pairs

Refractory Type	For each pair of materials there is given: "A": reaction was first observed "B": reaction first became damanging "*": not damaging													
	Silica		Fireclay		High Alumina		Chrome		Magnesite (low iron)		Magnesite (regular)		Forsterite	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Silica	---	---	1500	*	1600	*	No Reaction		1500	1600	1500	1600	1700	1700
Fireclay	1500	*	---	---	No Reaction		1600	*	1500	1500	1400	1500	1500	1600
High Alumina	1600	*	No Reaction		---	---	1600	1600	1700	*	1500	*	1700	1700
Chrome	No Reaction		1600	*	1600	1600	---	---	No Reaction		No Reaction		No Reaction	
Magnesite (low Iron)	1500	1600	1500	1500	1700	*	No Reaction		---	---	No Reaction		No Reaction	
Magnesite (regular)	1500	1600	1400	1500	1500	*	No Reaction		No Reaction		---	---	No Reaction	
Forsterite	1700	1700	1500	1600	1700	1700	No Reaction		No Reaction		No Reaction		---	---

NOTE: Readers are cautioned not to accept the above data as applying to all furnace conditions; the reaction temperatures would generally be lower in the presence of fuel ash or molten slag. Furthermore, the duration and other limitations of these experiments must be considered.

the test data in this instance would be to consider that fireclay or high alumina brick may react with silica brick, but that the reaction was too slow to have been damaging under the conditions of test. In this connection it is interesting to note that it is considered good furnace practice to lay up fireclay or high alumna brick with silica mortar, but that silica brick should never be laid up with fireclay or high alumina mortar.

The question of refractory mortars is not discussed in this paper, although the data should be of value in making a selection of proper type of bonding material for these refractories. Where the reaction between two types of refractories is slight there is a possibility that in practice, they need to be separated by a mortar joint of which the base material is non-reactive with each of the two refractories.

DETAILED RESULTS

Silica: The silica brick gave no visible reaction with chrome at 1700°C. Furthermore, there was no evidence of damaging reaction with fireclay and high alumina brick at this highest test temperature.

Since the distinction between damaging and non-damaging reactions is made frequently throughout this paper, and since the division is necessarily arbitrary, some explanation is in order. The best means of explaining the distinction is to give an example of a reaction which was judged to be non-damaging and one which was judged to be damaging:

(a) At all temperatures above 1400°C, the fireclay brick adhered to the silica refractory; they adhered so tightly that chunks of silica were pulled loose when the brick were separated; there was no perceptible reaction other than this surface effect, which may have been due to natural softening of the clay brick. Reporting this as a "reaction" is indicative of the breadth of interpretation placed on this word in the present bulletin. The reaction was reported as non-damaging.

(b) The reaction between low iron magnesite and fireclay brick was first observed at 1500°C and at that temperature was reported as damaging, since destruction of the fireclay brick had begun. Three was deep corrosion of the surface of the fireclay brick by a slag formed at the face of contact with the magnesite brick.

(c) The two types of magnesite brick behaved alike in their reaction with silica brick. At 1400°C there was no noticeable reaction, but at 1500°C the magnesite samples had indented the silica to a depth of about 1/32 in. At 1600°C, the magnesite samples had cut entirely through the silica brick on which they had been set. This reaction was unusual in appearance since the silica grains in the channel cut by the magnesite were severed as cleanly as if they had been sawed. Any slag developed by the reaction was not in evidence, although the silica brick was somewhat discolored, as shown by **Figure 1**.

This slicing away of the silica brick by the magnesite has been reported as occasionally occurring in firing magnesite brick in silica boxes, which is the common practice. It occurs only where the brick have been exposed to a firing temperature higher than normal. As in the present tests, the silica material seems to have disappeared, leaving no trace other than stains.

In view of these interesting aspects of the reaction between silica and magnesite refractories, supplementary tests were run to determine whether or not there could have been any appreciable volatilization of the silica. About six grams of silica brick material and six grams of low iron magnesite, each ground to pass 20-mesh and intimately mixed were heated to 1600°C in a platinum crucible. The heating schedule was the same as given on page 2. Included in the firing were another crucible containing about 12 grams of silica brick material alone, and a third crucible containing nothing but the low iron magnesite. It was felt necessary to include these blanks, since silica has been reported to volatilize at fairly low temperatures, and to suffer loss due to reduction and subsequent volatilization of metallic silicon [2]. After the five-hour hold at 1600°C the samples were reweighed with the following results:

Crucible	*Contents*	*Loss in Weight of Crucible + Sample*
A	Silica Brick	0.01%
B	Magnesite Brick	0.02%
C	{ 1 Part Silica Brick 1 Part Magnesite Brick	0.02%

These results show that there was no appreciable loss of silica. It is therefore concluded that in the case of the 1600°C test with full-sized magnesite and silica brick, the silica removed was either absorbed into the remainder of the silica brick or else it made its escape to the furnace hearth as slag. In either event, the resulting slag is show to have been extremely fluid.

This reaction between silica and magnesite was the most interesting phenomenon observed in a series of tests; at 1500°C the reaction was appreciable, and at 1600°F it was violent. It may be that if the brick had been in contact for a longer period at 1500°C than even at that temperature the magnesite might have been cut through the silica brick.

In practice it has long been recognized that the magnesite and silica react at high temperatures; it is reported that the majority of open hearth plants still use one or more courses of chrome brick to separate the magnesite bottom brick from the silica brick in the sidewall, although a smaller number of plants have not found this necessary.

Within the last year, one steel plant used some low iron magnesite brick for hot patching a silica open-hearth crown, and it was reported that the silica and magnesite did not react noticeably with each other.

The copper reverberatory furnace crown offers another example of the use of silica and magnesite, side by side, at high temperatures. It is frequent practice to use magnesite brick extending a number of courses upward from the skewbacks to where they meet the silica brick, which top out the crown. Although at some smelters it is not unusual to operate the reverberatory furnaces at 1593°C to 1649°C (2900°F to 3000°F) the manner in which the crowns wear away does not indicate that any appreciable reaction has occurred between the magnesite and silica.

These instances of the successful use of silica and magnesite brick in contact at temperatures above those at which our tests show them to react violently, may be explainable by the high conductivity of the magnesite brick, which causes the temperature to drop extremely rapidly away from the furnace face. There are other factors, possibly of importance, which need to be detailed here.

Silica and forsterite brick showed no reaction with each other below 1700°C, but at that temperature the reaction could be considered as damaging. **Figure 1** shows in striking contrast the behavior of forsterite and low iron magnesite brick when heated to 1600°C in contact with silica brick.

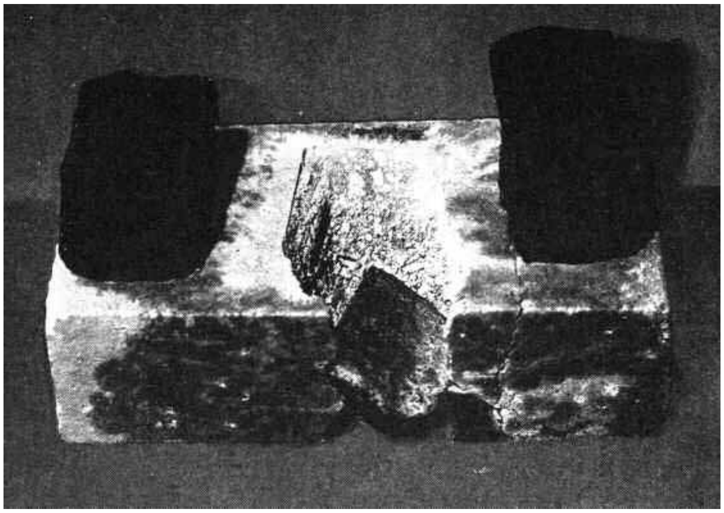

Figure 1. This photograph contrasts the appearance of low iron magnesite and forsterite brick in contact with silica brick, after heating to 1600°C. The quarter-brick of low iron magnesite which formerly rested on the face of the silica brick has cut a swath entirely through the silica brick. The samples of forsterite brick on either end show little or no reaction with the silica brick at this temperature.

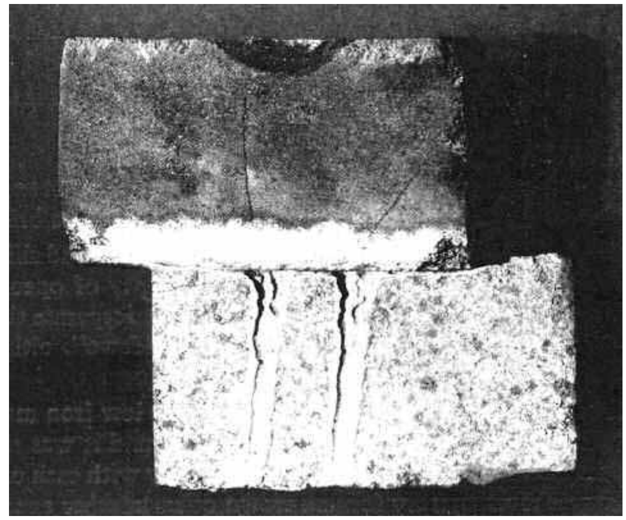

Figure 2. The reaction between regular magnesite (on top) and fireclay brick produced the above results after the reheat at 1500°C. A grey slag, formed at the contact face, corroded the fireclay brick in the manner shown and allowed the magnesite brick to slide out of position.

Fireclay: The tests seem to show, that at any of the temperatures studied, no damaging reaction occurred between fireclay brick and high alumina, chrome, or silica brick.

The fireclay brick had started to react with regular magnesite at 1400°C (2552°F). At 1500°C (2732°F) the reaction had developed to such an extent that a grey-colored slag, developed at the contact face, had run down over the sides of the fireclay brick; the lubricating action of this slag had permitted the magnesite brick to slip from the top of the fireclay brick. Due to the same effect the magnesite brick slipped off the fireclay brick to the furnace hearth in the 1600°C and 1700° tests.

The fireclay brick also reacted violently with low iron magnesite at 1500°C, (see **Figure 2**) and was entirely cut through at 1600°C (2912°F) by the magnesite fragment which had rested on it. Although the regular magnesite had begun to react with the fireclay brick at 1400°C (2552°F), the low iron brick had not. In view of the very severe reaction of both types of magnesite brick with fireclay brick at 1500°C (2732°F), it is doubtful if this denotes an appreciable difference.

The fireclay brick was only discolored by the forsterite sample at 1400°C (2552°F), but at 1500°C (2732°F) they showed a severe reaction. At 1600°C (2912°F) the forsterite brick had cut a channel completely through the sample of fireclay on which it rested.

High Alumina (70% Al_2O_3): No damaging reaction occurred at the temperatures studied, between the high alumina brick and fireclay, silica, or magnesite refractories.

Between the high alumina and chrome brick no reaction developed below 1600°C; at this temperature and at 1700°C, the contact surface of the high alumina brick showed softening, as a result of slag absorption.

Forsterite showed no reaction with the high alumina brick except at 1700°C, where the latter was fluxed slightly to a depth of about one-fourth inch.

Chrome: The tests seems to show that at any of the temperatures studied, there is no danger involved in laying chrome brick up with silica, fireclay, magnesite, or forsterite brick.

Chrome had a softening action on the high alumina brick at 1600°C and 1700°C, but this may or may not be serious enough to require consideration in furnace construction.

Magnesite: There was not enough difference between the behavior of the two types of magnesite brick to warrant their separate discussion. Although **Table 2** does not show for each of them the same temperatures for the inception of the reactions with other refractories, there were no differences in the temperatures at which these reactions became *damaging*. Perhaps differences in the closeness of contact between brick pairs had greater influence on the initial reaction temperature than on the latter and damaging phases of reaction.

There was no visible reaction between the magnesite brick and those made of chrome ore or forsterite, and with the high alumina brick the reaction, even at 1700°C, was too slight to be damaging.

Earlier paragraphs have given the discussion of the behavior of magnesite with silica and fireclay refractories.

A more or less unexpected result was notice in the test of regular (high iron) magnesite paired with low iron magnesite—the apparent migration of iron oxide from the high iron to the low iron brick. That periclase (magnesia) crystals have great absorptive powers for iron oxide, (i.e., absorption into solid solution) has been appreciated by a number of investigators, and lately McCaughey and Fisk have obtained at high temperatures, solid solutions of Fe_2O_3 in MgO wherein the iron oxide constitutes as much as 70% of the entire composition, although at normal atmospheric temperatures the upper limit of solid solution is reported to be at about 3% iron oxide [3]. In this unusual relationship one of the most remarkable features is the rapidity with which iron oxide is absorbed by periclase at high temperatures. Evidence of this drinking up of iron oxide, shows itself in a number of ways to the manufacture of refractories. McCaughey and Fisk show by means of an excellent photomicrograph, the penetration of iron oxide into a pure periclase grain in a single firing.

In our own tests, there had apparently been a migration of iron oxide from the regular magnesite brick, dark brown in color, to the low iron magnesite brick whose color is a much lighter brown. The low iron brick had become considerably darkened, the visible result being noticeable to a depth approaching one-fourth inch, at 1600°C. The following analyses confirm the supposition that a very considerable amount of iron oxide had migrated into the low iron magnesite brick. The samples analyzed were those which had been heated to 1700°C.

Magnesite Brick Type		Area of Interest	Fe_2O_3
Low Iron		Unaffected Region	6.58%
Regular	{	Darkened Upper 1/8”	5.15%
		Unaffected Region	2.34%

Forsterite: Within the temperature range studied, there was no reaction of forsterite with chrome, or magnesite, and with the high alumina and silica brick there was fluxing only at 1700°C.

ACKNOWLEDGEMENT

The tests described in this Bulletin were carried out by the Research Department staff of the Harbison-Walker Refractories Company at Hays Laboratory.

REFERENCES

1. This refers to the reactions between silica and magnesite reported by McDowell and Howe (Jour. Amer. Cer. Soc. 3 (3), 228 (1920) and Bischof (J. Iron Steel Inst. 49 pt. 1, 212, 1893), and between fireclay and magnesite, reported by McDowell and Howe
2. For a discussion of these phenomena see pages 106-109, The Properties of Silica; Robert B. Sosman; Chemical Catalogue Co., 1927. Sosman states that direct volatilization below 1600°C is unproved.
3. Equilibrium Studies in Systems Containing Magnesium Oxide, Iron Oxide, and Magnesium Aluminate; Ohio State Univ. Engr. Expt. Bul. No. 70, July 1932.

RAN

Obituary

Donald J. Stefl
May 31 1924 - July 2, 2010

By Vivian Nereim, Pittsburgh Post-Gazette

Donald J. Stefl was a no-nonsense businessman who could fix any problem. He was a decorated soldier who fought in the Battle of the Bulge, an engineer who re-designed a company and a tough negotiator who haggled with car salesmen and labor unions; he had little tolerance for excuses.

But at home, he softened. His family said he was a secret teddy bear, "Dad" to three sons and many of their friends. He relished planning picnics for his grandchildren. He returned from work daily for lunch with his wife, careful to leave his chair and desk perfectly aligned.

Mr. Stefl, of Natrona Heights, and later Crescent, died Friday. He was 86.

His family said he was a man with many sides, as likely to soothe as to lay down the law.

"Hell-raiser, kind person, gentleman, soldier, leader," said his son, Scott Stefl, of Mentor-on-the-Lake, Ohio. "He was a lot of different things to a lot of different people."

Until his retirement, the elder Mr. Stefl was executive vice president of Freeport Brick Co. He approached problems like an engineer: ready to dissect, solve and do.

"He was very thorough about everything that he did," said his wife, Marguerite Stefl, of Crescent.

And though he rarely talked about his service during World War II, he was a distinguished soldier who had participated in history.

"He was just my hero," said his younger brother, Harold Stefl, of Lancaster, Pa. "He was the guy I looked up to."

Born in Dunbar in 1924, Donald Stefl was the third of four sons.

He started studying engineering at Rutgers University, but was soon drafted into the Army, where he served as an engineer in the 10th Armored Division, stationed in Europe. He was stuck for many desperate weeks in Bastogne, Belgium, during the Battle of the Bulge, Germany's last major offensive.

After crossing a river under enemy fire to secure a bridgehead, he was awarded a Bronze Star, said his son. He was also awarded a Purple Heart after being injured while dynamiting a bridge that American planes had been told to bomb.

"He had a drawer full of medals," said Scott Stefl. "Never talked about it."

When the war was over, the elder Mr. Stefl returned to Rutgers, graduating in 1948 with a degree in ceramic engineering. There, he met his first wife, Marian, who attended a sister school.

From 1948 to 1953, he worked for Eljer Corp., a company that manufactured plumbing fixtures. Then he joined Freeport Brick Co., which made bricks for the enormous ladles used to pour molten steel.

"When he first got there, it was just this little rinky-dink 1800's-type operation," said Scott Stefl. "They were still using horses and mules."

To fire the bricks, the workers placed them in domed buildings, built a door, cooked the bricks and then dissembled the door.

Donald Stefl realized it would be easier to structure the operation like a car-wash: the bricks cooked while they traveled through a tunnel on a railway car. His change enabled the workers to produce bricks through a continuous process, instead of a stop-and-go operation.

"The company just went from zero to 100 in a matter of a few years," said Scott Stefl.

From 1973 until his retirement, Donald Stefl was the company's executive vice president, a far-reaching job that touched on production, quality control, engineering and labor relations.

He retired in the late 1980s. After his first wife died, he married Marguerite Stefl in 1999.

Together, the couple traveled frequently, often with their extended family.

Eager to serve his community, Donald Stefl was also a member of several boards. Scott Stefl said his father was chairman of the Allegheny Valley Chamber of Commerce for years. He also served on the board of directors of Allegheny Valley Hospital and the Allegheny Valley YMCA, a struggling organization he helped rescue.

"Everything he touched would get better," said his son.

In addition to his wife, his brother and his son, Donald Stefl is survived by another son, Donald J. Stefl II of Roanoke, Va., and five grandchildren. RAN

UNIFRAX ANNOUNCES ACQUISITION DEAL

Unifrax I LLC ("Unifrax"), the Niagara Falls, NY based manufacturer of ceramic fiber insulation products, announced today that it has entered into an agreement to acquire Brightcross Manufacturing Ltd. and Brightcross Insulation Ltd. (together "Brightcross"). Terms of the transaction were not disclosed.

Brightcross is located in Derby, in the United Kingdom. It is the leading supplier of vacuum formed ceramic fiber products in the U.K. and also does a substantial amount of export business into the EU. The business has approximately 60 employees who will be joining the Unifrax European team.

David E. Brooks, Unifrax President and CEO, comments "Brightcross is a business with a great reputation, a proud heritage and excellent people. We have been a supplier to them for many years and respect their capabilities. Brightcross will strengthen our European vacuum forming business and improve our competitive position in the European market".

Brooks added "This acquisition represents another positive step in the continued implementation of the long-term growth strategy for our Company". The acquisition is expected to close in the third quarter.

Unifrax I LLC is a leading global supplier of insulation products that are used in many high-temperature industrial, automotive and fire protection applications. The Company has 17 manufacturing facilities in the United States, Europe, Asia and Latin America and employs approximately 1,300 people worldwide.

For Further information, contact: Virginia Cantara, Unifrax I LLC, 2351 Whirlpool St., Niagara Falls, NY 14305, Tel:(716) 278-3832.

KERNEOS INVESTS €4 MILLION IN NEW BRIQUETTING LINE.

Neuilly sur Seine, 9th July 2010- Kerneos, the leading producer of calcium aluminates, has announced the investment of €4million in a new briquetting line at its Dunkirk factory in Northern France. Kerneos is a major purchaser of bauxite and is facing increasing difficulties in using the qualities of bauxite available from its traditional sources, principally in China and Greece.

Changes in calcining technology used to process bauxite in China and supply frailties in Greece require Kerneos to take increasingly higher percentages of fine bauxites from both sources rather than the large block bauxite that is ideally suited to its furnace technology.

Pierre Baillagou, VP manufacturing commented: "The reduced availability of large block material requires us to make our own blocks to guarantee our ability to meet the growing demand for our cements. Block materials are essential in maintaining high levels of energy efficiency. We have made strenuous efforts in recent years to minimise our energy consumption and it is not acceptable to allow our energy efficiency or product quality to fall because of raw material supply difficulties. Whilst briquetting raw materials adds to our costs it was the least expensive solution to the quality and supply problems we face and by far the most acceptable from an environmental point of view. In spite of these constraints of raw materials, we confirm our commitment to improve the quality of our products and services. "

The new plant is currently under construction and will come on stream in the second quarter 2011.

****

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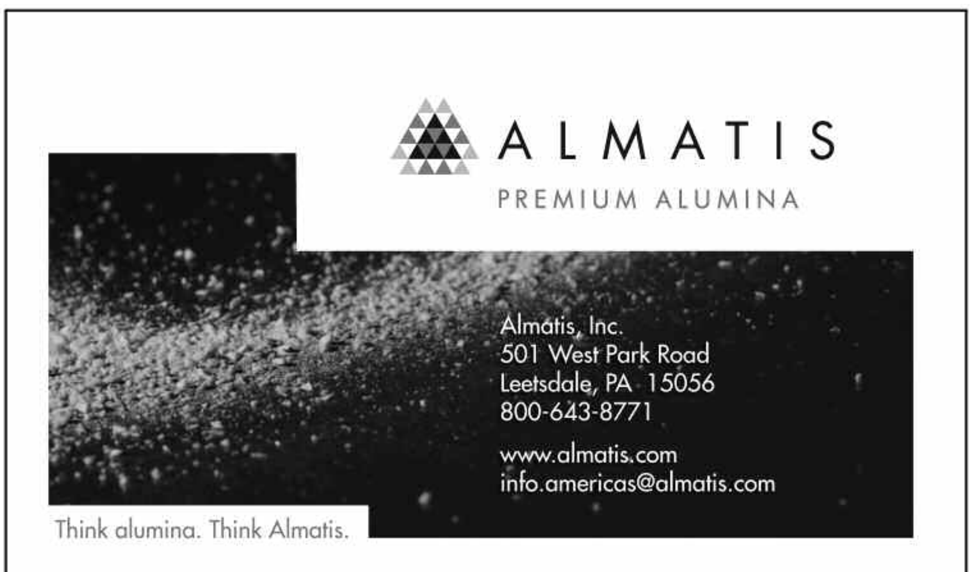

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www.almatis.com

AluChem, Inc.
One Landy Lane. Cincinnati, OH 45215
Tel: (513) 733-8519 Fax: (513) 733-0608
aluchem@aluchem.com

NABALTEC AG
Alustraße 50 - 52, 92421 Schwandorf, Germany
Tel: +49 9431 53-457 Fax: +49 9431 61557
ceramics@nabaltec.de www.nabaltec.de

ALUMINA-FUSED

C-E Minerals
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Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com www.ceminerals.com

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www.almatis.com

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One Landy Lane. Cincinnati, OH 45215
Tel: (513) 733-8519 Fax: (513) 733-0608
aluchem@aluchem.com

NABALTEC AG
Alustraße 50 - 52, 92421 Schwandorf, Germany
Tel: +49 9431 53-457 Fax: +49 9431 61557
ceramics@nabaltec.de www.nabaltec.de

ALUMINA-TABULAR

Almatis
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Tel: (412) 630-2800 Fax: (412) 630-2810
www.almatis.com

AluChem, Inc.
One Landy Lane. Cincinnati, OH 45215
Tel: (513) 733-8519 Fax: (513) 733-0608
aluchem@aluchem.com

C-E Minerals
901 East Eight Ave., King of Prussia, PA 19406
Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com www.ceminerals.com

ALUMINA-TRIHYDRATE

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BASIC BRICKS

Resco Products, Inc.
Penn Center West, Bldg. 2, Ste. 430
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Fax: (412) 494-4571
sales@rescoproducts.com www.rescoproducts.com

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901 East Eight Ave., King of Prussia, PA 19406
Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com
www.ceminerals.com

Christy Minerals
833 Booneslick, High Hill, MO 63350
Tel: (636) 585-2214 Fax: (636) 585-2220
info@christyco.com www.christyco.com

Great Lakes Minerals, LLC
1200 Port Rd., Wurtland, KY 41144-1635
Tel: (606) 833 8383 Fax: (606) 834 1106
www.greatlakesminerals.com

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Tel: (800) 284-4748 Fax: (716) 822-2858
info@electroabrasives.com

CALCIUM ALUMINATE CEMENT

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501 West Park Rd., Leetsdale, PA 15056
Tel: (412) 630-2800 Fax: (412) 630-2810
www.almatis.com

Calucem Inc
7540 Windsor Dr., Ste. 304, Allentown, PA 18195
Tel: (484) 223-2950 Fax: (484) 223-2953
www.calucem.com

Kerneos Inc.
1316 Priority Lane, Chesapeake, VA 23324
Tel: (757) 543-8832 Fax: (757) 545-8933
www.kerneosinc.com www.secar.net.

USEM
600 Steel St., Aliquippa, PA 15001
Tel: (724) 857-9880 Fax: (724) 857-9916
lcurimbaba@usminerals.com

CARBON

Cancarb Ltd.
1702 Brier Park Crescent N.W.
Medicine Hat, Alberta, Canada T1C 1T8
Tel: 1-(403) 527 1121 or 1-(888) 871-0077
Fax: 1-(403) 529-6093
Customer_service@cancarb.com www.cancarb.com/

CEMENT (AIR SETTING)

Resco Products, Inc.
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Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
Fax: (412) 494-4571
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CERAMIC COATINGS SPECIALTY MOLD RELEASE AGENTS

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Tel: (330) 938-2101 Fax: (330) 938-2574
sales@rsifibre.com www.rsifibre.com

UNIFRAX I LLC
2351 Whirlpool St., Niagara Falls, NY 14305
Tel: (716) 278-3800 Fax: (716) 278-3900
info@unifrax.com www.unifrax.com

ZIRCAR Ceramics, Inc.
100 North Main St., P.O. Box 519
Florida, NY 10921
Tel: (845) 651-6600 Fax: (845) 651-0441
dph@zircarceramics.com www.zircarceramics.com

CERAMIC FIBER SHAPES

Refractory Specialties, Inc.
230 W. California Ave., Sebring, OH 44672
Tel: (330) 938-2101 Fax: (330) 938-2574
sales@rsifibre.com www.rsifibre.com

ZIRCAR Ceramics, Inc.
100 North Main St., P.O. Box 519
Florida, NY 10921
Tel: (845) 651-6600 Fax: (845) 651-0441
dph@zircarceramics.com www.zircarceramics.com

CHEMICAL ADDITIVES FOR THE REFRACTORIES INDUSTRY

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Tel 478 454 1942 Fax 478 453 8854
PCuthbertZSUS@Windstream.Net
www.Zschimmer-schwarz.com

DRYING AND CURING OF REFRACTORIES (ON SITE)

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BGM. Dr Nebel Strasse 14
97816, Lohr am Main Germany
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Fax: 0049 (0) 9352 604419
fschwarzenau@excelsius-lohr.de
www.excelsius-global.com

Team Industrial Services
3640 W. 179th St., Hammond, IN 46323
Tel: (219) 838-0505 Fax: (219) 838-8558
contact@teamindustrialservices.com
www.teamindustrialservices.com

FIBERS - POLYPROPYLENE & GLASS

BassTech International
300 Grand Ave., Englewood, NJ 07631
Tel: :201) 569-8686 Fax: (201) 569-7511
info@basstechintl.com www.basstechintl.com

FIREBRICKS AND FIRECLAYS

C-E Minerals
901 East Eight Ave., King of Prussia, PA 19406
Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com www.ceminerals.com

Clayburn Refractories Ltd.
33765 Pine St., Abbotsford, BC, CA V2S 5C1
Tel: 604-859-5288 or 604-851-4556
rdlane@clayburngroup.com

FIRECLAYS

Christy Minerals
833 Booneslick, High Hill, MO 63350
Tel: (636) 585-2214 Fax: (636) 585-2220
info@christyco.com www.christyco.com

FURNACE/REFRACTORY PREHEATING (ON SITE)

Excelsius Global Services GmbH
BGM. Dr Nebel Strasse 14
97816, Lohr am Main Germany
Tel: 0049 (0) 9352 604400
Fax: 0049 (0) 9352 604419
fschwarzenau@excelsius-lohr.de
www.excelsius-global.com

FUSED ALUMINA

C-E Minerals
901 East Eight Ave., King of Prussia, PA 19406
Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com www.ceminerals.com

Great Lakes Minerals, LLC
1200 Port Rd., Wurtland, KY 41144-1635
Tel: (606) 833 8383 Fax: (606) 834 1106
www.greatlakesminerals.com

USEM
600 Steel St., Aliquippa, PA 15001
Tel: (724) 857-9880 Fax: (724) 857-9916
lcurimbaba@usminerals.com

FUSED MULLITE

C-E Minerals
901 East Eight Ave., King of Prussia, PA 19406
Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com www.ceminerals.com

USEM
600 Steel St., Aliquippa, PA 15001
Tel: (724) 857-9880 Fax: (724) 857-9916
lcurimbaba@usminerals.com

FUSED SILICA

C-E Minerals
901 East Eight Ave., King of Prussia, PA 19406
Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com www.ceminerals.com

Minco, Inc.
510 Midway Circle, Midway, TN 37809
Tel: (423) 422-6051 Fax: (423) 422-4802
sales@mincoitc.com mincoitc.com

FUSED SPINEL

C-E Minerals
901 East Eight Ave., King of Prussia, PA 19406
Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com www.ceminerals.com

USEM
600 Steel St., Aliquippa, PA 15001
Tel: (724) 857-9880 Fax: (724) 857-9916
lcurimbaba@usminerals.com

HIGH ALUMINA FIREBRICKS

Clayburn Refractories Ltd.
33765 Pine St., Abbotsford, BC, CA V2S 5C1
Tel: 604-859-5288 or 604-851-4556
rdlane@clayburngroup.com

Resco Products, Inc.
Penn Center West, Bldg. 2, Ste. 430
Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
Fax: (412) 494-4571
sales@rescoproducts.com
www.rescoproducts.com

Saint-Gobain Ceramics
1 New Bond St., MS 301-432,
Worcester, MA 01615-0136
Tel: (508) 795-2963 Fax: (508) 795-5011
patrick.m.stephan@saint-gobain.com
www.refractories.saint-gobain.com

Sunrock Ceramics Company
2625 S. 21st Ave., Broadview, IL 60155
Tel: (708) 344-7600, Fax: (708) 344-7636
dthurman@sunrockceramics.com
www.sunrockceramics.com

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AluChem, Inc.
One Landy Lane. Cincinnati, OH 45215
Tel: (513) 733-8519 Fax: (513) 733-0608
aluchem@aluchem.com

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Clayburn Refractories Ltd.
33765 Pine St., Abbotsford, BC, CA V2S 5C1
Tel: 604-859-5288 or 604-851-4556
rdlane@clayburngroup.com

IFB, Inc.
610 East Butler Rd., Butler, PA 16002
Tel: (724) 282-1012 Fax: (724) 285-7673
ifbinc@aol.com
www.insulatingfirebrick.com

Saint-Gobain Ceramics
1 New Bond St., MS 301-432
Worcester, MA 01615-0136
Tel: (508) 795-2963 Fax: (508) 795-5011
patrick.m.stephan@saint-gobain.com
www.refractories.saint-gobain.com

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Tel: (609) 518-9447 Fax: (609) 518-9445
nthdegreeproducts@Yahoo.com

Saint-Gobain Ceramics
1 New Bond St., MS 301-432
Worcester, MA 01615-0136
Tel: (508) 795-2963 Fax: (508) 795-5011
patrick.m.stephan@saint-gobain.com
www.refractories.saint-gobain.com

Sunrock Ceramics Company
2625 S. 21st Ave., Broadview, IL 60155
Tel: (708) 344-7600, Fax: (708) 344-7636
dthurman@sunrockceramics.com
www.sunrockceramics.com

KYANITE

Kyanite Mining Corporation
Dillwyn VA 23936
Tel Sales: (434) 983-2043
info@kyanite.com www.Kyanite.com

MONOLITHIC FIBER GUNNING

UNIFRAX I LLC
2351 Whirlpool St., Niagara Falls, NY 14305
Tel: (716) 278-3800 Fax: (716) 278-3900
info@unifrax.com www.unifrax.com

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UNIFRAX I LLC
2351 Whirlpool St., Niagara Falls, NY 14305
Tel: (716) 278-3800 Fax: (716) 278-3900
info@unifrax.com www.unifrax.com

MONOLITHIC REFRACTORIES

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1000 S. Elmwood, P.O. Box 754, Mexico, MO 65265
Tel: (800)708-9470
info@actchem-usa.com

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1000 S. Elmwood, P.O. Box 754, Mexico, MO 65265
Tel: (330)770-7714 Fax:(330)629-9252
info@xertechllc.com

MONOLITHIC REFRACTORIES-CASTABLE

Clayburn Refractories Ltd.
33765 Pine St., Abbotsford, BC, CA V2S 5C1
Tel: 604-859-5288 or 604-851-4556
rdlane@clayburngroup.com

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14025 N. Rivergate Blvd., Portland, OR 97203
Tel: 1 (800) 325-2492 Fax: (503) 737-0771
lesg@hightempinc.net www.hightempinc.net

Resco Products, Inc.
Penn Center West, Bldg. 2, Ste. 430
Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
Fax: (412) 494-4571
sales@rescoproducts.com www.rescoproducts.com

Saint-Gobain Ceramics
1 New Bond St., MS 301-432
Worcester, MA 01615-0136
Tel: (508) 795-2963 Fax: (508) 795-5011
patrick.m.stephan@saint-gobain.com
www.refractories.saint-gobain.com

MONOLITHIC REFRACTORIES GUNNING

Clayburn Refractories Ltd.
33765 Pine St., Abbotsford, BC, CA V2S 5C1
Tel: 604-859-5288 or 604-851-4556
rdlane@clayburngroup.com

Resco Products, Inc.
Penn Center West, Bldg. 2, Ste. 430
Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
Fax: (412) 494-4571
sales@rescoproducts.com www.rescoproducts.com

Saint-Gobain Ceramics
1 New Bond St., MS 301-432
Worcester, MA 01615-0136
Tel: (508) 795-2963 Fax: (508) 795-5011
patrick.m.stephan@saint-gobain.com
www.refractories.saint-gobain.com

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Resco Products, Inc.
Penn Center West, Bldg. 2, Ste. 430
Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
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Penn Center West, Bldg. 2, Ste. 430
Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
Fax: (412) 494-4571
sales@rescoproducts.com www.rescoproducts.com

MULLITE

Kyanite Mining Corporation
Dillwyn VA 23936
Tel Sales: (434) 983-2043
info@kyanite.com www.Kyanite.com

NABALTEC AG
Alustraße 50 - 52, 92421 Schwandorf, Germany
Tel: +49 9431 53-457 Fax: +49 9431 61557
ceramics@nabaltec.de www.nabaltec.de

OLIVINE

Minelco Inc.
2020 Scripps Ctr., 312 Walnut St.
Cincinnati, OH 45202
minelco.inc@minelco.com www.minelco.com

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Tel: 800-243-9004 Fax: 800-243-9005
metalcaster@unimin.com www.metalcaster.com

Buyer's Guide

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Tel: 1 (800) 325-2492 Fax: (503) 737-0771
lesg@hightempinc.net www.hightempinc.net

TFL, Incorporated
14626 Chrisman, Houston, TX 77039
Tel: 281-590-8500 or 800-828-5002
Fax: 281-590-5342
tfl@tflhouston.com www.TFLHouston.com

ZIRCAR Ceramics, Inc.
100 North Main St., P.O. Box 519
Florida, NY 10921
Tel: (845) 651-6600 Fax: (845) 651-0441
dph@zircarceramics.com www.zircarceramics.com

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Resco Products, Inc.
Penn Center West, Bldg 2, Ste. 430
Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
Fax: (412) 494-4571
sales@rescoproducts.com www.rescoproducts.com

Saint-Gobain Ceramics
1 New Bond St., MS 301-432
Worcester, MA 01615-0136
Tel: (508) 795-2963 Fax: (508) 795-5011
patrick.m.stephan@saint-gobain.com
www.refractories.saint-gobain.com

PRESS TOOLING

JLW Ventures, Inc., D/B/A Johnson Machine Co.
P.O. Box 669, 290 Bigler Ave., Clearfield, PA 16830
Tel: (814) 765-9648 Fax: (814) 765-9640
inquiry@johnsonmachineco.com
www.johnsonmachineco.com

Alcon Tool Company
587 Baird St., Akron, OH 44311
Tel: 330-773-9171 Fax 330-773-8042
www.alcontool.com rd@alcontool.com

PRODUCT ENGINEERING/QA SERVICES

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23 Pheasant Run Dr., Export PA 15632
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bvance23@comcast.net

REFRACTORY AGGREGATES

C-E Minerals
901 East Eight Ave., King of Prussia, PA 19406
Tel: (610) 768-8800 Fax: (610) 337-8122
inquire@ceminerals.com www.ceminerals.com

Resco Products, Inc.
Penn Center West, Bldg. 2, Ste. 430
Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
Fax: (412) 494-4571
sales@rescoproducts.com www.rescoproducts.com

Unimin Corporation
258 Elm St., New Canaan, CT 06840
Tel: 800-243-9004 Fax: 800-243-9005
metalcaster@unimin.com www.metalcaster.com

REFRACTORY ANCHORS

Resco Products, Inc.
Penn Center West, Bldg. 2, Ste. 430
Pittsburgh, PA 15276
Tel: (412) 494-4491 or (800) 354-1211
Fax: (412) 494-4571
sales@rescoproducts.com www.rescoproducts.com

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UNIFRAX I LLC
2351 Whirlpool St., Niagara Falls, NY 14305
Tel: (716) 278-3800 Fax: (716) 278-3900
info@unifrax.com www.unifrax.com

REFRACTORY BRICKWORK INSTALLATIONS

Clayburn Refractories Ltd.
33765 Pine St., Abbotsford, BC, CA V2S 5C1
Tel: 604-859-5288 or 604-851-4556
rdlane@clayburngroup.com

REFRACTORY GUNNING INSTALLATIONS

Clayburn Refractories Ltd.
33765 Pine St., Abbotsford, BC, CA V2S 5C1
Tel: 604-859-5288 or 604-851-4556
rdlane@clayburngroup.com

REFRACTORY GUNNING & SHOTCRETE EQUIPMENT

Blastcrete Equipment Company
2505 Alexandria Rd., PO Box 1964
Anniston, AL 36202
Tel: (256) 235-2700 or 1 (800) 235-4867
Fax: (256) 236-9824
jim@blastcrete.com or tripp@blastcrete.com

REFRACTORY LANCES

High-Temp, Inc.
14025 N. Rivergate Blvd., Portland, OR 97203
Tel: 1 (800) 325-2492 Fax: (503) 737-0771
lesg@hightempinc.net www.hightempinc.net

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RFI Construction Products
Division of Cangro Industries, Inc.
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Tel: (631) 752-8899 Fax: (631) 454-9155
cangrosales@ix.netcom.com
www.rficonstructionproducts.com/

Lancaster Products,
Div. of Kercher Industries, Inc.
920 Mechanic St., Lebanon, PA 17046
Tel: (717) 273-2111, (800) 447-7351
info@lancasterprd.com www.lancasterprd.com

REFRACTORY RECYCLING

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P.O. Box 58184, Pittsburgh, PA 15209
Tel: (412) 821-5566 Fax: (412) 821-5577
atencinci@verizon.net www.ceramicrecycling.com

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610 East Butler Rd., Butler, PA 16002
Tel: (724) 285-7222 Fax: (724) 431-0944
Sales@JHMacinc.com www.JHMacinc.com

REFRACTORY RAW MATERIALS

Unimin Corporation
258 Elm St., New Canaan, CT 06840
Tel: 800-243-9004 Fax: 800-243-9005
metalcaster@unimin.com www.metalcaster.com

REFRACTORY SHOTCRETE INSTALLATIONS

Clayburn Refractories Ltd.
33765 Pine St., Abbotsford, BC, CA V2S 5C1
Tel: 604-859-5288 or 604-851-4556
rdlane@clayburngroup.com

SILICA BRICK

Utah Refractories Corp.
P.O. Box 12536, Pittsburgh, PA 15241
Tel: (412) 851-2430 Fax: (412) 851-2425
tlmpgh@aol.com

SILICA FUME

Technical Silica Company
2250 N. Druid Hills Road, Atlanta, GA 30329
Tel: 404-321-0460 Fax: 404-633-0799
sales@technicalco.com

SILICA MATERIALS

Unimin Corporation
258 Elm St., New Canaan, CT 06840
Tel: 800-243-9004 Fax: 800-243-9005
metalcaster@unimin.com www.metalcaster.com

SILICON CARBIDE

Electro Abrasives LLC
701 Willet Rd., Buffalo, NY 14218
Tel: (800) 284-4748 Fax: (716) 822-2858
info@electroabrasives.com

International Minerals, Inc.
PO Box 1322, Coraopolis, PA 15108
Tel: (724) 857-9903 Fax: (724) 857-9917
jk@imi-minerals.com www.imi-minerals.com

SILICON CARBIDE REFRACTORY SHAPES

Saint-Gobain Ceramics
1 New Bond St., MS 301-432
Worcester, MA 01615-0136
Tel: (508) 795-2963 Fax: (508) 795-5011
patrick.m.stephan@saint-gobain.com
www.refractories.saint-gobain.com

SILICON METAL POWDER

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300 Grand Ave., Englewood, NJ 07631
Tel: :201) 569-8686 Fax: (201) 569-7511
info@basstechintl.com www.basstechintl.com

SODIUM SILICATE POWDERS

BassTech International
300 Grand Ave., Englewood, NJ 07631
Tel: :201) 569-8686 Fax: (201) 569-7511
info@basstechintl.com www.basstechintl.com

SPINEL-SINTERED

Almatis
501 West Park Rd., Leetsdale, PA 15056
Tel: (412) 630-2800 Fax: (412) 630-2810
www.almatis.com

STEEL FIBERS

Fibercon International Inc.
100 S. Third St, Evans City, PA 16033
Tel: (724) 538-5006 Fax: (724) 538-9118
info@fiberconfiber.com www.fiberconfiber.com

TITANIA

Sachtleben Chemical Company
104 Murphys Crossing Dr., Powell, OH 43065
Tel: (614) 284-9699 Fax: (614) 761-7722
vrestivo@hotmail.com www.sachtleben.com

TOLL CRUSHING & GRINDING

AluChem, Inc.
One Landy Lane. Cincinnati, OH 45215
Tel: (513) 733-8519 Fax: (513) 733-0608
aluchem@aluchem.com

Christy Minerals
833 Booneslick, High Hill, MO 63350
Tel: (636) 585-2214 Fax: (636) 585-2220
info@christyco.com www.christyco.com

TOLL PROCESSING

AluChem, Inc.
One Landy Lane. Cincinnati, OH 45215
Tel: (513) 733-8519 Fax: (513) 733-0608
aluchem@aluchem.com

VACUUM FORM SHAPES

Refractory Specialties, Inc.
230 W. California Ave., Sebring, OH 44672
Tel: (330) 938-2101 Fax: (330) 938-2574
sales@rsifibre.com www.rsifibre.com

ZIRCAR Ceramics, Inc.
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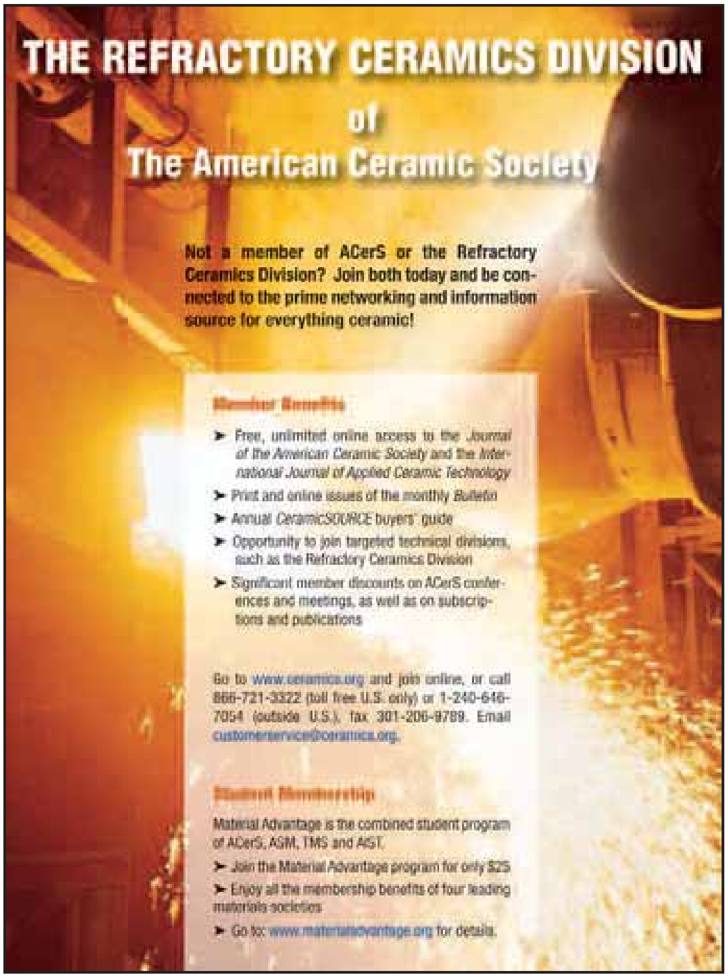
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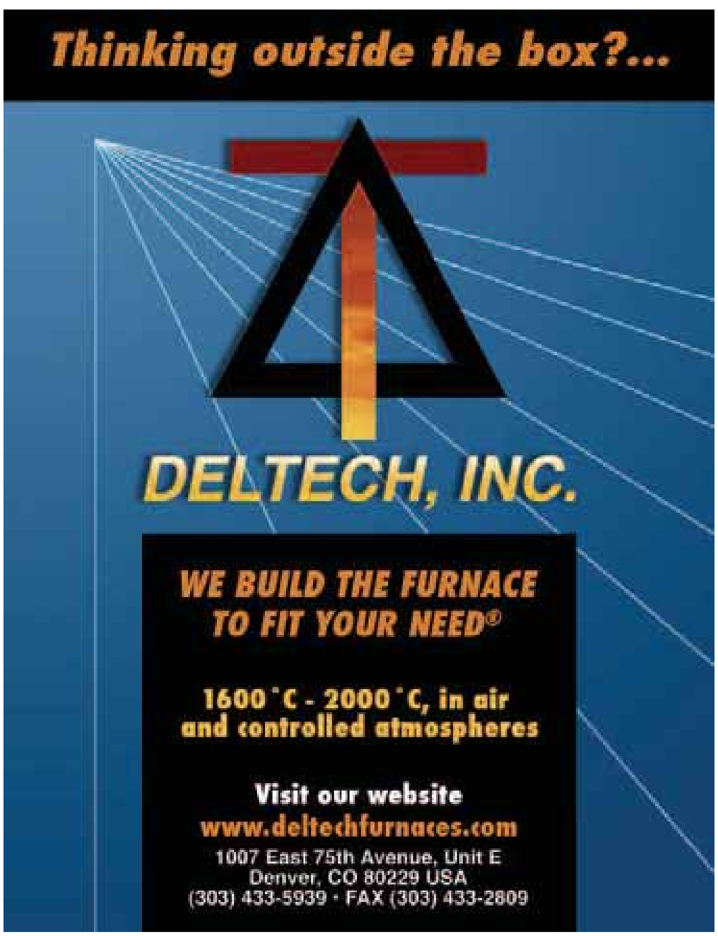
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