Tehran International Conference on Refractories

May 4-6, 2004
ALAFAR

2004

NOVEMBER 7-10, 2004
ANTIGUA, GUATEMALA

Conference topic: Technological and Logistical Leadership in a Global Environment

- Refractory applications for the steel, non-ferrous and cement industry
- Refractory applications for the ceramic, petrochemical and other industry
- Raw materials for refractories
- User’s points of view
- Quality and Environment
- Processes, equipment and controls
- Development of refractory products
- Logistics Considerations
- Recycling of materials

Comite Organizador ALAFAR / ALAFAR Organizing Committee

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UNITECR 2005

Call for Papers

General Session Topics

• Refractories for Iron and Steel, Glass, Ceramic Industries, Non-ferrous Metallurgy, Cement, Hydrocarbon, Waste Incineration, Pulp and Paper
• Refractory Applications of Advanced Ceramics
• New Tests and Test Development
• Refractory Engineering Systems and Design
• Advances in Manufacturing, Control, Equipment
• Raw Material Advancements, Selection and Application
• Process Control, Quality Control, Quality Assurance
• Advances in Refractory Services
• New Developments

Special Symposia Topics

• Environmental Sustainability
• Ultra High Temperature Materials
• Steelmaking Refractories–Dofasco, Inc.
• Fracture of Refractory Ceramics
• Worldwide Raw Materials
• Coatings and Surface Modifications
• Carbon Containing Castables
• Ex Situ and In Situ Characterization
• Refractories for Primary Aluminum
• Robert E. Moore Refractory Education Symposium
• Castable Rheology
• Hydrocarbon Processing
• Refractories for Rock Products

Abstract Deadline - November 30, 2004
for more information see:
www.unitecr.org
The Imam Mosque Isfahan/Iran, is marvel of Safavid art and magnificent example of the sumptuous architecture that constituted the glory of Isfahan at the time. The two minarets of the north portal, the high cupola (170 ft) and minarets of the south portal (160 ft) and the pointed roof of the minarets dominate the arcades of the square. The finest view of the mosque is from the upper story of Ali Qapu whence you can see the entire shafts of the minarets, the stalactite vaults of the portals, and the splendid cupola with its high drum and characteristic bulb-shaped dome. It was the work of Shah Abbas the great. This mosque was started in 1611 AD and building it took 18 years. Shah Abbas finally saw his mosque finished in 1629 AD, the last year of his reign, when the high cupola was completed. Apart from these few additions, the Imam Mosque is one of the rare examples of a grandiose building constructed at the behest of one man in one continuous operation lasting less than 18 years. This accounts for the remarkable unity of the decorations, colors, and motifs.

The name Iran means the country of Aryans. They immigrated to the Iranian plateau somewhere around 1000 BC. These immigrants established the first empire of the world which is known in the West as the Persian Empire by King Cyrus around 570 BC.

Iran is a land of historical sites and cultural heritage and with 2500 years history. A land of beauty, flowers, birds, poets and poetry, ancient and modern art and a great variety of cultures and sub-cultures in a
2004 REFRACTORIES RELATED MEETINGS

August 1-6, Gordon Research Conference on High Temperature Materials, Process and Diagnostics, Waterville, ME, Contact: K. Hilpert, E-mail: k.hilpert@fz-juelich.de, www.grc.org/programs/2004/hightemp.htm

August 22-25, COM 2004, The Conference of Metallurgists, Hamilton, Canada, Met. Soc. of CIM, 3400 de Maisonneuve West, #1210, Montreal, Quebec, Canada H3Z 3B8, Tel: (514) 939-2710, ext. 1317, Fax: (514) 939-9160, E-mail: metsoc@cim.org, www.metsoc.org

August 22-25, 4th International Symposium on Advances in Refractories for the Metallurgical Industries in conjunction with the Conference of Metallurgists, Hamilton, Canada, Tel 514-858-6471, michel.rigaud@polymtl.ca, www.metsoc.org; or www.metsoc.org/conferences/com2004

August 22-26, VII National Congress of the Mexican Electron Microscopy Association, Cancun, Mexico; Tel/Fax: +42(222)2114393, +52(222)2114394, www.viep.buap.mx/imrc2004.htm


September 7-9, Short course: Design & Inspection of Refractory Materials, course outline available at http://www.carmagen.com/810.htm; Edmonton, Canada, Carmagen Engineering, Inc., 4 West Main Street, Rockaway, NJ 07866, Tel: 973/627-4455, Fax: 973/627-3133

September 10, Refractory Improvements in Steelmaking, Carlton Park Hotel, Rotherham, South Yorkshire, England, Contact: Mr.Alan Hey, E-mail: alanhey@ireng.org, Fax 44 1226 762673

September 10-17, National Safety Council 92nd Annual Congress & Expo, New Orleans, Louisiana, for more information: http://www.appcluster05.com/app/homepage.cfm?moduleid=554&appname=349


September 15-16, GFC 2004, ORLEANS CONFERENCE ON REFRACTORIES, Orleans, France, Tel: +33 238494729, Fax: +33238417329, E-mail: jacques.poirier@univ-orleans.fr, http://www.univ-orleans.fr/polytech/colloque

September 15-17, AISTech 2004, The Iron & Steel Technology and Exposition, Opryland, Nashville, TN, contact Lynda Draper at 724-776-1535 ext. 629 or lyndad@iss.org, www.aistech.org


September 19-23, 10th International Symposium on Superalloys, Champion, PA, sponsored by the Minerals, Metals & Materials Society (TMS); Tel: 724/776-9000; E-mail: tmsgeneral@tms.org; www.tms.org

September 22-24, Aluminum 2004 – 5th World Trade Fair & Conference, Messe Essen, Germany; Tel: +49-211-90191-202; E-mail: info@aluminum-messe.com; www.Aluminum2004.com


October 5-7, Short Course on Advanced Techniques for Pore Structure Characterization; Ithaca, NY; Tel: 607/257-554 ext. 13; E-mail: conference@pmiap.com; www.pmiap.com


October 13-14, 47th International Colloquium on Refractories 2004, Refractories for Metallurgy EUROGRESS, Aachen, Germany, Forschungsgemeinschaft Feuerfest e.V. - Feuerfest-Kolloqium -An der Elisabethkirche 27, D-53113 Bonn, Tel:+49-228-91508-45, Fax:+49-228-91508-55, E-mail: 2004@feuerfest-kolloquium.de, www.feuerfest-kolloquium.de

October 13-15, 4th International Tube and Pipe Industry Technology Exhibition for Korea, Busan Exhibition and Convention Center, Seoul, Korea, www.e-pipe.co.kr/exhibition2004/img/eng1.gif or e-mail:exhibition@e-pipe.co.kr

October 18-19, Short Course on Refractory Applications for FCC Units, Process Heaters and Boilers, Hotel Sofitel Houston, Houston, Texas, E-mail: seminars@petroleumrefining.com; www.petroleumrefining.com

October 31-November 3, 3rd International Symposium on the Science of Engineering Ceramics, Osaka, Japan, Tel: 81-52-739-0155, E-mail: t-oji@aiast.go.jp

November 3-5, 15th IAS Rolling Conference, 2nd IAS Conference on Uses of Steel, Instituto Argentino de Siderurgia, Hotel Colonial, San Nicolas, Argentina, Contact: Cristian Genzano, IAS, E-mail: genzano@siderurgia.org.ar, Tel: 54-3461 460803, Fax: 54-3461 462989, www.siderurgia.org.ar/seminario/call_for_papers.htm.

November 7-10, 32nd ALAFAR, Congress of the Latin American Association of Refractories Manufacturers, Antigua, Guatemala, mpereyo@thermalceramics.co

December 6-8, International Symposium on Advanced Materials and Processing, Kharagpur, India, www.iitkgp.ernet.in/departments/home.php?deptcode=MS
EDUCATION SYMPOSIUM HONORS ROBERT E. MOORE AT UNITECR 2005

Mariano Velez, Editor

The refractories community lost one of its largest supporters when Professor Robert Eugene Moore died unexpectedly last year on July 9th. Bob Moore continuously promoted the field of refractories throughout the world and was the founder of *Refractories Applications and News* in 1996. The idea was to create a magazine that would primarily serve the industry and its people, covering practical issues as well as state-of-the-art matter. He also led the UMR Ceramic Engineering Department for almost thirty years, transforming one of the smallest academic departments on campus to one with international status and networking with different institutions across the globe. His work is being commemorated during the Robert E. Moore Refractory Education Symposium at UNITECR 2005 (www.unitecr.org).

The goal of this session, based on Professor Moore’s initiative in early 2003, is to survey the refractories research and teaching centers around the world. This update would include educational and research activities; for instance, the number of undergraduate and graduate students, formal refractories-related university courses, as well as industry-oriented, long-distance learning and short courses, on campus, off campus, seminars and web-based courses. A final objective is to summarize the information of the different centers to identify areas for development and research, and a vision of education for future generations. This could lead to potential collaboration between centers, institutes or universities, and the industry – while promoting the teaching centers, as information will be available to large audiences. More specifically, the session would identify the following:

- Number of teaching staff and research staff dedicating their efforts in this area.
- Course titles and enrollments in classes on refractories which are taught on campus; for the current year and a five-year average.
- Number of M.Sc. and Ph.D. graduate students.
- Courses taught away from the university or institute and/or courses taught through the Internet.
- Complete contact information of lead person(s), including E-mail address and website if available.

At this time we have around ten centers and universities from different countries committed to this symposium. In particular we have educators from Argentina, Canada, England, Japan, Korea, Mexico, Spain, USA, and Ukraine willing to participate. I invite other centers to participate; please write me or submit your abstract directly to the UNITECR 2005 website. Deadline is November 30th.

Although similar review sessions on education were conducted in 1997 and then in 2003, several issues ensure that this particular effort would be of benefit for all. On one hand, the economy is starting to improve; on the other hand, globalization is still an important issue. Refractory teaching at universities has been declining; however, new materials and techniques are being developed and long-distance and internet-based courses and information have increased. Resource optimization is a goal for everybody as research money is limited. This would lead to more collaboration between refractories-related centers with fresh information and status of each institute, region, or emphasis. UNITECR 2005 is planned for November 8-11 in Orlando, Florida.

Another important meeting where members of the international refractories community gather to collaborate is ALAFAR (www.alafar.org), now a bi-annual event. This year’s meeting will be held on November 7th to 10th, in Antigua, Guatemala. The topic of the event is the Technological and Logistical Leadership in a Global Environment. The sessions will include refractories for steel, non ferrous, cement, ceramic, petrochemical, as well as raw materials, quality and environment, process control, development and recycling of materials. We encourage you to attend both UNITECR and ALAFAR to help make these meetings successful.

In this issue we are summarizing the first Tehran International Conference on Refractories (see page 28). The event was well attended and a list of comments from some of the attendees is included.

UNITECR 2005
www.unitecr.org
See the inside front cover
Ohio Legislature Passes Important Silica Measure

In a victory for Ohio business, on May 24 the Ohio Senate passed, and the Ohio House concurred, HB 342, legislation that would require claimants contending they have silicosis or silica-based illnesses to meet precise medical criteria before proceeding with litigation. Claimants would have to show that they are indeed ill before a case could move forward. The medical standards are based on guidelines of the American Bar Association.

The legislation now goes to the governor for signature. Ohio Rep. Chris Widener was the chief sponsor of the bill. He is to be commended, as are the many Ohio businessmen and citizens who supported passage of the measure which should be considered a model for the rest of the nation. (Note: Thanks to contributing reporter Steve Nock of The Nock and Son Company for sharing this good news with the industry.)

Lafarge Calcium Aluminates Announces Personnel Updates

Ron Rohlletter, National Sales Manager to the North American refractory industry, will retire from Lafarge Calcium Aluminates (LCA) in June. Ron joined LCA in 1984, and, in his twenty years of service, held the positions of Midwest Sales Representative and Refractory National Sales Manager. Ron will continue to reside in Columbus, Ohio.

Nancy Bunt will assume the position of North American Refractory Market Manager for LCA in June. Nancy has been with Lafarge since 1991, previously holding the positions of Ceramic Engineer, Technical Manager, and, most recently, Corporate Market Manager based in Paris, France. Nancy may be reached at: Large Calcium Aluminates, 1316 Priority Lane, Chesapeake, VA 23324; phone: 757-284-3277; Fax: 757-284-3333; E-mail: nancy.bunt@aluminates.lafarge.com.

Quarterly Survey Finds Industry Recovering

Responses to the quarterly fax survey of TRI members conducted in early April show an industry that appears to have turned the corner to recovery. Of twenty-two completed survey forms, only one company reported sales down slightly. A very respectable 82% of respondents reported sales up slightly or up over 5%. This is a major turnaround from the anemic surveys of the past couple of years. Only three companies reported increased inventories, while half reported their inventories had decreased. About a third of the companies plan to hire more staff. The major complaint was the rising costs of raw materials, energy, and freight.

ACerS Makes Changes to Annual Meeting Format in 2006

The American Ceramic Society has announced that in 2006 it will switch its annual meeting from the spring to the fall and will meet in a joint meeting with AMS and TMS. ACerS had agreed to participate in the 2005 joint meeting of the two organizations as a “junior” partner while still having its annual meeting in the spring. In 2006, it will become a full-fledged participant. There is also talk of asking the Association for Iron and Steel (AIST) to participate, but it may be too early for that group which resulted from the merger of the Iron and Steel Society and the Association of Iron and Steel Engineers.

REGULATORY ISSUES

OSHA News

The Occupational Safety and Health Administration has recently acted in a number of areas of interest to the refractories industry.

New Fact Sheets: OSHA has posted seven new fact sheets on its web site. The publications include: “Voluntary Protection Programs,” “The OSHA Consultation Program,” State Job Safety and Health Programs,” “Hazardous Waste Operations and Emergency Response,” “Planning and Responding to Workplace Emergencies,” and “OSHA Requirements When a Worker Experiences a Job-Related Injury or Illness.” They can be found at www.osha.gov/wut-snew.html.

Hexavalent Chromium: Small business representatives, citing feasibility concerns, have petitioned the agency to increase its proposed PEL for hexavalent chromium and consider adopting a minimum PEL of 20 micrograms per meter of air. Suggested PELs in the agency’s draft regulation are as much as twenty times lower. The employers stated that as the “action level” is generally one half the PEL in most OSHA health standards, the cost and feasibility of meeting the very low levels are problematic.

Employers with High Injury/Illness Rates: OSHA has notified about 13,000 employers in the United States that their injury and illness rates are significantly higher than the national average, and that they should take steps to reduce them. There were 1,200 fewer notifications than last year, but OSHA evaluations were down by 14% as well.

EPA Toxics Release Inventory (TRI) Program

In a May 19, 2004 memorandum, Kimberly T. Nelson, EPA Assistant Administrator and Chief Information Officer, announced ongoing efforts to modernize and streamline the Toxic Release Inventory reporting program. A key initiative is the move to internet reporting. EPA is asking each facility to take advantage of available electronic reporting with the use of the TRI Made Easy (TRI-ME) software and EPA=s Central Data Exchange (CDX).

This year EPA intends to provide the public with an Electronic Facility Data Release (eFDR) in November. The eFDR will enable the public to access TRI data on a facility-specific, form-by-form level on or about November 20, 2004, via EPA=s Envirofacts Web site. For additional information on the TRI program, go to www.epa.gov/tri.

EPA Chemical Spills Regulations

The Environmental Protection Agency has revised and updated its chemical accident prevention regulations to require more timely reporting of incidents and additional administrative changes. The final rule was published in the Federal Register on April 9, 2004 (FR 4/9/04, Vol. 69, No. 69, pp. 18819-18832). You may access the Federal Register by going to the Government Printing Office web site at www.gpo.gov.

LEGISLATIVE ISSUES

Asbestos Bill Still Alive

Although it still faces an impasse on funding issues and other provisions, S.2290, a bill which would establish a trust fund to compensate asbestos victims, is still alive in the Senate, although as each day goes by, it becomes less likely we will see final action.
CELLULAR CONCRETE PURCHASES ALLENTOWN EQUIPMENT DIVISION

Cellular Concrete LLC, a fifty eight year-old supplier of admixtures for lightweight concrete in the roofing, flooring, geotechnical and precast business, has expanded into the shotcrete equipment business by purchasing Allentown Equipment. Cellular Concrete will take over all manufacturing and distribution of Allentown Equipment including all of the dry and wet process equipment at its plant located in Allentown, PA.

Rich Palladino, president of Cellular Concrete, thanked the transition team, headed by George Yoggy. “Many thanks have to go out to all those who gave their input in making this happen. Special thanks go out to George for his contribution of wisdom and experience in making this transition a success.”

Jeffrey Pool, the newly appointed President, stated today, “Allentown is in great shape and geared up to meet the new demand from its customers. Allentown is dedicated to a set of standards about product excellence and customer satisfaction that is reminiscent of ‘the good old days’ when your business associates knew your name and agreements were finalized with a handshake rather than a multi-page electronic document.”

Allentown Equipment is the successor to The Cement Gun Company, which originally commercialized the gunite process in 1911. Allentown Equipment has continually produced gunite and shotcrete equipment since that time in Allentown, PA. Allentown is the leading provider of shotcrete equipment, service and technology in the world.

Allentown Equipment was sold by Master Builders, the Admixture Systems Business Unit of Degussa Construction Chemicals. Allentown Equipment and Master Builders will continue to work together in a strategic alliance to supply Master Builders’ customers with shotcrete equipment.

Contact: Allentown Equipment, Emily Moore, Tel: 610-398-0451 ext. 18, E-mail:emoore@allentownequipment.com

STELLAR MATERIALS ACQUIRES THERMBOND REFRACTORY GROUP FROM JOHN ZINK LLC


Stellar immediately gained an experienced and knowledgeable sales and installation group that continues to fuel the rapid growth of their Thermbond business.

"This acquisition gives Stellar tremendous depth and the ability to pursue direct international sales and better support our existing distributor network,” said David Mintz, Vice President of Stellar Materials.

The deal adds 11 people to Stellar's staff, including nine technical sales people, and two technical service people. Eight of the 11 reside in the United States, three reside in Europe.

Stellar Materials Incorporated, a Michigan Corporation was founded in 1990 and is the manufacturer of Thermbond refractories and Phoscrete concretes. Both Thermbond and Phoscrete products utilize the patented Stellar Binder System™ that offers significant advantages over traditional refractories and concretes.

Thermbond and Phoscrete are distributed worldwide. For more information contact: Tom Atkins, Director of Worldwide Sales and Marketing, Stellar Materials Incorporated, E-mail: Tom.Atkins@thermbond.com, Tel: (561) 330-9300 Fax: (561) 330-9355 or visit www.stellarmaterials.com.

J.T. THORPE CO. EMERGES FROM CHAPTER 11

Houston-based specialty contractor J.T. Thorpe Company announced today that it has emerged from Chapter 11 Bankruptcy. On March 4, 2004 the United States Bankruptcy Court and District Court for the Southern District of Texas entered supplemental orders confirming the company's plan of reorganization, which grants injunctions against asbestos lawsuits filed against the Company and its affiliates and provides for the creation of a trust to benefit asbestos claimants. Although the Bankruptcy Court and District Court originally entered orders confirming the plan in January of 2003, the orders were appealed to the United States Court of Appeals for the Fifth Circuit. That appeal was dismissed after the parties to the appeal settled.

Based on the recent court orders, the Company was able to consummate its plan on April 21, 2004 and as a result may now operate its business in the usual manner under court protection from existing and future asbestos-related lawsuits.

J.T. Thorpe Company filed a voluntary petition for relief under Chapter 11 of the United States Bankruptcy Code on October 1, 2002, to resolve liabilities associated with activities related to asbestos dating back to its inception in 1953.

Gerald W. Scott, J.T. Thorpe’s President and Chief Executive Officer said, "During the past several years, we have been working diligently to bring about a comprehensive resolution of the asbestos liabilities of J.T. Thorpe Company. Based upon the conclusion of this process, J.T. Thorpe Company can now emerge free of any future exposure to these liabilities. Furthermore, this process affords legal protection from asbestos claims to Thorpe Corporation, Thorpe Products Company and Leacon-Sunbelt, Inc. by virtue of protective injunctions entered by the Court. Despite the fact that the company was otherwise healthy and profitable, the liability associated with asbestos claims necessitated the Chapter 11 reorganization. We are pleased to have concluded this reorganization such that we can turn our full, attention to serving our customers and the growth and long-term success of our organization. We appreciate the loyalty of our employ- ees, customers and suppliers who have allowed the company to conduct business as usual as we have worked through the bankruptcy process."

J.T. Thorpe Company maintains offices and warehouses in Houston and Beaumont, Texas and Sulphur, Louisiana. The company operates as a specialty contractor engaged in the design, installation, maintenance and repair of refractory and acid masonry linings and related products in industrial settings. J.T. Thorpe Company is affiliated through common ownership with...
Thorp Products Company and Leacon-Sunbelt, Inc.

For more information contact: Gerald W. Scott, 713-644-1247

IMERYS LAUNCH TWO NEW WEB SITES

Imerys announce as part of their ongoing Marketing Communication strategy, the launch of two new websites for their tableware and sanitaryware businesses. The two sites can be accessed at:

http://www.imerys-tableware.com

http://www.imerys-sanitaryware.com

For further information contact: Julia Pearson, Head of Communications: Performance Minerals Europe & Fine Ceramics, Tel: +44 1726 818112, Fax: +44 1726 623019, E-mail: julia.pearson@imerys.com

JAY ENGLEBRECHT RETURNS TO PLIBRICO SALES & SERVICE,

Plibrico Sales & Service, Inc. is happy to announce the return of Jay Englebrecht as a sales representative for us in the state of Washington. Jay sold Plibrico products while he worked for Plibrico's distributor, Refractories Northwest, for the years 1987 through 1993. Overall Jay has 25+ years experience in refractory sales and construction. "Jay brings knowledge and integrity to the table and we're happy he's back," states Bob Schultz, Plibrico's Vice President of Marketing. "Washington State will be well served by Jay!" For more information contact: Bob Schultz, Plibrico Company, Chicago IL, E-mail: Rschultz@PLIBRICO-USA.COM

RESEARCH PORTFOLIO UNVEILED

The biannual Industry Member Meeting of the Center for Innovative Sintered Products took place at the Penn State Conference Center on 10-11 May. Some highlights of the meeting were identification of the research portfolio for the upcoming year, dissemination of research results, networking with colleagues from industry and academia, information about NSF-SBIR innovation-through-partnership initiatives, assessment of opportunities and barriers of electrophoretic deposition, and a metal-cast-

ing and P/M perspective of dimensional precision. Over eighty delegates met at this excellent venue to hear reports on a wide variety of research topics as well as capability presentations from twelve member companies. The business climate continues on the upswing, as evidenced by the strong industry attendance, spirited discussions, and positive business reports.

With an emphasis on student training and research, member companies had an opportunity to vote on the suite of precompetitive research projects for the upcoming year. The projects identified as a top priority are:

- Multiple-Axis in-situ Monitoring of Dimensional Changes in Debinding, Delubrication, Sintering, and Heat Treatment
- Press and Sinter Processing Realities with Nanoscale Powders (nano-P/M)
- Fundamental Limitations and Capabilities of High-Density P/M
- Crack Detection in Green Compacts
- Selective Densification and Finishing of PM Gears by Ausforming
- Modeling Carbon and Oxygen Potentials during Sintering
- Oxyxon Furnace Evaluation
- Application of Full Density Hard Coatings to Ferrous P/M Materials

Positive feedback from delegates after this event confirmed its success. The Center offers a variety of services to help companies add value to their business. To help guide and direct this program, contact Sharon Elder, Executive Director, at: cisp@psu.edu.

US SPECIALTY SILICAS DEMAND TO REACH $1.5 BILLION IN 2008

Demand for specialty silicas in the US is expected to advance 6.5 percent yearly to $1.5 billion. In addition, gains will be fueled by a general pickup in economic activity from the 2000-2002 level, which will directly benefit such key specialty silica markets as paper, chemicals and industrial rubber products. These and other trends are presented in Specialty Silicas, a new study from The Freedonia Group, Inc., a Cleveland-based research firm.

Specialty Silicas (published 04/2004, 189 pages) is available for $3,900 from the Freedonia Group, Inc., 767 Beta Drive, Cleveland, OH 44143-2326. For further details, please contact Corinne Gangloff by Tel: (440) 684-9600, Fax: (440) 646-0484 or E-mail: pr@freedoniagroup.com. Information may also be obtained through: www.freedoniagroup.com.

ALMATIS ANNOUNCES EXPANSION

Almatis announced today the expansion of ground reactives batch mill capacity at their Bauxite, Arkansas manufacturing facility. The newly re-started reactives batch mill is now successfully producing Almatis’ super-ground reactive products. Rapid growth in global demand for reactive alumina products supports this expedited investment. The recently announced, new large capacity reactives batch mill at the Almatis Ludwigsafen, Germany plant is on schedule for 4th quarter 2004 startup. High-performance reactive aluminas supply the growing refractory and ceramic markets.

The successful mill startup has added capacity for Almatis’ broad family of reactive alumina products, which includes A-16 SG, A-1000 SG, RG-100, A-3000 FL, A-152 SG and more. Superground reactive aluminas are mainly used for specialty ceramic products, as well as refractory matrix improvements.

“As an independent organization, focused solely on our core strength of specialty alumina materials supply, Almatis is better able to serve all our customers. We are more agile, more able to quickly respond to market demand.” Gangolf Kriechbaum, Almatis’ Chief Commercial Officer stated.

Almatis is a global supplier of specialty alumina materials, including tabular alumina, calcined alumina, calcium aluminate cement, spinel, activated alumina, ground Bayer hydrate, white hydrated alumina and fine precipitated aluminum hydroxide. Formerly Alcoa World Chemicals, Almatis is an independent company headquartered in Frankfurt, Germany.

Contact: For Europe and Asia: Gabriele Drees, +49 69 95 73 41 44. For Americas: Marilyn Kunka, (412) 630-2809 or www.almatis.com
Mg-Al SPINEL: IS IT THE MULLITE OF THE 21st CENTURY?

Dr. Richard C. Bradt

In the latter half of the 20th Century, the refractory use of mullite, the 3:2 compound in the alumina/silica system, 3Al₂O₃•2SiO₂ became quite extensive. Although mullite is only found naturally on the Isle of Mull and just in rather small quantities there, it has been synthetically produced in very large quantities from high alumina clays. Commercial production began in earnest as time progressed into the latter half of the 20th Century. One US domestic producer even applied the name Mulcoa to their mullite products, giving this important synthetic refractory compound a sort of mineralogical identity that was all its own.

Within the United States in the states of Alabama and Georgia, the bauxitic kaolins that are common in the Eufaula area, near to those states’ common border, was a focal point for extensive mullite production. It remains that way, as mullite production is presently dominated by a single producer in the United States. There are, however, similar mullite production activities throughout the world, and they are located wherever the local clay mineralogy suggests that the process is a viable one.

It must not be overlooked, that in addition to the use of high alumina clays as raw materials, the sillimanite group of minerals (kyanite, andalusite and sillimanite) have also been a source of mullite for refractories. These minerals produce mullite via an in-situ decomposition reaction during the firing of the refractory shapes, rejecting silica from their 1:1, Al₂O₃•SiO₂ compounds at high temperatures. Mullites originating from the sillimanite minerals yield very different microstructures. They often have distinctive crystal geometries and correspondingly, superior properties with attendant advantages.

It is now history that synthetic refractory material production activity on a major scale was originally unique to this editorial. This editorial suggests that mullite may have only been the first of many, or at least of a couple of synthetic minerals that will achieve worldwide prominence in industrial refractory applications. As the title of the editorial suggests, spinel, and perhaps not only the magnesium aluminate spinel, MgAl₂O₄, but the entire class of spinel compounds, both normal and inverse may be on the horizon as the next of the synthetic refractory raw material giants.

That this might occur for spinel(s) is not wholly unexpected for the presence of phases of the spinel crystal structure in refractories is not new. The commercial production of several different varieties of mag-chrome refractories has been common for at least half a century. These very excellent chrome-ore-based refractory products consist of a solid solution mix of several chrome, ferrite and aluminate spinels. It is these spinels that impart the excellent properties to that mag-chrome refractory class. These refractories are well respected for their high temperature stability and their outstanding corrosion resistance. Those features may be directly attributed to the spinel crystalline phases of the constituents.

Prior to the mid-1980’s the use of the magnesium aluminate spinel, MgAl₂O₄, was not very common for the refractory linings of industrial processing vessels. Today, however, an entirely different situation exists as entire process vessel linings are made of this prototype synthetic spinel, or one of its derivative refractory products. It is also used in numerous applications at individual locations within some processing vessels. It is of interest to examine why the magnesium aluminate spinel MgAl₂O₄ has recently achieved such a high level of acceptance within a time span that amounts to just a couple of decades. Perhaps there is no better place to begin than to compare some of the most important refractory properties of the spinel with those of mullite, the historically leading synthetic refractory mineral.

While one may debate as to what are the most important properties for a refractory, this brief consideration will address just two of the most critical ones, the melting points of the compounds and their free energies of formation. Then a few related issues will be considered to provide additional contributions to the question, or the contention of this editorial article. The melting points of the two compounds are both above the usual temperatures of most steelmaking processes. Mullite melts at ~1900°C and the magnesium aluminate spinel at ~2100°C. This appears to give a slight thermal advantage to the spinel. The free energies are an indication of the chemical stability of the compound and they indicate an even greater advantage for spinel. The free energies are listed for a couple of high temperatures of interest.

This comparison of the two refractory compounds gives a distinct chemical stability advantage to the magnesium aluminate spinel. It also suggests that the spinel may be more readily formed from its constituent oxides, if all of the kinetic considerations are equal. Although they will not be discussed here, most of the other spinel structures have similarly high melting points and also large negative free energies of formation. Of course, this is partially the reason why the previously mentioned mag-chrome refractories have been so successful in highly aggressive and corrosive high...
temperature environments. Very few oxides, excepting CaO and MgO have superior melting point / free energy of formation combinations when compared to that of spinel. Many of them are not economically suitable for large scale refractory production. Of course MgO is extensively used in many steelmaking applications and CaO has sometimes been called the ultimate refractory.

Consideration of a couple of the other usually-considered refractory properties or characteristics is appropriate. Thermal expansion is always of concern. Of course the thermal expansion is a function of temperature, usually increasing with increasing temperatures. The average thermal expansion for mullite is ~3–5 x 10⁻⁶/°C, while that of the magnesium aluminate spinel is ~6–9 x 10⁻⁶/°C, both from room temperature through ~1200°C. The lower thermal expansion for mullite may be considered to be a distinct advantage as it suggests lower thermal stress development during temperature excursions during operating conditions of process vessels, as well as during the initial heating of a newly installed process vessel lining.

Other considerations must also certainly include the microstructure, or the texture of the refractory products. It is well known that the mullite crystals in most aluminosilicate refractory bodies have a lath-like, almost fibrous microstructure. They are reminiscent of a random fiber composite with their tortuous intergrowth networks. The magnesium aluminate spinel on the other hand has an equiaxed microstructure typical of many high-tech ceramics. Although no direct comparison of the R-curves of these two types of refractories has been published to the knowledge of this author, it is not too difficult to imagine that the intergrowths of the mullite crystal lathes may exhibit more rapidly rising R-curves than the equiaxed spinel microstructures. This suggests that the mullite may be more resistant to thermal shock damage.

Both mullite and the magnesium aluminate spinel experience a volumetric expansion when they are formed from their individual constituent oxides. This characteristic can provide a distinct advantage in applications for both materials. In the case of mullite, it is related to the familiar reheat expansion test and may be used to advantage when lining rotary kilns. A little additional mullite formation during operation at high temperatures tightens the rotating lining within the kiln shell. Expansion of the magnesium aluminate spinel has proven equally useful. Additional magnesia in the Al₂O₃-MgO-C refractory brick system allows for spinel formation during operation to continually tighten the linings of ladles and perhaps repair, or close thermal stress cracks as well during the campaign life of these refractories. Other advantages of the expansion are left to the design imaginations of the refractory engineers, but they clearly offer distinct advantages for both systems in particular applications.

How else can the two compounds be compared? Perhaps their respective phase equilibrium diagrams offer another basis from a fundamental perspective? Each is the only compound in their respective binary system, Al₂O₃-SiO₂ and Al₂O₃-MgO, respectively. Setting aside the controversy of the melting of mullite, any alumina-rich compositions in the alumina-silica system would not be expected to seriously compromise melting of the two phase mixture. However, the presence of excess silica would create liquids at higher temperatures for the silica-mullite eutectic is only ~1600°C. By contrast, the alumina-magnesia system, even though having eutectics on both sides of the centrally located spinel compound would not be expected to develop liquids on either side until ~1900°C, which corresponds to the alumina-rich side. This might be an advantage in some steelmaking processes. It is also another advantage, for both magnesia-rich and alumina-rich two phase spinel refractories are possible and in fact are currently commercially available. As an additional point, the range of stoichiometry of the magnesium aluminate spinel phase is considerably greater than that of mullite especially at very high temperatures where the phase field is quite expanded.

As a further consideration, it is probably also desirable to review or explore some of the applications of the magnesium-aluminate spinel to gain a perspective of its growth during the past couple of decades. One of the early applications was the use of spinel brick in cement kiln linings, an application which has continued to grow with the introduction of commercial non-stoichiometric varieties of the spinel. Uses in steelmaking, aluminum, petrochemical and glass melting applications continue to increase. The use in steel melting ladles, both as the spinel linings and as an additive to alumina castables continues to increase for the spinel has been found to increase the lifetime of the linings. The unique character of in-situ formation of spinel by adding magnesia to high alumina castables has been reported to have very beneficial effects on the corrosion resistance of those refractories. This is not surprising for when the spinel is formed in-situ, it expands and reduces the sizes of the internal pore channels. This naturally reduces the penetration of the refractory structure by molten metals and slags.

One of the most interesting technical utilizations of spinel relates to the spinel formation volumetric expansion. It has been in the Al₂O₃-MgO-C refractory system for steel melting ladles. The benefits of the two classes of MgO–C and Al₂O₃–C refractories, both with and without antioxidants, have been long appreciated in steelmaking process vessels. The use of a magnesium addition to the Al₂O₃–C variety has proven rather innovative. The magnesia addition does not initially fully react with the alumina to form the spinel phase. Rather, as the refractory lining gradually wears away, the hot zone penetrates deeper into the original refractory lining and continually promotes additional reaction of the free magnesia and alumina towards the cold face. This continual formation of additional spinel and its associated volumetric increase continually tightens the vessel lining. The spinel formation puts the refractory lining into compression, closing any cracks that may develop, significantly extending the lifetime of the vessel lining.

Similar to the aluminosilicates, the spinels have also been making significant advances in their castable technology. As history might be expected to dictate, the early spinel castables initially were bonded with the conventional calcium aluminate cements.

### Table: Free Energies of Formation (kJ/mol)

<table>
<thead>
<tr>
<th>TEMP (°C)</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>3Al₂O₃·2SiO₂</td>
<td>-21.05</td>
<td>-27.02</td>
<td>-31.10</td>
<td>-34.42</td>
<td>-37.31</td>
</tr>
<tr>
<td>MgO·Al₂O₃</td>
<td>-37.35</td>
<td>-40.44</td>
<td>-43.33</td>
<td>-47.07</td>
<td>-51.12</td>
</tr>
</tbody>
</table>
However, not unexpectedly, development of low melting compounds from the presence of CaO in the cement have proven less than optimal. Recent castable systems have tended to be based on intrinsic bonds developed with the use of transition aluminas. These bond systems are naturally compatible with the magnesium-aluminate spinel and being lime-free are also immune to lower melting temperature compound formation.

The above are only a partial summary of the virtues and applications of spinel as a refractory material. It should never be expected to be the catch all refractory that replaces all other refractories, but it clearly has some unique characteristics that make it extremely attractive for many applications. Some of them have been discussed above. However, in considering spinel, it is necessary to keep in perspective that much of the earlier industrial production of magnesium-aluminate spinels has been of the much more costly experimental-developmental variety. The industrial processes include: (i) adding magnesia to typical tabular alumina production processes, (ii) adding alumina to magnesia calcining shaft kilns, and (iii) the direct fusion of alumina and magnesia in electric arc furnaces. This type of production has naturally put spinel at a cost disadvantage in some applications and cost is an important consideration. It is not unreasonable to assume that the costs of the new spinels over the past decade has somewhat inhibited their commercial growth in metallurgical and other applications. This is true even when the spinel refractory has fundamental technical advantages. As with all new production processes, in the future these cost disadvantages are expected to gradually disappear and eventually increase the economical competitive nature of the magnesium aluminate spinel refractories and perhaps other spinels as well.

Please send meeting announcements along with complete contact information to Mary Lee at: leem@umr.edu
MECHANICAL TESTING AND RESEARCH LABORATORY-CERAMICS DIVISION AT INTEMA UNMdP/CONICET-ARGENTINA

M. Andrea Camerucci, Analía G. Tomba Martinez and Ana Lía Cavalieri, acavalie@fi.mdp.edu.ar

The research areas are the following.

Processing: This area mainly involves experimental activities devoted to the development of new or enhanced ceramics used in structural applications. The aim is to improve the mechanical response of ceramics by microstructural control through the study of the raw materials and the several steps of the processings, specially forming and sintering.

Mechanical tests and behavior: Research activities in this area are dedicated to evaluate the mechanical behavior (fractomechanic parameters measurements, fractographic analysis and determination of fracture mechanisms) of both advanced ceramics and refractories at high temperatures. The development of technological tools (methods and devices) for testing of ceramics is included in this area.

Numerical modeling: It constitutes a powerful tool used as a complement for some researches in thermomechanical data evaluation. A commercial FEM code is used in order to simulate temperature and thermal and mechanical stresses profiles.

The objectives of the work at Mechanical Testing and Research Laboratory are:

• to carry out basic and applied research in the field of ceramics with emphasis on their structural applications.
• to interact with local and national related industries offering technical assistance going from simple tests to jointly supported projects and consulting work to develop tests, processings, and products.
• to contribute actively to the formation of highly qualified human resources, by participating in teaching activities at the undergraduate and graduate levels through Engineering programs in the Materials Department at the Engineering School-UNMdP.
• to communicate the results of the research activities through publications, conferences, meetings.
• to cooperate through international research projects with other national and foreign institutions.

The usual sources of funding at the Mechanical Testing and Research Lab. are governmental institutions as the National University of Mar del Plata (UNMdP); National Research Council for Science and Technology (CONICET); Research Council of Buenos Aires (CIC); National Agency of Promotion for Science and Technology (ANPCyT); Cooperation Projects Spanish/Argentinean National Research Councils (CSIC/CONICET), and private sector as Antorchas Foundation. A part of the budget is supported since 1998 through a contract with a siderurgical industry (SIDERAR S.A.I.C.-TECHINT) concerning to refractories and through tests and consulting works currently required from local commercial companies.

MECHANICAL TESTING AND RESEARCH LABORATORY

The research group on structural ceramics started its activities in 1993 as the Mechanical Testing and Research Laboratory at the Ceramics Division. This laboratory has currently one Principal Investigator, two Postdoctoral Research Associates, A. L. Cavalieri, and M. A. Camerucci and A. G. Tomba Martinez- and part-time technical and administrative people. The non-permanent staff comprises visiting scientists, and undergraduate and graduate students who work to obtain their degrees in Materials Engineering or the Materials Science MSc and Ph.D., respectively.

MECHANICAL TESTING AND RESEARCH LABORATORY

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The groups are connected with national and foreign institutions or researchers: a) Technology Center of Minerals Resources and Ceramics (CETMIC); Physical Dept.-National Commission of Atomic Energy (CNEA); Bariloche Atomic Center (CAB); Argentinean Iron and Steel Institute (IAS); Argentine Geological and Mining Survey (SEGEMAR); Materials Dept.-Institute of Scientific and Technical Researches of Argentine Army (CITEFA); National University of Rosario; National Technological University of San Nicolás at Argentina and b) Institute of Ceramics and Glass (ICV) and Materials Institute of the Spanish National Research Council (CSIC), Madrid-Spain; University of La Habana-Cuba; Department of Ceramic Engineering of Missouri, Rolla-USA; and the Department of Materials at Federal University of San Carlos-Brazil.

The main facilities of the Laboratory are the following:

**Universal testing machine (Instron 8501):** For flexure, compression and tension or tension/tension fatigue tests of advanced ceramics and refractories at high temperatures. The machine is a servo-hydraulic system with high load frame stiffness, 100 kN loadcell, hydrostatic bearing actuator; hydraulic power pack flow rate 45 l/min; cooler system by air. For room temperature tests, compression anvils with spherical seat; COD (5x2) and dynamic extensometer (12.5mm ± 20%) and a two channel crack-length system controlled by crack-gages (Fractomat 1288) are available and both bend 3-point with variable span and biaxial flexure fixtures were designed and constructed.

**1500°C split furnace:** Furnace has MoSi₂ heating elements (SFL 5666C), alumina compression pushrods with water cooling adapters and fully articulated bend SiC fixtures with (4-point) and without (3- and 4-point) integral LVDT center point deflectometer are available in order to carry out high temperature bending tests of advanced ceramics. A second furnace with MoSi₂ heating elements (SFL 822D), a high temperature capacitive extensometer (± 0.1 mm) and calibrator and tensile grips that allow to improve the alignment of the specimen gripped outside of the furnace hot zone are available for advanced ceramics tensile testing. The appropriated loading devices to measure the thermal expansion and creep in compression and stress/strain curves of monolithic refractories and bricks, in air or in controlled atmospheres such as N₂, were design and constructed. Loads are applied through dense sintered bars of mullite-alumina (composition from Cetmic-MRE S.A., Argentina) in an own design system using the water cooling adapters. An axial extensometer (15mm LVDT) for high temperature based in a scissors system was designed and constructed.

**Indentation hardness tester:** (Tukon 300, Wilson Instruments) that employs both the Vickers and the Knoop diamond indenters with loads from 1 to 10,000 g to test porcelain, ceramics and glasses.

**Thermal shock system:** A methodology to study the thermal shock behavior by sudden cooling in air and mechanical evaluation in biaxial flexure to test advanced ceramics was implemented. The equipment was designed and constructed and a software for the test control and the temperature data acquisition was created.

**Hot adhesion system:** A test to do a quantitative evaluation of the adhesion of monolithic refractories hot gunned on refractory bricks was established. The test is based on the measurement of torsional forces at high temperatures. For gunning, a pressure projection system was design and constructed.

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Iran is one of the only countries in the world which has the complete four seasons. In summer, the weather can be cool as well as warm, and in the cold winters, it can be mild.

Iran has a variety of climates, ranging from very cold and snowy to very hot and dry regions, providing the opportunity to ski on the mountains and swim in the sea on the same day in many seasons.

From numerous important historical sites in Iran, we can mention for example: Persepolis in Shiraz, Naqsh-e-Jahan Square in Isfahan, Choqazanbil temple in Ahvaz, Arg-e-Bam in Kerman.

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**Journées Spécialisées sur les Réfractaires (Selected Topics on Refractories – A Short Conference)**

Orléans, France, September 15-16, 2004; organized by Groupement Français de la Céramique, the University of Orléans, the Polytechnical Institute of Orléans, the Laboratoire de Mécanique des Systèmes et des Procédés, and the Center of Research of High Temperature Materials. For more information see http://www.univ-orleans.fr/polytech/colloque/

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diverse land with lakes, deserts, seas, mountains and valleys.

Iran, as a bridge, links the Caspian Sea, to the Persian Gulf, and also it is a crossroads on the way of east to west, i.e. the junction of cultural, intellectual and political manifestations of the worlds of east and west.

Limpid water springs, pomegranate orchards, pistachio gardens, rows of Lombard poplars, decampment of nomads in different seasons, stelliferous night, rocks, mountains, endless high and low lands, snow clad extinct volcanoes, luxuriant forests of Alborz mountains range, and coastlines of the Caspian Sea are amongst the eye-catching and memorable landscapes of Iran’s nature which leave unique memories in the minds of tourists.

Iran is one of the only countries in the world which has the complete four seasons. In summer, the weather can be cool as well as warm, and in the cold winters, it can be mild.

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KEY PROPERTIES FOR THE OPTIMIZATION OF REFRACTORY CASTABLE DRYING

M. M. Akiyoshi, F. A. Cardoso, M. D. M. Innocentini and V. C. Pandolfelli, Department of Materials Engineering, Federal University of São Carlos 13565-905, S. Carlos, SP, Brazil, vicpando@power.ufscar.br

Drying is one of the most complex steps in refractory castable processing due to the considerable risk of damage or explosive spalling during the first heat-up. To provide a basis to optimize the drying step of refractory castables, this work correlates the mechanical strength and permeability with the mass loss rate and surface temperature profiles of high-alumina, ultra-low cement castables cured at different temperatures.

1. INTRODUCTION

The increasing demand for better and cheaper pre-cast refractory products has motivated the search for safer and shorter drying schedules in the refractory industry. However, drying is still a crucial step in castable processing, because improper heating schedules may lead to mechanical damage or even explosions when the tensile stress generated by pressurized vapor inside the refractory exceeds the material's mechanical strength.

Low curing temperatures of less than 20ºC [1-8], followed by fast heating rates, have been identified as one of the most important factors to promote spalling. More comprehensive analyses have revealed that the curing temperature and its time affect permeability and mechanical strength, both associated with the likelihood of spalling [2, 3]. This work therefore aims to correlate the permeability and mechanical strength with the mass loss rate and surface temperature profiles of high-alumina, ultra-low cement castables cured at 10ºC and 50ºC, in order to provide the basis for a better understanding of this important step in the production of refractory castables.

2. EXPERIMENTAL PROCEDURE

The castables tested here consisted of high-alumina, ultra-low cement (2 wt%), containing 4.50 wt% of water (dry basis). The particle size distribution was adjusted to a theoretical curve, based on Andreasen’s packing model with a coefficient of distribution of q=0.21 (maximum aggregate size: 4.5 mm). Alcoa S.A. supplied all the raw materials, and further details of the composition are given elsewhere [3]. Castable samples having a 7.5 cm diameter and 2.5 cm thickness were prepared for the permeability tests, while those for the mechanical strength and drying tests were cast in the shape of 4 cm x 4 cm cylinders. The samples subjected to permeability and mechanical strength evaluations were pre-dried in silica gel at the curing temperature [7]. Considering the same length of time [7], low curing temperatures provide a smaller degree of hydration than higher temperatures. Therefore, the castable samples were cured up to 16 days, allowing the ones cured at 10ºC and those cured at 50ºC to be exposed to a similar degree of hydration.

Mechanical strength was evaluated through a splitting test [9], at a loading rate of 42 N/s to keep the stress rate within a range of 690-1380 kPa/min. The splitting tensile strength was calculated by:

$$\sigma_t = \frac{2P}{\pi h d} \text{ (MPa)} \quad (1)$$

where P (N) is the maximum load, and d (mm) and h (mm) are the samples' diameter and height, respectively.

Air permeability at room temperature was evaluated based on Forchheimer’s equation [10] for compressible fluids and adjusting the k1 (Darcian) and k2 (non-Darcian) constants:

$$\frac{P_i^2 - P_o^2}{2P_o L} = \frac{\mu}{k_1} v_s + \frac{\rho}{k_2} v_s^2 \quad (2)$$

where Pi (Pa) and Po (Pa) are, respectively, the absolute air pressures at the entrance and exit of the sample, vs (m/s) is the fluid velocity, L (m) is the sample’s thickness, \(\mu\) (Pa·s) is the air viscosity and \(\rho\) (kg/m³) is the air density, evaluated for \(P_o = 690 \text{ mmHg} \times (92\times10^3 \text{ Pa})\) and \(T = 25^\circ\text{C}\).

Dewatering tests were performed in a thermogravimetric apparatus [11] consisting of a digital scale (400±0.001 g) coupled to a furnace (maximum working temperature: 1000ºC). The tendency for explosive spalling was evaluated at a heating rate of 20ºC/min, while the drying profiles were performed at 10ºC/min.

Mass loss during drying was assessed through the parameters W and \(W_d\), defined as:

$$W = 100 \times \left( \frac{M_0 - M_t}{M_0} \right) \% \quad (3)$$

$$W_d = 100 \times \left( \frac{M_0 - M_t}{M_t} \right) \% \quad (4)$$

where M is the instantaneous mass recorded at time \(t_i\) during the heating stage, \(M_0\) is the initial mass and \(M_t\) is the final (dry) mass of the tested sample. The variable W evaluates the cumulative fraction of water expelled during the heat-up per total amount of water initially present in the body (W varied from zero to 100% during the test), while \(W_d\) relates the water loss to the dry weight of the body (in the range of 4.5% in the composition studied).

The mass loss and surface heating rates were then evaluated using equations (5) and (6), respectively:

$$\frac{dW}{dt} \bigg|_{t_i} = \frac{d}{dt} \left( \frac{M_0 - M}{M_0 - M_t} \right) \%/\text{min} \quad (5)$$

$$\frac{d}{dt} \left( \frac{M_0 - M}{M_0 - M_t} \right) \%/\text{min} \quad (6)$$
In equation (6), $T_s$ is the surface temperature and $t$ is the time.

**3. RESULTS AND DISCUSSION**

The castables cured at 10°C and 50°C are identified here as castable-10 and castable-50, respectively. Table 1 lists the explosion temperature at a 20°C/min heating rate, the splitting tensile strength ($\sigma_f$) and the permeability constants ($k_1$ and $k_2$) for the castables studied. As expected, the curing temperature and time affected the castable permeability and mechanical strength.

All the castables cured at 10°C (regardless of the curing time) exploded when tested at 20°C/min, while castable-50 did not undergo spalling. During two days of curing, castable-10 displayed lower permeability ($k_1=2.4\times10^{-16}$ m$^2$ and $k_2=176\times10^{-16}$ m) and lower mechanical strength ($\sigma_f=1.3$ MPa) than did castable-50 ($k_1=3\times10^{-16}$ m$^2$, $k_2=311\times10^{-16}$ m and $\sigma_f=2.0$ MPa). These differences confirmed the greater tendency for explosion of castables cured at low temperatures.

According to the literature [8-10], low curing temperatures induce the formation of low density hydrates such as CaO•Al$_2$O$_3$•10H$_2$O (CAH$_{10}$, $\rho=1.72$ g/cm$^3$) and alumina gel, providing stronger and less permeable structures. On the other hand, at higher curing temperatures, denser hydrates such as 2CaO•Al$_2$O$_3$•8H$_2$O (C$_2$AH$_8$, $\rho=1.95$ g/cm$^3$), 3CaO•Al$_2$O$_3$•6H$_2$O (C$_3$AH$_6$, $\rho=2.52$ g/cm$^3$) and Al(OH)$_3$ (AH$_3$, $\rho=2.42$ g/cm$^3$) are formed and more permeable, weaker castables are generated.

The curing temperature affects the cement hydration kinetics [3,8], which is the main factor responsible for mechanical strength before firing. Although curing at low temperatures favors the formation of stronger structures, the lower mechanical strength after curing at 10°C for two days may be associated with the slower hydration rate of the cement at low temperatures. The greater strength attained in castable-10 after 16 days of curing reinforces this assumption. Due to its faster hydration kinetics, the hydration of castable-50 was almost complete after two days, while the mechanical strength of castable-10 increased continuously as the curing time progressed [3].

Despite its slower hydration rate, the permeability constants $k_1$ and $k_2$ were smaller for castable-10 due to the low density phases formed. The permeability continued to decrease as the curing time progressed because the amount of these phases increased as the hydration proceeded.

Comparing castable-10 cured for different lengths of time, one finds that, after 16 days, although its permeability was lower, its superior mechanical strength allowed the explosion temperature to increase from 426°C to 440°C. However, analyzing castable-10 and castable-50 cured for 16 days, the former’s explosive spalling when heated at 20°C/min can be ascribed to its lower permeability, even though it displayed greater mechanical strength.

Correlations between mechanical strength, permeability and explosive tendency can be assessed by analyzing the mass loss and surface temperature profiles.

The drying steps of pre-fired, moistened, refractory castables subjected to a constant heating rate can be divided into three stages [11] that are associated, respectively, to the evaporation and ebullition of free water, and the dehydration of chemically bonded water due to cement and reactive alumina hydration. The same association was used here to analyze the unfired castables cured at 10°C and 50°C. However, because unfired samples were used, the evaporation and ebullition profiles may show some overlapping contribution of the cement hydrate phases (CAH$_{10}$ and C$_2$AH$_8$) that decompose below 200°C.

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**Table 1.** Castable’s curing temperature and time, explosion temperature (20°C/min heating rate), dry splitting tensile strength ($\sigma_f$) and permeability constants ($k_1$ and $k_2$).

<table>
<thead>
<tr>
<th>Curing time (days)</th>
<th>Curing Temperature (°C)</th>
<th>Explosion Temperature (°C)</th>
<th>$\sigma_f$ (MPa)</th>
<th>$k_1$ ($10^{-16}$ m$^2$)</th>
<th>$k_2$ ($10^{-16}$ m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>10</td>
<td>426±3</td>
<td>1.3±0.1</td>
<td>2.4±0.1</td>
<td>176±17</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>no explosion</td>
<td>2.0±0.3</td>
<td>3±1</td>
<td>311±023</td>
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<tr>
<td>16</td>
<td>10</td>
<td>440±7</td>
<td>2.9±0.4</td>
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<tr>
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<td>50</td>
<td>no explosion</td>
<td>2.0±0.2</td>
<td>2.2±0.1</td>
<td>189±23</td>
</tr>
</tbody>
</table>
Table 2. Total amount of water (dry-basis), peak temperature (T), and mass loss (W) at each stage (i=1, 2 or 3 for stages I, II or III, respectively) for castables cured at 10°C or 50°C for two days (results based on Figure 1a).

<table>
<thead>
<tr>
<th>Curing temperature (°C)</th>
<th>W₁ (%)</th>
<th>T₁ (°C)</th>
<th>W₂ (%)</th>
<th>T₂ (°C)</th>
<th>W₃ (%)</th>
<th>T₃ (°C)</th>
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<td>55</td>
<td>363</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>4.36</td>
<td>82</td>
<td>32</td>
<td>180</td>
<td>54</td>
<td>304</td>
<td>14</td>
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</tr>
</tbody>
</table>

Figure 1a presents the mass loss (W) and the mass loss rate (dW/dt), while Figure 1b shows the heating rate (dT/s/dt) for castable samples cured for two days at 10°C and 50°C. The samples for these experiments were heated at 10°C/min (dashed line in Figure 1).

The actual mass loss rate is given by the balance between factors, which favors dewatering (evaporation, ebullition, and dehydration) and the receding of the drying front into the bulk of the castable. The amount of water lost (W) in each drying stage (I, II or III) is illustrated in Figure 1a. Table 2 lists the results for each stage and curing condition.

Although the total amount of water used to prepare the castables was 4.50 wt%, castable-50 showed a lower W₁ value (4.36 wt%) than castable-10 (4.49 wt%) because, even when curing is carried out in a moistened environment, higher temperatures favor the natural loss of water due to the reduction in water viscosity and the higher kinetic energy of its molecules.

In stage I (Figure 1a), the temperatures were lower than 100°C and evaporation was the main dewatering process. The lower water loss during the curing stage and the slower hydration kinetics favored a larger amount of free water in castable-10 than in castable-50. Thus, despite the lower permeability of castable-10, this composition lost a larger amount of water in stage I (W₁=38%) than did castable-50 (W₁=32%).

Also during stage I (Figure 1b), the heating rate of castables cured at 10°C and 50°C was similar because external factors, such as humidity and furnace heating rate, exerted a greater impact on evaporation than did permeability. In this stage, a fraction of the heat received by the sample was used to evaporate the water, slowing down the sample’s heating rate when compared to the rate in the furnace (10°C/min). Because there was no pressurization of the structure in the first stage, even the weaker castable (cured at 10°C for two days) would not have been damaged had the drying taken place at temperatures below 100°C.

Water ebullition starts around 100°C, at which point the effects of the permeability levels become more relevant, because a larger amount of vapor can be trapped within low permeability structures, raising the pressure inside the castable.

The permeability differences between castable-10 and castable-50 were evident above 100°C (stage II) from the discrepancies between their surface heating rates (Figure 1b). During ebullition, the vapor from the castable bulk reached the surface, preventing it from following the furnace heating rate. Because of its superior permeability, the vapor was released more rapidly from castable-50, resulting in a temporarily slower surface heating rate than that of castable-10.

During the ebullition stage, the vapor trapped inside the castable may become pressurized, and the less permeable the structure the greater the possibility of pressurization. Fracture or explosion will take place when the stress generated by the pressure surpasses the material’s mechanical strength. Thus, the greater the mechanical strength, the higher the explosion temperature.

In the case of the samples tested here, after two days of curing, castable-50 presented a larger amount of hydrated phases than castable-10 [7], as indicated by the superior intensity of peak T₃ in Figure 1a. This may represent an additional problem in castables with higher cement content because C₃AH₆ and AH₆ will decompose, reducing the mechanical strength and generating large amounts of vapor at higher temperatures.

In stage II, the amount of water loss in the castables was similar because part of the hydrates formed at 50°C decomposed below 250°C. Comparing the behaviors in stage III, castable-50 (W₃=14%) displayed a 7% higher weight loss than castable-10 (W₃=7%). This value (7%) is similar to the difference in the castables’ water loss in the first stage.

The correlation of the mechanical strength and permeability with the mass loss and surface temperature profiles led to conclude that low permeability is the main cause for the tendency for explosive spalling of castables cured at low temperatures, since it favors the entrapment of vapor inside the structure, exposing the castable to higher pressures and higher real heating rates.

4. CONCLUSIONS

In high-alumina, ultra-low cement castables, curing temperatures of 10°C and 50°C promoted significant differences in mechanical strength and permeability, whose effects were illustrated by the mass loss and surface heating rate profiles. The greater explosive tendency during the first heat-up for this class of castables cured at low temperatures (<20°C) can be associated with its low permeability and the presence of low density hydrates that decompose at temperatures close to 100°C. These hydrates increase the amount of water to be released within the ebullition range, and low permeability traps the vapor inside the refractory, generating pressurization and exposing the castable to higher pressures and higher real heating rates.

Acknowledgements: The authors are grateful to the Brazilian research funding institutions CAPES and FAPESP and to ALCOA S.A. and MAGNESITA S.A. for supporting this work.

REFERENCES

1. W. Gitzen and L. D. Hart, “Explosive Spalling of Refractory Castables Bonded with Calcium Aluminate


40 YEARS OF THE ST. LOUIS SYMPOSIUM

Jeffrey D. Smith, Associate Professor, Department of Ceramic Engineering, University of Missouri-Rolla, jsmith@umr.edu

In 1965, as the Gateway Arch was being completed overhead, the St. Louis Section of the American Ceramic Society held its first Annual Symposium at the Engineers Club in downtown St. Louis. The goal of the one-day event was to gather together experts in refractory technology to make presentations and discuss critical issues related to production and performance of refractories. Having the meeting in St. Louis was especially fitting as Missouri, with its high quality refractory clay deposits, was the location of a large number of refractory plants.

The technical portion of the Symposium featured fundamental issues in the morning session and applications based issues in the afternoon. Professors representing the three universities affiliated with the section, the University of Missouri-Rolla, the University of Illinois and Iowa State University, made morning presentations while Industry leaders representing steel and glass offered afternoon presentations. A list of the original presentations and authors is included as Table 1.

The Symposium Committee was comprised of leaders from the refractory industry located in and around the St. Louis area. A photo of the original Symposium Committee is included as Figure 1. These individuals were instrumental in organizing the first of many successful symposia. Special mention should be made of George MacZura, the 1965 immediate past chair of the section and Tom Smith, the 1965 chair, whose efforts made the symposium a possibility. Bill Fabianic, then Director of Research at H.K. Porter, functioned as the program chair for the meeting.

The first symposium was more than just technical presentations as it included a lively panel discussion as well. A photo of some of the initial panel members is included as Figure 2. Time was also devoted to social activities, a trend that has now continued for forty years. At noon the group walked six blocks to

<table>
<thead>
<tr>
<th>Table 1. 1965 Symposium Presentations and Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.W. Allen, University of Illinois, “Material Characterization in Refractory Technology”</td>
</tr>
<tr>
<td>D.R. Wilder, Iowa State University, “Ceramic Fundamentals”</td>
</tr>
<tr>
<td>R.E. Moore, University of Missouri-Rolla, “Statistical and Factor Design Methods Applied to Research and Development”</td>
</tr>
<tr>
<td>K. Kappmeyer, US Steel, “Recent Changes in Steel Plant Refractories”</td>
</tr>
<tr>
<td>J. Poole, Brockway Glass, “Refractory Needs of the Glass Industry”</td>
</tr>
<tr>
<td>B. Dorsey, Jones and Laughlin Steel, “Steel by Stopwatch and BOF Refractories in Both Large and Small Units”</td>
</tr>
</tbody>
</table>
the Salad Bowl restaurant for a convivial gathering that included a luncheon address from Bill Lowe of A.P. Green Firebrick, another tradition that continues today. At the end of the day, attendees enjoyed more social activities (the free bar was prominently indicated on the initial symposium brochure) at the Engineers Club. Many of the attendees continued with dinner on “The Hill” and capped off the evening frequenting some of St. Louis’ downtown attractions.

A number of modifications were made to the symposium during subsequent years. In 1967, the section opted to provide proceedings for the event. The officers and volunteers in the section met prior to the symposium to mimeograph the manuscripts and bind the proceedings so they could be presented to attendees at registration. Although this practice is fairly common at a number of current meetings, it was a considerable undertaking in 1967, another indication of the section’s commitment to offering the best possible product.

In 1968 the section unveiled the St. Louis Refractories Award, which was to be presented “for Distinguished Achievement in the Field of Refractories.” A photo of the first recipient, John McMullen of Carborundum Company, is included as Figure 3. The objective of the award was to recognize outstanding contributions to the engineering and science of refractory ceramics. This fairly broad objective was intended to allow consideration of all individuals including raw material suppliers, refractory producers, refractory users/consumers, consultants, academics, etc.

The next year marked the beginning of theme-based programming for the symposium. The organizers believed that a meeting focused on a fairly narrow topic would bring continuity to the Symposium. In 1969 the theme was “Corrosion of Refractories” with George MacZura as the program chair. A focused theme allowed the symposium organizers to seek out imminently qualified program chairs to ensure the quality of the technical content remained high. This approach has again withstood the test of time as the program is organized in the same manner today.

Over the years, the technical content of the symposium has been considerable and the significance of many of these manuscripts should not be underestimated. A number of technical papers have provided a much clearer picture of complicated concepts related to refractories while many of the more practical papers have found widespread industrial application. A few excerpts from nearly 40 years of proceedings are included in this manuscript.

In 1971, Allen discussed heat transfer in refractories and the role of porosity. One of his hand drawn figures is reprinted here as Figure 4. In 1974, Limes discussed the effects of phosphates on the deformation of basic refractories, showing that phosphates did not have a detrimental effect on high temperature properties. Some of his load to failure curves are included as Figure 5. In 1982, Funk, Dinger and Funk introduced their “Alfred Distribution” a modification of the Andraesen distribution that was commonly used for particle sizing refractory formulations. Their mathematical adjustment eliminated the infinitely small particle requirement that existed in Andraesen’s approach, making the purely theoretical distribution a practical reality.
A full reprint of the Funk, Dinger and Funk manuscript is included on pages 21-26 of this issue of RAN. Other reprints of important contributions from the St. Louis Section Refractories Symposium will be included in future issues of RAN.

The section introduced its own “modification” that same year when the officers changed the name of their award to “The Theodore J. Planje-St. Louis Refractories Award” in honor of Ted Planje who had passed away the previous year. Dr. Planje had been a long time member of the Ceramic Engineering faculty, serving as Department Chair and Dean of the School of Mines and Metallurgy at UMR, and had been a champion of the symposium since its inception (see 1965 panel members Figure 2).

<table>
<thead>
<tr>
<th>Table 2. St. Louis Refractories Award</th>
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<tbody>
<tr>
<td>1968 John C. McMullen, Carborundum Company</td>
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<tr>
<td>1969 Raymond E. Birch, Harbison-Walker Refractories</td>
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<tr>
<td>1970 Charles A. Smith, Kaiser Refractories</td>
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<tr>
<td>1971 Harold A. Heilgman, E.J. Lavino Company</td>
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<tr>
<td>1972 Walter H. Gitzen, Aluminum Company of America</td>
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<tr>
<td>1973 Theodore J. Planje, University of Missouri-Rolla</td>
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<tr>
<td>1974 Frederick H. Norton, Massachusetts Institute of Technology</td>
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<td>1975 Hobart M. Kriner, Bethlehem Steel</td>
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<tr>
<td>1976 Robert W. Limes, Republic Steel Corporation</td>
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<tr>
<td>1977 William L. Fabianice, Libery Glass Company</td>
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<tr>
<td>1978 Roland B. Snow, U.S. Steel Corporation</td>
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<tr>
<td>1979 Walter S. Trefafer, General Refractories</td>
</tr>
<tr>
<td>1980 George MacZura, Aluminum Company of America</td>
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<td>1981 William J. Smothers, Bethlehem Steel Corporation</td>
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<tr>
<th>Table 3. The Theodore J. Planje – St. Louis Refractories Award</th>
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<tr>
<td>1982 David H. Hubble, U.S. Steel Corporation</td>
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<tr>
<td>1983 Leroy D. Hart, Aluminum Company of America</td>
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<tr>
<td>1984 Ben Davies, Harbison-Walker Refractories</td>
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<tr>
<td>1985 Samuel J. Schneider, National Bureau of Standards</td>
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<tr>
<td>1986 James A. Crookston, A.P. Green Refractories</td>
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<tr>
<td>1987 Harry M. Mikami, Consultant</td>
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<tr>
<td>1988 Richard C. Bradt, University of Washington</td>
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<tr>
<td>1990 Roy W. Brown, The Carborundum Company</td>
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<tr>
<td>1991 Robert E. Moore, University of Missouri-Rolla</td>
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<tr>
<td>1992 Michael S. Crowely, Crowley and Associates</td>
</tr>
<tr>
<td>1993 Wate T. Bakker, Electric Power Research Institute</td>
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<tr>
<td>1994 Otto L. Forchheimer, The J.E. Baker Company</td>
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<tr>
<td>1995 Charles E. Semler, Semler Materials Services</td>
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<tr>
<td>1996 Louis J. Trostel, Consultant</td>
</tr>
<tr>
<td>1997 Robert O. Russell, LTV Steel Company</td>
</tr>
<tr>
<td>1999 Richard A. Landy, Consultant</td>
</tr>
<tr>
<td>2000 Keni Weisenstein, Missouri Refractories Company</td>
</tr>
<tr>
<td>2001 Mark A. Scott, National Refractories &amp; Minerals Corporation</td>
</tr>
<tr>
<td>2002 Roy J. Bottjer, Consultant for Strategic Analysis, Inc.</td>
</tr>
<tr>
<td>2003 Dilip C. Jain, C-E. Minerals</td>
</tr>
<tr>
<td>2004 Michel A. Rigaud, CIREF, Ecole Polytechnique</td>
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</table>

Through the years a total of 37 members of the refractory community have been awarded what has come to be known simply as the Planje award; a complete list is included in Tables 2 and 3.

In 2002, the St. Louis Section began co-hosting its symposium with the Refractory Ceramics Division of the American Ceramic Society, formally moving to a two day symposium; although infrequent two day meetings had been held before for special situations and had normally been quite successful. ASTM and The Refractory Institute also participated in the 2002 meeting, effectively creating “Refractories Week” in St. Louis.

Another change was initiated in 2003, when the section awarded the first St. Louis scholarship to William Maass, a junior in Ceramic Engineering at the University of Missouri-Rolla. The purpose of the scholarship is to promote awareness of ceramic engineering, highlighting high temperature materials applications.

The 2004 symposium marked the first meeting without Professor Robert E. Moore. His untimely death in the summer of 2003 had a considerable impact on the section and the symposium and the 2004 proceeding was dedicated in his memory. Through presentations and participation in panel discussion, chairing programs and sessions, preparing proceedings, etc. Dr. Moore played a critical role in the success of the section symposium for nearly 40 years.

Today a new group of officers (Table 4) are carrying on the long standing traditions of the section and their role is perhaps more critical than ever before. With consolidations and plant closings ravaging the refractories community in the United States, the symposium remains a constant reminder that the industry will persevere through consistent product improvement and technological advances.

For 40 years the symposium has been, and in the future will continue to be, successful thanks to the hard work and dedication of the St. Louis Section volunteers. Assistance from volunteers with the Refractory Ceramics Division, The Refractories Institute and ASTM will help to make the symposium even stronger in the future. After 40 years it is safe to say that the experiment that is the St. Louis Section Refractories Symposium has been a tremendous success.

See refractories related meetings on page 3.
PARTICLE SIZE DISTRIBUTION CONTROL FOR REFRACTORY FORMING RHEOLOGY

J. E. Funk, D. R. Dinger, J. E. Funk, Jr., Alfred University, Alfred, NY, ddingerg@prodigy.net, www.dingerceramics.com

Presented at “Changes in Refractory Technology Symposium,” Engineers Club of St. Louis, 4359 Lindell Blvd., St. Louis, MO, March 12, 1982

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ABSTRACT

A model for maximizing particle packing efficiency while retaining the necessary colloid fraction for good rheological properties has been developed and tested on fluid slurries at up to 75 volume % solids. This paper will discuss the rheology of ceramic forming, maximizing particle packing efficiency, the electrochemistry necessary to attain specific rheological responses, and the measurement techniques for each.

INTRODUCTION

Refractory shapes are conventionally produced from a variety of powder-water mixes of different ratios. Fine grained $A_2O_3$ may be slip cast at 50 volume % solids; plastic fireclay may be formed at 60 volume % solids; and some ramming or dry press mixes may contain only a few percent water. Such high solids content mixes require special forming properties appropriate to each specific forming process. Where the process may be classed as wet, the rheological properties must be understood, quantified, and controlled. For dry pressing and the nearly dry ramming mixes the low moisture content depends upon the effectiveness of packing the powders, but so do the rheological properties of the two wet processes. This paper will deal particularly with these wet processes, but many of the points made are also applicable to the dry processes. The presentation is based upon the theoretical packing of spheres using a new packing algorithm. It has been successfully applied to coal-water slurries and to some whiteware compositions, and is offered to test on additional particle-fluid systems.

RHEOLOGY

There exist two time dependent and six time independent rheological systems. Figure 1 shows the typical curves for thixotropy and rheopexy where viscosity decreases and increases respectively with time at a constant shear rate. That is, while mixing at a constant agitator speed the viscosity will change with time to some new terminal viscosity. Thixotropy is of considerable importance in ceramic systems because upon cessation of agitation the viscosity will again increase due to some mechanism of gellation in the body.

Figure 2 shows the six rheograms for fluids which depend upon the rate of shear rather than time. These are plotted in the standard format of shear stress vs shear rate. Notice that the pseudoplastic, Newtonian, and dilatent fluids all intersect the origin; they exhibit no yield stress which must be overcome before flow can occur. These simple fluids are useless for any ceramic forming system because with no yield stress the powders will settle from the slip according to Stokes Law. In crowded slurry the specific gravity and viscosity of the slurry itself rather than the interparticle water will reduce the rate of settling, but it will never prevent settling. To prevent settling, a yield stress, $\tau_y$, is necessary which is sufficient to overcome the difference between gravitational settling stress minus the buoyant stress. This is easily calculated for spheres from geometric considerations as:

$$\tau_y = \frac{\text{Gravitational Force Down}}{\text{Equatorial Area}} - \frac{\text{Buoyant Force Up}}{\text{Equatorial Area}}$$

$$= \frac{2}{3} D_l (\rho_p - \rho_{slurry}) g$$

where

$$\tau_y = \text{True yield stress}$$

$$D_l = \text{Largest particle in the slurry}$$

$$\rho_p = \text{Particle specific gravity of DL}$$

$$\rho_{slurry} = \text{Slurry specific gravity}$$

$\tau_y$ is related to $\tau_y$ by viscometer geometry rather than by a physical mechanism. In Figure 2 are also shown the three fluid responses which exhibit a yield stress, $\tau_y$. Also shown are the equations which describe each fluid. Varying the value of the exponent, $n$, from $<1$ to $1$ to $>1$, $\tau_y$ from zero to any finite value, and the significance of $K$ from a true slope of $\eta_N$ for Newtonian viscosity or $\eta_B$ for a Bingham plastic viscosity which are linear with shear rate to $K$ which is non-linear with respect to shear rate, a single power law equation for all fluid systems is possible:
Perhaps a better way to view these fluids is shown in Figure 3 which plots the apparent viscosity $\eta_a$ vs shear rate $\gamma$ where $\eta_a = \tau/\gamma$ as measured by any conventional viscometer capable of varying speed. The $\tau$ vs $\gamma$ plot, Figure 2, is linear-linear whereas the $\eta_a$ vs $\gamma$ plot is ln-ln which must be recognized in comparing the curves. At "zero shear rate", the Bingham fluid has an "infinite viscosity" but at higher shear rates the viscosity approaches a Newtonian, or terminal viscosity. Similarly, the "infinite viscosity" effect of each fluid with a yield stress, $\tau_y$, approaches its counterpart at high shear rates. It should be apparent that either dilatent system would be disastrous as a fluid pumped at high velocities, but for relatively low velocity movement it could be a useful property in forming. Of vital concern is the reversibility of these curves so that upon setting after movement, the yield strength returns. The yield-pseudoplastic rheology as plotted indicates that the viscosity will continue to decrease according to the power law. Of course, in real systems there will always be a terminal viscosity in laminar flow, so the yield-pseudoplastic flow curve is really a special case of a Bingham fluid. A thixotropic-Bingham plastic body is probably the most useful and the most common in ceramic forming of crowded systems, although a thixotropic-yield dilatent body may find some useful application provided it is not pumped at high shear rates.

Figure 4 shows a hypothetical rheogram comparing two Bingham fluids with the same terminal viscosity $\eta_B$. Curve A shows a much higher yield stress than B and would therefore be more mechanically stable in place after releasing any forming pressures. However, both would flow equally at terminal viscosity.

From work done on coal-water slurries [1, 2] as well as in sanitaryware casting Slips [1,2] and electrical porcelain filter press Slips [4, 5, 6, 7] it has frequently been observed that a fairly wide...
range of rheological responses result from any given powder-water slip merely by changing the chemistry and that all powder-water slips do not behave the same way. From full deflocculation to full flocculation some slips will vary from Bingham to Newtonian to dilatant at the same solids content merely by changing the chemistry of the fluid. As a result of these observations it is believed that different rheograms are due to the following two major parameters.

a) Particle size distribution - designed to minimize the interstitial pore volume and to provide an adequate colloidal fraction or surface area to react with the slip chemistry.
b) Electrokinetic potential - surfactants or polyelectrolytes are added to enhance or negate the repulsive electrokinetic potential of the colloid fraction to maximize the interparticle distance allowed by the dilution water and control the gel structure contiguous with the colloid fraction.

Figure 5 shows, in a conceptual illustration, that the various behaviors in Figure 3 can result from different parts of the size distribution and which also may or may not be modified by chemistry. To the right of the vertical line drawn arbitrarily through the low viscosity point of the yield-dilatent fluid, the slope of the curves is analogous to the exponent in the general power law equation. The slope will depend upon the frequency of collision of coarse particles. A very narrow size distribution or one which contains a large percentage of large particles will tend to be dilatent. Reducing the size or the fraction of coarse particles will tend to reduce the exponent n toward the yield-pseudoplastic rheogram. The yield stress, \( \tau_y \), or the height of the curve to the left of the vertical line is determined by the colloidal fraction in combination with the chemistry used. The vertical displacement is determined by the packing efficiency of the entire particle size distribution. The more efficient the packing the greater the fraction of water will be available to separate particles thereby reducing collision frequency.

**PARTICLE SIZE DISTRIBUTION**

High solids loading can only be achieved by maximizing the packing efficiency of the powders in order to minimize the interstitial pore space. This pore space must first be filled with water before additional water can separate the particles thereby impart-

Figure 4. Two Bingham fluids with the different yield stress, \( \tau_y \), but the same terminal viscosity, \( \eta \alpha \).*

Figure 5. Contribution of various parts of the particle size distribution to rheological responses in slurries.*

Two main theories of particle packing have been proposed and developed over the years. High solids loading can be accomplished by following either of these two theories.

1. Theories based on mixtures of monodispersions of particles with the size classes separated by diameter ratios in excess of 200:1 were proposed by Furnas [8,10] and Westman and Hugill [9], to name a few. These algorithms were based on the idea that each distinct class of particles is capable of packing to 60% of theoretical density and that if the size ratios are great enough, each distinct class will fill 60% of the porosity remaining after the addition of all the larger particle size classes. In this way, the first class packs to 60%, the second packs to 84%, the third to 93.6% and so on. The problems for these theories have arisen when attempts were made to extend them to handle discrete distributions with diameter ratios \( << 200:1 \) or to handle continuous distributions. However, most work in concrete mixes, refractory ceramic mixes, pigments, and in many other areas have used the basic principles of these theories with varying degrees of success.

2. A theory based on optimum packing of continuous distributions was presented by Andreasen [12]. According to this theory, optimum packing occurs when the distribution modulus, n, in the following equation is between 0.33 and 0.5.

\[
\text{Andreasen} \quad \frac{CPFT}{100} = \left( \frac{D_s}{D_L} \right)^n
\]

This theory, however, requires infinitely small particles, that is, those approaching 0.0 \( \mu m \). The Alfred researchers have revised this equation by introducing a finite smallest particle size \( D_s \) and have determined that optimum packing occurs when \( n \) in the following equation is 0.37.
Alfred CPFT = \frac{D^n - D_s^n}{D_L^n - D_s^n} \quad (4)

where CPFT = cumulative percent finer than
D = any particle diameter in the distribution
D_L = largest particle diameter in the distribution
D_s = smallest particle diameter in the distribution
n = exponent is the slope at D_L

This equation describes a size distribution which when \( n = 0.37 \) produces the maximum packing efficiency for any width distribution [11]. The broader the size distribution, the higher the packing efficiency will be. For illustration, Figure 6 shows two size distributions where \( D_s \) and \( n \) are constant and \( D_L \) changes. According to Figures 7 [13], the calculated porosity of the size distribution with \( D_L = 4 \) mesh is about 1.5% whereas for \( D_L = 40 \) mesh the porosity is about 3.5%. From the standpoint of packing efficiency the broader size distribution with \( D_L = 4 \) mesh is a better packing body which may be ideal for dry pressing or ramming mixes. However, referring back to Figure 6, it is very apparent that the amount of colloidal material, < 1 µm, is far too low for attaining required rheological properties for wet processing. Assuming spheres in these bodies, the specific surface area calculated by integration over the size distribution are 2.92 M²/cc and 1.57 M²/cc. Non-spherical particles will not pack to this high efficiency, but the effects will still be relative. If a high yield stress is necessary, then at least the same specific surface area is necessary on the broader size distribution. To achieve this, the porosity must be compromised. Figure 8 shows such a compromise giving "best" curves for the same surface area.

Perhaps the rheological importance of the fines can be shown by using a simple model as in Figure 9. Monospheres will usually pack in an average orthorhombic array at about 60 volume percent regardless of size [14]. As shown in Figure 9a, in order to shear, the structure must "open" (dilate) to a cubic array where the porosity increases from 40 to about 48%. To prevent dilatency, or interparticle collisions in shear, the system must be diluted as in Figure 9b such that the interparticle spacing, IPS, is at least

\[
IPS = 2 - \sqrt{3} D
\]  \quad (5)

Since small water dilutions are desired, D must necessarily reflect very small particles. Obviously, in a broad size distribution no array of particles such as in Figure 9 can exist because there are relatively few particles of any one size but the principle of the small interparticle spacing requirements is illustrated. Further, only those particles which have a high surface to mass ratio (< 1 µm) are capable of reacting to the electrochemistry to effect the required interparticle separation. If a distribution such as in Figure 6b was produced, when sufficient water was added to allow flow to occur under shear, upon removal of the shearing force the powder would settle in a dense pack on the bottom of the vessel and be very difficult to resuspend regardless of its chemistry. However, the compromise distribution of Figure 8b should contain sufficient colloidal fraction to react to the chemistry and develop a stable fluid with a yield stress to allow plastic forming.
IMPLICATIONS FOR REFRACTORIES

In view of the fact that refractory bodies used for in place forming usually contain a top particle size of about 4 mesh for high temperature load resistance, it is probable that such a body would be thixotropic-yield-dilatent as shown in Figures 3 and 5 top line. For so called thixotropic casting or placing, the frequency of vibration is associated with shear rate $\gamma$ and the amplitude would be associated with the shear stress $\tau$. Therefore, a particular frequency and amplitude would be optimum for a particular body. Large variations in the size distribution and/or chemistry would change the mechanical requirements for best flow behavior. For example, if good flow is attained at given vibrator conditions for "standard body A" in Figure 10 and a change in the grind produces a change in the rheogram to yield curve B, then the same vibrator settings may be inadequate for good forming. Knowledge of the flow curve would permit design of the optimum vibration parameters and also serve as a production quality control device to guarantee product performance.

ELECTROCHEMISTRY

The effectiveness of the deflocculant or flocculant depends upon the amount of colloidal matter present and the fundamental surface chemistry of those particles. A constant addition of surfactant will not have the same effect if there is a change in colloidal content. Fortunately there is no simple way to measure exactly the size distribution of particles below 1 µm. However, surface area measurements which integrate the area of the distribution are a helpful means of assessing this effect. Devices such as BET adsorption of N$_2$, H$_2$O vapor, or CO$_2$, and the simpler methylene blue index (MBI) determinations are commonly used. In this modelling work, surface area was determined by computer integration of the equivalent sphere areas in the distribution.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>(\zeta)-potential Requirements For Stability of Colloids (After Riddick [1])</th>
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<tbody>
<tr>
<td>Stability Characteristics</td>
<td>Average (\zeta)-potential (mv)</td>
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<tr>
<td>Maximum agglomeration and precipitation</td>
<td>0 to +3</td>
</tr>
<tr>
<td>Strong agglomeration and precipitation</td>
<td>+5 to -5</td>
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<tr>
<td>Threshold of agglomeration</td>
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</tr>
<tr>
<td>Threshold of delicate dispersion</td>
<td>-16 to -30</td>
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<tr>
<td>Moderate stability</td>
<td>-31 to -40</td>
</tr>
<tr>
<td>Fairly good stability</td>
<td>-41 to -60</td>
</tr>
<tr>
<td>Very good stability</td>
<td>-61 to -80</td>
</tr>
<tr>
<td>Extremely good stability</td>
<td>-81 to -100</td>
</tr>
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</table>

Since most oxides and carbides are fundamentally electronegative, the work of the chemicals added is either to maximize the electro negativity (deflocculation) or to minimize it (flocculation). Riddick [15] gives the following table to quantify the \(\zeta\)-potential which produces deflocculation or flocculation as follows:

Zeta-potential is measured by several devices, such as an electrophoretic mobility analyzer, as the electrokinetic potential at the plane of shear between the adsorbed, or hydrated, water hull around the particle, which travels with the particle, and the surrounding free liquid. Figure 11 gives the classical picture of the decay curve of the repulsive fundamental surface potential \(\Psi_0\) as a function of distance from the particle surface. The net response resulting from a summation of the attractive and repulsive forces, showing both the energy barrier to flocculation and the secondary minimum for effective stabilization is indicated by the dotted line. For oxide surfaces, adding multivalent counterions such as Mg$^{2+}$, Ca$^{2+}$, or Al$^{3+}$ will compress the double layer and reduce the \(\zeta\)-potential effecting flocculation due to the attractive Van der Waal's forces overcoming the repulsive surface electrical forces as explained by Adams [16] utilizing the DLVO theory.
Any polyelectrolyte or surfactant which is water soluble and is capable of screening the adsorption of the neutralizing counterions will function as deflocculants. Anionic organic polymers will also serve this purpose and if they are of medium to high molecular weight will also serve as bridging polymers to form a steric gel structure and increase the yield strength, $\tau_y$. A combination of anionic surfactant to deflocculate plus a non-ionic polymer to build the gel structure for controlled rheology is likely to be needed. Selection of these surfactants is left as an exercise for the specific application. Examples which may be effective are those commonly used in ceramics systems such as the alkali polyacrilates, naphthalene sulfonic acids, lignosulfonates as well as silicates, hexametaphosphates, and carbonates, etc.

REFERENCES


*Handwritten symbols in figures were replaced to ensure clarity.
The 106th Annual Meeting & Exposition of the American Ceramic Society

Helio Guimaraes Neto, Xiaoting Liang and Alireza Rezaie University of Missouri-Rolla, eddings@umr.edu

The 106th Annual Meeting & Exposition of The American Ceramic Society was held in Indianapolis, April 18-21, 2004 at the Indiana Convention Center & RCA Dome. Over 1400 participants from North America, Asia, Europe and other places over the world attended the meeting. The meeting is by far the largest North American gathering of international professionals in the fields of ceramics, glass, cement and composites. A large range of technical programs were presented. More than 1000 topics were given in three days. Key focus areas included fuel cells, wireless communications technology, nanomaterials, gas turbines, superconductors, electronic components, thermal and environmental coatings, nuclear waste containment, photonic devices, cement, concrete, composites, and bioceramics.

Parallel to the technical programs, the new industry track program was presented this year. The industry track program emphasized the industrial and commercial side of ceramics through sessions on improving manufacturing processes, commercializing new technologies and materials, meeting regulatory requirements, industry technology road-mapping and other topics of commercial interest. Topics covered by the industry track program included Raw Material Processing, Forming Processes, Decorating and Design of Ceramics, Environmental Issues, Advanced Ceramic Technology Forecasting, Glass Manufacturing.

Various technical reference books were available for sale along with the meeting abstracts and proceedings. The new ACerS-NIST Phase Equilibria Diagrams CD-ROM Database version 3.0 with over 19,000 diagrams was displayed and available for sale.

The event provided an excellent opportunity to learn the latest on processing equipment, testing instruments, furnaces and kilns, and most importantly what the future holds for the ceramic and glass industry.

The 107th Annual Meeting & Exposition will be held from April 10-13, 2005 in Baltimore, MD. New characterization techniques, nanomaterials and nanotechnology, fuel cells, low-temperature co-firing of ceramics, ceramic armor, aging effects of materials, wireless technology and coatings will be included in the symposia.
TEHRAN INTERNATIONAL CONFERENCE ON REFRACTORIES

Farhad Golestani-Fard, Professor in Ceramics and Refractories and Amir Reza Hanifi, Refractory Researcher, Refractory Research Group, Department of Materials and Metallurgical Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran, rrg@iust.ac.ir
William L. Headrick, Assistant Research Professor, Department of Ceramic Engineering, University of Missouri-Rolla

Tehran International Conference on Refractories was held on 4-6 May 2004 in Ejlas convention center in Tehran. This was the first international event on refractories that took place in the Middle East. Seventy four scientific and technical papers received as invited articles prepared by renowned scientists from different organizations, were presented in three halls during the three days of the conference. The statistic of papers distribution is shown in Figure 1.

Sixty papers were submitted by overseas experts and fourteen by Iranian specialists. More than 900 people participated in this conference out of which 150 were from overseas. These were mainly from Refractories companies, Steel, Cement, Copper, Petrochemical and Aluminum Industries.

Representatives from 27 countries participated in this conference were mainly from Germany, UK, Austria, Netherlands, India, France, Czech, Russia, Spain, China, Italy, Japan, Turkey, Brazil, France, Canada, and USA.

An exhibition was set up along side the conference in a 460 square meter area where 62 Iranian and foreign companies exhibited their products and presented their expertise in 50 booths. This provided a unique opportunity for everyone to take advantage of such a strong presence by the most well known internal and external companies and to enter mutual communication regarding scientific and marketing discussions.

In addition to conference presentations program, two short courses were organized. One was presented by Dr. Jansen from Refractechnik in Isfahan on Thursday 29th April and the other by Prof. Lee from University of Sheffield, UK on Thursday 6th of May.

Two excursion tours in Tehran to visit the palace and to a carpet museum were arranged for the interested guests. Also visits to historical places in Isfahan was carried out during a two days visit on May 7-8. The tours also included the sightseeing excursion and a visit to Azar refractory research center.

For a list of the organizers, main sponsors and organizing committee whose support and effort resulted in this event see Table 1 below.

COMMENTS

The follow are comments of refractory professionals who took part in this important event:

Table 1. Organizers, Main Sponsor and Organizing Committee.

<table>
<thead>
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<th>Organizers &amp; Main Sponsors:</th>
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<tr>
<td>Iran University of Science &amp; Technology</td>
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<td>National Iranian Steel Company</td>
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<td>National Iranian Copper Company</td>
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<td>The Ministry of Industry and Mines</td>
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<table>
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<th>Chairman of Conference:</th>
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<tbody>
<tr>
<td>Prof. F. Golestani Fard</td>
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<tr>
<td>Organizing Committee:</td>
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<td>F. Aryanpour</td>
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<tr>
<td>A. Eilaghi</td>
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<tr>
<td>A. Ghaffari</td>
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<td>A. R. Hanifi</td>
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<td>A. Najafi</td>
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<td>A. Saberi</td>
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<td>E. Salahi</td>
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<td>A. Shojaie</td>
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</table>
An excellent conference beyond my expectations. I enjoyed many rich exchanges about the status and development of the Iranian refractory industry along with the forecasted growth potentials. I particularly look forward to watching the predicted progress of monolithic refractories materialize over the next years. To find over 800 participants was a huge reflection of the effort made by the organizers and to this end I wish to thank Prof. Golestani-Fard and his team for the hard work they had obviously put in to make this conference a success. The papers were well selected and informative, it was a pity that not all the Iranian written papers could be orally presented. Chris Parr, Lafarge Aluminates, France, E-mail: Chris.parr@aluminates.lafarge.com

The Tehran International Conference on Refractories (TICR) was a success of a team of great stature under the leadership of Professor Golestani-Fard, a world wide recognized scientist and mentor of many graduate students passionately involved in research in the field of refractory ceramics. Among many things which impressed me during my stay in Tehran it was this meeting at 11 o’clock at night, when the graduate students from the Iran University of Science and Technology (IUST) were having a meeting with their professor and Chairman of the Conference in the Hotel Azadi lobby in preparation for the next day opening of the Conference at the Tehran Conference Center. That was not only the hard work of a team running a show; it was the dedication to the cause and the pride of their Refractories Research Group at IUST to exceed everybody’s expectations. I think they did that and I congratulate all of them for their efforts. I wish that TICR will become a traditional event for the refractories community in a hopefully more relaxed politically Middle East region”. Senior Research Associate, Lecturer, Refractory Materials, The University of British Columbia, Metals and Materials Engineering, Vancouver, BC Canada, E-mail: oprea@interchange.ubc.ca

I was keen to attend the conference in Iran as I have had three Iranian Ph.D. students in Sheffield working with me on ceramics/refractories who are now back in Iran: Touradj Ebadzadeh is at the Materials and Energy Research Center and Hamid Rezaie and Hussain Sarpoolaky are at IUST in Tehran. In addition, Kazem Ahari (originally from Iran and very much involved in the conference) was a post doc working with me on refractory castables. On arrival in Tehran we were met by TV cameras, which was fun and whisked off like VIP’s in waiting cars. The conference venue was fantastic, the whole thing remarkably well organized with 900 attendees and an excellent exhibition. Sheffield was well represented with talks by myself, Shaowei Zhang and Kazem Ahari. In addition I gave a one day short course on refractories microstructures, properties and processing, which attracted 250 attendees and was exhausting. I have never been asked so many questions by such an appreciative audience. We were treated with the utmost hospitality and after the conference some of us went to Isfahan to visit the Azar refractories well appointed research labs. While there we stayed in the best hotel in Iran; the Abbasi Hotel which was once a caravanserai. It was great to meet up with my exstudents and see how they are doing. The whole experience was good. William E. Lee, Professor, Department of Engineering Materials, United Kingdom, E-mail: W.E.Lee@sheffield.ac.uk

Dr. Zhou Ningsheng, Professor, Henan University of Science and Technology, China, E-mail: lyzhouns@public2.lyptt.ha.cn

The First Tehran International Conference in Refractories” has been a success... with some 900 attendees, 142 of whom were from 27 different countries. The conference was well organized, thanks to the efforts of Dr. Golestani-Fard, his research group and his colleagues from the Iranian Refractory Community. The hospitality was great... the exchanges, diversified and to the points. It was great to learn about the ambitions plans the Iranian community has for the future, for their metallurgical industries as well as for their refractory industry. The restructuring and unifying efforts of the private sector, around Pars Refractories Co., are to be followed... The research efforts
by the Iranian University Professors are well focussed and the number of students to be about to graduate in ceramics and refractories is impressive. Michel Rigaud, Professor Emeritus, Director of CIREP, Mathematics and Industrial Engineering Department, École Polytechnique, CRIQ Campus, Montréal (Québec) Canada, E-mail: michel.rigaud@polymtl.ca

TICR was an excellent conference, achieving a blend of technical and economic papers, educational courses and exhibition. Ample time was provided during the conference for networking in and around the exhibition hall. Tours of palaces, museums and Isfahan were arranged for invited guests before and after the conference. Of most interest to me where the papers presented regarding the status and development of Iranian Industry; the predicted growth and progress is to be tremendous. The organizing committee worked round the clock. I was shocked when an entourage of students and cameras picked me up at the airport after midnight. It was not unusual to observe the organizing committee working with invited authors well into the night.

The country was absolutely beautiful. There were bodies of water, mountains with skiing and desert all within an hour’s drive of the hotel. The buildings, some over 300 years old are a showcase of science combined with architecture. During the tour of Isfahan, we visited mosques, churches and some of the most fascinating bridges I have ever or probably will ever see. On the final day of the Isfahan tour we visited the refractories research center managed by Azar Refractories Co. The refractories research center has state of the art testing, production and microscopic capabilities.

Finally, I would like to thank the RRG for sponsoring this event, for their sponsorship of me to speak at this event and for their gracious hospitality. William L. Headrick, Assistant Research Professor, University of Missouri-Rolla, E-mail: bill@umr.edu.
I am so happy that my team at Iran University of Science & Technology, including young and enthusiastic students could carry on such a big job, holding the first international conference on refractories in the Middle East. The feedback from local industry shows that the conference and exhibition has been very successful. I am grateful to our guests from 27 countries, specially the invited speakers who presented very interesting papers. Also I should thank our main sponsors whose valuable support enabled us to perform in a standard level. Farhad Golestani-Fard, Professor in Ceramics and Refractories, Refractory Research Group, Department of Materials and Metallurgical Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran, E-mail: golestanifard@iust.ac.ir

**EXCERPTS FROM PRESENTED PAPERS IN THE OPENING CEREMONY (NOT INCLUDED IN PROCEEDINGS)**

“Opening Speech” by M. Moazenzadeh, Chairman of the Board, Iranian Mines and Mining Industries Development and Renovation Organization (IMIDRO)

“As you know, materials have played a vital role in the human life to such extent that they have been used as a basis for classification and designation of historical ages. Early human who originally lived in the Stone Age gradually entered the age of bronze and finally evolved to the Iron Age or Period. Having passed different historical stages and now in the third millennium, we have ended up with a new era called age of new and advanced materials of which refractories form an important part. These materials, formed from mud which is a mixture of water and soil, are dried by air (wind) and baked in fire. So, man could produce these materials from the very early human civilization through combining four conflicting elements.”

This statement summed up the challenges faced by the attending investigators, government officials and industrial participants. M. Moazenzadeh continued with an overview of Iranian refractory companies. He stated that Iran has one percent of the global production of refractories and ranks first among the Middle East countries. He predicts that due to Iran’s 4th Economic, Social and Cultural development Plan the current level of refractory production of 200,000 tons will be increased to more than 500,000 tons per year in five years.


R. Ashraf Semnani summed up the plans for refractory improvement in Iran in the following quotes.

“There are various strategies for industry, but the overall strategy is based on global industrial competition. Competition with global criteria and an increase in share based on country’s potentials in global commerce is the main goal of this sector. Hence, the strategies of replacing imported goods, total reliance on own natural resources, absolute support of manufacturers and consumers are not in mind, since the industry can not be the sole motivator of the economical development in the country.

The general consideration in industrial development is aimed at economical and social welfare promotions that within the global economical transformation, the present Iranian economical growth must be transformed at a faster paste.”

“Iran has many mineral resources and in some of them with respect to the universal class and standards, Iran is highly propounded. Metallic and non-metallic mines, minerals, oil and gas are among the highest comparative advantages in Iran. The progress in petrochemical industries based upon the clean gas resources with regards to the global environmental sensitivity is among our major priorities. Iran has the second largest gas reserves in the world.”

“With regards to the theme of this seminar "Refractory Development" whose direct influence is dependent upon the essential metal productions, cement and smelting factories and also the general intention to export these goods, which in turn enhance the need for more refractory consumption. The essential metal productions with total reliance on essential mineral and auxiliary materials and also energy, particularly environmentally clean energy (gas) and a growing, market till the country and in the region utilize such comparative advantages. Hence, the development of such industries is in our utmost priority list in order to secure our internal industrial needs as well as safeguarding the export of such products.”

“In addition to the research activities carried out in the country, partnership with those in possession of high technologies, industries and markets of refractories will facilitate smooth and fast development in this industry.

Industry and mines ministry gives full support for movements in the direction of research, technology, education, and industrial and commerce partnership.

I hope that the academic and applied papers presented by Iranian and foreign specialists prepare the necessary grounds for achieving mutual cooperation for this vital industry in our country.

Finally, I wish to express my gratitude to all the participants and hope that you all have a great time during the conference.”

For further information and purchasing the conference proceedings and CD you may contact with: Professor F. Golestani-Fard, Refractory Research Group, Materials & Metallurgical Engineering, Iran University of Science & Technology, P.O. Box: 16845-195, Narmak, Tehran, Iran, Tel/Fax: +98-21-7491034 or +98-21-7451518, E-mail: rrg@iust.ac.ir, Website: http://rrg.iust.ac.ir
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<th>PRODUCTS</th>
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<td><strong>MISSOURI REFRACTORIES CO. INC.</strong></td>
<td><strong>CHRISTY MINERALS COMPANY</strong></td>
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<td>Aarón Saenz 1918 Pte Monterrey N.L. 64650 Mexico Tel: 52 81 83784343 Fax: 52 81 83783434 E-mail: <a href="mailto:info@fibratec.com">info@fibratec.com</a> Website: <a href="http://www.fibratec.com">www.fibratec.com</a> NUTEC FIBRATEC is a major producer of ceramic fiber products.</td>
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<td>833 Booneslick High Hill, Mo 63350 Tel: (636) 585-2214 Fax: (636) 585-2220 E-mail: <a href="mailto:info@christyco.com">info@christyco.com</a> Website: <a href="http://www.christyco.com">www.christyco.com</a> Christy Minerals mines, processes and markets a variety of clays and minerals for the refractories industry. Products include calcined MO flint clays, raw clays (including Hawthorn Bond®), bauxite, burley and diaspore. Custom calcining, grinding and packaging also available.</td>
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Azadi Tower which is one of the first things a visitor sees coming from the airport and Qazwin.