Celebrating 100 years

AMERICAN CERAMIC SOCIETY

bulletin

emerging ceramics & glass technology

DECEMBER 2021

Game-changers:

How ceramic and glass materials enhance performance and provide safety to sports

PLUS ceramicSOURCE Buyers Guide

AND Ceramic & Glass MANUFACTURING

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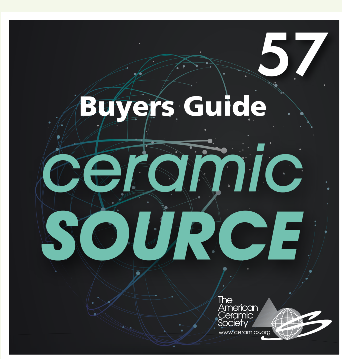
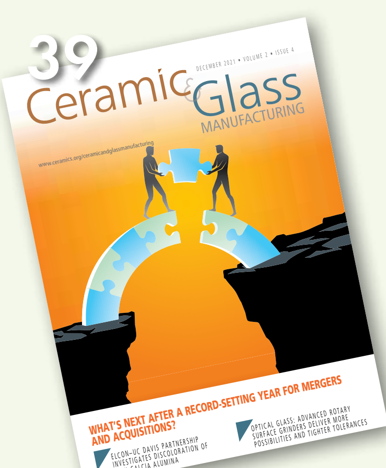
feature articles





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As seen on *Ceramic Tech Today*...

Credit: yasin hm, Unsplash

Reducing the need for trial and error—systematic selection of inorganic binders for refractories

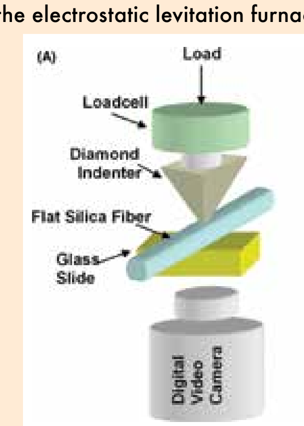
The binder used in refractory production requires careful consideration because it can influence the refractory's final mechanical and chemical properties. Researchers in Germany advanced a selective and systematic method for choosing an inorganic binder.

Read more at www.ceramics.org/inorganicbinders

Also see our ACerS journals...

Effects of temperature and humidity on adhesion of water scale to glass substrates
By S. Hayashi, T. Kobayashi, S. Sakai, et al.
International Journal of Ceramic Engineering & Science

Densities of liquid lanthanoid sesquioxides measured with the electrostatic levitation furnace in the ISS
By C. Koyama, T. Ishikawa, H. Oda, et al.
Journal of the American Ceramic Society



A threshold heating rate for single-stage heat treatments in glass-ceramics containing seed formers
By A. Zandona, C. B. M. Groß, B. Rüdinger, and J. Deubener
Journal of the American Ceramic Society

Radial cracking at Vickers indentations in pristine flat/square silica fibers
By C. R. Kurkjian, S. M. Allameh, and S. Yoshida
International Journal of Applied Glass Science

Journal of the American Ceramic Society | International Journal of Applied Ceramic Technology | International Journal of Applied Glass Science | International Journal of Ceramic Engineering & Science

Read more at www.ceramics.org/journals

American Ceramic Society Bulletin covers news and activities of the Society and its members, includes items of interest to the ceramics community, and provides the most current information concerning all aspects of ceramic technology, including R&D, manufacturing, engineering, and marketing. The American Ceramic Society is not responsible for the accuracy of information in the editorial, articles, and advertising sections of this publication. Readers should independently evaluate the accuracy of any statement in the editorial, articles, and advertising sections of this publication. *American Ceramic Society Bulletin* (ISSN No. 0002-7812). ©2021. Printed in the United States of America. *ACerS Bulletin* is published monthly, except for February, July, and November, as a "dual-media" magazine in print and electronic formats (www.ceramics.org). Editorial and Subscription Offices: 550 Polaris Parkway, Suite 510, Westerville, OH 43082-7045. Subscription included with The American Ceramic Society membership. Nonmember print subscription rates, including online access: United States and Canada, 1 year $135; international, 1 year $150.* Rates include shipping charges. International Remail Service is standard outside of the United States and Canada. *International nonmembers also may elect to receive an electronic-only, email delivery subscription for $100. Single issues, January–October/November: member $6 per issue; nonmember $15 per issue. December issue (*ceramicSOURCE*): member $20, nonmember $40. Postage/handling for single issues: United States and Canada, $3 per item; United States and Canada Expedited (UPS 2nd day air), $8 per item; International Standard, $6 per item.

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ACSBA7, Vol. 100, No. 9, pp 1– 138. All feature articles are covered in Current Contents.

Total knee replacement: Global markets

By BCC Publishing Staff

The global market for total knee replacement was valued at $6.3 billion in 2020. The market is expected to grow at a compound annual growth rate of 4.1%, to reach $8.0 billion by 2026.

Total knee replacement is a procedure whereby an artificial joint replaces a damaged knee joint. If a procedure is being performed for the first time on a patient, it is called a primary replacement procedure. Revision procedures are performed once degradation of the joint prostheses or other conditions, such as fracture, cancer, or other causes, has occurred. Generally, 90% to 95% of patients are satisfied with the outcome of their procedure. In some cases, 95% of the knee replacements remain in use after 10 to 15 years post-surgery.

Key factors driving growth in the total knee replacement market are the increasing incidence of orthopedic disorders among the population—including osteoarthritis, lower limb joint pain, and medial cartilage tear—and an aging population. Other growth factors include increasing approvals of technologically advanced products and rising R&D investments in knee replacement implants. Also, the increasing incidence of orthopedic disorders related to the growing incidence of both diabetes and obesity cases is pushing growth in the total knee replacement market.

Although the overall design of total knee implants varies, total knee implants generally have three basic components:

- **The femoral component** attaches to the end of the femur. It has a groove that provides the patellar component to slide up and down smoothly as the knee bends and straightens.
- **The patellar component** is a dome-shaped piece that mimics the kneecap. Because the patella rests against the femur, the alignment of the patellar and femoral components is crucial for proper function.
- **The tibial component** is a flat, two-piece component attached to the tibia. It typically consists of a metal part, which lies on top of the tibia and has a stem inserted into the tibia for stability, and a plastic part, which acts as a cushion between the metal tibial component and the femoral component.

These three components are cemented in place, but some physicians use a cementless procedure that supports the bone growth into the implant to help strengthen stability.

The growing demand for tighter surgical fit has made manufacturers of total knee implants acknowledge the need for patient-centric implant designs. In response to such demands, implant manufacturers have made incremental moves to develop personalized implants. However, because customized total knee replacement surgery is a relatively new concept, there is limited data to determine if the use of custom implants offer better patient outcomes and functionality than standard knee replacement systems.

North America is estimated to have the highest market share and the Asia-Pacific region is anticipated to have the highest growth rate during the forecast period 2021–2026. Subjects younger than 65 years of age represent the fastest-growing population of total knee replacement recipients and are anticipated to account for more than 50% of knee replacement procedures by 2030.

Table 1. Global market for total knee replacement, by product category, through 2026 ($ millions)

Product category	2019	2020	2021	2026	CAGR % (2021–2026)
Primary total knee replacement	4,514.4	4,675.3	4,825.6	5,830.0	3.9
Revision total knee replacement	1,564.3	1,635.9	1,704.9	2,160.3	4.8
Total	6,078.7	6,311.2	6,530.5	7,990.3	4.1

Table 2. Global market shares of total knee replacement, by manufacturer, 2020 (%)

Company	Market share (%)
Zimmer Biomet	33.9
Stryker	21.1
DePuy Synthes	16.7
Smith & Nephew	12.0
Others	16.3

About the author

BCC Publishing Staff provides comprehensive analyses of global market sizing, forecasting, and industry intelligence, covering markets where advances in science and technology are improving the quality, standard, and sustainability of businesses, economies, and lives. Contact the staff at Helia.Jalili@bccresearch.com.

Resource

BCC Publishing Staff, "Total knee replacement: Global markets" BCC Research Report MDS053A, September 2021. www.bccresearch.com.

By Lisa McDonald

Into the Bulletin Archives—A look back at our 100 years in print

Since May 1922, the *ACerS Bulletin* has served the ACerS community, providing them updates on member news, Division meetings, and the latest research in ceramics and glass.

In celebration of Volume 100 this year, the *Bulletin* editorial team is running a special column in each issue of the 2021 *Bulletin* that looks at the history of the *Bulletin* by decade. This issue highlights the 2000s–present.

We hope you enjoyed following the journey of the *Bulletin* from its early years to today. As an ACerS member, you have access to all 100 years of the *Bulletin* on the *Bulletin Archive Online* at https://bulletin-archive.ceramics.org. 100

Into the Bulletin Archives—2000s–present

Since its launch, the *Bulletin* published 12 issues every year, but that changed in the 2000s. The *Bulletin* dropped to 10 issues in 2009 (by combining June/July and October/November) and then nine issues in 2010 (by combining January/February).

Expansions to the Society structure is one of the main trends tracked by the *Bulletin* in the 2000s and 2010s. These expansions were driven by concerns in the early 2000s about declines in participation, membership, and finances, so "the Board…took a more hands-on approach in addressing these issues," according to a state of the Society report in the October 2006 issue. Some of the changes to better serve membership include

- 2005—Formation of the Material Advantage student program with ASM, AIST, and TMS. (Read more in the September 2005 issue, p. 23)
- 2008—Formation of the President's Council of Students Advisors. (Read more in the June 2008 issue, p. 20)
- 2009—Formation of the Young Professionals Network. (Read more in the September 2009 issue, p. 43)
- 2017—Formation of ACerS International Chapters. (Read more in the September 2017 issue, p. 3)

The Society also launched the Ceramic and Glass Industry Foundation in 2014, as described in the January/February 2014 issue. The Foundation's goal is to promote the formation of a working association between industries and universities to develop the next generation of ceramic and glass scientists and engineers.

The ACerS journals also witnessed significant expansion in the last two decades, with the launch of three new journals:

- 2004—*International Journal of Applied Ceramic Technology*, announced in the October 2003 issue.
- 2010—*International Journal of Applied Glass Science*, announced in the June/July 2009 issue.
- 2019—*International Journal of Ceramic Engineering & Science*, announced in the October/November 2018 issue.

Several changes occurred to the Society Division structure in the 2000s. The July 2000 issue reported

Credit: *ACerS Bulletin* (February 2007) Vol. 86 Iss. 2, p. 14

For three decades, The American Ceramic Society conducted the International Conference on Advanced Ceramics & Composites in Cocoa Beach, Fla. In 2007, however, the Society moved ICACC to Daytona Beach, Fla., to accommodate increased attendance and an expanded number of exhibits. Above are images from the first ICACC at Daytona Beach.

2000s

that the Materials & Equipment Division and the Whitewares Division merged to form a single Division after struggling for several years with programming needs and a decline in meeting attendance. However, because the ACerS Constitution does not have a procedure to allow Divisions to merge, each Division petitioned the Board to change its name to Whitewares & Materials and adopted the same purpose. The July issue also reported that the Design Division changed its name back to Art, the name it originally held before changing to Design in the 1940s.

The 2010s witnessed a few more changes to the Divisions, bringing us to the structure that the Society has today. The March 2013 issue reported on the renaming of the Art Division to the Art, Archaeology & Conservation Science Division, a change made to better reflect "the numerous intersection points between art and materials science." Two years later, the May 2015 issue announced the transformation of the inactive Whitewares & Materials Division into the new Manufacturing Division, which has a much broader focus to meet the needs of today's manufacturers.

The Society witnessed the creation of an entirely new Division in 2017. The January/February 2018 issue announced the launch of the Bioceramics Division, which was formed out of the ~90-member Bioceramic Technical Interest Group. The last Division to undergo a rebranding was the Nuclear & Environmental Technology Division, which became part of the new Energy Materials and Systems Division in 2020, as announced in that year's March issue.

Credit: *ACerS Bulletin* (January/February 2017) Vol. 96 Iss. 1, p. 15

William "Bill" Lee, left, receives the ceremonial ceramic gavel from Mrityunjay Singh. Lee was the first Society president who resided outside the United States during his term.

DIVISIONS OF THE SOCIETY

During the 2000s, the Society had 10 Divisions.

- Art (previously Design)
- Basic Science
- Cements
- Electronics
- Engineering Ceramics
- Glass & Optical Materials
- Nuclear & Environmental Technology
- Refractory Ceramics
- Structural Clay Products
- Whitewares & Materials (merger of Whitewares and Materials & Equipment)

During the 2010s, the Society had 11 Divisions.

- Art, Archaeology & Conservation Science (previously Art)
- Basic Science
- **Bioceramics (New)**
- Cements
- Electronics
- Energy Materials and Systems (previously Nuclear & Environmental Technology)
- Engineering Ceramics
- Glass & Optical Materials
- Manufacturing (previously Whitewares & Materials)
- Refractory Ceramics
- Structural Clay Products

Credit: *ACerS Bulletin* (June/July 2015) Vol. 94 Iss. 5, p. 48

The first Ceramics Expo took place April 26–28, 2015, in Cleveland, Ohio. ACerS is the founding partner of the annual show, which is run by U.K.-based event company Smarter Shows.

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partners:

BEKESON GLASS

– Bekeson Glass, LLC

PETROCERAMICS
Turn natural complexity into technology®

– Petroceramics S.P.A.

To learn about the benefits of ACerS Corporate Partnership, contact KevinThompson, membership director, at (614) 794-5894 or kthompson@ceramics.org.

2021 Pittsburgh Section annual golf outing

The Annual Golf Outing of the ACerS Pittsburgh Section returned on Monday, Sept. 13, at Lenape Heights Golf Resort. Participants enjoyed a complete program of special events, including 18 holes of golf, dinner, prizes and awards, and more. Thank you to Fiven North America, Inc. for sponsoring the $10,000 Hole in One challenge. Golfers enjoyed competing for the prize even though no one took it home.

ACerS welcomes new Southern California Section

At ACerS Annual Meeting at MS&T21, the ACerS Board of Directors approved the establishment of the Southern California Section. The officers of the new Section are

Chair: **Toby Schaedler**, HRL Laboratories
Secretary: **Ryan McCarty**, SAFCell
Treasurer: **Ellen Heian**

Congratulations to the newest ACerS Section!

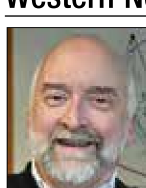
Central Pennsylvania Section welcomes new Section chair

With the recent retirement of John Hellmann, FACerS, the Central Pennsylvania Section welcomes Allen Kimel from The Pennsylvania State University as its chair. Congratulations, John Hellmann, on your retirement, and welcome, Allen Kimel!

Thailand Chapter plans ICAPMA-JMAG for December 2021

The Joint International Conference on Applied Physics and Materials Applications & Applied Magnetism and Ferroelectrics is Dec. 1–4, 2021. Visit the website at https://www.matscitech-thailand.com/2021/index.php for more information.

Western New York Section October meeting focuses on processing



Carty

William Carty, FACerS, Emeritus Professor of Ceramic Engineering in the Kazuo Inamori School of Engineering at New York State College of Ceramics, Alfred University, spoke on Thursday, Oct. 7, 2021, at the Western New York Section meeting on the topic, *It starts with ceramic processing (Think like a particle)*.

FOR MORE INFORMATION:

ceramics.org

ACerS members in ASM's 2021 Class of Fellows


Armstrong

Beth L. Armstrong, FASM
Senior research staff
Oak Ridge National Laboratory
Oak Ridge, Tenn.


Balani

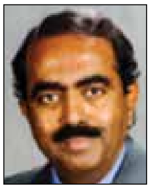
Kantesh Balani, FASM
Professor
Indian Institute of Technology
Kanpur, India


Du

Jincheng Du, FACerS, FASM
Professor
University of North Texas
Denton, Texas


Madsen

Lynnette D. Madsen, FACerS, FASM
Program director
National Science Foundation
Alexandria, Va.


Shareef

Iqbal Shareef, FASM
Professor, industrial and manufacturing engineering
Bradley University
Peoria, Ill.


Sundaram

S.K. Sundaram, FACerS, FASM
Inamori Professor of Materials Science and Engineering
Kazuo Inamori School of Engineering
The New York State College of Ceramics
Alfred University, Alfred, N.Y.

Volunteer spotlight

ACerS Volunteer Spotlight profiles a member who demonstrates outstanding service to the Society.


Reaney

Ian Reaney is the Dyson Chair in Ceramics at University of Sheffield in Sheffield, United Kingdom, and the director for the £2 million Transforming Foundation Industries Network Plus. He obtained his Ph.D. from the University of Manchester, U.K., and has served as an adjunct professor at The Pennsylvania State University and University of Aveiro, Portugal.

Reaney currently serves as the chair of the ACerS United Kingdom Chapter. He previously won the ACerS Electronics Division Edward C. Henry Award. Additionally, he was awarded the Verulam Medal for Ceramics and the Robert E. Newnham Award, and is a Fellow of the Royal Microscopical Society and Institute of Mining Minerals and Materials.


Gerhardt

Rosario Gerhardt, FACerS, is senior Goizueta Faculty Chair at the Georgia Institute of Technology. Prior to Georgia Tech, she was at Rutgers University.

Gerhardt's membership with ACerS began in the 1980s as a graduate student at Columbia University. An ACerS Fellow since 2000, she was profiled in a book focused on women in ceramics and glass in 2015, received the Friedberg Lecture award in 2017, and was recently elected to the World Academy of Ceramics. She is also a Senior Member of the Institute of Electrical and Electronics Engineers.

Gerhardt is active in the Electronics Division of ACerS. In addition to serving on its executive committee, she served as chair of the Electronics Division. She also served on the *ACerS Bulletin* Advisory Board; as advisor to the Georgia Tech student chapter of ACerS; and as a judge of student posters, papers, and GEMS awardees. Most recently, she served as a member of the awards committee for the Education and Professional Development Council.

We extend our deep appreciation to Reaney and Gerhardt for their service to our Society!

Names in the news

Members—Would you like to be included in the Bulletin's Names in the News? Please send a current head shot along with the link to the article to mmartin@ceramics.org. The deadline is the 30th of each month.


Boccaccini

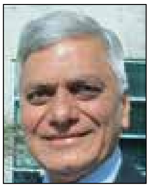
Aldo R. Boccaccini, FACerS, professor and head of the Institute of Biomaterials at University of Erlangen-Nuremberg, Germany, was elected vice-president of the Federation of European Materials Societies. Boccaccini has been a member of the Executive Committee of FEMS since 2016, representing the German Materials Society.


McGuffin-Cawley

Jim McGuffin-Cawley, professor of materials science and senior associate dean of the Case School of Engineering, received the Meritorious Service Award, which recognizes outstanding service to the Case Alumni Association and to Case Western Reserve University in Cleveland, Ohio.

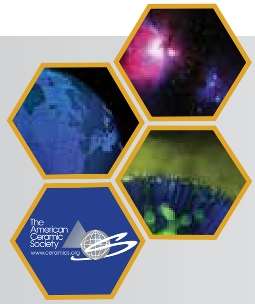

Seal

Sudipta Seal, FACerS, FASM, MSE, AMPAC Materials Science & Engineering, University of Central Florida, was awarded the 2021 Alpha Sigma Mu Lecture, titled *Innovation through design strategy: A material's journey from coatings to biomedical intervention.*


Varshneya

Arun Varshneya, FACerS and ACerS DLM, was honored by the Case Alumni Association for his professional achievements and his support of today's students. He received the Gold Medal, the association's highest annual honor, at Case Western Reserve University's Homecoming and Reunion Weekend, Oct. 9–10, 2021.

more SOCIETY DIVISION SECTION CHAPTER NEWS



Free to ACerS members

Frontiers of Ceramics & Glass Webinar Series

DECEMBER 9, 2021
2:00 P.M. EASTERN US TIME

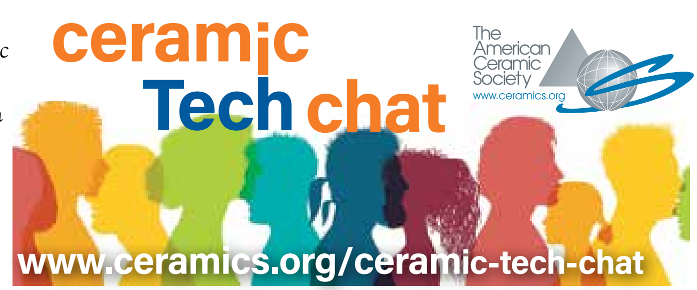
Title: *A Density Functional Theory (DFT) Investigation of Small Molecule Adsorption on Mineral Surfaces in Cultural Heritage*

PRESENTER:
JESSICA HEIMANN – University of Maryland Baltimore County (UMBC)

Hosted by: Art, Archaeology and Conservation Science Division

Ceramic Tech Chat: Sossina Haile and Olivia Graeve

Hosted by ACerS Bulletin editors, Ceramic Tech Chat talks with ACerS members to learn about their unique and personal stories of how they found their way to careers in ceramics. New episodes publish the second Wednesday of each month.



September guest, Sossina Haile, FACerS, Walter P. Murphy Professor of Materials Science and Engineering at Northwestern University, discusses fuel cell technology, her experience as an immigrant pursuing science, and tips for diversification in both of these areas.

In the October episode, Olivia Graeve, FACerS, professor of mechanical and aerospace engineering at the University of California, San Diego, discusses growing up in Tijuana, Mexico, why she believes compassion is the key to a diverse community, and describes her work building bridges between Mexico and the U.S. as director of the CaliBaja Center for Resilient Materials & Systems.

Listen to Haile and Graeve's interviews—and all of our other Ceramic Tech Chat episodes—at http://ceramictechchat.ceramics.org/974767. 100

IN MEMORIAM

Michael Hardwick

Akio Kato

Patrick J. Leonard

Vojislav Mitic

Some detailed obituaries can also be found on the ACerS website, www.ceramics.org/in-memoriam.

Lithoz celebrates 10 years

Lithoz GmbH (Vienna, Austria) celebrated its 10-year anniversary as a provider of 3D printing machines and materials. Initially founded as a spin-off from TU Wien in 2011, Lithoz was created to establish ceramic 3D printing as a reliable manufacturing process for industrial mass production. View a video with anniversary celebration highlights at https://www.youtube.com/watch?v=1NxzuCSPtqE. 100

Mo-Sci Corporation and ETS Technology Holdings sold to Hereaus

The Heraeus Group (Hanau, Germany) acquired Mo-Sci Corporation and ETS Technology Holdings, LLC, both located in Rolla, Mo. Mo-Sci was founded by Delbert Day in 1985, and ETS was founded in 2012. See p. 44 for more details. 100

AWARDS AND DEADLINES

ACerS runs a thriving awards program that recognizes the contributions of deserving individuals and companies within the ceramics and glass community. For more information, visit ceramics.org/awards or contact Erica Zimmerman at ezimmerman@ceramics.org.

Division	Award	Nomination Deadline	Description
AACS	**Anna O. Shepard**	Jan. 15, 2022	Presented to an individual(s) who has made outstanding contributions to materials science applied to art, archaeology, architecture, or cultural heritage.
BSD	**Early Discovery**	Jan. 15, 2022	Recognizes an early career member of ACerS who has demonstrated a contribution to basic science in the field of glass and ceramics.
Cements	**Early Career**	Jan. 15, 2022	Recognizes an outstanding early career scientist who is conducting research in the field of cement and concrete in academia, industry, or a government funded laboratory.
GOMD	**Norbert J. Kreidl**	Jan. 21, 2022	Recognizes research excellence in glass science. Open to all degree-seeking graduate students (M.S. or Ph.D.) or those who have graduated within a twelve-month period of the annual GOMD meeting.
GOMD	**George W. Morey**	Jan. 21, 2022	Recognizes new and original work in the field of glass science and technology. The criterion for winning the award is excellence in publication of work, either experimental or theoretical, done by an individual.
GOMD	**L. David Pye Lifetime**	Jan. 21, 2022	Given to deserving a individual(s) in recognition of lifetime dedication, vision, and accomplishments in advancing the fields of glass science, glass engineering, and glass art.
GOMD	**Stookey Lecture**	Jan. 21, 2022	Recognizes an individual's lifetime of innovative exploratory work or noteworthy contributions of outstanding research on new materials, phenomena, or processes involving glass, that have commercial significance or the potential for commercial impact.
GOMD	**Varshneya-Mauro-Jain Guru-Chela Travel Fund**	Jan. 21, 2022	Recognizes the special bond of knowledge, trust, and growth between a teacher ("Guru") and a student ("Chela"), benefitting both.

FOR MORE INFORMATION:

ceramics.org/members/awards

more AWARDS AND DEADLINES

Society and Division award nominations due mid-January

Nominations are encouraged for candidates from groups that have been underrepresented in ACerS awards relative to their participation in the Society, including women, underrepresented minorities, industry scientists and engineers, and international members. We urge you to submit nominations by **Jan. 15, 2022**, for many Society and Division awards.

ACerS Corporate awards: January 15 deadline

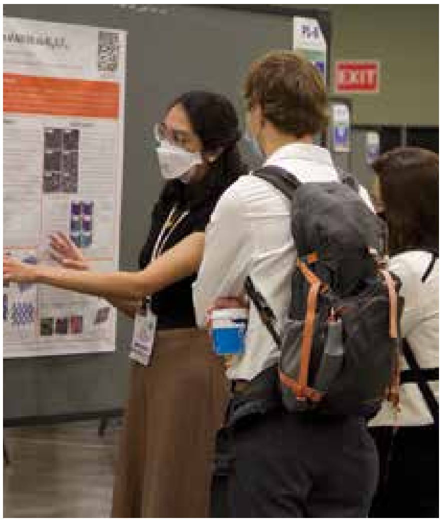
While ACerS has a large and varied awards program, there are awards specifically designed for our important group of Corporate Partners. Each award will be presented at the ACerS Annual Meeting in October 2022 in Pittsburgh, Pa. Corporate awards are a wonderful way for your organization and talented employees to be recognized for their achievements.

For more information about each award, visit ceramics.org/awards or contact Erica Zimmerman at ezimmerman@ceramics.org.

EMSD logo contest

Are you creative? Could you use a $500 Amazon gift card? The Energy Materials and Systems Division seeks design submissions for their Division logo! Deadline is **Jan. 5, 2022**. For more details, visit https://bit.ly/EMSDLogoContest.

STUDENTS AND OUTREACH



ACerS Morgan Medal and Global Distinguished Doctoral Dissertation Award

Plan to submit a nomination for the Morgan Medal and Global Distinguished Doctoral Dissertation Award. This award recognizes a distinguished doctoral dissertation in the ceramics and glass discipline. The award is generously sponsored by Morgan Advanced Materials and includes the Morgan Medal.

Nominations should be made by a person very familiar with the student's work, such as the research supervisor. It is expected that the student will collaborate in the preparation of the nomination package.

Review nomination instructions at www.ceramics.org/doctoraldissertationaward, and submit the nomination materials by **Jan. 15, 2022.**

BSD Ceramographic awardees

Roland B. Snow Award for Best in Show

Single crystalline galaxy
Joseph Wood and Klaus van Benthem
University of California, Davis

Transmission electron microscopy category

First place: *Nano penguin*
Boyi Qu and Klaus van Benthem
University of California, Davis

Scanning electron microscopy category

First place: *Single crystalline galaxy*
Joseph Wood and Klaus van Benthem
University of California, Davis

Second place: *A starry night*
Bo Yang, Xin Li Phuah, Haiyan Wang, and Xinghang Zhang
Purdue University

Third place: *Pollen derived carbons*
Jialing Tang and Vilas Pol
Purdue University

Scanning probe microscopy category

First place: *Hummingbird plastically imprinted*
Xufei Fang[1, 2], Tingting Zhu[1], Kuan Ding[1], and Atsutomo Nakamura[2]

[1]Technical University of Darmstadt, Germany
[2] Osaka University, Japan

Second place: *Micro domain city*
Oliver Preuss, Fangping Zhuo, Jürgen Rödel, and Xufei Fang
Technical University of Darmstadt, Germany

FOR MORE INFORMATION:

ceramics.org/students

more STUDENTS AND OUTREACH

MS&T21 student contest winners

The Material Advantage Student Program sponsored various contests for undergraduate and graduate students during MS&T21 in Columbus, Ohio. Thank you to all who helped judge and organize the contests this year, and congratulations to all the student winners.

Material Advantage Graduate Student Poster Competition

1st place – $250
Celia Chari, California Institute of Technology

2nd place – $150
Rupesh Rajendran, Georgia Institute of Technology

3rd place – $100
Gaurav Singh, Indian Institute of Technology Madras

Material Advantage Undergraduate Student Poster

1st place – $250
Amelia Martinez, University of Missouri Science and Technology

2nd place – $150
Mirra Rasmussen, Case Western Reserve University

3rd place – $100
Hugh Smith, Case Western Reserve University

Material Advantage Undergraduate Student Speaking Contest

1st place – $500
Alison Nunes, University of Illinois, Urbana-Champaign

2nd place – $250
Mingwei Xu, Case Western Reserve University

3rd place – $150
Yulia Kirina, Virginia Polytechnic Institute and State University

4th place – $100
Yuxi Zhang, Wuhan University of Technology

Material Advantage Ceramic Mug Drop Contest–Organized by Keramos

Winner – $100 and trophy
Sophie Grier, Missouri University of Science and Technology

Most aesthetic mug – $50
Elliot Sutalski, Missouri University of Science and Technology

VIRTUAL: Most aesthetic mug – $50
Claire Pallett, Missouri University of Science and Technology

Material Advantage Ceramic Disc Golf Contest–Organized by Keramos

Winner – $100 and trophy
Camden Holloway, Virginia Polytechnic Institute and State University

VIRTUAL: Most aesthetic disc – $100
Jacob Stacy, Missouri University of Science and Technology

Material Advantage Social Media Contest

$100
Neelam Meena, Indian Institute of Technology Bombay

more STUDENTS AND OUTREACH

Congratulations to the 2021 GEMS awardees

The ACerS Basic Science Division recently announced the winners of its 2021 Graduate Excellence in Materials Science Awards.

Congratulations to the 2021 GEMS Award Finalists.

Diamond Ranking:

- **Corey Carlos**, University of Wisconsin-Madison
- **Eeshani Paresh Godbole**, University of Minnesota
- **Spencer Dahl**, University of California, Davis

Graduate students whose abstracts are accepted for a talk at ACerS Annual Meeting at MS&T22 in Pittsburgh, Pa., should consider applying for the 2022 GEMS Awards. For more information, visit www.ceramics.org/gems.

Grad students: Choose GGRN to advance your career

Build an international network of peers within the ceramic and glass community by joining the Global Graduate Researcher Network. GGRN is ACerS membership option that addresses the professional and career development needs of graduate level research students who have a primary interest in ceramics and glass.

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New neural network demonstrates enhanced symmetry awareness

Researchers from Lehigh and Stanford universities developed a new machine learning algorithm that includes symmetry-aware features to improve modeling of materials.

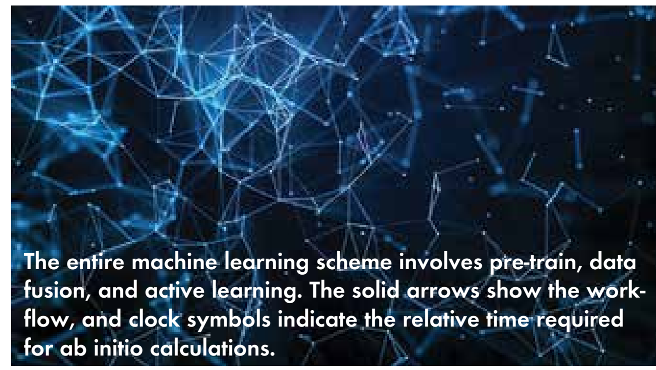
A material's structure plays a major role in determining the material's properties and behavior. Unfortunately, convolutional neural networks (CNNs), a type of machine learning commonly used to analyze visual imagery, are unable to easily detect these structural features because of their inability to recognize an image when it is rotated.

Techniques such as 2D-rotational equivariant and 3D-euclidian neural networks can correct this limitation, but the fact remains that CNNs do not inherently understand symmetry. Thus, the corrective techniques generally only allow for narrow-bounded conclusions, and if a new example lies on the periphery of the training data distribution, the predictions might be nonsensical.

Currently, it is not possible to develop a neural network that inherently understands symmetry. However, improving a neural network's ability to approximate symmetry without relying on corrective techniques is an achievable goal—and the one aimed for by the researchers of the recent study.

They began by developing and training two complementary neural network-based algorithms. One neural network can classify natural images, and the other can classify images that belong to wallpaper group symmetries, i.e., mathematical classifications of 2D repetitive patterns. After training the algorithms, they used manifold learning techniques to create 2D projections that correlated images based on their composition and structure, irrespective of the length scale of the images. Repeated exploration revealed more nuanced details of the image similarities.

After proving the potential of their network on the generated images, the researchers applied their neural network to piezoresponse force microscopy images collected on diverse materials systems over five years at the University of California, Berkeley. The results? The network successfully grouped similar classes of materials together and observed trends, even though it did not have an inherent understanding of the materials system, structure, or underlying symmetry.


The entire machine learning scheme involves pre-train, data fusion, and active learning. The solid arrows show the workflow, and clock symbols indicate the relative time required for ab initio calculations.

In an email, Lehigh assistant professor of materials science and engineering Joshua Agar says the results of this study are exciting not only because of the successful approximations but because they offer a first "use case" of an innovative new data-storage system called DataFed.

DataFed is a federated system housed at Oak Ridge National Laboratory that manages "the data storage, communication, and security infrastructure present within a network of participating organizations and facilities," according to the ORNL website. An interdisciplinary team at Lehigh University, called the Presidential Nano-Human Interface Initiative, played an active role in the design and development of DataFed.

Agar is a part of the Presidential NHI team, and he says the new symmetry algorithm they developed will be integrated with the DataFed system to address what he sees as the two-sided problem of data science.

"There are no suitable data repositories for collecting, collating, and searching scientific data, and there are no good tools to extract knowledge simply from scientific databases. DataFed

Research News

Dancing with the light: A new way to make crystals bend by shining light

Waseda University researchers validated a new mechanism to generate fast bending motion in thick crystals using ultraviolet light. Called the "photothermal effect," this phenomenon occurs when heat is generated by exciting materials with light. However, the bend angle dropped rapidly with increasing crystal thickness, revealing that the bending was caused by photoisomerization. Because the bending motion can now be simulated as well, it provides the basis for practical applications such as in light-driven actuators. For more information, visit https://www.waseda.jp/top/en/news.

Lithium-ion batteries made with recycled materials can outlast newer counterparts

Worcester Polytechnic Institute researchers extracted the electrodes from shredded spent batteries and recovered over 90% of three key metals—nickel, manganese, and cobalt—which they used to create new cathodes. In tests of how well batteries maintain their capacity to store energy after repeated use and recharging, batteries with recycled cathodes outperformed those made with all-new commercial materials of the same composition. Specifically, it took 11,600 charging cycles for the batteries with recycled cathodes to lose 30% of their initial capacity, which is about 50% better than the 7,600 cycles for batteries with new cathodes. For more information, visit https://www.sciencenews.org.

addresses the former, and the manuscript addresses the latter," he says.

The open-access paper, published in *npj Computational Materials,* is "Symmetry-aware recursive image similarity exploration for materials microscopy" (DOI: 10.1038/s41524-021-00637-y).

Excess aluminum extends Hall-Petch relation in nanocrystalline ceramics

Two researchers at the University of California, Davis, showed that adding extra aluminum to zinc aluminate can extend the Hall-Petch relation.

The Hall-Petch relation is a quantitative description of how yield strength of a material increases as grain size decreases. In other words, a ceramic becomes harder as its grains become smaller. However, once grains become smaller than 100 nm, researchers have observed an inverse Hall-Petch relation. Instead of the ceramic becoming harder, researchers have witnessed what they call a "softening," i.e., its hardness begins to decrease.

Researchers for years have debated the mechanisms behind inverse Hall-Petch in ceramics. In 2019, a team led by Ricardo Castro, ACerS Fellow and professor of materials science and engineering at the University of California, Davis, suggested that cracking caused by "the activation of new energy dissipation modes" was the cause.

At that time, Castro said the next step was to define a strategy to control cracking and thereby avoid the inverse Hall-Petch relation. Now, in a paper published almost exactly two years later, Castro and graduate student Luis Sotelo Martin describe one approach to mitigate inverse Hall-Petch and extend the Hall-Petch relation.

They begin by recounting what they determined in the 2019 study—that as grain sizes decrease, the corresponding increase in grain boundary energy leads to intergranular fracture and a decrease in hardness.

"This proposed relationship between grain boundary energy (or grain boundary strength) and Hall-Petch behavior suggests that the inverse Hall-Petch relation could be mitigated by avoiding an increase in grain boundary energy, suggesting 'colossal' hardening may be achieved in nanoceramics," they write.

The researchers suggest off-stoichiometric compounds, or those that do not have the expected integer ratios between components, could be a way avoid an increase in grain boundary energy.

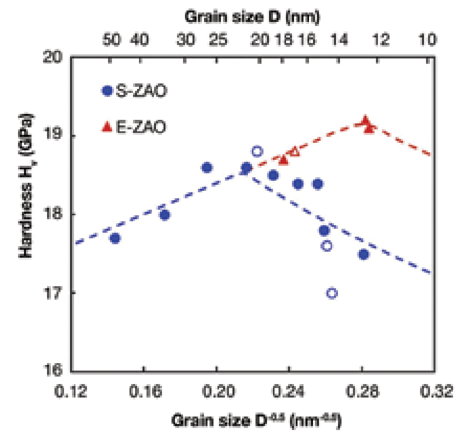
Previous studies found that ceramics featuring off-stoichiometric formulations have altered grain boundary properties. For example, studies on magnesium aluminate showed excess aluminum affected the local space charge layer and phenomena such as grain boundary migration. Also, a study on zinc aluminate showed that increasing the ratio of aluminum to zinc can suppress coarsening during sintering.

Despite its potential for altering grain boundary properties, the effect of off-stoichiometry has not been well studied in the context of the Hall-Petch relation. Castro and Sotelo Martin looked to fill that gap with their recent study, which was funded by the Army Research Office.

They used coprecipitation to synthesize a quasi-stoichiometric nanocrystalline zinc aluminate ($ZnAl_{2.01}O_4$) powder and an aluminum-rich $ZnAl_{2.87}O_4$ nanopowder. Then, they sintered the nanopowders either by deformable-punch spark plasma sintering or high-pressure spark plasma sintering.

They sintered the nanopowders in two ways to address a question arising from previous studies. Specifically, some studies that used high-pressure spark plasma sintering for fabrication reported the occurrence of inverse Hall-Petch, while some studies that fabricated their ceramics via deformable-punch spark plasma sintering did not. Because these results could indicate an effect of sintering condition on the inverse Hall-Petch relation, Castro and Sotelo Martin wanted to account for this possibility.

Following Vickers hardness testing, the researchers determined that sintering technique does not substantially affect the occurrence of inverse Hall-Petch in nanocrystalline oxides. In contrast, excess aluminum did have an effect—while the quasi-stoichiometric samples prepared by high-pressure spark plasma sintering exhibited a maximum hardness of 18.6 GPa at a grain size of 21.4 nm, the aluminum-rich samples produced by the same technique strengthened up to 19.2 GPa at 12.6 nm grain sizes.



Vickers hardness plotted in Hall-Petch form for quasi-stoichiometric zinc aluminate (S-ZAO, blue) and aluminum-rich zinc aluminate (E-ZAO, red) samples along with their fits (dashed lines) according to the Sheinerman et al. model. Samples sintered using deformable-punch spark plasma sintering are denoted in hollow symbols.

In the paper, Castro and Sotelo Martin explain that analysis of the samples showed aluminum enrichment altered the cracking patterns formed beneath the Vickers indentations, which affects how the samples accommodate load. Specifically, the aluminum "improves grain boundary toughness by serving as a pinning agent for grain shearing, similar to reports for rare-earth doping," they write.

Castro adds that they have some preliminary tests showing toughness can also be improved in transparent nanoceramics with similar mechanisms. "We are expanding this concept now," he says.

The paper, published in *Journal of the American Ceramic Society*, is "Al excess extends Hall-Petch relation in nanocrystalline zinc aluminate" (DOI: 10.1111/jace.18176).

ceramics in manufacturing

3D fabrication of transparent optical ceramics by lithography-based digital projection

In a recent paper, Alfred University graduate student Guangran Zhang and SUNY Empire Innovation Professor Yiquan Wu developed highly transparent yttrium aluminum garnet ($Y_3Al_5O_{12}$) ceramics via a lithography-based digital projection method.

Transparent optical ceramics are part of a special category of ceramics with unique transparent features, which lead to applications in scintillators, infrared domes, transparent windows, laser gain media, lamp envelope, phosphors, high-power LED light, optoelectronic devices, and many more.

To date, the most widely used shaping methods for transparent ceramics fabrication are powder pressing and slurry casting methods. However, to meet the industry's growing demand for customized manufacturing, scientists and researchers seek to process transparent ceramics using additive manufacturing, or 3D printing, methods.

Zhang and Wu used a CeraFab 8500 commercial 3D printer from Lithoz to perform the layer-by-layer printing process, after which they put the ceramics through pre-conditioning at 120°C, debinding at 500°C, pre-sintering at 1,000°C, and vacuum sintering at 1,750°C.

One of the challenges in the fabrication of transparent ceramics via additive manufacturing is the issue of bubbling and cracking during the debinding and sintering steps. To overcome this issue, Zhang and Wu introduced a multiple stepwise heating profile to reach the debinding temperature, followed by a single-step pre-sintering process at the appropriate temperature for $Y_4Al_2O_9$ (YAM) phase formation. The YAM serves as a "binder" to connect the Al_2O_3 and Y_2O_3 ceramic powder, which can prevent the bubbling and cracking during the final sintering process.

Credit: Zhang and Wu

Highly transparent yttrium aluminum garnet (YAG) ceramics with 3D structures, created via a lithography printing method.

The fully densified ceramics were highly transparent, without distortion of the original designed geometries. Ultimately, "It is believed that additive manufacturing will enable massive fabrication of customized complex structure and scalable transparent ceramics depending on specific applications in the future," Zhang and Wu say.

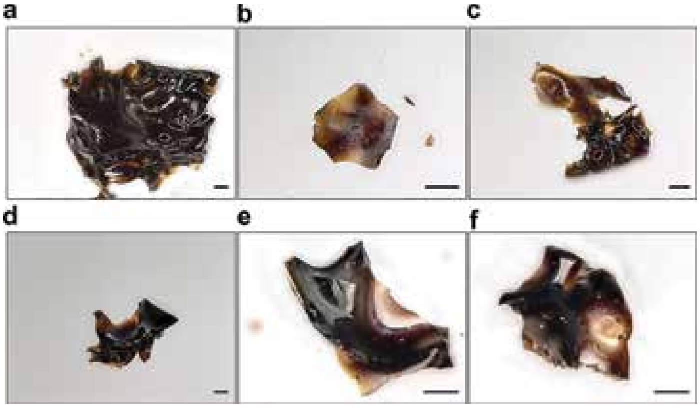
The paper, published in *Additive Manufacturing*, is "Three-dimensional printing of transparent ceramics by lithography-based digital projection" (DOI: 10.1016/j.addma.2021.102271). 100

Melting the unmeltable—new method extends the range of meltable MOF materials

Researchers from the University of Jena in Germany and the University of Cambridge in the United Kingdom found a way to extend the range of meltable metal-organic framework (MOF) materials.

MOFs are highly porous crystalline compounds composed of highly ordered 3D networks of metal ions and organic ligands. MOFs are of great interest to researchers due to the material's porosity, which allows diffusion of guest molecules into the bulk structure and thus makes MOFs ideal for storage, separation, and catalysis applications.

To date, MOFs have not achieved commercial viability due to difficulties synthesizing these materials in bulk form. The relatively weak metal–ligand coordination bonds in MOFs make the materials chemically unstable, thus giving them low endurance in different types of chemical environments.



Credit: Nozari et al., *Nature Communications* (CC BY 4.0)

Examples of ionic liquid-incorporated ZIF-8 showing evidence of melting and glass formation after treatment in low temperature (a–c) and high temperature (d–f) conditions. Scale bars are 100 µm.

The discovery a few years ago that forming MOFs in a glassy phase gives them enough stability for bulk production was a milestone, and there are now several studies on the properties of such glasses.

Researchers have devoted particular interest to MOF glasses made from zeolitic imidazolate frameworks (ZIFs). ZIF-based MOFs exhibit higher thermal and chemical stability than other MOF subsets.

Frustratingly, only a handful of ZIFs have led to melt-quenched glasses due to the limited meltability of many ZIFs, which results from the organic ligands decomposing before the metal–ligand coordination bonds can break and reform. If the material could be modified so that the melting temperature is reached before decomposition, it would enable access to a much more diverse array of MOF glasses.

The researchers of the recent open-access paper explored the potential of ionic liquid to decrease the melting temperature. Ionic liquids are salts that exist as liquid at temperatures below 100°C. Researchers have conducted extensive experimental and computational investigations on ionic liquid–MOF composites because interaction between these materials can create new functional sites favorable for adsorption, catalysis, and ion conduction.

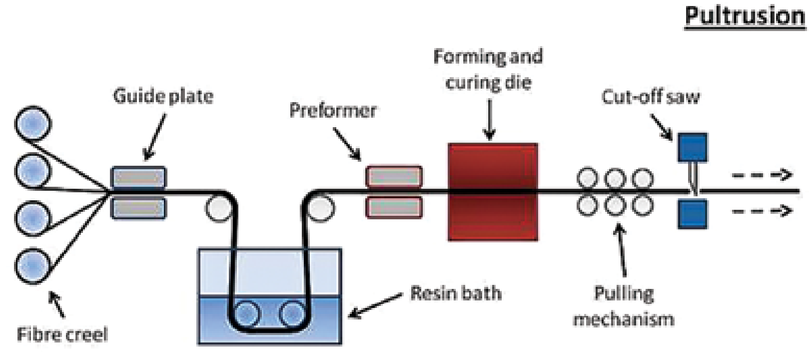
In 2017, a paper by researchers in Turkey clarified another result of the ionic liquid–MOF interaction. Specifically, they showed that the ionic liquid weakened the bond between the organic ligands and metal ions, resulting in lower thermal stability—and thus making the composite easier to melt.

For the recent study, the researchers loaded ZIF-8 with hydrophobic ionic liquid [EMIM][TFSI]. After confirming through X-ray diffraction and scanning electron microscopy that incorporating the ionic liquid did not damage the crystal structure or morphology of ZIF-8, they used thermogravimetric analyses coupled with differential scanning calorimetry to investigate what happened to the composite upon heating.

They discovered that the ionic liquid began decomposing upon heating, and the partially decomposed ionic liquid fragments helped stabilize the rapidly decomposing ZIF-8 organic ligands. This stabilization kept the material from decomposing too soon and allowed the material to reach the decreased melting temperature—and successfully undergo the process to become a glass.

"It offers exciting opportunities to melt other nonmeltable crystalline MOFs, potentially enabling a broad range of hybrid glasses with a variety of physicochemical properties and corresponding applications, in particular, ones which are derived from MOF architectures with large pore sizes," they conclude.

The open-access paper, published in *Nature Communications*, is "Ionic liquid facilitated melting of the metal-organic framework ZIF-8" (DOI: 10.1038/s41467-021-25970-0). 100



Fibres are pulled from a set of fibre reels and through a resin bath. They then pass through a preformer, which aligns the fibres into the required cross-sectional shape. The forming and curing dies finalise the shape of the composite, remove any excess resin and cure the composite so that it can be cut into sections of the necessary length by the cut-off saw. This technique is suitable for high volume, continuous production, and is able to produce parts with high fibre density and good resin dispersion.

Credit: CORE-Materials, Flickr (CC BY-NC-SA 2.0)

The potential of pultrusion to produce shape memory polymer composites

Researchers from the Skolkovo Institute of Science and Technology in Russia, plus a colleague from the University of Southern Queensland in Australia, explored the potential of pultrusion to produce shape memory polymer composites (SMPs).

SMPs are polymeric smart materials that can recover their initial shape under the influence of external stimuli, such as temperature, light, moisture, acidity, or electricity. SMPs are quickly making their mark on the materials world with applications in aerospace, biomedicine, the automotive industry, 4D printing, temperature sensors, and electronic devices.

A drawback of SMPs is their comparatively low tensile strength and stiffness, which can limit their application in demanding environments. Fortunately, researchers can improve the mechanical properties of SMPs by reinforcing the polymer matrix with various fibers, such as carbon, basalt, or glass.

Researchers have described several methods for producing SMP composites in the literature, yet surprisingly, the highly automated and continuous pultrusion process is not one of them.

In pultrusion, reinforcement fibers are impregnated with resin and then fed into a heated die where the resin is polymerized, after which the cured composite is cut to the required lengths. Not only does pultrusion offer several benefits over traditional manufacturing processes—such as high production speed, low waste, and virtually indefinite length of the produced profiles—the final composites have a high volume fraction of reinforcement, thus ensuring excellent mechanical properties.

Based on these benefits, "it is believed that pultrusion can be successfully used to produce new types of shape memory structural components with unique combinations of geometries and mechanical properties," the researchers write in the recent paper.

They evaluated the shape memory performance of pultruded glass fiber reinforced epoxy-based composites via a series of bending tests on flat, rectangular specimens with either 0° or 90° fiber orientation.

Test results showed that the shape programming angle had no effect on the shape fixity and shape recovery ratios. In addition, the researchers established a linear relationship between the shape fixing angle and shape programming angle, allowing them to obtain the desired shape after programming.

"Considering these results, pultruded [SMP composites] show significant promise for structural applications based on shape memory composites," they conclude.

The paper, published in *Composites Part A: Applied Science and Manufacturing*, is "Shape memory behavior of unidirectional pultruded laminate" (DOI: 10.1016/j.compositesa.2021.106609) 100

bulletin | cover story

GAME-CHANGERS: How ceramic and glass materials enhance performance and provide safety to sports

By April Gocha and Lisa McDonald

Sports are integral to society—not only do they provide entertainment, physical activity, and leisure, but sports are deep parts of identities, cultures, and economies worldwide. The $1.1 trillion sports market includes ripe potential for ceramic and glass materials in both established products and innovative new technologies.

At the Tokyo 2020 Summer Olympics, athletes set 20 new world records.[1] Yet human bodies today are not much different than they were decades ago—so how do athletes keep pushing the limits of what is physically possible?

U.S. professional tennis player Serena Williams plays in the first round of Women's Singles at the Rio 2016 Olympic Games. Williams used a Wilson Blade 104 racket, which features a braided graphite and basalt frame to improve the flex of the racket.

Part of the continual improvement of athletic performance can be attributed to our enhanced understanding of human physiology, which allows for more strategic training plans and coaching, improved nutrition to fuel athletes' bodies, and better recovery to prevent injury. Yet physiology by itself does not tell the full story. Sydney McLaughlin's sprint at Tokyo 2020, which set a new world record in the women's 400-meter hurdles at a blistering 51.46 seconds, nearly one-half second faster than the previous world record, cannot be attributed solely to tailored training and recovery plans and proper nutrition.

McLaughlin and countless other track and field athletes who competed in Tokyo can probably attribute some of their swift success to the $1.5 million rubber track that they competed on. The track, developed by Italian company Mondo, consists of an upper layer of rubber granules engineered to provide bounce and a lower layer filled with air cavities to absorb shock, a two-part strategy that offers athletes better return of their energy. Mondo estimates that returning the energy rather than allowing it to dissipate provides athletes with as much as a 2% competitive advantage, a difference in performance that can mean setting a new world record.[2]

So, the question of how athletes keep pushing the limits is answered partly by technology. Advances in the materials for equipment, apparel, surfaces, and more within the sports industry have enabled bounds in performance and continue to push the limits of what the human body is athletically capable of achieving. We laud the athletes for their feats of incredible athletic performance—yet materials also play a pivotal role in enhancing and extending human performance in sports.

A big market means big potential for materials—ceramics and glass in sports

The global sports market is estimated to be worth $1.1 trillion, according to a recent report by Signa Sports United and Boston Consulting Group.[3] While that figure also includes sporting events and other sports-associated value, sports retail including equipment and apparel holds a significant share. "Sports retail is the largest part of the sports market, accounting for $475 billion of spending and anticipated to grow 7% annually to reach $670 billion in 2025—at 1.4x the rate of GDP growth," the report indicates.

In other words, sports is a big, growing market with big potential for materials (Table 1).

Figure 1. A look at the many uses of ceramic and glass materials in sports.

So how do ceramic and glass materials contribute to the world of sports? While metals and polymers might be more immediately recognized in some applications, ceramics and glass are found throughout sports as well, where the materials' desirable mechanical, electrical, and optical properties are often leveraged in combination with other materials. Though this article cannot cover every use of ceramic and glass materials in every sport around the world, we hope to show just how integral and valuable ceramic and glass materials are throughout sports (Figure 1).

Early iterations of most sports equipment relied on natural materials such as wood, cotton, rubber, and leather. Indeed, many sports still do—professional baseballs consist of a cork or rubber core wound with yarn (mostly wool, although the outermost layer is now a cotton-polyester blend) and encased in leather, a composition largely unchanged over decades of play.[4]

But countless other types of equipment evolved sometimes drastically over the years, often leaving behind natural materials in favor of the enhanced performance offered by engineered materials. Table 2 presents a small sampling of engineered materials in sports to demonstrate the enormous breadth of applications.

Many uses of ceramics and glass in sports are realized by composite materials, which dominate in modern sports equipment. Due to their low weight and high strength, composites have infiltrated nearly every part of the sports industry, finding applications in bicycles, rackets, golf clubs, hockey sticks, fishing rods, surfboards, skis, snowboards, boats, kayaks, canoes, race cars, bobsleds, skateboards, archery bows and arrows, gymnastics bars, and even some unusual sports (see sidebar: *Obscure sports*).

Many of the composite materials used consist of a polymer matrix reinforced with fibers of ceramic or glass materials. Glass or carbon fiber-reinforced composites are most common in sports equipment, although fibers made of silicon carbide or other materials can be found as well. Sometimes, both carbon fiber and fiberglass are incorporated together. Generally, however, such equipment can be found with different varieties of fiber-reinforced composites depending on the level of competition and price range of the equipment, among other sport, region, and/or athlete preferences.

The total global market for carbon fiber reached $4.3 billion in 2019 and is projected to be valued at $5.5 billion in 2025. Of that entire market, sporting

Game-changers: How ceramic and glass materials enhance . . .

Table 1. Select companies involved in the sports industry*

Company (location)	Annual revenue (millions)*	Website	Role in value chain
Supply carbon fibers or carbon fiber composites			
Hexcel (Stamford, Conn.)	$1,502	www.hexcel.com	Manufactures advanced composites, particularly carbon fiber, for diverse markets including recreation and marine.
SGL Carbon (Wiesbaden, Germany)	$1,061	www.sglcarbon.com	Manufactures carbon and graphite materials, including fibers and composites, for diverse markets including automotive.
Teijin Carbon (Tokyo, Japan) Parent company: Teijin	– $7,513	www.teijincarbon.com	Manufactures carbon fiber composites for diverse markets including automotive and sporting goods.
Solvay (Woodland Park, N.J.)	$10,269	www.solvay.com	Manufactures various materials and chemicals, including composites, across diverse markets including sports and automotive.
Mitsubishi Chemical (Tokyo, Japan) Parent company: Mitsibishi Chemical Holdings	– $29,259	www.mca-golf.com	Manufactures composite golf club shafts.
Toray Industries (Tokyo, Japan)	$19,892	www.toray.com	Manufactures various chemicals and materials, including carbon fiber composites, for diverse markets including sports and automotive.
Supply glass fibers or glass fiber composites			
Owens Corning (Toledo, Ohio)	$7,055	www.owenscorning.com	Manufactures insulation, roofing, and fiberglass composite materials for building and industrial applications, including boating and consumer goods.
China Jushi Co. Ltd. (Tongxiang, China)	$1,770‡	www.jushi.com	Manufactures fiberglass for diverse product markets including sports and recreation, automotive, marine, electronics.
Saint-Gobain Vetrotex (Courbevoie, France) Parent company: Saint-Gobain	– $44,025	www.vetrotextextiles.com	Manufactures fiberglass for diverse markets including marine, automotive, electronics, and sports.
Nippon Electric Glass (Otsu, Japan)	$2,180	www.neg.co.jp/en	Manufactures glass products, including fiberglass, for diverse markets including automotive.
AGY (Aiken, S.C.)	$221‡	www.agy.com	Manufactures fiberglass for diverse markets including sports, automotive, and marine.
Johns Manville (Denver, Colo.)	$2,000‡	www.jm.com	Manufactures insulation, roofing, and engineered products including fiberglass and composites for diverse markets including automotive and marine.
Most valuable sports brands worldwide†			
Nike (Beaverton, Ore.)	$36,800	www.nike.com	Designs, develops, manufactures, and markets sports apparel, footwear, equipment, accessories, and services.
ESPN (Bristol, Conn.)	$13,100	www.espn.com	Sports media conglomerate that includes cable channels, broadcasting, and radio.
Adidas (Herzogenaurach, Germany)	$11,200	www.adidas.com	Designs, manufactures, and markets sports apparel, footwear, and accessories.
Gatorade (Chicago, Ill.)	$6,700	www.gatorade.com	Brand of sports-themed beverage and food products.
Sky Sports (London, U.K.)	$4,400	www.skysports.com	Group of British subscription sports channels.
Puma (Herzogenaurach, Germany)	$4,000	www.puma.com	Designs, manufactures, and markets athletic apparel, footwear, and accessories.
Under Armour (Baltimore, Md.)	$3,500	www.underarmour.com	Designs, manufactures, and markets sports apparel and footwear.
Ultimate Fighting Championship (UFC) (Las Vegas, Nev.)	$2,400	www.ufc.com	Mixed martial arts promotion company.
Yankee Entertainment and Sports (YES) Network (Stamford, Conn.)	$1,500	www.yesnetwork.com	Regional sports television network primarily serving the northeast U.S.
Reebok (Boston, Mass.)	$800	www.reebok.com	Designs, manufactures, and markets athletic apparel and footwear.

*Conversions per Google as of October 6, 2021. All financial data obtained from company reports unless otherwise noted.

‡Private company or data not available; revenue estimated from dnb.com or google.com.

†Statista data from 2019 (https://www.statista.com/statistics/253349/brand-value-of-sports-businesses-worldwide).

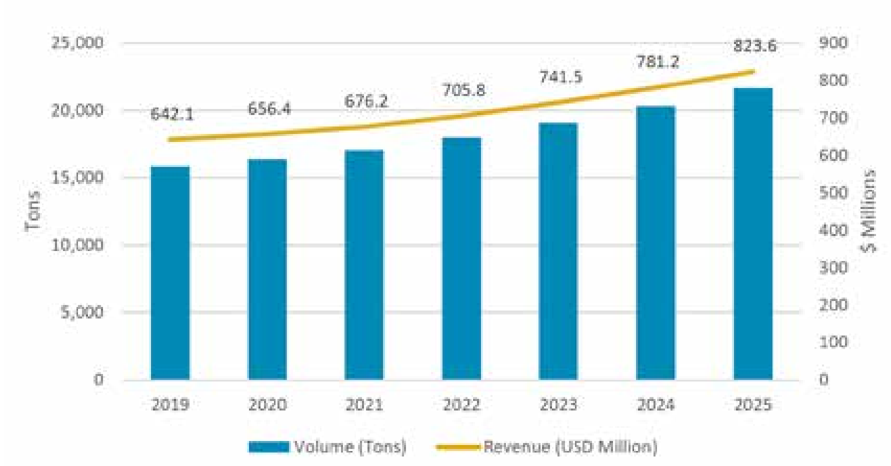
goods accounted for 15.7% of the carbon fiber market in 2019, representing nearly 16 tons of the material's annual use (Figure 2).[5] Carbon fiber composites are 40% lighter than aluminum, and thus offer significant weight savings in addition to high strength and stiffness and resistance to chemicals, corrosion, and fatigue.

Golf clubs account for the largest segment of sports uses of carbon fiber. Similar to most other types of modern sports equipment, golf clubs are multimaterial—various parts of the same piece of equipment may contain several materials, and different makes and models of the equipment may incorporate a range of materials as well.

For example, the shafts of golf clubs are often made of carbon or boron fiber-reinforced composites but also may be steel, aluminum, or "titanium carbon" (a titanium alloy and carbon composite). Club heads for drivers are usually made of carbon-based composites, metals, or woods (sometimes filled with polymer foam), while heads of irons, wedges, and putters are generally composed of metals such as steel, titanium, or tungsten. Face inserts on golf club heads (a separate piece of material positioned where the club comes into contact with the ball) may be zirconia ceramic or titanium metal matrix ceramic composite.[6]

For decades, Formula One vehicles have incorporated a substantial amount of carbon fiber to reduce weight, thanks to the sport's willingness to invest in composites despite its early expensive price. Modern F1 vehicles are composed of 80% by volume composite materials, most of which are carbon fiber.[7] As the price of carbon fiber decreases, motorsports in general continue to incorporate more carbon fiber composites to increase efficiency, in addition to the material's ability to enhance safety and handling through its high strength and stiffness.

Another place carbon fiber can be found, perhaps surprisingly, is on athletes' feet. (Table 2). A company called Carbitex (Kennewick, Wash.) developed an asymmetrically flexible carbon fiber/thermoplastic composite material that is flexible in one direction yet rigid in another, mimicking and protecting the



Credit: BCC Research[5]

Figure 2. Global market for carbon fiber used in sports equipment, 2019–2025. The market is expected to grow at a compound annual growth rate of 5.7% during this time.[5]

OBSCURE SPORTS

Around the world, athletes engage in more than 200 sports recognized by national or international federations,[a] yet estimates suggest there are actually more than 8,000 indigenous sports or sporting games around the world.[b] No matter how you tally the count or what you consider a "sport," it is clear that humans find a lot of ways to play and compete.

While some of the more popular sports worldwide include soccer, football, baseball, auto racing, basketball, hockey, tennis, and golf, there are diverse ways that athletes engage. The following is a sample of some more obscure sports with which you may not be familiar.[c–e]

- **Lawnmower racing**—Competitors race modified lawnmowers around a track.
- **Underwater hockey**—also called octopush, players wear snorkels and play a form of hockey on the floor of a pool.
- **Bossaball**—Somewhat akin to volleyball, except that the game is played on a giant inflatable and involves a player on a trampoline designated as the "attacker."
- **Zorbing**—Racing downhill in large inflatable plastic balls, akin to a hamster ball.
- **Cheese rolling**—Racing down a hill on foot to try to catch a rolling ball of cheese, which can reach speeds of about 70 mph.
- **Bog snorkeling**—Racing through a 55-meter peat bog using a snorkel and flippers.
- **Chess boxing**—A hybrid of chess and boxing, with players alternating between the two.
- **Kabaddi**—A combination of wrestling, tag, and holding players' breath, originating from South Asia.
- **Cycleball**—A combination of bicycling, soccer, hockey, and basketball, in which players hit a ball using their bicycle wheels.
- **Extreme ironing**—Ironing clothes in extreme places such as while skydiving, on a glacier, or on the roof of a speeding car.
- **Face slapping**—Competitors take turns slapping one another until someone taps out or is knocked out. 100

[a]Topend Sports, "Complete list of sports from around the world," https://www.topendsports.com/sport/list/index.htm

[b]"How many sports are there in the world?" In World Encyclopedia of Sports (ISBN: 9780760316825). Archived copy available at: https://web.archive.org/web/20100723160638/http://www.sportencyclopedia.com/index.php?mod=book

[c]K. Baumer, "The 18 strangest 'sports' in the world," March 3, 2011, Business Insider. https://www.businessinsider.com/obscure-weird-sports-2010-11

[d]E. Ortiz, "Strangest sports in the world," June 4, 2021, Stadium Talk. https://www.stadiumtalk.com/s/worlds-strangest-sports-a8bef81c8b8941b3

[e]D. Gachman, "Meet the fearless women of the Lone Star Mower Racing Association," September 22, 2021, Texas Monthly. https://www.texasmonthly.com/arts-entertainment/meet-fearless-women-texas-lone-star-mower-racing-association

motion of human joints.[8] In another footwear application, Nike's Vaporfly 4% running shoes incorporate a curved carbon fiber plate in the shoe's midsole designed to maximize energy return in a runner's foot. That energy return amounts to an average 4% improvement in the energy a runner needs to exert to run a certain pace, called running economy.[9]

Carbon fiber, too, is finding its way into protective equipment applications. For example, professional baseball uses aerospace-grade carbon fiber composite helmets that are 300% stiffer and 130 times stronger than previous ABS plastic helmets. While those previous helmets could protect players from ball strikes up to 68 mph, the new helmets provide protection up to 100 mph.[10] As carbon fiber's price continues to decrease, the material is expected to find more applications in protective sports equipment.

Besides carbon fiber, Table 2 points to other carbon-based materials that find use in sports equipment for their high strength and low weight, including carbon nanotubes, carbon nanoparticles, and fullerenes, especially for applications to increase gliding, resist abrasion, and repel moisture.

Glass fiber-reinforced composites are another predominant composite in sports equipment. They similarly offer high strength and low weight yet at a lower cost than carbon fiber composites. Fiberglass composites can be found in many of the same sports equipment as carbon fiber composites, but they are often used in lower-cost versions, such as equipment marketed to amateurs and beginners. Composites reinforced with glass fibers are preferable to carbon fibers in some applications that do not require high stiffness

Protective sports equipment is an important use of fiberglass composites. The U.S. market for protective sports equipment reached $1.9 billion in 2016 and is expected to reach a value of $2.2 billion by 2022.[10] While the market is dominated by polymers due to their light weight and impact resistance, fiberglass can be found in the outer shells of many helmets and goalie/catcher masks. In addition to composites, other form factors of glass are sprinkled throughout sports for basketball backboards, safety barriers, reflective clothing, and more (Table 2).

Motorsports vehicles incorporate many sensors, electronics, and other components that use ceramic and glass materials. The rising popularity of racing series for electric vehicles, such as Formula E, offer additional opportunities for ceramic and glass materials in the vehicles' batteries as well.

Increasingly, athletes use wearable devices and electronics to track, time, and monitor athletic performance. These devices rely on ceramic and glass materials in diverse ways for the sensors, electronic components, and batteries. Further, ceramic components are found in LED lights that enable viewing of sports events and provide visibility and safety to athletes in the dark.

Other applications of ceramics include equipment that requires wear and corrosion resistance, which is especially useful for various wheel-based components that provide athletes with

Table 2. Sampling of ceramic and glass materials used in sports equipment

Carbon fiber composites	
Bicycles	Frames, forks, saddles, handlebars, wheels
Implements	Tennis rackets, hockey sticks, pole vaulting poles, ski poles, golf clubs, fishing rods
Skeleton sleds	Base plates
Racing sailboats	Up to 2,000 lbs in a 50-foot racer
Formula One cars	80% composite by volume (mostly carbon) Body components: spoilers, fenders, engine hoods, doors, roof Structural components: rear seats, roof frames, struts, door sills, pillar reinforcements System components: powertrain, motor block, brake system
Footwear	Snowboarding, cycling, watersports, running shoes, hiking boots
Protective equipment	Helmets, goalie and catcher masks
Carbon nanotube, nanoparticles, fullerenes	
Sliding sports	Ski wax, kayak coatings, ice skate blade coatings
Fiberglass composites	
Protective equipment	Helmets, goalie and catcher masks
Implements	Tennis rackets, hockey sticks, pole vaulting poles
Winter sports	Skis, snowboards, bobsleds, luge sleds
Water sports	Surfboards, paddleboards, canoes, kayaks
Field sports	Hurdles, goals and goalposts
Bulk glass	
Backboards	Tempered glass basketball backboards
Safety barriers	Hockey rinks, racquetball and squash courts, underwater aquatic viewing windows
Safety apparel	Reflective glass apparel
Electronic materials	
Auto racing	Sensors, Formula E electric vehicle racing batteries
Wearable devices	Sensors, batteries
Lighting	LED venue and athlete safety lighting
Ceramics	
Wheeled equipment (Bicycles, skateboards, wheelchairs)	Ceramic bearings, brackets, brakes, boron nitride lubricants
Shoes	Cleat tips
Skiing	Inrun ski jump tracks
Playing venues	Concrete courts, ceramic tile swimming pools, tiled aquatic arenas

SPORTS EQUIPMENT AT THE PARALYMPICS

While many eyes tuned in for the Tokyo 2020 Summer Olympics that took place in July 2021, another major international sports competition took place at the end of August—the Tokyo 2020 Paralympic Games.

The Paralympics are a series of international contests for athletes with disabilities that are associated with and held following the summer and winter Olympic Games. Developing from a 1948 sports competition for British World War II veterans with spinal cord injuries, the Paralympics has grown to welcome more than 4,500 athletes in 2021 to compete in 539 events across 22 sports.

Below is a look at some of the equipment used in the Paralympics that contain ceramic and glass materials.

Running blades

Running blades are prosthetic lower limbs used by amputee runners. American medical engineer Van Phillips developed the first running blade, called the "Flex-Foot," in the 1970s after losing part of his left leg in a motorboat accident. Unlike previous prosthetics that tried to mimic human bones, he focused on replicating ligaments and tendons. He observed animals like kangaroos and cheetahs as well as the mechanics of diving boards and pole vaulting to develop the blade design.[a]

Carbon fiber is the material of choice for running blades, from the very first Flex-Foot to today. Between 30–90 sheets of carbon fiber are fused together to form the blade. Running spikes are typically fitted to the blade to help with gripping to the track.

Engineers continue to explore improvements in running blade design. For example, in 2013, Paralympian runner Blake Leeper challenged attendees at the Industrial Designers Society of America to advance the technology of running blades. Two companies, Altair (known for product design and development) and Eastman (a chemicals and plastics manufacturing supplier) consulted with Leeper and together developed a new "F1" concept for running blades that differs from traditional blades in the following ways.[b]

- **The spike plate**. Running blades are normally flat planes, but the F1 concept features a curvature that acts like an ankle, providing increased speed and efficiency on corners.
- **Blade shape**. The F1 concept modifies the blade shape to direct more power forward instead of into the ground, improving aerodynamics.
- **Blade attachment**. To keep the blade from falling off, the F1 concept uses both a fabric shroud and latch to lock the socket into place.

Icelandic prosthetics firm Össur hf. is a main player in the running blade industry. They acquired the original Flex-Foot line of blades from Phillips in 2000,[c] but what they are most well-known for is the Cheetah line of blades, which features blades not only designed for short- and long-distance running but also for long jumps.[d]

Sports wheelchairs

Just like prosthetic limbs, sports wheelchairs must become one with the athlete's body, otherwise performance is negatively affected. Some considerations when designing sports wheelchairs include[e]

- **The seating system**. A snug and well-fitted seat ensures the shoulder joints are in a neutral safe position.
- **The seat dump**, i.e., the angle of the seat with respect to horizontal. A larger seat dump increases pelvic stability by holding the pelvis against the backrest and improves balance by reducing the angle between the thighs and the trunk.
- **The backrest.** Backrest height should be set as low as possible to provide support to the lower back and allow the upper torso to move freely.

Wheelchairs for different sports require different designs.[f] For example, fencing wheelchairs are equipped with leg straps and sturdy handles to help the athlete stay solidly seated while striking and dodging. Racing wheelchairs are designed for high speeds, so they often feature a third wheel in the front to enable a low, elongated shape, and smooth disks instead of spoked wheels to generate less air turbulence. For sports requiring maneuverability, such as basketball, the wheels are slanted to allow for faster and tighter turns.

Ceramic materials used in wheelchairs include

- **Carbon fiber**. Modern advancements have increased the use of carbon fiber in sports wheelchairs. For example, carbon fiber wheels and frames are used in racing chairs such as the Top End Eliminator NRG,[g] and custom molded carbon fiber seats are found in basketball chairs such as the RGK Elite CX.[h]
- **Ceramic bearings**. Well-made ceramic bearings roll faster thanequivalent steel bearings, thereby allowing an athlete to save their energy and achieve faster cruising speeds. AITA Ceramic–Australia International Ceramic, a Melbourne-based bearing business, worked with Australian Paralympic athlete Sam McIntosh to develop hybrid ceramic bearings specifically for wheelchair sports.[i] Draft Wheelchairs Ltd., a Godmanchester, U.K.-based company that provides equipment to people with disabilities, endorsed the ceramic bearings produced by CeramicSpeed, a small specialist Danish manufacturing company, for use in racing wheelchairs.[j] 100

Credits: Left, Canadian Paralympic Committee, Flickr (CC BY-NC-ND 2.0). Right, Farrukh, Flickr (CC BY-NC 2.0)

Wheelchairs feature different designs depending on the sport for which it will be used. Left, the gold medal game in men's wheelchair basketball at the Beijing 2008 Summer Paralympics. Right, wheelchair fencing at the London 2012 Summer Paralympics.

[a] "Running blades and their evolution," *National Paralympic Heritage Trust*, n.d. https://www.paralympicheritage.org.uk/running-blades-and-their-evolution

[b] A. Schwartz, "These reinvented running blades could let more Paralympians into the Olympics," *Fast Company*, 14 Aug. 2014. https://www.fastcompany.com/3034308/these-reinvented-running-blades-could-let-more-paralympians-into-the-olympics

[c] "50 years of memorable moments, 1971–2021," *Össur*, n.d. https://www.ossur.com/global/about-ossur/our-company/milestones

[d] "All products," *Össur*, https://www.ossur.com/en-us/prosthetics/products

[e] "Wheelchair sports technology and biomechanics," *Musculoskeletal Key*, n.d. https://musculoskeletalkey.com/wheelchair-sports-technology-and-biomechanics

[f] S. Bushwick, "How Paralympic wheelchairs and prostheses are optimized for speed and performance," *Scientific American*, 31 Aug. 2021. https://www.scientificamerican.com/article/how-paralympic-wheelchairs-and-prostheses-are-optimized-for-speed-and-performance

[g] Top End Eliminator NRG, https://topendwheelchair.invacare.com/eliminatorNRG

[h] RGK Elite CX, https://rgkwheelchairs.com/wheelchairs/sport-wheelchairs/elite-cx.html

[i] "Wheelchair bearing," *AITA Ceramic–Australia International Ceramic*. https://aitaceramic.com/wheelchair-bearing

[j] "Ceramic bearings for racing wheelchairs and handcycles?" *Draft Wheelchairs*, http://www.draftwheelchairs.com/ceramic-bearings-racing-wheelchairs-handcycles

motion (summarized in Table 2 and the sidebar: *Paralympics*). Other examples of ceramics are found sporadically throughout sports. For instance, clay pigeons or clay traps, while not made of clay, are manufactured from petroleum pitch and calcium carbonate, and the inner weighted core of bowling balls contains a mixture of minerals embedded in a polymer resin. Readers will know of many similar applications.

In addition to sports equipment, ceramic and glass materials can be found in sports apparel (see sidebar: *A softer side*) as well as some athletic surfaces.[11]

Game-changer: Materials innovations shift sports

Materials often enable technologies for athletic performance—so it is no surprise that as the materials used in sports evolve, so too does athletic competition.

"If you would have watched tennis 20 years ago on the professional level, you would have seen a much slower paced game," says Jeff Bardsley, vice president of marketing for racket sports in North America at Head, a global manufacturer and provider of various sports equipment and apparel. "The ball would have been moving a lot slower, and therefore demands on the actual player wouldn't be as high as they are today. Today's game is very, very fast."

That evolution can be traced back to the equipment. By reducing the weight of tennis racket frames while simultaneously increasing their stiffness, modern composite tennis rackets can be swung faster and generate more power than early wooden tennis rackets. Modern composite rackets are 22.4% lighter on average that wooden versions,[12] resulting in 17.5% faster serve speeds overall since the game's inception in the 1870s.[13] "Rackets now offer more power, more spin, and that's been changing the game up just in terms of how the game is played," Bardsley says.

Modern tennis racket frames are made of various lightweight materials, depending on the level of competition and the price point. For instance, Head manufactures lower-price rackets intended for beginners made from aluminum nylon frames. The company also manufactures mid-level rackets from graphite composites, a combination of aluminum and graphite fiberglass or graphite composite. For its higher-level rackets, Head uses graphite, which is more expensive due to higher material cost and its more complex construction. There are variations of these types of materials in each category, but most of Head's tennis rackets consist of carbon-based and fiberglass materials.

Despite this slight variability in materials, tennis rackets have not changed much in the past several decades, partially based on parameters set by the ruling body, the International Tennis Federation, that restrict variability in tennis rackets. "Looking at a tennis racket, there's really only so much that you can do because it has to have a head, it has to have some form of throat, and it has to have a handle," Bardsley says. Manufacturers can adjust some external parameters of a tennis racket frame, such as the racket length and head size, but they are relatively limited in terms of completely redesigning a racket that can be used in competition play.

That does not mean all tennis rackets are the same, however—and some of these small changes can have a significant impact on the resulting equipment. For instance, adjusting how a tennis racket is balanced from the head to the handle impacts performance. Perhaps even more adjustments can come from internal changes to the racket frame. Part of these adjustments come from changing the materials, but also changing the orientation of the materials' fibers in one part of the frame or another, Bardsley says.

"We can also change by placing materials at different areas on the actual head of the racket to determine how the racket is going to play. The size of the sweet spot is going to be determined by the placement of the materials, the layup on the materials. By taking a similar tennis racket construction and changing the layup, changing the actual balance point of the racket, changing minor configurations, you can take two different rackets that look exactly the same and they will play completely different," he says.

Overall, though, these variations result in relatively minor tweaks to tennis rackets. Manufacturers generally are not drastically altering the design or researching entirely new materials to incorporate into the frame. They are altering the fiber orientation, slightly adjusting the frame dimensions, or testing the effect of adjusting a material in certain areas of the racket, for example.

Yet that is not to say that Head does not innovate with new materials in tennis rackets. In the early 2000s, Head introduced a new line of tennis rackets, the Intelligence collection, that incorporated piezoelectric fibers in the frame. "Our concept with the piezoelectric fibers was transforming mechanical energy into electrical energy, causing a faster snap back, giving us an opportunity to stiffen up the throat section of the racket," Bardsley says. Those lead zirconate titanate fibers, supplied by Advanced Cerametrics Inc. (Lambertville, N.J.), generated an electrical current when the racket deformed upon contacting a tennis ball.[14] A chip located in the racket's handle amplified the signal, stiffening the frame to generate more power and reduce vibrations.

The Intelligence rackets, despite an expensive price of about $400 almost 20 years ago, sold much better than Head anticipated. Yet Head discontinued the high-end line after being on the market for less than a decade. "We didn't necessarily abandon it. It was more just moving on in terms of technology goes," Bardsley says.

Today, Head's primary focus for new technology in its tennis rackets is on graphene. The 2D carbon material provides the ability to further decrease the weight of a racket by using less material, without sacrificing stiffness or strength. While Head initially used graphene in only key limited areas of the racket—focusing on the throat section, which is a high point of distortion on the racket—it is now incorporating graphene all along the racket head and throat with its Graphene 360+ technology. "So that gives us the opportunity to really play different, and it gives a consistent and solid feel for the racket where we've got a consistent flexpoint, which allows more of a consistent hit or performance when the ball actually is coming off the racket," Bardsley says.

A SOFTER SIDE: CERAMIC AND GLASS MATERIALS OFFER FUNCTIONALITY TO SPORTS FABRICS

Athletic apparel is a significant segment of the sports industry. In 2020, total global revenue for sports apparel exceeded $188 billion, with expectations of reaching nearly $208 billion by 2025.[a]

While synthetic fabrics that provide stretch, breathability, odor control, and moisture-wicking capabilities dominate sports apparel, this segment of the sports market is not entirely devoid of ceramic and glass materials.

Apparel designed to make athletes visible in low-light conditions, such as runners jogging at night, use retroreflectivity to maximize the light reflected light back to its source, such as a vehicle's headlights. This reflection is via microscopic yet precise glass beads, which reflect light directly back rather than scattering it. Often applied as a film on top of another fabric, retroreflective materials are found on a wide variety of shoes, jackets, apparel, and accessories.

In 2017, 3M released a new retroreflective material, Carbon Black, that appears black in daylight, as opposed to the silver color of most retroreflective materials. The company achieved the black color through a proprietary process that "makes the color inherent to the material's construction," according to a 3M press release.[b]

3M's Carbon Black technology appears black in daylight yet contains small glass beads that are highly retroreflective. Most retroreflective materials appear as a silver color.

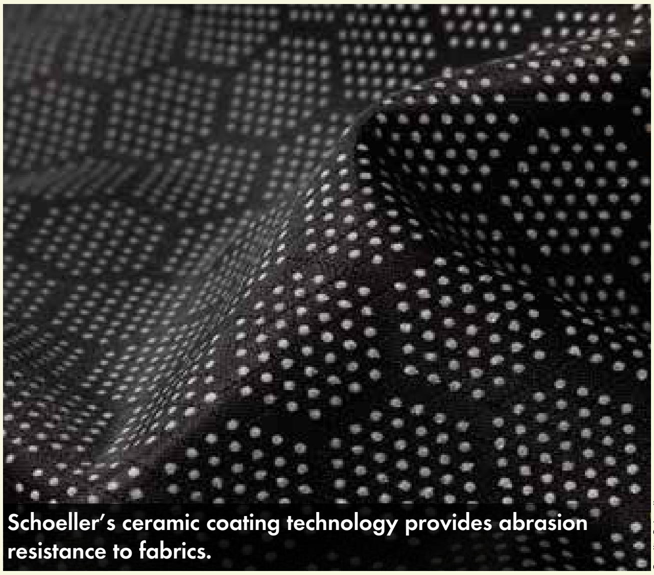
Credit: 3M

In addition to visibility, ceramic materials can be found on sports apparel fabrics designed to provide abrasion and wear resistance.

For example, Swiss company Schoeller manufactures a durable and abrasion-resistant textile with a ceramic coating for applications such as cycling. "The ceramic finishes fit together with the selected raw materials and the textile design to offer not only abrasion resistant materials with ceramic coatings, but also fall protective materials in the motorcycle or bike category," the company says.

One version of the ceramic-coated fabric, called ceraspace, is Schoeller's "particularly high-performance" fabric for applications that require maximum protection such as motorcycling. The company puts its materials through rigorous performance tests, including standardized tear and tensile strength, abrasion, elongation, pilling, weight, deformation, and weather tests, in addition to the company's own unique testing methods. According to its testing, Schoeller says ceraspace provides around three-times the abrasion resistance of high-quality leather.[c]

While the composition of the ceramic is proprietary, Schoeller says the coating can be applied as either a finishing or printing process, with the ceramic applied in various designs such as small dots. The durable coatings stay on the fabric even after washing. As the company says, "they are developed to last the lifetime of the garment."



Schoeller's ceramic coating technology provides abrasion resistance to fabrics.

Credit: Schoeller

[a]Statista, 2021. https://www.statista.com/statistics/254489/total-revenue-of-the-global-sports-apparel-market

[b]3M, "3M reinvents reflective material for activewear with Carbon Black technology," 2017. https://news.3m.com/2017-05-02-3M-Reinvents-Reflective-Material-for-Activewear-with-Carbon-Black-Technology

[c] Schoeller. https://www.schoeller-textiles.com/en/technologies/ceraspace

Head's approach is reflective of that of other major companies manufacturing sports equipment in more mature product markets, in which they offer equipment manufactured with various materials for different levels of athletes. They innovate with materials and design to sell more pieces of equipment, often incrementally pushing those markets in one direction or another. But are there opportunities for bigger innovations in the sports world?

A testbed for materials innovation

"Sports is actually a great market to test your materials. You can show off your material, you can market your material, you can test your material in the very extreme conditions," says Erik Khranovskyy, CEO of Grafren AB (Linköping, Sweden). Grafren specializes in graphene-coated textiles, which provide the ability to incorporate sensing and power functions within clothing, including athletic apparel (Figure 3).

Many sports markets are well-funded, willing to take chances to gain a competitive advantage, and offer a relatively lower-risk testing environment compared to medical or aeronautical markets, for example.

In addition, while regulatory bodies set guidelines or standards for use of technology in sports competitions, those rulings often are reactions to new developments rather than in anticipation of potential innovations. For instance, Speedo's LZR Racer swimsuit, which debuted at the Beijing 2008 Summer Olympics, featured a lining with thin yet stiff polyurethane panels that reduced skin friction drag by 24% compared to the company's previous racing suit fabric.[15] The swimsuit improved swimmers' performance and speed so much that 98% of swimming medals won at the 2008 Olympics were by swimmers wearing the LZR Racer. The suit was so fast that some claimed it amounted to "technological doping," and by 2010 the LZR Racer and similar types of suits were banned by the international body that regulates competition in water sports.

Yet unless regulations ban or exclude certain technologies—and there often is not a precedent to do so until that technology debuts on the market—the world of sports is usually wide open to innovation, creating a ripe environment for new materials.

For example, Grafren's nano-engineering process wraps graphene flakes precisely around individual fibers of a textile, allowing control of the graphene layer's thickness. Because every fiber is coated with a thin layer of graphene, the overall weight and porosity of the textile changes very little, making it ideal for sports apparel that needs to be breathable.

The first step of Grafren's three-step process is infiltrating graphene into the fiber. "We learned how to put the flakes inside, in the depth of the fiber," Khranovskyy says. "The second step in the process was how to fix the flakes on every single fiber, so that they lay down on the fiber."

Grafren's technique causes the graphene flakes to wrap around the textile fiber, bonding individually to the fibers. "It involves both physical forces, weak van der Waals forces, but also depending on the material, much stronger chemical bonds as well," Khranovskyy says.

The final step builds up the depth of graphene flakes on the fibers. "That's what I called graphene mâché, in analogy to papier mâché. Every flake coming in surrounds the fiber more and more, so you actually have a core–shell structure around the fiber." The graphene flakes overlap one another, creating a dense yet thin coating on individual fibers.

Grafren's water-based process does not use any binders, resulting in homogeneous, precise, and durable graphene coating of individual textile fibers. And the process can be applied to natural fibers like cotton, synthetic fibers like polyamide, and even glass and carbon fibers.

Figure 3. Graphene-coated textile produced at lab scale by Grafren, which has now mastered industrial scale at 200 cm roll-to-roll.

Credit: Grafren

Further, Grafren's fiber-coating process can be applied to other 2D materials, Khranovskyy says, noting that Grafren already filed a patent related to this technology. "Those ideas which researchers are discussing on flat surfaces, they can be realized inside of fabric on individual fibers as well," he says.

Because of graphene's conductivity, Grafren's coated fabrics offer several functional capabilities. The fabrics can collect signals from the body to act as a biomonitor or biosensor; they provide thermal management, either removing or providing heat to an athlete depending on the surrounding conditions; they can function as a strain sensor if the graphene is coated onto a stretchable fabric (so that stretching changes conductivity); and they can function as pressure sensors or impact sensors by creating an electrically conductive channel from several fibers grouped together.

"Imagine shoes—the soles could measure pressure. The more points you have, you can actually measure pressure distribution" Khranovskyy says. "The shoe could also measure the force when you kick a ball. Or consider boxing gloves that could measure pressure. So any textile, any fabric, any clothing which is in contract may be active and may provide a signal about the force and the place where it was applied."

In addition to performance, such sensors could play an important role in athlete safety as well. "If we imagine any type of a sport activity where we have helmets, then the pressure sensors can be simply integrated in the lining," Khranovskyy says. Helmet-affixed sensors could provide valuable information for assessing player injuries, such as the strength of the hit, the area of the head where the impact was localized, and when the athlete gets up from the impact.

Khranovskyy says that one of the biggest challenges Grafren faces is the vast possibilities for graphene-coated fibers—

just deciding which direction to pursue can be difficult.

"From our experience, graphene provides several functions to textiles, which enable 10 times more directions of further product development, and the amount of products is even 10 times more." Grafren works with its customers to tailor its graphene-coated textiles to a particular application.

"For every product the value may be different. So in order to commercialize it, we have to really identify what is it exactly customers would like to enable," Khranovskyy says.

A potential direction that Grafren currently is working on with one its customers is to develop heatable clothing. The company already developed a functioning prototype of its graphene-coated heated textile—although it looks nearly indistinguishable from a standard athletic textile, the fabric is coated with graphene and incorporates conductive threads running throughout the fibers that, with the press of a button on a connected energy source, gently warm the fabric.

Such fabrics have applications for athletes in cold environments but also could provide warming at specific locations for therapeutic purposes, to enhance athletic recovery.

Thermal management is a hot topic in sports apparel, with other similar types of developments using fabrics coated with carbon fibers or incorporating ceramic nanoparticles to warm or cool athletes depending on the surrounding environment.[16]

Grafren's conductive textiles demonstrate just one possible application of graphene in sports, for which there is diverse potential due to the material's long list of desirable properties.

The Graphene Flagship, a joint research venture funded by the European Commission, already helped develop several other sports-related applications of graphene, including an impact-resistant graphene-coated motorcycle helmet,[17] a transdermal patch to monitor fitness using graphene optical sensors, [18] and a graphene-based lubricant for auto and motorcycle engines.[19]

Sensing the future: Optimizing performance and enhancing safety

Sports equipment was once designed solely for mechanical performance, but advanced materials offer new design freedoms and thus new functionalities to change how sports are played, experienced, and enjoyed.

"Now, within the past decade or so, we're starting to get multifunctionality, so the materials offer say thermal control or odor control, or they're able to sense things like the pH of your sweat or your heartbeat. And that's an area really where ceramics and glasses can play an important role and already do in sports," says Jud Ready, principal research engineer at Georgia Tech Research Institute, deputy director of innovation initiatives at the Institute for Materials, and adjunct professor in the School of Materials Science and Engineering at Georgia Institute of Technology. Ready teaches a popular Georgia Tech course on materials science and engineering in sports.

The power of sensors is that they provide physical data about how athletes play sports, to inform sports strategy and improve safety, as well as physiological data about how athletes' bodies function during and after athletic exertion, to enhance performance. While vast sensors and sensing technologies are already widely incorporated into motorsports—such as ceramic oxygen sensors in motor engines—technological developments have more recently enabled biosensors and biomonitors to track a vast array of individual parameters of athletes as they practice, compete, and recover.

Devices that monitor physical performance and safety collect data on an athlete's position, motion, impact, and biomechanical forces. These devices include wearable devices to monitor head injuries in contact sports to prevent concussion or traumatic brain injury, such as helmets, headbands, caps, or neck-worn collars.

For example, several companies developed mouthguards with embedded sensors to monitor head impacts. One such device contains embedded sensors that detect collision intensity, providing a visual readout with front-facing LED lights that can alert trainers and coaches about dangerous impacts. Other developments include wearable sensors to monitor joint mechanics during play as a means to prevent injury.[20]

Other sensing devices monitor athletes' physiological status to optimize performance, collecting data on parameters such as heart rate and sleep. Optical sensors to monitor heart rate are relatively well-established technologies, with new trends toward development of skin-worn patches as well as integrated textiles that can measure heart rate. Yet while heart rate provides a global measure of physical activity and exertion, it cannot provide information on the response in specific muscles—data that is important for professional athletes seeking to optimize their performance.

In response, an emerging trend is monitoring muscle oxygen saturation to inform how specific muscle groups respond to activity, using optical technologies to measure oxygenation of blood in muscles with near-infrared light.[20]

While more widely available wearable sensors currently measure these physical and physiological parameters, there also exists vast potential to monitor biochemical parameters that affect athletes' performance, and many sensors are being developed in this space as well.

Such devices can sample sweat or saliva to measure biochemical signals such as electrolytes, enzymes, and neurochemicals, providing a means to noninvasively monitor health and performance in real time. These types of biosensors include mouthguards that detect chemicals in saliva that indicate muscle fatigue, contact lens sensors for ocular diagnostics, or skin-based sensors to monitor neurochemical markers of stress in sweat.

Biochemical sports sensors also offer corollary functions within medical diagnostics, and some of these sensors are adapted from existing medical technologies. For example, healthcare company Abbott (Chicago, Ill.) developed a commercial wearable continuous glucose monitor for athletes. Applied to an athlete's arm, the small wearable device, called Libre Sense, uses a thin filament inserted just under the skin to measure glucose levels in the fluid surrounding cells.

"The biosensor is designed to provide a glucose monitoring experience that will enable athletes to understand the efficacy of their nutrition choices during training and competition," according to company's website.[21]

The device is similar to that used by diabetics, but it is tailored to athletes by providing more frequent minute-by-minute glucose readings. "It will therefore inform athletes about how to fuel appropriately, to fill their glycogen stores prior to a race and to know when to replenish during a race to maintain athletic performance," the company's website explains.

Conversely, technologies developed to monitor athletic parameters are often not confined to sports contexts, as these innovations can extend into markets and aspects of life beyond sports as well. For example, innovations in sensor technologies to track athletes often can be adapted to monitor or manage health aspects in a medical context, providing much wider value to these technologies.

That is something Grafren CEO Erik Khranovskyy recognizes for its graphene-coated textile sensor technologies. "So all the sensors which I described, they can bring a lot of value to one athlete and one nation once per four years," he says. "On the other hand, they can bring a lot of value to millions of people on a longer-term perspective."

Despite the technological capability to measure and collect such rich data, however, interpretation to the athlete often lags behind. For instance, in the case of Abbott's Libre Sense, blood sugar and performance have a complicated relationship—low blood sugar levels do not necessarily mean performance will suffer, and conversely elevated blood sugar levels will not ensure maximum athletic performance, especially in high-functioning endurance athletes. These parameters are variable with time, exertion, and athlete, so interpretation of the data is nuanced. More extensive datasets and further data analyses are needed to improve data interpretation to an athlete's performance.[22]

Despite the lag in data interpretation, the possibility to track and collect such rich data for athletic performance will continue to push development of all kinds of sensors across the sports industry in the future. These trends offer significant potential for the ceramic and glass components that enable these sensors, monitors, and electronic components with the lucrative sports industry.

Similarly, many wearable devices and sensors require a power source, another area that offers significant potential for ceramic and glass materials in the future of the sports industry. The continued push for batteries with higher power density that offer longer life in smaller form, allowing smaller devices that can provide more functionality, provides opportunity for innovation with new

PLAYING THROUGH A GLOBAL PANDEMIC

The global COVID-19 pandemic has affected businesses around the world, disrupting supply chains for seemingly everything and drastically impacting the workforce. Not surprisingly, the world of sports was not spared.

Cancellation of major sports events in early 2020 were some of the earliest indications to many people of just how serious the pandemic was, as trends within sports often reflect larger trends in society. Gyms and fitness centers closed, entire sports seasons were missed, and perhaps most telling, the Tokyo 2020 Olympic Games were postponed until 2021.

While the cancellations, closures, and postponements had a negative economic impact on the sports industry, the pandemic's effects on sports were not all negative.

"If you would have asked me 18 months ago, pre-COVID, the tennis business was struggling," says Jeff Bardsley, Head's vice president of marketing for racquet sports for North America. "Participation was down, people were playing other sports, people weren't engaged in sports, period. I think all sports for the most part were struggling."

The pandemic shifted that dynamic for many sports as people worldwide increasingly turned to sports and outdoor activities for physical as well as mental health benefits. That statement is particularly true for sports that offer the ability to play while maintaining social distance—games like golf, tennis, and disc golf saw increased participation and market value as a result of the pandemic.

In the U.S., golf experienced a 2% increase in the number of individuals playing at least one round of golf in 2020 compared to 2019, the largest increase in the game in nearly two decades. And this participation is not limited to only seasoned players pulling their clubs out of the closet, according to a *CNBC* report.[a] "'New participants are increasingly younger; they're hooked on the game and they want to get better,' David Maher, CEO of golf conglomerate Acushnet Holdings, said on the company's second-quarter earnings call with analysts in August. 'A lot of the energy is coming from avid dedicated players who are simply playing more and consistently; more juniors, more women, more younger [players], and more families.'"

For golf, that increased enthusiasm for the sport translated to manufacturers and retailers as well—Acushnet, the company that owns popular golf brands Titleist and FootJoy, reported 117.1% growth in net sales in the U.S. in the second quarter of 2021. Golf brand Callaway and sporting goods store Dick's also noted growth in golf sales.[a]

Tennis also saw pandemic-fueled gains, with participation rising 22% in the U.S. in 2020 compared to 2019.[b] Bardsley says Head has had difficulty keeping up with the surge in demand. "We have struggled over the last 18 months to try and keep product on shelves. We're the largest producer of tennis balls in the world, and we can't supply our retailers in the U.S., North America, globally with tennis balls."

Bardsley is hopeful that the increased interest will not wane with the pandemic. "From the trends that we've seen so far in sporting goods sales, I definitely perceive that as an upward trend… In my 29 years in business, I've never ever seen anything like this—so I'm hopeful for the sport."

[a]CNBC, "Golf's growth in popularity is much bigger than a pandemic story," September 26, 2021, *CNBC*. https://www.cnbc.com/2021/09/26/callaway-dicks-sporting-goods-score-with-growth-of-golf.html

[b]M. Futterman, B. Pennington, "The pandemic drove people to tennis and golf. Will they keep playing?" March 11, 2021, *New York Times*. https://www.nytimes.com/2021/03/11/sports/tennis/tennis-golf-participation-pandemic.html

materials. For example, the Whoop fitness tracker is powered by a slim yet high-density battery that continuously monitors heart rate, sleep, recovery, and more. The battery gets a boost from technology by Sila, a company that developed a silicon powder that replaces conventional graphite anodes with higher-density silicon anodes, offering up to 20% higher energy density.[23] Other batteries technologies and developments are sure to find their way into wearable sports sensors as well.

Yet another possibility could be ditching the power source altogether, and instead leaning on self-powered piezoelectric materials to provide power to wearables and sensors, as the ability to convert mechanical energy to electrical energy is well-suited for sports contexts. While the heyday for incorporating piezoelectric fibers into sports equipment—which included not only Head's Intelligence tennis rackets, but also various skis, snowboards, mountain bicycles, baseball bats, and golf clubs—seems to have passed (as this equipment often relied more heavily on marketing rather than enhanced performance to sell piezoelectrics' possibilities[24]), new future potential for the materials might be found in the ability to power sports sensors.

Fans get in the game

Beyond enhancing athletic performance and improving safety, sensors offer another function that is likely to be significant in the future of sports—the fan experience.

"You can use that same data that you're collecting to measure athletic performance, health, wellness and prevention, to create an immersive fans' experience," says Leslie Saxon, professor of medicine and executive director of the University of Southern California's Center for Body Computing, in a *BBC News* article.[25] "What if I record my own heart rate while watching my favorite football player play, looked at my response and compare it to his response on the field?"

Digital technologies to enhance fan engagement experienced a significant boost since the start of the COVID-19

American professional golfer Bryson DeChambeau, above, uses graphite shafts made from carbon fiber in all his clubs. His choice contrasts with other professional golfers, who generally only use graphite shafts in their driver and other wood-type clubs.

pandemic, as health and safety precautions shifted in-person experience of sports events to virtual platforms (see sidebar: *Playing through a global pandemic*). Continued investments in the infrastructure to support streaming platforms, digital content, and even augmented and virtual reality experiences will continue moving the trend forward, incorporating the data provided by athlete-worn biosensors to further engage fans.

"As this technology matures, there will be more and more biosensors out there," Saxon says in the article. "It is truly the next frontier in sports and technology."

Ensuring fair play

As technology continues to play an increasing role in sports, moral questions begin to arise. One long-standing question involves equity in access, as expensive technologies introduce disparities between those who can afford the devices and those who cannot. Yet another quandary surrounds the potential for technologies to extend beyond simply sensing and instead offer functional improvements to athletic performance.

"What about if there's an opportunity to make an implant on your bone that could make it more structurally sound so you could run further, or it's a piezoelectric sensor that measures the stress in the bone?" says Ready. "Maybe that's bad to use in competition because it's giving feedback that you can actively use in competition, but maybe it's useful during rehabilitation—so is it okay in one scenario and not in the other?"

The line between where materials enhance athletic performance and where materials provide an unfair advantage or artificially exaggerate human capabilities is colored in various shades of gray. And it is often difficult to discern or quantify just how much advantage a technology might provide to an athlete, further complicating the picture.

Yet Ready suggests that sports are based on advantage and competition. "That's the whole point of sports—you're trying to prove that you're better than somebody else," Ready says. Technologies provide means to improve the game, and as long as they follow the rules, innovation is fair game. "That is, I think, what materials science tries to do, is to give you an unfair competitive advantage. But we do it in a rules-compliant way, whether that rule does not yet exist, and therefore we're in compliance with it, or because we go right up to the boundary," he says.

So what does the future of sports look like? Despite debates about the fairness of new technologies, materials science offers the ability to enhance and improve existing aspects of sports as well as innovate in new and sometimes unexpected ways. Technology will continue to infiltrate sports, in some ways enhancing athletic performance and improving the safety and fan experience of the game. Athletes, enabled by technology, will continue to get better, setting new world records—and those feats of athleticism will be backed by materials science. 100

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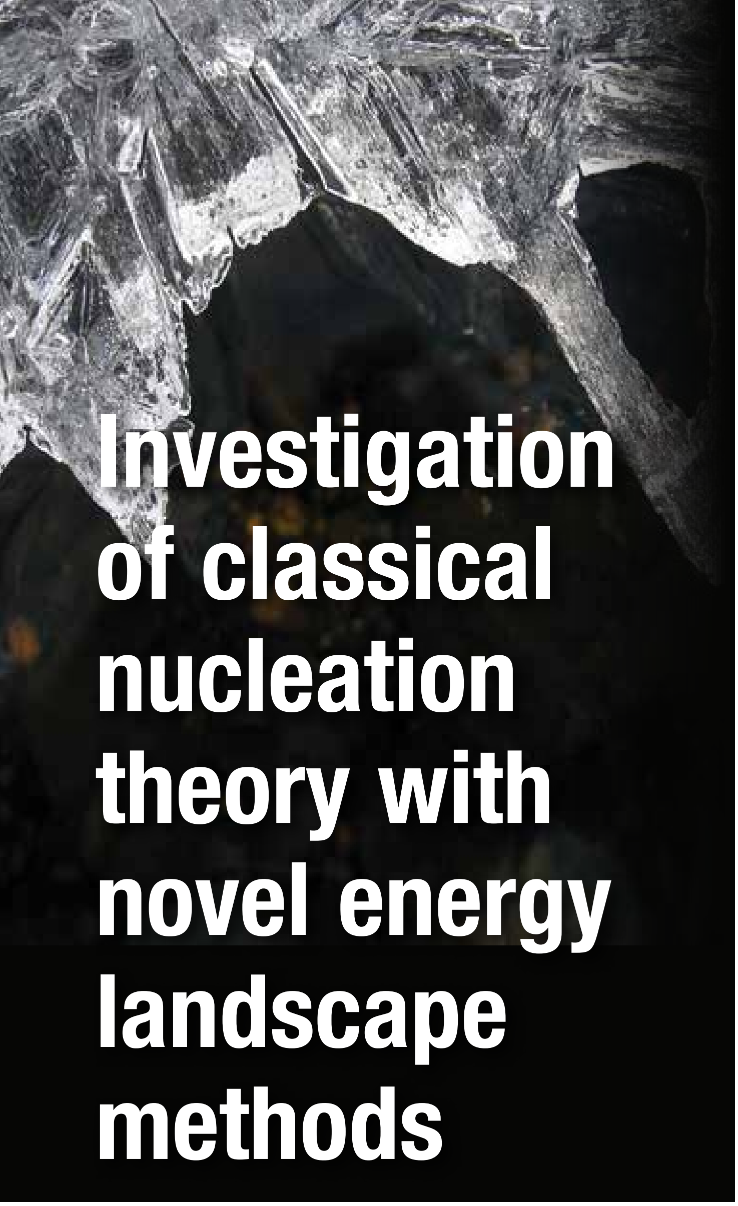

Investigation of classical nucleation theory with novel energy landscape methods

By Collin J. Wilkinson & John C. Mauro

The methods and the software developed in this work offer a promising step to gain insights into the fundamental nature of glass-ceramic nucleation and the validity of classical nucleation theory.

Crystallization (and by extension nucleation) is a critical process in all material systems that determines how a material will form. Manufacturers have generated billions of dollars of economic development by creating new materials through manipulation of crystallization.

There are two phenomenological steps in the process of phase transformation from a supercooled liquid to a crystal: a nucleation step and a crystal growth step. The growth step is described well by Wilson-Frenkel's theory,[1] but the underlying physics of nucleation remains elusive. For glass-ceramics, or composite materials consisting of crystals in a glassy matrix, having a clear idea of how nucleation occurs would aid significantly in finding the optimal thermal history for the desired crystallite distribution.

In this study, we employed first principles and energy landscape methodologies to provide insights into the fundamental nature of nucleation for the barium disilicate system. Our exploration also enabled a test of classical nucleation theory, which is the most common approach to understanding nucleation. Although it is not the first study to computationally examine the theory's validity,[2–4] it is the first independent parameterization of each variable in an attempt to calculate the resulting nucleation rate.

Challenges in optimizing glass-ceramic design

The difficulty in designing a glass-ceramic is apparent when considering the high dimensional phase space of parameters that can be adjusted. A glass system has d dimensions over which it can be optimized, where d is the number of components ($d-1$ mutually independent compositional dimensions and at least one thermal history dimension). A glass-ceramic system has four additional phase dimensions (two for the nucleation/growth temperatures and two for nucleation/growth times) that require optimization. Therefore, a glass-ceramic system has $d+4$ dimensions over which the system must be optimized.

There are some tools such as topological constraint theory[5] that can help optimize over the glassy space; however, the four additional dimensions (for nucleation and growth temperatures/times) remain poorly understood. Thus, designing computational methods to easily optimize over this large space is of utmost importance to developing a new generation of custom glass-ceramic materials.

Crystal nucleation is historically difficult to simulate computationally because the phenomenon happens on spatial scales of nanometers and over many orders of magnitude of time scales. Recent approaches using grand canonical Monte Carlo successfully predicted the short time dynamics of nuclei formation while enabling greater thermodynamic insights[6]; however, it remains computationally expensive.[2] Molecular dynamics also falls short in simulating crystal nucleation of glass-forming systems due to the need for longer spatial and temporal scales to capture nucleation effects accurately.

The energy landscape offers another approach for simulating crystal nucleation. The energy landscape is a high dimensional construct that relates the location of every atom to the total energy of the system. It has become crucial to studies of biomolecules, glasses, and catalysts[7–9] because it can show the relevant atomic configurational changes and can calculate the associated changes in kinetics and thermodynamics.

An energy landscape can be thought of as a $3N$-dimensional hyperspace, where each coordinate represents an x, y, or z position of the N atoms considered. As an energy landscape is mapped, most configurations become unnecessary to record as they represent energies much higher than the local minima. These local minima are often called inherent structures (IS), and these states control the thermodynamics of the system. The kinetics of the system are then controlled by the lowest energy saddle point between each pairwise set of IS. Using this information, we can decrease the complexity of the system by just considering the IS and the saddle points.

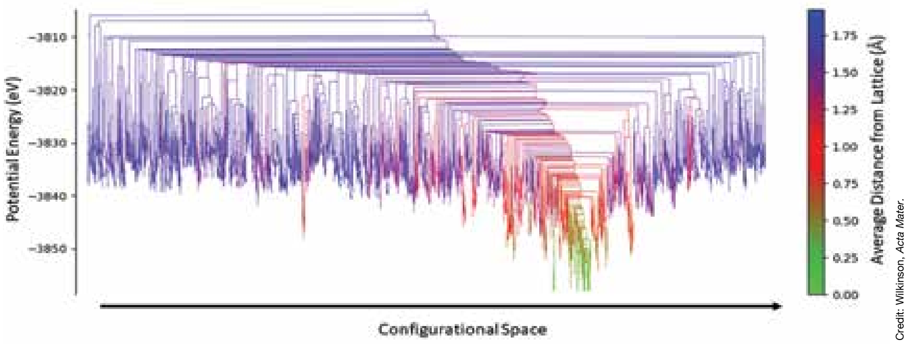

Figure 1. The energy landscape for a barium disilicate glass-ceramic shown in a disconnectivity graph. The *x*-axis is an arbitrary phase space and the *y*-axis is the potential energy calculated from the Pedone potentials.[14] Each terminating line represents an inherent structure and the point where two lines meet represents a transition point. The colors are indicative of the crystallinity. Reproduced from Ref. 15 with permission of the author.

In classical nucleation theory, the work (W) needed to generate a spherical isotropic nucleus[1] consists of a volume term related to the free energy difference of a crystal and glass (ΔG), as well as a surface energy term (σ). By determining these three temperature-dependent functions, prediction of the overall nucleation rate is possible. Though there are existing methods in literature to approximate each of these quantities, the approximations often include large errors and assumptions about the behavior of the system.[16] Experimentally, the kinetic function is often approximated with the Stokes-Einstein relationship, the ΔG term is calculated from heat capacity curves, and σ is fitted.[16]

Exploring glass-ceramic nucleation through the energy landscape

In this study, we explored the energy landscape of a barium disilicate system capturing the glassy and crystalline basins. We chose barium disilicate because it is a commonly studied glass-ceramic with multiple reliable experimental datasets in literature.[10–12]

The energy landscape for this investigation was generated using the software ExplorerPy,[13] starting with the orthorhombic barium disilicate crystalline structure. The mapped landscape then allowed for the free energy difference and the kinetic transition rates to be calculated directly. The interfacial free energy was obtained from molecular dynamics simulations. The Pedone potentials[14] were used and the volume of the cell was fixed, due to simulation instability when pressure was fixed. The resulting energy landscape is seen in Fig. 1.[15]

Once the temperature-dependent parameters were derived from the landscape, they were used to calculate the nucleation rates in classical nucleation theory. Classical nucleation theory is given by the product of a kinetic function (K) and a thermodynamic term,

$$I = K \exp[-W/kT] = K \exp[-(16\pi\sigma^3)/(3(\Delta G)^2 kT)] \quad (1)$$

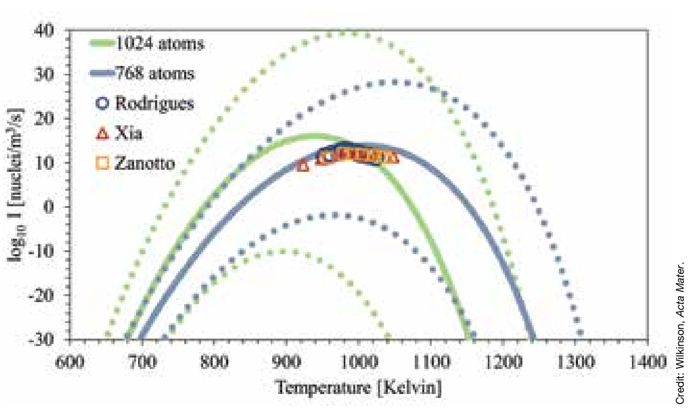

Figure 2: The nucleation curve for barium disilicate as predicted using the model presented in this work. The data referenced can be found in Refs. 12, 18, and 19. The dotted lines show uncertainty for the prediction calculated from the interfacial energy. Reproduced from Ref. 15 with permission of the author.

Classical nucleation theory is known for giving widely varying results depending on how the parameters are determined.[1,6,17] When crystal nucleation rates are calculated, it is not atypical to be 10+ orders of magnitude off from experimental values. The inability to get accurate predictions consistently for nucleation curves means that choosing an appropriate nucleation temperature must be done empirically, which can prove to be one of the most challenging and time-consuming aspects for optimizing the design of a glass-ceramic.

As shown in Fig. 2, the resulting nucleation curves agree well with the experimental nucleation rates. However, when the individual properties are compared, the interfacial free energy and kinetics show disagreement with the experimental calculations while the thermodynamic barrier shows good agreement.

Conclusions

This study is, as far as the authors know, the first reporting of a real energy landscape for a complicated glass-ceramic system. In the future, this model could be used for either developing commercial glass-ceramics or for predicting the critical rate needed to keep a liquid glassy. Additionally, the technique presented here can provide additional insights into the physics of nucleation and the validity of classical nucleation theory.

About the authors

Collin J. Wilkinson is a doctoral graduate of the Department of Material Science and Engineering at The Pennsylvania State University. He worked on using energy landscapes to understand complex behavior centered on relaxation and crystallization under the supervision of John Mauro. Contact Wilkinson at cxw824@psu.edu

Editor's note

Wilkinson will present the 2021 Kreidl Award Lecture at the virtual Glass & Optical Materials Division Annual Meeting on Dec. 15, 2021. Learn more about the conference at https://ceramics.org/pacrim14.

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Sustainability is key at ceramics expo 2021

From left, moderator Kayleigh Porter talks with Shawn Allan, Dror Danai, and Jesse Blacker about the commercial viability of various ceramic additive manufacturing techniques.

After a year of going virtual in response to the COVID-19 pandemic, Ceramics Expo experienced a highly successful return as a live event on Aug. 31–Sept. 1, 2021, in Cleveland, Ohio.

The leading annual supply chain exhibition and conference for the advanced ceramic and glass industry welcomed dozens of exhibitors and hundreds of attendees to its new location at the Huntington Convention Center of Cleveland. During the two-day event, more than 30 expert speakers shared insights into the latest developments in applications and manufacturing of technical ceramics and the critical role that they will play in "enabling a clean, efficient, and electrified future."

"Ceramics Expo 2021 was a resounding success. It was fantastic for ACerS leadership and staff to be able to interact and engage with many of our Corporate Partners and members in person. This show continues to help us meet the need of our industrial members to interact with existing and prospective customers," says Mark Mecklenborg, ACerS executive director.

Day 1 of Ceramics Expo focused on research and initiatives to improve sustainability in ceramic and glass manufacturing, particularly through developing new materials and improving system infrastructures.

The first panel discussion kicked off the day by exploring sustainability in supply chains, a topic that has received increased attention this past year due to the COVID-19 pandemic revealing weaknesses in the current supply systems. Later sessions throughout the day covered topics such as facilitating environmentally friendly practices, the potential role of flow batteries in the future of energy storage, and understanding the implications of emission control regulations on clean mobility technology.

Day 2 of Ceramics Expo also looked at improving sustainability, but the focus this day was on processes for fabricating materials.

The first panel discussion of Day 2 considered how to bridge the gap between research & development and commercial viability of ceramic additive manufacturing. Later sessions throughout the day covered topics such as improving efficiency of sintering processes, using powder X-ray diffraction for microstructural analysis, and improving properties of ultrahigh-temperature ceramics.

Throughout the sessions, many panelists mentioned the challenge of finding people to fill labor shortages in the industry. During the last panel session of Day 1, Jennifer Benson (Raytheon Technologies, chief engineer), Elizabeth Dickey (Carnegie Mellon University, Teddy & Wilton Hawkins Distinguished Professor and Department Head of Materials Science and Engineering), and Eileen De Guire (ACerS, director of technical content and communications) discussed how the gender gap in STEM fields can contribute to this challenge.

"If we're only pulling from half of the population, we're not going to make it," Dickey says.

After giving some statistics on the underrepresentation of women in STEM, they offered several solutions for closing the gender gap. For example, creating more awareness of what materials scientists do, so women will want to enter the field; offering flexible work schedules, so women can start a family while pursuing their career; and launching programs to help women transition back into the field following a career break.

Join us at the 7th annual Ceramics Expo, which will take place at the Huntington Convention Center of Cleveland on Aug. 29–31, 2022.

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PACRIM 14

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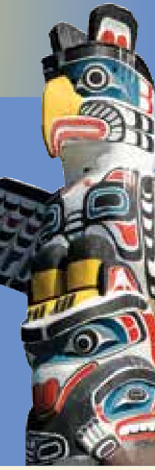
14TH PACIFIC RIM CONFERENCE ON CERAMIC AND GLASS TECHNOLOGY

including Glass & Optical Materials Division Meeting (GOMD 2021)

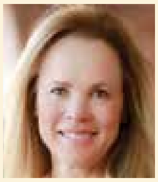


PACRIM14 will provide a unique forum for knowledge exchange and sharing, and facilitate the establishment of new contacts from all over the world. The technical program will cover a wide range of exciting and emerging topics organized into a seven-track system, which includes 42 symposia planned that will identify global challenges and opportunities for various ceramic technologies.

We anticipate strong participation of colleagues from cooperating societies, including CerSJ, KCerS, CCS, AusCerS, and other ceramic societies from around the world. ACerS Glass & Optical Materials Division will host its Division meeting at PACRIM14.

PACRIM PLENARY SPEAKERS

MONDAY, DEC. 13



MELISSA ORME
Vice president, Boeing Additive Manufacturing, The Boeing Company, USA

Recent advances in the disruptive technology of additive manufacturing at Boeing

JAW-SHEN TSAI
Professor, Tokyo University of Science, Department of Physics, Japan; Laboratory Head of Macroscopic Quantum Coherence Research, RIKEN Center for Quantum Computing (RQC), Japan

Superconducting quantum computer and its future issues

MARY ANNE WHITE
Harry Shirreff Professor of Chemical Research (Emerita), Department of Chemistry, Dalhousie University, Canada

Thermal properties of advanced ceramics

SANG IL SEOK
Distinguished Professor, Laboratory for Energy Harvesting Materials and Systems (LEHMS), School of Energy and Chemical Engineering, Ulsan National Institute of Science and Technology (UNIST), Korea

Halide perovskite-based photovoltaics—from materials to devices

PACRIM 14 TECHNICAL PROGRAM

- → Multiscale Modeling, Simulation, and Characterization
- → Innovative Processing and Manufacturing
- → Nanotechnology and Structural Ceramics
- → Multifunctional Materials and Systems
- → Ceramics for Energy Systems
- → Ceramics for Environmental Systems
- → Biomaterials, Biotechnologies, and Bioinspired Materials

GOMD 2021 TECHNICAL PROGRAM

- → S1: Fundamentals of the Glassy State
- → S2: Glass and Water: Degradation of Amorphous Materials
- → S3: Optical and Electronic Materials and Devices — Fundamentals and Applications
- → S4: Glass Technology Aand Cross-cutting Topics
- → S5: Glass Education

GOMD 2021 AWARD SPEAKERS

TUESDAY, DEC. 14
GEORGE W. MOREY AWARD

Walter Kob
Professor, University of Montpellier, France

Glass: We love it, but it breaks

WEDNESDAY, DEC. 15
NORBERT J. KREIDL AWARD FOR YOUNG SCHOLARS

Collin Wilkerson
The Pennsylvania State University, USA

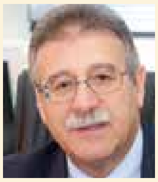
Confirming classical nucleation theory with novel energy landscape methods

THURSDAY, DEC. 16
VARSHNEYA GLASS TECHNOLOGY AWARD

Heike Ebendorf-Heidepriem
Professor, University of Adelaide, Australia

Nanocrystal doped glass and fibers: Fabrication challenges and opportunities for novel photonics applications

THURSDAY, DEC. 16
ALFRED R. COOPER AWARD



Efstratios I. Kamitsos
Director of research, Theoretical and Physical Chemistry Institute of the National Hellenic Research Foundation, Athens, Greece

Structure and ion dynamics in glass

REGISTER TODAY! JAN. 19–21, 2022

ELECTRONIC MATERIALS AND APPLICATIONS 2022

DoubleTree by Hilton | Orlando, Fla., USA | ceramics.org/ema2022 | Hybrid Conference

ORGANIZED BY THE ACerS ELECTRONICS AND BASIC SCIENCE DIVISIONS

ACerS is pleased to announce the addition of a hybrid option for EMA '22 to allow participation by individuals who cannot attend in-person due to travel restrictions. We plan to provide a hybrid solution that will incorporate prerecorded talks from virtual attendees into the live onsite programming. All live sessions will be recorded for all attendees to view at the conclusion of the live conference, available until March 31, 2022.

Electronic Materials and Applications 2022 (EMA 2022) is an international conference focused on electroceramic materials and their applications in electronic, electrochemical, electromechanical, magnetic, dielectric, biological, and optical components, devices, and systems. Jointly programmed by the Electronics Division and Basic Science Division of The American Ceramic Society, EMA 2022 will take place at the DoubleTree by Hilton Orlando at Sea World, Jan. 19–21, 2022.

EMA 2022 is designed for scientists, engineers, technologists, and students interested in basic science, engineering, and applications of electroceramic materials. Participants from across the world in academia, industry, and national laboratories exchange information and ideas on the latest developments in theory, experimental investigation, and applications of electroceramic materials.

Students are highly encouraged to participate in the meeting. Prizes will be awarded for the best oral and poster student presentations.

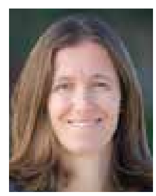
The technical program includes plenary talks, invited lectures, contributed papers, poster presentations, and open discussions. EMA 2022 features symposia focused on dielectric, piezoelectric, pyroelectric, magnetoelectronic, (multi)ferroic, quantum, relaxor, optoelectronic, and photonic ceramics; complex oxide thin films, heterostructures, and nanocomposites; semiconductors; superconductors; ion-conducting ceramics; 5G materials for millimeter-wave technology; and functional biological materials. Other symposia emphasize broader themes covering processing, microstructure evolution, and integration; effects of surfaces and interfaces on processing, transport, and properties; point defects, dislocations, and grain boundaries; mesoscale phenomena; and advanced characterization and computational design of electronic materials.

EMA includes several networking opportunities to facilitate collaborations for scientific and technical advances related to materials, components, devices, and systems. The Basic Science Division will again host a tutorial session in addition to the regular conference programming.

The grand finale of the meeting will again be Failure: The Greatest Teacher. We invite anyone interested to submit a brief abstract for this educational and engaging event that concludes the meeting.

Please join us in Orlando, Fla., to participate in this unique experience!

ORGANIZING COMMITTEE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University of California, Irvine, USA
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TECHNICAL PROGRAM

- **S1 – Characterization of Structure–Property Relationships in Functional Ceramics**
- **S2 – Advanced Electronic Materials: Processing Structures, Properties, and Applications**
- **S3 – Frontiers in Ferroic Oxides: Synthesis, Structure, Properties, and Applications**
- **S4 – Complex Oxide Thin Films and Heterostructures: From Synthesis to Strain/Interface-engineered Emergent Properties**
- **S5 – Mesoscale Phenomena in Ferroic Nanostructures: From Patterns to Functionalities**
- **S6 – Emerging Semiconductor Materials and Interfaces**
- **S7 – Superconducting and Related Materials: From Basic Science to Applications**
- **S8 – Structure–Property Relationships in Relaxor Ceramics**
- **S9 – Ion-conducting Ceramics**
- **S10 – Point Defects and Transport in Ceramics**
- **S11 – Evolution of Structure and Chemistry of Grain Boundaries and Their Networks as a Function of Material Processing**
- **S12 – 5G Materials and Applications Telecommunications**
- **S13 – Agile Design of Electronic Materials: Aligned Computational and Experimental Approaches and Materials Informatics**
- **S14 – Functional Materials for Biological Applications**
- **S15 – Advanced Microelectrics**

REGISTER TODAY! JAN. 23–28, 2022

46TH INTERNATIONAL CONFERENCE AND EXPOSITION ON ADVANCED CERAMICS AND COMPOSITES

Hilton Daytona Beach Resort and Ocean Center | Daytona Beach, Fla., USA | Hybrid Conference | ceramics.org/icacc2022

ORGANIZED BY THE ENGINEERING CERAMICS DIVISION OF THE AMERICAN CERAMIC SOCIETY

We are pleased to announce that the 46th International Conference & Exposition on Advanced Ceramics & Composites (ICACC 2022) will be held from Jan. 23–28, 2022, in Daytona Beach, Fla. This conference has a strong history of being the preeminent international meeting on advanced structural and functional ceramics, composites, and other emerging ceramic materials and technologies. The Engineering Ceramics Division (ECD) of The American Ceramic Society has organized this esteemed event since 1977. Due to the high quality of technical presentations and unique networking opportunities, this event has achieved tremendous worldwide interest and has attracted active participation from ceramic researchers and developers from the global technical community thanks to the dedication and support of our membership.

We look forward to seeing you in Daytona Beach, Fla., in January 2022. Check out our hybrid option if you are unable to travel.

Palani Balaya, program chair, ICACC 2022
National University of Singapore | mpepb@nus.edu.sg

PLENARY SPEAKERS

Monday, Jan. 24

THOMAS SPECK, University of Freiburg and Cluster of Excellence Living, Adaptive and Energy-autonomous Materials Systems (livMatS), Germany

Plant materials systems and structures: Bio-inspiration for a "greener" technology in the 21st century

Y. SHIRLEY MENG, Zable Chair Professor in Energy Technologies and professor in Materials Science & NanoEngineering, University of California San Diego, USA

Designing better ceramic materials for future batteries

GLOBAL YOUNG INVESTIGATOR AWARD

Sunmi Shin, National University of Singapore, Singapore

Thermal engineering using infrared photonic structures: Probing coherent thermal emission in a single nano-object

MECHANICAL PROPERTIES OF CERAMICS AND GLASS 2022 SHORT COURSE

Jan. 27–28, 2022 | 8:30 a.m. – 5 p.m.

Location: In conjunction with ICACC2022, Hilton Daytona Beach Resort and Ocean Center, Daytona Beach, Fla., USA

Instructor: **George D. Quinn, NIST**

SYMPOSIA

- S1: **Mechanical Behavior and Performance of Ceramics and Composites**
- S2: **Advanced Ceramic Coatings for Structural, Environmental, and Functional Applications**
- S3: **19th International Symposium on Solid Oxide Cells (SOC): Materials Science and Technology**
- S4: **Armor Ceramics – Challenges and New Developments**
- S5: **Next Generation Bioceramics and Biocomposites**
- S6: **Advanced Materials and Technologies for Rechargeable Energy Storage**
- S7: **16th International Symposium on Functional Nanomaterials and Thin Films for Sustainable Energy Harvesting, Environmental and Health Applications**
- S8: **16th International Symposium on Advanced Processing and Manufacturing Technologies for Structural and Multifunctional Materials and Systems (APMT16)**
- S9: **Porous Ceramics: Novel Developments and Applications**
- S10: **Modeling and Design of Ceramics and Composites**
- S11: **Advanced Materials and Innovative Processing Ideas for Production Root Technologies**
- S12: **On the Design of Nanolaminated Ternary Transition Metal Carbides/Nitrides (MAX Phases) and Borides (MAB Phases), Solid Solutions thereof, and 2D Counterparts (MXenes, MBenes)**
- S13: **Development and Applications of Advanced Ceramics and Composites for Nuclear Fission and Fusion Energy Systems**
- S14: **Crystalline Materials for Electrical, Optical, and Medical Applications**
- S15: **6th International Symposium on Additive Manufacturing and 3D Printing Technologies**
- S16: **Geopolymers, Inorganic Polymers, and Sustainable Materials**
- S17: **Advanced Ceramic Materials and Processing for Photonics and Energy**
- S18: **Ultrahigh-temperature Ceramics**

REGISTER TODAY! March 15–18, 2022

The Unified International Technical Conference on Refractories (UNITECR) is a biennial international conference that contributes to the progress and exchange of industrial knowledge and technologies concerning refractories.

SYMPOSIA TITLES

- Advances in Installation Techniques, Manufacturing, and Equipment
- Advances in Monolithic Technology
- Iron and Steelmaking Refractories
- Modeling and Simulation of Refractories
- New Developments in Refractory Formulation
- Nonoxide Refractory Systems
- Raw Materials
- Refractories for Aluminum
- Refractories for Cement and Lime
- Refractories for Glass
- Refractories for Other Applications
- Refractories for Petrochemical Applications
- Refractory Education
- Refractory Characterization and Testing
- Refractory Technology and Techniques for Energy Savings
- Safety, Environmental Issues, and Recycling
- Use of Artificial Intelligence, Machine Learning, and Big Data in Refractory Technology
- Refractory Student and Young Professionals Symposium
- Theodore J. Planje Award Symposium

TENTATIVE SCHEDULE OF EVENTS

Tuesday, March 15, 2022	
Welcome event	6–10 p.m
Wednesday, March 16, 2022	
Opening ceremony	8:30–9:30 a.m.
Exhibits	9:30 a.m. – 7 p.m.
Technical sessions	9:30 a.m. – 5:30 p.m.
Exhibit reception and posters	5–7 p.m.
Thursday, March 17, 2022	
Exhibits	9:30 a.m. – 4:30 p.m.
Technical sessions	8 a.m. – 5 p.m.
Banquet	7–10 p.m.
Friday, March 18, 2022	
Technical sessions	8 a.m. – 12:30 p.m.
Lunch/Panel discussions/Closing	12:30–5:30 p.m.

EXHIBITS AND SPONSORSHIPS

Companies who want to network and do business with refractory related manufacturers, users, technologists, and scientists should contact us today for premium exhibit space and special sponsorship opportunities. For more information, contact:

Andrea Ross | 614-794-5820 | aross@ceramics.org

International Journal of Ceramic Engineering & Science

Peer-reviewed proceedings articles will be published in ACerS' open-access *International Journal of Ceramic Engineering & Science*. All articles will be posted online for conference attendees. Go to www.UNITECR2022.org for full meeting details, including publishing options.

A regular column offering the student perspective of the next generation of ceramic and glass scientists, organized by the ACerS Presidents Council of Student Advisors.

Ambra Paterlini
Guest columnists

Lithography-based additive manufacturing of ceramics for orthopedic joint implants: A focus on the tribology

During the last few decades, additive manufacturing became more popular in the biomedical field because of the ability to create complex shapes and porous or semiporous geometries without extra steps in the production process. An increasing number of printed metal and polymer products are well-established in the market, and quite a few printed ceramic and composite products are gaining interest as well.

Stereolithography is one of the most used additive manufacturing techniques for ceramic materials. Based on selectively photopolymerized ceramic-loaded slurries, this technology allows manufacturers to obtain highly dense final parts (around 99%), as well as good shape accuracy, with a lateral resolution of around 20–30 µm.

Inspired by the benefits of stereolithography, our work aims to create entirely ceramic implants for joint replacements. Implants made of metal can be related to allergies or undesired reactions, and due to their lower hardness and poor tribological behavior, doctors often prefer metal–ceramic composite implants instead. However, composite implants can lead to multicomponent interfaces that result in weak points, and that is why entirely ceramic implants are desirable.

To ensure biocompatibility, we selected materials with a long history in the orthopedic field for the current case study: alumina, zirconia, and two zirconia toughened alumina (ZTA) composites with 10 wt.% and 20 wt.% of zirconia, respectively.

We focused on analyzing the tribological behavior of the implants because the main movement of a joint is the continuous sliding between its two counterparts. Thus, studying the tribological behavior can help us to guarantee a part that experiences low wear. Tribological tests were performed in ambient air and liquid environments, using a bovine serum to mimic the in vivo conditions.

Friction coefficients under an average Hertz contact pressure of 800 MPa are in the range of 0.45–0.50 for alumina and ZTA, while in the order of 0.80 for zirconia. These values are comparable to the friction coefficients of conventionally processed alumina and ZTA parts in air conditions.[1] The zirconia coefficient, however, is significantly higher due to the well-known tetragonal-to-monoclinic transformation at the surface,[2] detected through Raman spectroscopy.

On the other hand, in lubricated conditions, the friction behavior is more homogeneous among the different samples, and friction coefficients are in the range of 0.18–0.20. These coefficients are in the same range of conventionally processed parts.[3] Surface properties such as roughness, wettability, and porosity show a direct influence on friction mechanisms.

Regarding wear volume, alumina and zirconia present significantly higher wear volume compared to ZTA composites in both air and lubricated conditions. In air conditions, for both alumina and zirconia, a tribofilm is detected on worn surfaces. A tribofilm is a film formed on a surface because of tribology stresses that induce a chemical transformation or compact wear debris—as in this case study. Alumina tribofilm (Figure 1b) is adherent enough to resist the whole tribological test cycle (around 8 hours) and protect the surface from further wear. On the other hand, zirconia tribofilm is continuously generated and detached so the wear volume never attains a plateau and thus constantly increases.

Printed ZTA parts present an optimal tribological behavior, with a very low wear volume in both air and lubricated conditions. There is no sign of tribofilm (Figure 1d). However, the debris generated during the test "fill" the open porosity on sample surface, homogenizing the surface and decreasing the roughness.

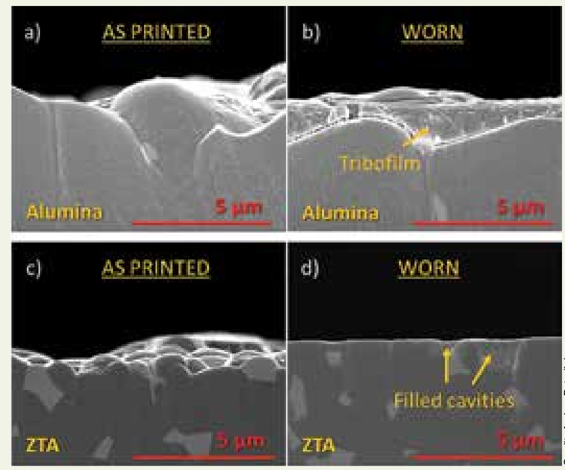

Figure 1. As printed and worn surfaces of alumina (a, b) and zirconia toughened alumina (c, d) samples.

To conclude, based on both reciprocating friction coefficients and wear volume, ZTA seems to be an optimal candidate for creating additively manufactured parts for orthopedic joint implants.

References

[1]Blau PJ, "Four great challenges confronting our understanding and modeling of sliding friction," *Tribology Series* 1998; 34:117-128.

[2]Chevalier J, Gremillard L, Virkar A V., Clarke DR, "The tetragonal-monoclinic transformation in zirconia: Lessons learned and future trends," *J Am Ceram Soc.* 2009; 92(9):1901–1920.

[3]Gispert MP, Serro AP, Colaço R, Saramago B, "Friction and wear mechanisms in hip prosthesis: Comparison of joint materials behaviour in several lubricants," *Wear* 2006; 260(1–2):149–158.

Ambra Paterlini is a Ph.D. candidate at the University of Birmingham. Her doctoral fellowship is part of a European Marie-Curie project named DOC-3D Printing, which is focused on additive manufacturing of ceramics for medical and aeronautical applications. In addition to research, 3D printing is also a personal hobby of hers, along with outdoor activities such as camping and hiking. 100

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Ceramic & Glass MANUFACTURING

www.ceramics.org/ceramicandglassmanufacturing

WHAT'S NEXT AFTER A RECORD-SETTING YEAR FOR MERGERS AND ACQUISITIONS?

ELCON–UC DAVIS PARTNERSHIP INVESTIGATES DISCOLORATION OF HIGH-CALCIA ALUMINA

OPTICAL GLASS: ADVANCED ROTARY SURFACE GRINDERS DELIVER MORE POSSIBILITIES AND TIGHTER TOLERANCES

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INDUSTRY NEWS


The Cornell Center for Materials Research.

CORNELL, NORTH CAROLINA A&T PARTNER TO IMPROVE DIVERSITY IN ENGINEERING

The Cornell University Center for Materials Research and North Carolina Agricultural and Technical State University began a research collaboration to increase diversity in the materials science field. North Carolina A&T said the college produces more Black engineers than any other university in the United States. Its students will visit Cornell for its state-of-the-art instrumentation and to work with Cornell faculty in electron microscopy, optics, and electrocatalysis. The National Science Foundation funded the project with a three-year, $800,000 seed grant.

ITALIAN GLASS MAKER BUYS A COMPETITOR IN CHINA

Italian technical glass manufacturer Vetrerie Riunite has acquired 70% of the capital of Suizhong Minghui Industrial Technology, a China-based manufacturer of washing machine portholes. Vetrerie Riunite manufactures technical glass for household appliances. The integration of the Chinese company will allow Vetrerie Riunite to improve its market share from 40% to more than 50%.


Vetrerie Riunite manufactures technical glass for household appliances.


Corning invests strategically to support broadband network buildouts.

CORNING TO EXPAND ITS OPTICAL CABLE MANUFACTURING

Corning Inc. announced it is expanding its longtime collaboration with AT&T. The two companies will extend their investments in fiber infrastructure, expand U.S. broadband networks, and accelerate 5G deployment. Corning said it will invest $150 million in optical cable manufacturing in North Carolina, initially adding 200 jobs. AT&T previously announced plans to significantly expand its fiber footprint.

SCHOTT TO INCREASE CAPACITY AT PHARMA GLASS PLANT IN INDIA

SCHOTT will invest 70 million euro to expand its pharmaceutical glass tubing site in Jambusar, Gujarat, India. The expansion will increase its production capacity in India by more than 30%. It is part of a more than $1 billion investment program through 2025, leveraging the company's pharma tubing and packaging business.

SCHOTT's expansion supports the Indian government's vision to become a global pharmaceutical hub.

O-I to invest in high-growth markets in Latin America, the U.S., and the U.K.

O-I GLASS PLANS TO INVEST $680 MILLION IN PLANT EXPANSIONS

O-I Glass announced plans to invest up to $680 million globally to expand its glass packaging capacity. The Perrysburg, Ohio-based company plans to add up to 700,000 tons of glass packaging capacity by adding up to 11 lines of its Modular Advanced Glass Manufacturing Asset (MAGMA) production process. The investment will include $100 million to expand one of the company's facilities in Colombia, and up to $580 million in targeted markets.

HARBISONWALKER SCOUTING SITES FOR A NEW PLANT

HarbisonWalker International, the largest supplier of refractory products and services in North America, plans to build a manufacturing and service hub for steel customers in the U.S. and substantially increase production of steelmaking products. The facility, which is expected to open as early as the third quarter of 2022, will produce refractories designed for use in low emission electric arc furnaces. The company is assessing site options.

Pittsburgh-based HWI has 18 manufacturing plants and 20 global sourcing centers around the world.

Nobel laureate Novoselov, far left, and National University of Singapore officials announced the launch of a new institute.

MATERIALS SCIENCE RESEARCH CENTER INAUGURATED IN SINGAPORE

The National University of Singapore (NUS) launched an institute dedicated to the design, synthesis, and application of functional intelligent materials. Co-directed by Nobel-Prize-winning materials scientist Konstantin Novoselov, it will be the sixth research center of excellence in Singapore, and the fourth hosted at NUS. The institute is supported by the Singapore Ministry of Education, which is providing funding of S$100 million (roughly US$74 million) and a matching contribution of S$100 million from the university.

HERAEUS GROUP PLANS TO ACQUIRE MO-SCI CORP.

Heraeus Group, a family-owned portfolio company based in Germany, announced its acquisition of Mo-Sci Corp., a supplier of medical and specialty glass, and ETS Technology Holdings, a provider of innovative wound care technologies. Both Mo-Sci and ETS are located in Rolla, Mo. Mo-Sci was founded by Delbert Day in 1985, and was led by Ted Day, his son, until his passing in September 2020. Heraeus said it plans to keep the existing Mo-Sci team and facilities in Rolla. Heraeus employs 14,800 people in 40 countries.

Mo-Sci supplies the medical device industry as well as the aerospace, automotive, and electronics industries.

WHAT'S NEXT AFTER A RECORD-SETTING YEAR FOR MERGERS AND ACQUISITIONS?

By David Holthaus

We're at the close of one of the most active years in merger and acquisition activity in recent memory, as several factors converged to make it a record-setting year for deals.

Low interest rates, a rising stock market, and the availability of capital all contributed to the hot market of 2021, says David Ruf, head of the chemicals and materials investment banking practice at KeyBanc Capital Markets. The biggest factor was COVID-disrupted 2020, he says. The deep uncertainty caused by the global pandemic led to business being put on hold.

"People were saying, 'I don't know if the sky is falling,' or 'I don't know if we still have a world to continue to live in,'" he says. "If I buy something in May 2020, does the world even exist by August?"

Ruf's practice generally focuses on deals under $2 billion. Heading into 2021, deal activity that had been suppressed due to the pandemic uncertainty opened up as the economy recovered and again showed signs of stability.

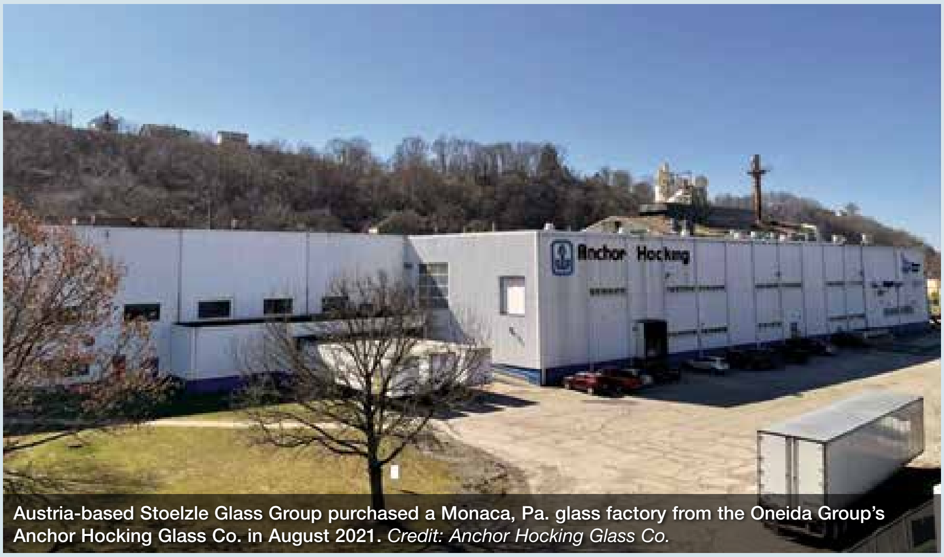
"A lot of things that were scheduled to be sold in 2020 never got sold or didn't come to the market in the first place," he says. "As a result, everything that wasn't nailed down and everything that wasn't for sale or didn't come to the market in 2020 was suddenly hitting the market in the second quarter of 2021."

Pitchbook Data, the Seattle-based company that researches the venture capital, private equity, and merger and acquisition markets, reported that dealmaking through the third quarter of 2021 already broke 2019's record for annual deal value, at more than $787 billion.

"The U.S. private equity industry is storming through 2021, smashing records as investors take advantage of a bullish climate, and remain undeterred by the possibility of inflation and interest rate hikes," the company wrote in an October analysis.

James Bauerle is a cofounder of Renaissance Partners, a Pittsburgh-based investment banking and business advisory firm. His firm's focus is on middle-market firms—ranging from a few million in sales to $500 million—and on the lower middle market—ranging from $1 million to $150 million. He recently assisted in the sale of the Paul Wissmach Glass Co., a 117-year-old family-owned business based in West Virginia.

He also has witnessed the frothy market for dealmaking. "It's an excellent time to be a seller if you have a good operating business. The multiples that people are paying are as good as they've been in my career of 40 years," he says.



Austria-based Stoelzle Glass Group purchased a Monaca, Pa. glass factory from the Oneida Group's Anchor Hocking Glass Co. in August 2021. *Credit: Anchor Hocking Glass Co.*

In the life cycle of nearly every business there comes a time when the owners reach a crossroads that may demand fundamental decisions: Do we expand or stay the course? Is it time to buy or time to sell? Who's next in line to run the business?

These questions not only need to address the state of the business but also need to be answered in the context of the marketplace, the economy, and the prospects for the future.

Deciding whether and when to sell or buy should be an ongoing topic among business management, Bauerle says.

"People who have companies should be thinking proactively about what their strategy is and whether they should be buying, selling, expanding, or not expanding," he says. "That should be a constant top-of-mind point."

There are many reasons buyers may be looking around. One is to enter new markets, as acquiring can be a quick way to do that if the business to be purchased has built a reliable customer base.


David Ruf

In August, Austria-based Stoelzle Glass Group announced it had purchased a glass factory in Pennsylvania from Anchor Hocking Glass Co. for an undisclosed amount. It is Stoelzle's first glass plant in the U.S., and its first outside of Europe. The acquisition, along with further investment and modernization, will promote the company's goal of "becoming the leading supplier for high-quality glass containers in the United States and North America," the company says in a news release.

Berlin Packaging, the Milan, Italy-based supplier of glass packaging, has expanded around the world through acquisition. In August, it announced the purchase of The Juvasa Group, a family-owned packaging firm based in Spain. The acquisition "continues our efforts to expand our presence in Europe, the Middle East, and Africa," says Bill Hayes, Berlin Packaging's global CEO and president, in a press release.


James Bauerle

It was Berlin's sixth acquisition in the Europe, Middle East, and Africa region in 2021 alone, and its sixteenth since 2016.

In February, the company announced the acquisition of Sodis-Uhart, a family-owned glass packaging concern in southern France. It was the company's eleventh acquisition in Europe since 2016.

"Expanding our presence in Europe remains a critical objective for us in 2021," Hayes said at the time. "Targeted acquisitions continue to be an important way for us to execute on our strategic growth plans for Europe."

Kyocera Corp., the global company that supplies components for the auto and electronics industries, and many others, is constantly scanning the horizon for partnerships, some of which may eventually become acquisitions. "Kyocera is absolutely interested in new technologies and new companies," says Mark Wolf, vice president of Kyocera's Fine Ceramics Group.

Kyocera prefers to work with smaller companies as suppliers or possibly in joint ventures first before considering an acquisition. "We really like to work with companies first to get to know them before we do anything else," Wolf says. That way, company leaders can determine whether a tie-up will gel before making a bigger investment.

In January, Kyocera completed the acquisition of SLD Laser, a California-based tech company that was started in 2013 by Nobel laureate in physics Shuji Nakamura. SLD had commercialized gallium nitride-based laser light sources that can be used in the production of fine ceramics and in other applications.

"We know innovation is happening across the world," Wolf says. "People are going to come up with ideas and exploit those, and Kyocera is interested in those ideas."

Other recent Kyocera acquisitions include its purchase in 2019 of H.C. Starck Ceramics, an advanced ceramics manufacturer and sales company based in Selb, Germany. That deal gave Kyocera its first ceramic manufacturing facility in Europe, and it brought with it a new processing technology that enabled the production of high-rigidity, large, complex-shaped materials.

Later that year, Kyocera expanded its presence in Europe with the acquisition of the advanced ceramics business of Friatec GmbH, a 156-year-old business based in Mannheim, Germany.

Private equity firms are often looking to buy or invest in companies with leading-edge technology and superior products, and they have the capital to do that. "There's more than $2 trillion of private equity that's looking for a home and good deals," Bauerle says.

Artemis Capital Partners, a Boston-based private equity firm, bought Superior Technical Ceramics in 2018, citing STC's technical advantages in materials and processes, its engineering expertise, and its customer-centric culture, "the hallmarks of scalable growth," the firm said when it announced the deal. Vermont-based STC was founded in 1898 and provides advanced ceramic products used in a range of applications.

Sometimes a family-owned company will transition after a generational event. Mo-Sci Corp. was founded in 1985 by Delbert Day to


ETS Technologies' first product, a synthetic skin substitute.
Credit: ETS Technologies

develop and supply specialty glass and ceramic products for specific market applications. The company grew into a leading supplier to the medical device industry with glass microspheres, fibers, and powders. It also provides sealing glass and test services for the aerospace, automotive, and electronics industries.

The company was led by Ted Day, Delbert's son, until he passed away in September 2020 at the age of 59. A year later, Mo-Sci announced it would be acquired by the Heraeus Group, a large portfolio company based in Hanau, Germany. Heraeus is a global Fortune 500 company whose roots date to a family pharmacy started in the 17th century. Today, the Heraeus Group includes businesses in the environmental, electronics, health, and industrial applications sectors.

The acquisition also included ETS Technology Holdings, a company founded in 2012 to develop and commercialize a novel, borate-based bioactive glass technology platform for wound care.

"Mo-Sci and Heraeus have been in contact for many years, and prior to his passing, Ted identified Heraeus as a preferred partner to take Mo-Sci and ETS to the next stage of development," says Kimberly Day, the owner of both companies, in a press release.

With 2021 merger and acquisition activity setting records, what does that mean for 2022?

KeyBanc's Ruf expects dealmaking to continue to be robust, but perhaps drop off slightly following this year's torrid market. "I would expect a slightly lower volume of M&A [mergers and acquisitions] in Q1, just because we had everything being pushed through in 2021," he says.

He expects capital to continue to be readily available for borrowing, and interest rates to remain low.

The big question, he says, is what will happen to tax rates if a big spending package is passed by Congress. The tax rates on capital gains could go up significantly, he explains, which might make prospective sellers wait. Or conversely, it could make them jump into the market before any new rates take effect.

There are several tailwinds that could help propel a robust market in 2022, according to a September report from UBS Global Wealth Management. They are

- Low interest rates and government stimulus packages that are still working their way through the economy,
- Record levels of capital available in both the private and public markets,
- Pent-up supply and demand from both sellers and buyers,
- The feeling that the worst may be behind us as it relates to the pandemic, and
- Possibly speeding up exit planning due to uncertainty related to capital gains and corporate taxes.

"Companies that performed well over the COVID period are trading at attractive valuation levels and are in demand by buyers," says Alan Felder of UBS Investment Bank.

Companies planning to sell should review their operations and get them in shape before going out on the market, Bauerle says. "It's no different than selling your house," he says. "You want a house that people look at and say that's a house that I'd like to live in and I'll pay fair value for."

Steps to take could include reviewing senior management and making sure the right people are in the right roles, and creating a succession plan. Bauerle recommended finding an independent set of eyes to evaluate the business to determine what value could be expected in a sale, and what needs to be done to tune up the enterprise, both operationally and financially.

Ruf advises sellers to prepare well and prepare deeply because momentum matters in a deal. If the seller needs to gather information while the deal is in process, a delay could raise doubts, he says. "Invariably, everybody's going to wonder why the process slowed down, what problem is occurring," he says.

Crafting the story of the business and describing what sets it apart from others in the field is critical, he says. That includes describing the quality of the customer base, the product differentiation, intellectual property, and the speed and quality of service.

"We spend a lot of time with management in advance of doing anything in the capital markets, months and months of gathering data, refining the story, putting that into a single package that makes sense," he says.

Decades of working with small- to midsized manufacturers like the Paul Wissmach Glass Co., whose colored glass is shipped from Paden City, W.Va., to customers around the globe, has shown Bauerle what their story is: "It's people who know how to do what they do, and go about it without a lot of fanfare, and whose products are valued all over the world."

And that's something to take to the bank any day.

STONY BROOK'S CENTER FOR THERMAL SPRAY RESEARCH CELEBRATES A MILESTONE

The Center for Thermal Spray Research (CTSR) at Stony Brook University (Stony Brook, N.Y.) has reached the significant milestone of 25 years.

The Center was established in 1996 when a team led by professor Herbert Herman, along with professors Christopher Berndt and Sanjay Sampath, converted a fledgling but successful academic activity in thermal spray materials processing into a major, multidisciplinary materials research program. A multiyear, $4 million grant from the National Science Foundation Materials Research Science and Engineering Center (MRSEC) program provided the necessary support.

The team's premise was that thermal spray allows materials to be synthesized from extreme conditions with novel microstructures that allow important functionalities in engineering systems.

The research included contributions from scientists at the National Institute of Standards and Technology, who applied small-angle, X-ray and neutron scattering to study porosity and interfaces in layered materials. A parallel effort used neutrons to conduct depth profiles of residual stresses.

Working with colleagues at MIT, studying the mechanics of layered, defected materials offered new insights into the mechanical behavior of nontraditional materials systems. A partnership with the Stony Brook Geoscience Department allowed examination of the role of the high pressures generated during impact formation of metastable materials. Researchers also studied particle dynamics both during the melting and deposition phases.

NSF renewed the program for a second, five-year term to expand into new strategies including studies of liquid feedstock to synthesize novel chemistries, and applications of the process into electronic, magnetic, and sensor functions.

An Industrial Consortium for Thermal Spray Technology was established in 2002 with 10 companies, which allowed knowledge transfer from fundamental research to industrial practice. The Consortium continues to thrive today with 30 contributing members.


Thermal spray rig at CTSR.
Credit: Ashton Worthington Photography

The Center's output is significant: some 50 Ph.D. students, 40 M.S. students, and 30 postdoctoral researchers were trained. Hundreds of undergraduates learned to handle complex materials processing equipment and characterization methods. More than 500 K–12 students participated in field trips. The Center's results include more than 400 refereed publications, 12 book chapters, seven patents, and three licenses.

CTSR plans a celebratory workshop in 2022 to mark this milestone, which coincides with the 20th anniversary of the Consortium partnership.

For more information, visit www.stonybrook.edu/ctsr or contact Sanjay Sampath at sanjay.sampath@stonybrook.edu or 631-632-8480.

ELCON–UC DAVIS PARTNERSHIP INVESTIGATES DISCOLORATION OF HIGH-CALCIA ALUMINA

By Tim Dyer and Nikki Do

As a high-tech manufacturing company that produces precision components for critical applications in several industries, Elcon Precision (San Jose, Calif.) is always investing in new technologies and developing better processes to not only meet customer specifications but also satisfy scientific curiosity.

One puzzle that Elcon has encountered for many years is discoloration of some alumina compositions during ceramic metallization, a service that Elcon offers. In this process, a proprietary thick film moly-manganese paint is applied to bare ceramic substrates to prepare them for subsequent brazing into assemblies. After metallization, parts undergo wet hydrogen firing at around 1,400°C. For aluminas with high calcia concentrations (1–2%), greyish discoloration is often observed on the surface of the ceramic (Fig. 1). This phenomenon is often called nucleation.

Although nucleation does not reduce bond strength or affect the part's physical or electrical properties, it is a cosmetic issue many customers prefer to avoid. Yet, to our knowledge, there is no published research on why this discoloration only occurs in certain aluminas and how it can be prevented.

In the spring of 2021, Elcon had the opportunity to investigate this question when a team of undergraduate students at the University of California, Davis, reached out to Elcon to collaborate on a project. Rebecca Salcedo, Elcon's process engineer, and Tim Dyer, Elcon's president, agreed to support a project with six students from professor Subhash Risbud's EMS 188 course: Rachel Altovar, Clayton Braga, Miranda Bell, Nicole Shuman, Ethan Suwandi, and Jiaying Li.

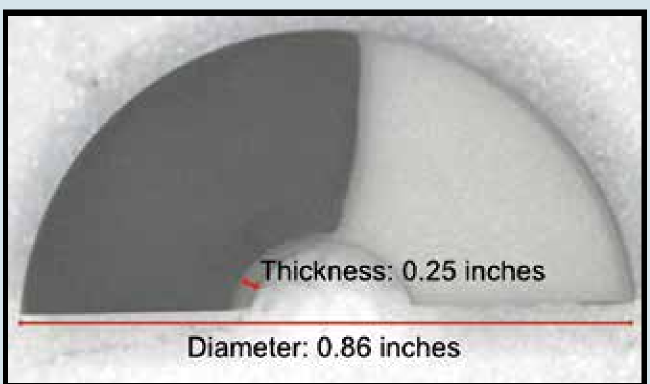


Figure 1. Alumina sample exhibiting light nucleation and discoloration after first metallizing fire. Metallization on left, discoloration of bare ceramic on right. *Credit: Elcon Precision*

The students were excited to explore the question of nucleation and discoloration in high calcia alumina. As Shuman explains, "although our courses discussed topics such as viscosity and brittleness, there weren't any courses where we focused on ceramics or polymers. The attraction for all of us with this project was the opportunity to broaden our knowledge and skills working with ceramics." The team took to the project enthusiastically and, with a 10-week project timeline, assigned roles best suited to their strengths—project manager, literature research, material characterization, computer modeling, and experimental design.

The team focused on 97% and 97.5% aluminas from two different manufacturers that had 1–2% calcia concentration. Commonly used in defense and electronics applications, these aluminas contain calcia because the calcia acts as an alumina flux and reduces the sintering temperature significantly by formation of a calcia-alumina eutectic, which in turn reduces firing cycle times.

At Elcon, it often takes one to two weeks to get a sample run for a research and development project because resources are reserved for production. However, that approach would not have worked if the project was to meet its deadline, so the Davis team decided to start with computational modeling.

"Modeling allows you to test things before they actually happen," Suwandi says. In the case of ceramic microstructures, which are very complicated systems, understanding the composition of the material and its reactive properties under simulated conditions can pave the way to running much faster and smoother experiments.

To develop an accurate model, the team reviewed academic papers by Klaus et al.,[1] investigating the phase formation and thermal stability of the $CaO–Al_2O_3–MgO$ system under different sintering temperatures and times. These papers showed that the ternary hexa-aluminate phases CAM I ($C_2M_2A_{14}$) and CAM II (CM_2A_8) can form at a narrow temperature range of 1,400–1,700°C. In addition, Martinez et al.[2] found that hibonite can form as well in calcia-containing alumina materials processed between 1,150–1,500°C. These phases function as an interlock in the alumina matrix and strengthen the bonds of compounds, enhancing the substrate's thermal and mechanical properties. This microstructure observation of an aluminate ceramic system under different sintering temperatures and times pointed the team to consider these factors as the cause of discoloration.

The team used Thermo-Calc, a modeling and prediction tool commonly used in industry, in conjunction with CALPHAD (CALculation of PHAse Diagrams) to produce high-resolution phase diagrams (Fig. 2). CALPHAD uses a database of experimental and theoretical values including phase compositions at equilibrium to calculate the Gibbs free energy for a specific phase. Though Thermo-Calc hosts a robust methodology and database, there is little to no experimental data available for the ternary ceramic systems being analyzed. Using Thermo-Calc Python, the team rewrote the script to add flexibility to defining the phase boundaries and necessary kinetics. Having multiple sophisticated resources and systems provided by the university allowed the team to quickly adapt to the project's needs.

Armed with this set of tools, the modeling team input compositions for the high calcia alumina samples (Al_2O_3, SiO_2, and CaO) into the program using the metal oxide ceramics database.[3] Modeling was performed in both atmospheric (1 atm) and vacuum conditions (1 x 10^{-7} atm) with a temperature range of 200°C to 1,750°C to create ternary phase diagrams. Alumina samples included both discs and thin boards of 97.5% alumina (Sample A) and 97% alumina (Sample B).

Several relevant phases were identified in the high calcia alumina models, including

- **Corundum (Al_2O_3):** Dominant phase. Colorless.
- **Anorthite (CaO • Al_2O_3 • $2SiO_2$):** Forms in most phase regions. White to grayish.
- **Hibonite (CaO • 6 Al_2O_3):** Forms in both samples above ~1,000°C. Brownish/black
- **Mullite ($Al_6Si_2O_{13}$):** Forms in phase regions adjacent to 97% alumina at all temperatures. Colorless, but other technical ceramic papers show a graying effect around 1,400°C.

A significant finding from these phase diagrams was that hibonite developed in the firing temperature range where the surface discoloration occurs. Hibonite is an alumina-calcia phase that is known for forming brown and grey colors between 1,150–1,500°C.[2] Furthermore, due to composition variations, the calcia-containing alumina samples have the disposition to form both mullite and hibonite. These findings led the team to form an early hypothesis that the discoloration was due to hibonite and/or mullite formation at temperatures above 1,000°C.

The team used these phase diagrams, the literature review, and historical production data provided by Elcon to design their experiments around this hypothesis. Designing the investigation around the phase diagrams and material compositions allowed the team to have a more directed approach while also applying their theoretical knowledge to a relevant experiment.

Suwandi says that "Within the simulation and microstructure characterization research that I do, there's a propensity for computational people to get stuck in their own world. Although you're dealing with complex models, at the end of the day, if they're not implemented into an experimental setting or connected to one, it kind of exists on its own. This project allowed us to apply these models to industry and pushed me onto a more specialized path, which consists of microstructure characterization and reconstruction."

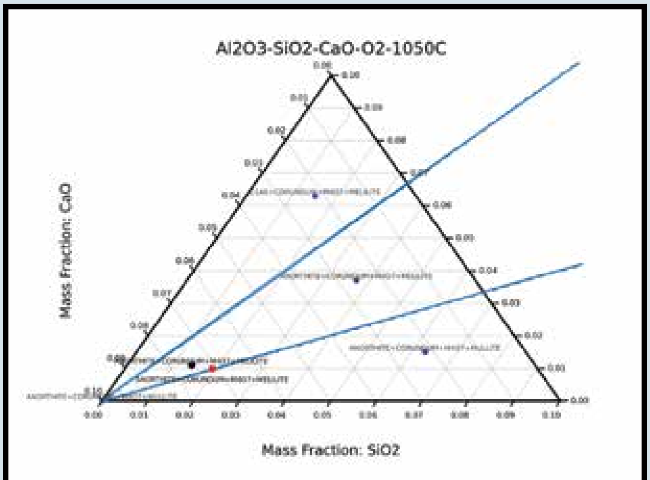


Figure 2. Phase diagram produced using Thermo-Calc for high-calcia alumina at 1,050°C and a pressure of 1 ATM (760 Torr). *Credit: Elcon Precision*

Conducted at Elcon Precision and Prairie Ceramics (San Leandro, Calif.), the experiment consisted of making adjustments in the thermal profiles, i.e., various holds under high temperatures, quenching the ceramics with rapid and slow cooling rates, and subjecting the substrates to different heat treatments. In addition, thin 99.9% pure alumina boards were painted using mixed silica and calcia glazes to serve as proxy samples to study the phase composition of the ceramic surfaces over a wide range of chemistries (Fig. 3). Lastly, there were a few trials in which the alumina disks were coated with a pure calcia wash, manipulating the surface composition.

It is important to not only understand the phases present in the ceramics, but to also understand the phase dependence and the properties of each phase. This understanding can be accomplished with tools such as X-ray diffraction (XRD) and scanning electron microscopy (SEM). Using these methods can shed light on the origins and properties of the discoloration such as phase, thermostability, and temperature dependence.

Figure 3. Ring sample cross sections demonstrating nucleation-based discoloration extending far below the original surface. *Credit: Elcon Precision*

To understand the different phases present before and after metallization sintering, the alumina

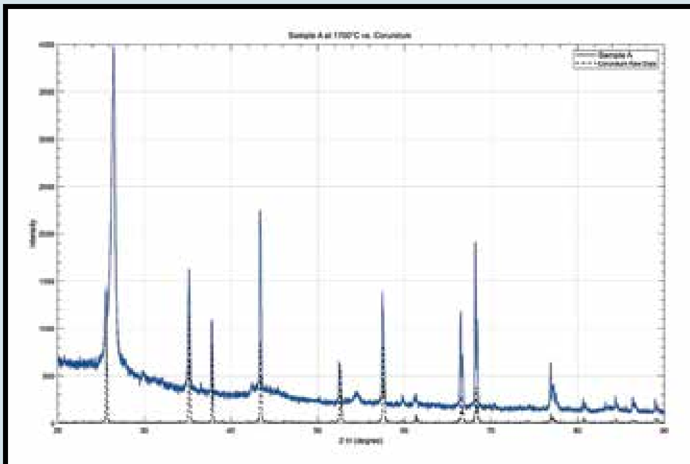


Figure 4. XRD diffraction data shown with overlapping peaks of sample A (97.5%) fired at 1,700°C with corundum. *Credit: Elcon Precision*

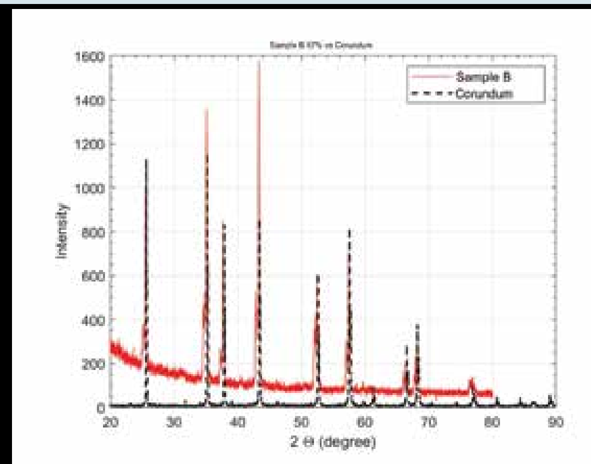


Figure 5. XRD diffraction data shown with overlapping peaks of sample B (97%) fired at 1,450°C with corundum. *Credit: Elcon Precision*

samples were characterized through XRD and SEM carried out in the Advanced Materials Characterization and Testing Laboratory at UC Davis. The unmetallized ceramic contains four major ternary compounds: gehlenite ($Ca_2Al_2SiO_7$), anorthite ($CaAl_2Si_2O_8$), clinopyroxene ($CaAl_2SiO_6$), and grossular ($Ca_3Al_2Si_3O_{12}$).[4]

The diffraction patterns of the alumina samples generated by XRD were compared with the expected phase's diffraction patterns to determine the phases existing in the samples. Diffraction patterns produced for sample A (97.5%) at 1,700°C and sample B (97%) fired at 1,450°C matched almost perfectly with that of corundum, suggesting that corundum is the major phase present (Figs. 4 and 5). Because it is a very common phase, identifying it prompts the hypothesis that a small amount of another phase is influencing the nucleation-based discoloration.

To improve XRD characterization of potential phase formation above 1,200°C, 99% alumina substrates were painted with a calcia-silica wash and then analyzed after metallization sintering. The diffraction patterns of some samples lined up closely with that of hibonite. This finding lends some support to the hypothesis that hibonite formed at specific temperatures, causing the discoloration.

SEM analysis of each alumina sample identified possible phases present on the surface. Based on these results, potential minority phases were identified—anorthite, mullite, and hibonite. These findings correlated with the phase diagrams generated from Thermo-Calc and also supports the hibonite formation hypothesis.

The team discovered that the discoloration created by metallization firing could be cleared by air sintering above 1,700°C followed by rapid cooling. A possible explanation for this solution is that hibonite is kinetically outcompeted by anorthite and corundum grain growth, possibly altering the local composition faster than hibonite can form.

Though the team accomplished the goal of exploring and disentangling the nucleation-based discoloration phenomenon, this academic–industry partnership sparked an even more significant realization. The culmination of literature reviews, computational modeling and characterization, and practical experiments not only accelerated learning, but it is a powerful problem-solving strategy that many companies still overlook. This team showed that using skills and expertise from both universities and companies collaboratively can improve materials processing performance.

When the students were asked what they wished to see more of regarding academic-industry partnerships in the future, Braga says he would "like to see more companies branch out and use university hires." Supporting that, Suwandi believes that "there are a lot of opportunities for small companies, especially in the materials industry," that should leverage the fact that "our curriculum is very theoretical, so we lack industry experience." Suwandi adds that this project gave them an "experience with an entirely different set of rules and expectations than what goes on in the research side in a lab."

ACKNOWLEDGEMENTS

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OPTICAL GLASS: ADVANCED ROTARY SURFACE GRINDERS DELIVER MORE POSSIBILITIES AND TIGHTER TOLERANCES

By Carlo Chatman, Power PR

To combat the loss of seasoned operators to retirement, glass job shops are turning to more modern automated surface grinders.

Older flat glass grinding equipment has limited mechanical controls and can require significant expertise, as well as time and labor to accomplish a task. For instance, such machines often use large wheels and dials to control the grinder's movement, meaning that the soft touch of an expert machinist is required to run them instead of programmable machine controls.

However, experienced operators who can successfully run such equipment are in increasingly short supply, and this shortage presents challenges to companies that rely on the older equipment.

"When I started almost 20 years ago, we were still using old, rotary surface grinders from the 1940s and '50s. They are tried-and-true, but not very accurate without an experienced machinist using them," says Brennan Cipro, chief engineer of Worcester, Mass.-based Howard Glass Company, which specializes in glass grinding and polishing for industries such as optics, biomedical, electronics, and aerospace.

Howard Glass focuses on 2D glass shapes, so factors such as thickness, parallelism, and surface condition are very important. Cipro notes that the glass materials provided by factories have varying degrees of standard thickness, meaning that glass materials often must be ground to smaller, precise dimensions. When using older grinding equipment, achieving such precision often requires the use of another machine to provide the final grind and polish, which adds hours to the fabrication process and contributes to inefficient production.

Modern automated rotary surface grinders offer advanced sensors and controls that can reliably achieve tighter dimensional tolerances, flatness, parallelism, and surface finish in much less time. The equipment can be used to grind flat glass to precise dimensions before polishing, significantly reducing intermediate lapping steps as well as preventing breakage of what is often a high-value product.

"The possibilities are endless with the new automated grinders," says Cipro. "Operators can enter the specific requirements, for example, 712 RPMs on the spindle, 22 RPMs on the table, with a down-feed rate of 0.003 inches a minute, with a certain dwell cycle. Essentially, operators can program the machine to do whatever they want."

Three years ago, Howard Glass had the opportunity to purchase a used, vertical spindle rotary table surface grinder from another shop that had completed a project and no longer needed it. The IG 280 SD from Winona, Minn.-based DCM Tech, a designer and builder of industrial rotary surface grinders, has a 24-inch, variable speed table and a 20-horsepower, variable speed grinding spindle motor.

Modern rotary surface grinders like those from DCM Tech offer advanced sensors and controls that can reliably achieve tighter dimensional tolerances, flatness, parallelism, and surface finish in much less time. *Credit: DCM Tech*


DCM Tech automated rotary surface grinders can be used to grind flat glass to precise dimensions before polishing, significantly reducing intermediate lapping steps as well as preventing breakage of what is often a high-value product. Above, glass discs before and after grinding. *Credit: DCM Tech*

In this machine, grinding is not performed by the peripheral edge of the wheel but rather by the entire diameter of the abrasive surface. In addition, digital technology allows for an interface with easy-to-use touchscreen controls. When combined with automation, the surface grinder operators no longer need to be highly trained individuals.

"The IG 280 from DCM Tech had a digital readout, memory, and could remember where 'zero' was, so it was an important upgrade that helped with efficiency, accuracy, and surface finish," Cipro says. "It enabled us to grind the glass very close to the final dimensions, so only a tiny bit had to be removed in the polishing process, which saves tremendous time."

After a decades-old traditional surface grinder stopped working, Howard Glass decided to invest in a new IG 280, and shortly thereafter a larger format IG 380, which comes with a 36-inch, variable speed table and a 30-horsepower spindle motor. Cipro says he was immediately impressed with the automation and refinements made by DCM since the early version of the IG 280.

One example of innovation involves the automation of the initial contact between the wheel and the part. Traditionally, this contact had to be finessed by the operator, but with the new machine, the advanced sensor technology senses vibration. In addition, it automatically fine-tunes not only the pressure of the spindle motor but also how quickly it moves the abrasive wheel down onto the part.

When the machine senses the abrasive wheel has contacted the part, it automatically begins the grind cycle, which helps to minimize the potential breakage of sensitive glass or crystal parts. This capability is important in loud manufacturing facilities where operators cannot rely on listening for the sound of initial contact between the abrasive wheel and the part. Given that many such parts are high value, an operator coming in too aggressively and breaking a part can cost the company hundreds or thousands of dollars.

"I was amazed at the refinements and tighter tolerances now possible," Cipro says. "Previously, when precision down to ten-thousandths of an inch was required, it could take three hours to remove the excess on our interim machine. Now, we can grind down to ten-thousandths of an inch quickly and effortlessly without extra steps."

In addition to reducing the needed number of finishing steps, the process repeatably achieves high throughput and eliminates variability, which enables job shops to achieve high-quality final parts, batch after batch.

Making parts in less time does no one any good if half of the parts do not pass the final inspection and cannot be used. So, the more job shops can optimize the upfront glass grinding process, the less polish time is required, thus improving not only the cycle time but also lowering costs and increasing revenue.

Perhaps even more important to Howard Glass were improvements in flexible processing that allow operators to enter virtually any requirement into a touch screen with programmable human machine interface controls. Cipro adds that, with this kind of flexibility, if a piece of glass breaks, it is easy to back any factor down a little to prevent the issue from reoccurring.

He points out that for routine processes, the use of different grind "recipes," with sets of parameters for specific parts, can further speed production, enhance quality, and aid in quick changeover.

"If the glass is a little off in the first pass, the DCM grinder can be programmed to take corrective actions on subsequent passes. There is no need to pick up the glass and measure it after every move, as with older machines," he says.

As the tolerances for glass and crystal grinding become stricter and production requirements more demanding, job shops that take advantage of advanced, automated rotary surface grinders will stay competitive even as experienced operators retire.

"Every day I hear my operators discussing ways to improve our glass grinding process because of the versatility of the advanced equipment. We are still discovering its potential," concludes Cipro.

For more information, visit www.dcm-tech.com or send an email to info@dcm-tech.com.

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September 2021	Productive partnering with industry, academia, and government
December 2021	Navigating acquisitions

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Calendar of events

December 2021

1–4 ICAPMA-JMAG (Joint International Conference on Applied Physics and Materials Applications & Applied Magnetism and Ferroelectrics) – Nongnooch Pattaya International Convention and Exhibition Center (NICE), Pattaya, Thailand; https://www.matscitech-thailand.com/2021/index.php

12–17 14th Pacific Rim Conference on Ceramic and Glass Technology (PACRIM 14) including Glass & Optical Materials Division 2021 Annual Meeting (GOMD 2021) — VIRTUAL EVENT ONLY; https://ceramics.org/pacrim14

13–14 85th Annual Session of the Indian Ceramic Society presents Advances in Ceramics & Cement Technologies: Materials & Manufacturing — VIRTUAL EVENT ONLY; http://www.icskc.in

January 2022

18–21 Electronic Materials and Applications 2022 (EMA 2022) – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla.; https://ceramics.org/ema2022 – HYBRID EVENT

23–28 46th International Conference and Expo on Advanced Ceramics and Composites (ICACC2022) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; https://ceramics.org/icacc2022 – HYBRID EVENT

March 2022

9–10 Sustainable Industrial Manufacturing (SIM) – Brussels, Belgium; https://sustainableindustrialmanufacturing.com/europe

15–18 17th Biennial Worldwide Congress Unified International Technical Conference on Refractories – Hilton Chicago, Chicago, Ill.; https://ceramics.org/unitecr2021

May 2022

9–12 ACerS 2022 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Omni Charlotte Hotel, Charlotte, N.C.; https://ceramics.org/scpd2022

22–26 Glass & Optical Materials Division Annual Meeting (GOMD 2022) – Hyatt Regency Baltimore, Baltimore, Md.; https://ceramics.org/gomd2022

June 2022

13–15 12th Advances in Cement-Based Materials (Cements 2022) – University of California, Irvine; https://ceramics.org/cements2022

21–22 ceramitec 2022 – Munich, Germany; https://www.ceramitec.com/en/trade-fair/information/exhibition-sectors

July 2022

3–8 ➨ ICG Annual Meeting 2022 – Berlin, Germany; https://ceramics.org/event/icg-annual-meeting-2022

10–14 International Congress on Ceramics (ICC9) – Krakow, Poland; https://ceramics.org/event/international-congress-on-ceramics-icc9

24–28 Pan American Ceramics Congress and Ferroelectrics Meeting of Americas (PACC-FMAs 2022) – Hilton Panama, Panama City, Panama; https://ceramics.org/PACCFMAs

October 2022

14–19 ACerS 124th Annual Meeting with Materials Science & Technology 2022 – David L. Lawrence Convention Center, Pittsburgh, Pa.; https://ceramics.org/event/acers-124th-annual-meeting-with-materials-science-technology-2022

August 2023

NEW DATE

27–31 The International Conference on Sintering 2023 (Sintering 2023) – Nagaragawa Convention Center, Gifu, Japan; https://www.sintering2021.org

July 2024

14–19 International Congress on Ceramics – Hotel Bonaventure, Montreal, Canada; www.ceramics.org

Dates in **RED** denote new event in this issue.

Entries in **BLUE** denote ACerS events.

➨ denotes meetings that ACerS cosponsors, endorses, or otherwise cooperates in organizing.

denotes International Year of Glass event

denotes virtual meeting

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Career Opportunities

Statement of Ownership

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3. Sales through dealers and carriers, street vendors, counter sales and other non-USPS paid distribution	1,595	1,723
4. Other classes mailed through the USPS	none	none
C. Total paid and/or requested circulation	4,440	4 613
D. Free distribution by mail (samples, complimentary and other free)		
1. Outside-county	2,220	3,014
2. In-county	none	none
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4. Free or Nominal Rate Distribution Outside the Mail (Carriers or other means)	127	286
E. Total Free or Nominal Rate Distribution	2,347	3,300
F. Total distribution	6,787	7,913
G. Copies not distributed	57	38
H. **Total**	6,844	7,951
I. Percent paid and/or requested circulation	65.42%	58.30%

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FCT Ingenieurkeramik GmbH Germany
FELDCO Intl CA
Ferrotec Ceramic Products China
Free Form Fibers NY

II-VI Aerospace & Defense CA **See ad on page 61**
Morgan Advanced Materials CA
O'Keefe Ceramics Inc CO
Ortech Inc CA
Precision Ceramics FL
Precision Ferrites and Ceramics Inc CA
PremaTech Advanced Ceramics MA
Rauschert Industries Inc GA
Refratechnik Ceramics GmbH Germany
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
Silicon Carbide Products Inc NY
Starfire Systems Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
TevTech LLC MA **See ad on page 89**
Zhengzhou Mission Ceramic Products Co Ltd China

Silicon Nitride Products
Accuratus Corp NJ

Silicon Nitride Products
Actech Precision Ceramic (HK) Limited China
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Beijing Cerametek Materials Co Ltd China
CoorsTek CO
FELDCO Intl CA
Ferrotec Ceramic Products China
Free Form Fibers NY
Induceramic Canada
International Ceramic Engineering MA
Morgan Advanced Materials CA
O'Keefe Ceramics Inc CO
Precision Ceramics FL
Precision Ferrites and Ceramics Inc CA
Rauschert Industries Inc GA
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
Technology Assessment and Transfer Inc (TA&T) MD
Zhengzhou Mission Ceramic Products Co Ltd China

Thickening Agents
Lubrizol Performance Coating OH Agents

Thread Guides
Akron Porcelain & Plastics Co OH
Associated Ceramics & Technology Inc PA
Astro Met Advanced Ceramics Inc OH
Ceramco Inc NH
CeramTec North America Corp SC
Industrial Ceramic Products Inc OH
International Ceramic Engineering MA
Ortech Inc CA
Rauschert Industries Inc GA
Superior Technical Ceramics Corp VT
Zhengzhou Mission Ceramic Products Co Ltd China

Transparent Ceramics
CeraNova Corp MA
CoorsTek CO
Ferrotec Ceramic Products China
Israel Ceramic & Silicate Inst Israel
nGimat LLC KY
Precision Ferrites and Ceramics Inc CA
PremaTech Advanced Ceramics MA
Surmet Corp MA

Tubes

Accuratus Corp NJ
AdValue Technology LLC AZ **See ad on page 51**
Advanced Ceramics Manufacturing AZ
Akron Porcelain & Plastics Co OH
Aremco Products Inc NY
Associated Ceramics & Technology Inc PA
Astro Met Advanced Ceramics Inc OH
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CeramTec North America Corp SC
CoorsTek CO
Du-Co Ceramics Company PA
Dunhua Zhengxing Abrasive Co Ltd China
EBL Products Inc CT
Elcon Precision LLC CA
Ferrotec Ceramic Products China
Induceramic Canada
Industrial Ceramic Products Inc OH
International Ceramic Engineering MA
Jyoti Ceramic Industries Pvt Ltd India
McDanel Advanced Ceramic Technologies LLC PA
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
Precision Ceramics FL
Progressive Technology Inc CA
Rauschert Industries Inc GA
Refractron Technologies Corp NY
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
Silicon Carbide Products Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Superior Technical Ceramics Corp VT
Xiamen Unipretec Ceramic Technology Co Ltd China
Zhengzhou Mission Ceramic Products Co Ltd China
Zircoa Inc OH

Wear-Resistant Parts

Accuratus Corp NJ
AdValue Technology LLC AZ **See ad on page 51**
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Akron Porcelain & Plastics Co OH
Associated Ceramics & Technology Inc PA
Astral Material Industrial Co Ltd China
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd India
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CeramTec North America Corp SC
CeramTec-ETEC Germany
CerCo LLC OH
CoorsTek CO
Diamorph AB UK
EBL Products Inc CT
FCT Ingenieurkeramik GmbH Germany
FELDCO Intl CA
Ferro Ceramic Grinding Inc MA
Ferrotec Ceramic Products China
Ipsen Ceramics IL
Jyoti Ceramic Industries Pvt Ltd India
McDanel Advanced Ceramic Technologies LLC PA
Morgan Advanced Materials CA
Morgan Technical Ceramics Auburn CA
NEVZ-Ceramics Close JSC Russia
New Tech Ceramics Inc IA
NGK Spark Plug Co Ltd Japan
O'Keefe Ceramics Inc CO
Ortech Inc CA
P-Ker Engineering NY
Precision Ceramics FL
PremaTech Advanced Ceramics MA
Progressive Technology Inc CA
Rauschert Industries Inc GA
Refrac Systems AZ
Refractron Technologies Corp NY
RocCera LLC NY
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
Silicon Carbide Products Inc NY
Starfire Systems Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Superior Technical Ceramics Corp VT
Technology Assessment and Transfer Inc (TA&T) MD
Xiamen Unipretec Ceramic Technology Co Ltd China
Zhengzhou Mission Ceramic Products Co Ltd China
Zircoa Inc OH

Zirconia Products

Accuratus Corp NJ
Actech Precision Ceramic (HK) Limited China
AdTech Ceramics TN

AdValue Technology LLC AZ **See ad on page 51**
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Akron Porcelain & Plastics Co OH
Associated Ceramics & Technology Inc PA
Astral Material Industrial Co Ltd China
Astro Met Advanced Ceramics Inc OH
Beijing Cerametek Materials Co Ltd China
Bharat Heavy Electricals Ltd India
Ceramco Inc NH
CeramTec North America Corp SC
CeramTec-ETEC Germany
CoorsTek CO
EBL Products Inc CT
ENrG Inc NY
FCT Ingenieurkeramik GmbH Germany
Ferro Ceramic Grinding Inc MA
Ferrotec Ceramic Products China
Imerys Fused Minerals Murg GmbH Germany
Induceramic Canada
Innovnano - Advanced Materials SA Portugal
International Ceramic Engineering MA
Israel Ceramic & Silicate Inst Israel
Jyoti Ceramic Industries Pvt Ltd India
Lithoz GmbH NY
McDanel Advanced Ceramic Technologies LLC PA
Morgan Advanced Materials CA
MSE Supplies AZ
Nanoe France
NEVZ-Ceramics Close JSC Russia
Nyacol Nano Technologies Inc MA
O'Keefe Ceramics Inc CO
Ortech Inc CA
PicoParts Ltd Israel
P-Ker Engineering NY
Polymer Innovations Inc CA
Precision Ferrites and Ceramics Inc CA
PremaTech Advanced Ceramics MA
Progressive Technology Inc CA

Rauschert Industries Inc GA
Refractron Technologies Corp NY
Robocasting Enterprises LLC NM
RocCera LLC NY
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain NorPro OH
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Superior Technical Ceramics Corp VT
Wistra GmbH Germany
Xiamen Unipretec Ceramic Technology Co Ltd China
Zhengzhou Mission Ceramic Products Co Ltd China
Zibo Guangtong Chemical Co Ltd China
Zircoa Inc OH

ARTWARE

Ceramic Artware

Arlimin Industries CO
Art On Ceramic NY
Ceramic Arts Network OH
Milestone Decal Art LLC NY
StudioLX - Home Decor IL
Tethon 3D NE
Viridis3D LLC MA

Glass Artware

Arlimin Industries CO
RISE Research Institutes of Sweden RISE Glass Sweden
StudioLX - Home Decor IL
Viridis3D LLC MA

Lighting

Akron Porcelain & Plastics Co OH
Viridis3D LLC MA

Ornamental Artware

Ceramic Arts Network OH
StudioLX - Home Decor IL
Viridis3D LLC MA

Pottery

ACCCO Inc/Burley Clay Products Co OH
Arlimin Industries CO
Ceramic Arts Network OH
North Star Equipment Inc WA
Peter Pugger Mfg Inc CA
Petro Mold Company PA
Ram Products Inc OH
Sheffield Pottery MA
StudioLX - Home Decor IL
Viridis3D LLC MA

■ CERAMIC & METALLIC POWDERS & MATERIALS

Abrasive Grains
Alteo NA LLC OH
Baikowski Malakoff Inc NC
Electro Abrasives Corp NY
FELDCO Intl CA
GMA Industries Inc MI
Imerys Refractory Minerals GA
Kyanite Mining Corp VA
Prince Minerals Inc (Prince International Corporation) TX
Saint-Gobain Abrasives MA
Saint-Gobain Ceramics & Plastics MA
Specialty Glass Inc FL
Washington Mills Electro Minerals Co NY

Adsorbants & Catalysts
GFS Chemicals Inc OH
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain NorPro OH

Alumina, Activated
AluChem Inc OH
Applied Ceramics Inc CA
Denka Corp NY
Momentive Performance Materials Inc NY
Nanoe France

Paul O. Abbe Inc IL **See ad on page 69**
Prince Minerals Inc (Prince International Corporation) TX
Sauereisen Inc PA

Alumina, Calcined
Almatis Inc PA
Alteo NA LLC OH
AluChem Inc OH
APF Recycling Inc OH
Baikowski Malakoff Inc NC
Denka Corp NY
Electro Abrasives Corp NY
Fusion Ceramics Inc OH
Hindalco Industries Limited India
Maryland Refractories Co OH
Nabaltec AG Germany
Nanoe France
PIDC (Pacific Industrial Development Corporation) MI
Prince Minerals Inc (Prince International Corporation) TX
Refractory Minerals Co Inc PA
Sauereisen Inc PA

Alumina, Fused
Alteo NA LLC OH
APF Recycling Inc OH
Denka Corp NY
Electro Abrasives Corp NY
GMA Industries Inc MI
Imerys Refractory Minerals GA
Lithoz GmbH NY
McDanel Advanced Ceramic Technologies LLC PA
Nanoe France
Prince Minerals Inc (Prince International Corporation) TX
Washington Mills Electro Minerals Co NY

Alumina, Fused Brown
Alteo NA LLC OH
APF Recycling Inc OH
BassTech Intl NJ
Bosai Minerals Group Co Ltd China
Electro Abrasives Corp NY
GMA Industries Inc MI
Imerys Refractory Minerals GA
Washington Mills Electro Minerals Co NY

Alumina, Fused White
Alteo NA LLC OH
APF Recycling Inc OH
Electro Abrasives Corp NY
Imerys Refractory Minerals GA
Sauereisen Inc PA
Washington Mills Electro Minerals Co NY

Alumina, High-Purity
Actech Precision Ceramic (HK) Limited China
Alteo NA LLC OH
AluChem Inc OH
APF Recycling Inc OH
Applied Ceramics Inc CA
Associated Ceramics & Technology Inc PA
Baikowski Malakoff Inc NC
CARBO Texas
CoorsTek CO
Denka Corp NY
International Ceramic Engineering MA
Ipsen Ceramics IL
Lithoz GmbH NY
Materion Advanced Materials NY
Materion Ceramics AZ
Nanoe France
PIDC (Pacific Industrial Development Corporation) MI
Pred Materials International Inc NY
Prince Minerals Inc (Prince International Corporation) TX
Rauschert Industries Inc GA
Sauereisen Inc PA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Valley Design Corp MA
Xiamen Unipretec Ceramic Technology Co Ltd China

Alumina, Hydrated
Almatis Inc PA
Alteo NA LLC OH
Denka Corp NY
Fusion Ceramics Inc OH
Hindalco Industries Limited India
Nanoe France
PIDC (Pacific Industrial Development Corporation) MI
Prince Minerals Inc (Prince International Corporation) TX
RE Carroll Inc PA

Alumina, Other Grades
Almatis Inc PA
Alteo NA LLC OH
Associated Ceramics & Technology Inc PA
Baikowski Malakoff Inc NC
CoorsTek CO
Denka Corp NY
Hindalco Industries Limited India
Imerys Refractory Minerals GA
Nanoe France
PIDC (Pacific Industrial Development Corporation) MI
Prince Minerals Inc (Prince International Corporation) TX
Trinity Ceramic Supply Inc TX
Wesbond Corp DE

Alumina, Reactive
Almatis Inc PA
Alteo NA LLC OH
AluChem Inc OH
Baikowski Malakoff Inc NC
Denka Corp NY
Hindalco Industries Limited India
Nabaltec AG Germany
Nanoe France
Prince Minerals Inc (Prince International Corporation) TX

Alumina, Single Crystal
Denka Corp NY
Nanoe France
Prince Minerals Inc (Prince International Corporation) TX

Alumina, Tabular
Almatis Inc PA
Alteo NA LLC OH
AluChem Inc OH
APF Recycling Inc OH
Denka Corp NY
GrainBound LLC PA
Imerys Refractory Minerals GA
Nanoe France
Prince Minerals Inc (Prince International Corporation) TX
Sauereisen Inc PA

Alumina, Zirconia Toughened
Actech Precision Ceramic (HK) Limited China
Applied Ceramics Inc CA
Associated Ceramics & Technology Inc PA
CerCo LLC OH
Denka Corp NY
Innovnano - Advanced Materials SA Portugal
Nanocerox UT
Nanoe France
PicoParts Ltd Israel
PIDC (Pacific Industrial Development Corporation) MI
Prince Minerals Inc (Prince International Corporation) TX
Rauschert Industries Inc GA
Sauereisen Inc PA
Washington Mills Electro Minerals Co NY
Xiamen Innovacera Advanced Materials Co Ltd China
Zircoa Inc OH

Aluminum & Compounds
Atlantic Equipment Engineers NJ
BassTech Intl NJ
Denka Corp NY
Hindalco Industries Limited India
Leico Industries Inc NJ
Refractory Minerals Co Inc PA
Valley Design Corp MA
Xiamen Unipretec Ceramic Technology Co Ltd China

Aluminum Nitride
Actech Precision Ceramic (HK) Limited China
Applied Ceramics Inc CA
Atlantic Equipment Engineers NJ
Bullen OH
Centerline Technologies MA
Denka Corp NY
Goodfellow Corp PA
International Ceramic Engineering MA
North American Hoganas PA
Pred Materials International Inc NY
Reade Advanced Materials RI
Surmet Corp MA
Toyal America Inc IL
Valley Design Corp MA

Aluminum Silicate
Goodfellow Corp PA
Sauereisen Inc PA

Antimony & Compounds
Alfa Aesar Johnson Matthey MA
Atlantic Equipment Engineers NJ
Goodfellow Corp PA
Pred Materials International Inc NY

Arsenic Oxide
Alfa Aesar Johnson Matthey MA

Barium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements Inc CA — **Outside back cover, 54**
BassTech Intl NJ
Bosai Minerals Group Co Ltd China
CerPoTech AS Norway
FELDCO Intl CA
GFS Chemicals Inc OH
Trinity Ceramic Supply Inc TX

Barium Carbonate
BassTech Intl NJ
Fusion Ceramics Inc OH
Hexion Inc OH

Barium Titanate
AVX Corp SC
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
CerPoTech AS Norway
Euro Support Advanced Materials The Netherlands
Haiku Tech Inc FL
Hexion Inc OH
nGimat LLC KY

Bauxite, Sintered
Alteo NA LLC OH

Beryllium & Compounds
APF Recycling Inc OH
Centerline Technologies MA
Leico Industries Inc NJ
Materion Advanced Materials NY
Materion Ceramics AZ

Bismuth & Compounds
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
CerPoTech AS Norway
FELDCO Intl CA
Fusion Ceramics Inc OH
nGimat LLC KY

Boric Acid

Paul O. Abbe Inc IL — **See ad on page 69**
Sauereisen Inc PA
U.S. Borax Inc | Rio Tinto IL — **See ad on page 73**

Boron & Compounds
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
Denka Corp NY
Electro Abrasives Corp NY
FELDCO Intl CA
Fusion Ceramics Inc OH
New Tech Ceramics Inc IA
North American Hoganas PA

U.S. Borax Inc | Rio Tinto IL — **See ad on page 73**

Boron Carbide
Atlantic Equipment Engineers NJ
CoorsTek CO
Custom Processing Services PA
Denka Corp NY
Dunhua Zhengxing Abrasive Co Ltd China
Electro Abrasives Corp NY
FELDCO Intl CA
Free Form Fibers NY
Goodfellow Corp PA
North American Hoganas PA
Reade Advanced Materials RI
Superior Graphite Co IL
Washington Mills Electro Minerals Co NY

Boron Nitride
Atlantic Equipment Engineers NJ
Denka Corp NY
Diamorph AB UK
FELDCO Intl CA
Goodfellow Corp PA
International Ceramic Engineering MA
Momentive Performance Materials Inc NY
North American Hoganas PA
Precision Ceramics FL
Reade Advanced Materials RI
Saint-Gobain Ceramics & Plastics MA
Xiamen Unipretec Ceramic Technology Co Ltd China

Cadmium & Compounds
Alfa Aesar Johnson Matthey MA
FELDCO Intl CA
GFS Chemicals Inc OH
Hunter Chemical LLC PA

Calcium & Compounds
C&L Development Corp CA
CerPoTech AS Norway
Denka Corp NY
GFS Chemicals Inc OH
Prince Minerals Inc (Prince International Corporation) TX

Calcium Aluminates
Almatis Inc PA
CerPoTech AS Norway
Gorka Cement Poland — **See ad on page 71**
Mineral Research Processing France
nGimat LLC KY
Sauereisen Inc PA

Calcium Carbonate
Arkema Inc PA
Fusion Ceramics Inc OH
Prince Minerals Inc (Prince International Corporation) TX
RE Carroll Inc PA
Unimin Corp CT

Calcium Silicate
Fusion Ceramics Inc OH
Mineral Research Processing France
Sauereisen Inc PA

Carbon Fibers
Goodfellow Corp PA

Carbons, Carbon Black
Cancarb Limited Canada

Carbons, Diamond
Goodfellow Corp PA

Carbons, Graphite
APF Recycling Inc OH
FELDCO Intl CA
Goodfellow Corp PA
Pred Materials International Inc NY
Semco Carbon OH
Superior Graphite Co IL

Cements
Aremco Products Inc NY
ESL ElectroScience PA
Gwent Electronic Materials Ltd UK

Cements, Refractory
Almatis Inc PA
Aremco Products Inc NY
Diamorph AB UK
Gorka Cement Poland — **See ad on page 71**
Kerneos Inc VA
Mineral Research Processing France
Sauereisen Inc PA
Unifrax I LLC NY

Cerium & Compounds
American Elements Inc CA — **Outside back cover, 54**
Arlimin Industries CO
CerPoTech AS Norway
FELDCO Intl CA
GFS Chemicals Inc OH
nGimat LLC KY
PIDC (Pacific Industrial Development Corporation) MI
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD — **See ad on page 81**
Treibacher Industrie AG Austria

Cerments


Gorka Cement Poland — **See ad on page 71**

Chamotte
Imerys Refractory Minerals GA

Chrome & Compounds
Arlimin Industries CO
Atlantic Equipment Engineers NJ
CerPoTech AS Norway
Hunter Chemical LLC PA
Monofrax LLC NY
North American Hoganas PA

Clay Bodies, Formulated
American Art Clay Co Inc IN
Imerys GA
Laguna Clay Co CA
Sheffield Pottery MA
Tethon 3D NE
Unimin Corp CT

Cobalt & Compounds
Arlimin Industries CO
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
Ceramic Color & Chemical Mfg Co PA
CerPoTech AS Norway
FELDCO Intl CA
Fusion Ceramics Inc OH
Goodfellow Corp PA
Hunter Chemical LLC PA
nGimat LLC KY

Copper & Compounds
American Chemet Corp IL
APF Recycling Inc OH
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
Ceramic Color & Chemical Mfg Co PA
CerPoTech AS Norway
Goodfellow Corp PA
Shoei Chemical Inc Japan

Dielectric Powders
AVX Corp SC
CerPoTech AS Norway
Euro Support Advanced Materials The Netherlands
Gwent Electronic Materials Ltd UK
Haiku Tech Inc FL
North American Hoganas PA
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Dysprosium Oxide
Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
PIDC (Pacific Industrial Development Corporation) MI
Treibacher Industrie AG Austria

Electrically Conducting Powders
BassTech Intl NJ
CerPoTech AS Norway
Hunter Chemical LLC PA
Innovnano - Advanced Materials SA Portugal

Erbium Oxide
C&L Development Corp CA
CerPoTech AS Norway
FELDCO Intl CA
Leico Industries Inc NJ
MSE Supplies AZ
PIDC (Pacific Industrial Development Corporation) MI
Treibacher Industrie AG Austria

Europium Oxide
Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
MSE Supplies AZ
PIDC (Pacific Industrial Development Corporation) MI
Treibacher Industrie AG Austria

Ferrites & Ferromagnetics
Centerline Technologies MA
Powder Processing & Technology LLC IN
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Fibers, Ceramic
Free Form Fibers NY
MemPro Materials Corp
Thermal Products Co Inc GA
Unifrax I LLC NY
Wesbond Corp DE

Fibers, Glass
BassTech Intl NJ
Mo-Sci Corp MO **See ad on page 95**
RISE Research Institutes of Sweden RISE Glass Sweden
Schott North America Inc NY
Unifrax I LLC NY

Fluorides
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
Sauereisen Inc PA

Frit
Ceradyne Inc a 3M Co KY
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Laguna Clay Co CA
RISE Research Institutes of Sweden RISE Glass Sweden
Trinity Ceramic Supply Inc TX
Zibo Guangtong Chemical Co Ltd China

Gadolinium Oxide
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
CerPoTech AS Norway
PIDC (Pacific Industrial Development Corporation) MI

Gallium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
Beijing Cerametek Materials Co Ltd China
CerPoTech AS Norway
Goodfellow Corp PA
MSE Supplies AZ

Germanium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
Beijing Cerametek Materials Co Ltd China
C&L Development Corp CA
MSE Supplies AZ
Treibacher Industrie AG Austria

Grain, Refractory
Christy Minerals LLC MO
Imerys Refractory Minerals GA

Graphite
APF Recycling Inc OH
Applied Ceramics Inc CA
Aremco Products Inc NY
Beijing Cerametek Materials Co Ltd China
CoorsTek CO
Momentive Performance Materials Inc NY
Semco Carbon OH
Superior Graphite Co IL
TevTech LLC MA **See ad on page 89**

Indium & Compounds
American Elements Inc CA **Outside back cover, 54**
CerPoTech AS Norway
FELDCO Intl CA
Goodfellow Corp PA
MSE Supplies AZ
Pred Materials International Inc NY

Iron & Compounds
Beijing Cerametek Materials Co Ltd China
CerPoTech AS Norway
GFS Chemicals Inc OH
Goodfellow Corp PA
Kyanite Mining Corp VA
Leico Industries Inc NJ
Prince Minerals Inc (Prince International Corporation) TX

Iron Oxide
Fusion Ceramics Inc OH
Prince Minerals Inc (Prince International Corporation) TX
Reade Advanced Materials RI

Lanthanides (also see Rare-Earths)
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
C&L Development Corp CA
FELDCO Intl CA
GFS Chemicals Inc OH
MSE Supplies AZ
Nanocerox UT
PIDC (Pacific Industrial Development Corporation) MI
Treibacher Industrie AG Austria

Lanthanum & Compounds
Alfa Aesar Johnson Matthey MA
BassTech Intl NJ
C&L Development Corp CA
CerPoTech AS Norway
Fusion Ceramics Inc OH
GFS Chemicals Inc OH
Goodfellow Corp PA
North American Hoganas PA
PIDC (Pacific Industrial Development Corporation) MI

Lead & Compounds
Goodfellow Corp PA

Lithium & Compounds
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
Ceramic Color & Chemical Mfg Co PA
CerPoTech AS Norway
GFS Chemicals Inc OH
MSE Supplies AZ
nGimat LLC KY
Pred Materials International Inc NY
Trinity Ceramic Supply Inc TX

Magnesia, Fused
APF Recycling Inc OH
Du-Co Ceramics Company PA
Fluid Energy Processing & Equipment Co PA
Washington Mills Electro Minerals Co NY

Magnesia-Alumina, Sintered
Baikowski Malakoff Inc NC
Fluid Energy Processing & Equipment Co PA

Magnesium & Compounds
Atlantic Equipment Engineers NJ
BassTech Intl NJ
Bosai Minerals Group Co Ltd China
CerPoTech AS Norway
FELDCO Intl CA
Fusion Ceramics Inc OH
GFS Chemicals Inc OH
Goodfellow Corp PA
Pred Materials International Inc NY
Prince Minerals Inc (Prince International Corporation) TX
Atlantic Equipment Engineers NJ
BassTech Intl NJ
CerPoTech AS Norway
Fusion Ceramics Inc OH
Goodfellow Corp PA
nGimat LLC KY
Prince Minerals Inc (Prince International Corporation) TX
RE Carroll Inc PA

Metallic Salts
Alfa Aesar Johnson Matthey MA

American Elements Inc CA **Outside back cover, 54**
Arlimin Industries CO
Hunter Chemical LLC PA

Metallizing Compounds
Alfa Aesar Johnson Matthey MA
Elcon Precision LLC CA
Gwent Electronic Materials Ltd UK
Sigma Advanced Materials NY

Microspheres, Hollow
Washington Mills Electro Minerals Co NY

Molybdenum & Compounds
APF Recycling Inc OH
Atlantic Equipment Engineers NJ
C&L Development Corp CA
CerPoTech AS Norway
Elcon Precision LLC CA
GFS Chemicals Inc OH

Nanomaterials

American Elements Inc CA **Outside back cover, 54**
Cerion Nanomaterials NY
CerPoTech AS Norway
Innovnano - Advanced Materials SA Portugal
MSE Supplies AZ
Nanocerox UT
nGimat LLC KY
Nyacol Nano Technologies Inc MA
Pred Materials International Inc NY
TevTech LLC MA **See ad on page 89**

Neodymium Oxide
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
MSE Supplies AZ
PIDC (Pacific Industrial Development Corporation) MI

Nickel & Compounds
American Chemet Corp IL
American Elements Inc CA **Outside back cover, 54**
APF Recycling Inc OH
Arlimin Industries CO
Atlantic Equipment Engineers NJ
Ceramic Color & Chemical Mfg Co PA
CerPoTech AS Norway
FELDCO Intl CA
GFS Chemicals Inc OH
Hunter Chemical LLC PA
Shoei Chemical Inc Japan

Niobium & Compounds
American Elements Inc CA **Outside back cover, 54**
CerPoTech AS Norway
FELDCO Intl CA
Leico Industries Inc NJ

Organic Precursors
Starfire Systems Inc NY

Pastes, Conductor
Aremco Products Inc NY
Haiku Tech Inc FL
Polymer Innovations Inc CA
Sauereisen Inc PA
Shoei Chemical Inc Japan

Phosphates
Arkema Inc PA
BassTech Intl NJ
nGimat LLC KY
Refractory Minerals Co Inc PA
Sauereisen Inc PA

Piezoelectric Compositions
APC International Ltd PA
AVX Corp SC
CerPoTech AS Norway
Polymer Innovations Inc CA
Sparkler Ceramics Pvt Ltd India

Pigments
Arlimin Industries CO
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Hunter Chemical LLC PA
Mason Color Works Inc OH
Sauereisen Inc PA
Wistra GmbH Germany

Plaster, Gypsum
Sheffield Pottery MA

Plaster, Industrial
Sheffield Pottery MA

Potassium & Compounds
CerPoTech AS Norway
GFS Chemicals Inc OH

Powdered Metals
Alfa Aesar Johnson Matthey MA
Arlimin Industries CO
Beijing Cerametek Materials Co Ltd China
Cancarb Limited Canada
Hunter Chemical LLC PA
Pred Materials International Inc NY

Praseodymium Oxide
Alfa Aesar Johnson Matthey MA
C&L Development Corp CA

CerPoTech AS Norway
Leico Industries Inc NJ
Nanocerox UT
PIDC (Pacific Industrial Development Corporation) MI

Precious Metals

Alfa Aesar Johnson Matthey MA
APF Recycling Inc OH
Gwent Electronic Materials Ltd UK
Leico Industries Inc NJ
Polymer Innovations Inc CA
Shoei Chemical Inc Japan

Rare-Earth Titanates

CerPoTech AS Norway
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Rare-Earths

Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
Beijing Cerametek Materials Co Ltd China
C&L Development Corp CA
FELDCO Intl CA
GFS Chemicals Inc OH
Innovnano - Advanced Materials SA Portugal
MSE Supplies AZ
Nanocerox UT
PIDC (Pacific Industrial Development Corporation) MI
Pred Materials International Inc NY
Spontaneous Materials CO
Treibacher Industrie AG Austria
Wistra GmbH Germany

Refractory Oxides

Arlimin Industries CO
Christy Minerals LLC MO
Hunter Chemical LLC PA
Innovnano - Advanced Materials SA Portugal
Leico Industries Inc NJ
nGimat LLC KY

Resins, Molding

Hexion Inc OH
Polymer Innovations Inc CA
Starfire Systems Inc NY

Samarium Oxide

Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Nanocerox UT
PIDC (Pacific Industrial Development Corporation) MI

Sand, Foundry

Kyanite Mining Corp VA
U.S. Silica Co MD

Sand, Glass

Fusion Ceramics Inc OH
RISE Research Institutes of Sweden RISE Glass Sweden
U.S. Silica Co MD

Sand, High-Purity Silica

BassTech Intl NJ
Maryland Refractories Co OH
U.S. Silica Co MD
Unimin Corp CT

Scandium & Compounds

Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
C&L Development Corp CA
FELDCO Intl CA
Leico Industries Inc NJ
Nanocerox UT
Trinity Ceramic Supply Inc TX

Selenium & Compounds

Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
FELDCO Intl CA
Pred Materials International Inc NY

Semiconducting Powders

American Elements Inc CA **Outside back cover, 54**

SiAlON Powder

Pred Materials International Inc NY

Silica

Arkema Inc PA
Denka Corp NY
Ipsen Ceramics IL
Maryland Refractories Co OH
Momentive Performance Materials Inc NY
Nanocerox UT
Saint-Gobain Ceramics & Plastics MA
Saureisen Inc PA
Sibelco Benelux Belgium
U.S. Silica Co MD

Silica, Fused

APF Recycling Inc OH
BassTech Intl NJ
Bosai Minerals Group Co Ltd China
Centerline Technologies MA
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
Momentive Performance Materials Inc NY
Technical Glass Products Inc Ohio
Valley Design Corp MA

Silicates

BassTech Intl NJ
Denka CorpNY
Nanocerox UT
Sauereisen Inc PA

Silicon & Compounds

Atlantic Equipment Engineers NJ
Elkem Metals Inc PA
FELDCO Intl CA
McDanel Advanced Ceramic Technologies LLC PA
Reade Advanced Materials RI
Valley Design Corp MA

Silicon Carbide

American Elements Inc CA **Outside back cover, 54**
APF Recycling Inc OH
Applied Ceramics Inc CA
Atlantic Equipment Engineers NJ
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
Bullen OH
Cancarb Limited Canada
CerCo LLC OH

CoorsTek CO
Custom Processing Services PA
Electro Abrasives Corp NY
FELDCO Intl CA
Goodfellow Corp PA
Imerys Refractory Minerals GA
Momentive Performance Materials Inc NY
North American Hoganas PA
Ortech Inc CA
Pred Materials International Inc NY
Rauschert Industries Inc GA
Saint-Gobain Ceramics & Plastics MA
Starfire Systems Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Superior Graphite Co IL
Texers Technical Ceramics Inc Canada
Treibacher Industrie AG Austria
Valley Design Corp MA
Washington Mills Electro Minerals Co NY

Silicon Nitride
Alteo NA LLC OH
Applied Ceramics Inc CA
Atlantic Equipment Engineers NJ
Bullen OH
CerCo LLC OH
CoorsTek CO
Denka Corp NY
FELDCO Intl CA
Goodfellow Corp PA
International Ceramic Engineering MA
McDanel Advanced Ceramic Technologies LLC PA
North American Hoganas PA
Ortech Inc CA
Pred Materials International Inc NY
Rauschert Industries Inc GA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Texers Technical Ceramics Inc Canada
Xiamen Unipretec Ceramic Technology Co Ltd China

Sodium & Compounds
Atlantic Equipment Engineers NJ
GFS Chemicals Inc OH

Spheres, Ceramic
Saint-Gobain NorPro OH

Spheres, Glass
Imerys Refractory Minerals GA
Mo-Sci Corp MO **See ad on page 95**
RISE Research Institutes of Sweden RISE Glass Sweden

Strontium & Compounds
Alfa Aesar Johnson Matthey MA
BassTech Intl NJ
CerPoTech AS Norway
Fusion Ceramics Inc OH
GFS Chemicals Inc OH
nGimat LLC KY

Superabrasives
Alteo NA LLC OH
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Saint-Gobain Ceramics & Plastics MA

Superconducting Powders
Alfa Aesar Johnson Matthey MA
nGimat LLC KY

Tantalum Metal Powder
Leico Industries Inc NJ

Tantalum Oxide
CerPoTech AS Norway
FELDCO Intl CA
PIDC (Pacific Industrial Development Corporation) MI

Terbium Oxide
Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
Nanocerox UT

Thickening Agents
Lubrizol Performance Coating OH

Thick-Film Materials
CerPoTech AS Norway
ESL ElectroScience PA
New Tech Ceramics Inc IA
Polymer Innovations Inc CA
Shoei Chemical Inc Japan

Thin-Film Materials

American Elements Inc CA **Outside back cover, 54**
Cerakote Ceramic Coatings OR
CerPoTech AS Norway
FELDCO Intl CA
Innovnano - Advanced Materials SA Portugal
Materion Advanced Materials NY
New Tech Ceramics Inc IA
Valley Design Corp MA

Tin & Compounds
Arlimin Industries CO
CerPoTech AS Norway
FELDCO Intl CA
Goodfellow Corp PA
Trinity Ceramic Supply Inc TX

Titanium & Compounds
APF Recycling Inc OH
Atlantic Equipment Engineers NJ
C&L Development Corp CA
FELDCO Intl CA
Goodfellow Corp PA
Leico Industries Inc NJ
Nanocerox UT
North American Hoganas PA
TAM Ceramics NY

Titanium Carbide
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
FELDCO Intl CA
North American Hoganas PA
Reade Advanced Materials RI

Titanium Diboride
Dunhua Zhengxing Abrasive Co Ltd China
FELDCO Intl CA
Momentive Performance Materials Inc NY
New Tech Ceramics Inc IA
North American Hoganas PA
Pred Materials International Inc NY
Surmet Corp MA

Titanium Dioxide
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
FELDCO Intl CA
Fusion Ceramics Inc OH
Nanocerox UT
nGimat LLC KY
Pred Materials International Inc NY

Titanium Nitride
Atlantic Equipment Engineers NJ
FELDCO Intl CA
North American Hoganas PA
Pred Materials International Inc NY

Tubes
Technical Glass Products Inc Ohio

Tungsten Carbide
Associated Ceramics & Technology Inc PA
Atlantic Equipment Engineers NJ
C&L Development Corp CA
Centerline Technologies MA
Custom Processing Services PA
FELDCO Intl CA
MSE Supplies AZ
North American Hoganas PA
PicoParts Ltd Israel
Pred Materials International Inc NY

Tungsten Oxide
CerPoTech AS Norway
FELDCO Intl CA

Uranium & Compounds
Wistra GmbH Germany

Vanadium & Compounds
Atlantic Equipment EngineersNJ
CerPoTech AS Norway
FELDCO Intl CA

Wetting Agents
Lubrizol Performance Coating OH

Yttria
APF Recycling Inc OH
Associated Ceramics & Technology Inc PA
Bullen OH
CoorsTek CO
ESL ElectroScience PA
Innovnano - Advanced Materials SA Portugal
Nanocerox UT
nGimat LLC KY
North American Hoganas PA
PIDC (Pacific Industrial Development Corporation) MI
Pred Materials International Inc NY
Washington Mills Electro Minerals Co NY

Yttrium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
C&L Development Corp CA
CerPoTech AS Norway
GFS Chemicals Inc OH
Nanocerox UT
nGimat LLC KY
PIDC (Pacific Industrial Development Corporation) MI

Zinc & Compounds
CerPoTech AS Norway
FELDCO Intl CA
Leico Industries Inc NJ
Prince Minerals Inc (Prince International Corporation) TX
RE Carroll Inc PA
Saureisen Inc PA
TevTech LLC MA **See ad on page 89**

Zinc Borate
U.S. Borax Inc I Rio Tinto IL **See ad on page 73**

Zinc Oxide
American Chemet Corp IL
FELDCO Intl CA
Fusion Ceramics Inc OH
nGimat LLC KY
Prince Minerals Inc (Prince International Corporation) TX
Sauereisen Inc PA
uttam industries India

Zirconia
Applied Ceramics Inc CA
C&L Development Corp CA
Custom Processing Services PA
Innovnano - Advanced Materials SA Portugal
International Ceramic Engineering MA
Leico Industries Inc NJ
Nanocerox UT
Nanoe France
nGimat LLC KY
Ortech Inc CA
PIDC (Pacific Industrial Development Corporation) MI
PremaTech Advanced Ceramics MA
Rauschert Industries Inc GA
Saint-Gobain Ceramics & Plastics MA
Sauereisen Inc PA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
TAM Ceramics NY
Washington Mills Electro Minerals Co NY
Xiamen Unipretec Ceramic Technology Co Ltd China
Zibo Guangtong Chemical Co Ltd China
Zircoa Inc OH

Zirconia, Engineering-Grade
Innovnano - Advanced Materials SA Portugal
Leico Industries Inc NJ
McDanel Advanced Ceramic Technologies LLC PA
Nanoe France
Zibo Guangtong Chemical Co Ltd China
Zircoa Inc OH

Zirconia, High-Purity
APF Recycling Inc OH
Applied Ceramics Inc CA
CARBO Texas
CoorsTek CO
Innovnano - Advanced Materials SA Portugal
International Ceramic Engineering MA
Nanocerox UT
Nanoe France
Sauereisen Inc PA
Zibo Guangtong Chemical Co Ltd China

Zirconia, Refractory-Grade
McDanel Advanced Ceramic Technologies LLC PA
Nanoe France
Washington Mills Electro Minerals Co NY
Zircoa Inc OH

Zirconium & Compounds
Atlantic Equipment Engineers NJ
C&L Development Corp CA
CerPoTech AS Norway
FELDCO Intl CA
Goodfellow Corp PA
Innovnano - Advanced Materials SA Portugal
Luxfer MEL Technologies NJ
Monofrax LLC NY
PIDC (Pacific Industrial Development Corporation) MI
Saint-Gobain Ceramics & Plastics MA
Zibo Guangtong Chemical Co Ltd China

Zirconium Carbide
Cancarb Limited Canada
North American Hoganas PA

Zirconium Carbonate
C&L Development Corp CA
Zibo Guangtong Chemical Co Ltd China

Zirconium Diboride
North American Hoganas PA
North American Hoganas PA

■ CLAY & NATURAL MINERALS

Bauxite
APF Recycling Inc OH
Bosai Minerals Group Co Ltd China
Fluid Energy Processing & Equipment Co PA
Hindalco Industries Limited India
Imerys Refractory Minerals GA
Prince Minerals Inc (Prince International Corporation) TX

Bentonite
Custom Processing Services PA
Reade Advanced Materials RI
Trinity Ceramic Supply Inc TX
Vanderbilt Minerals LLCCT

Borax
Dehybor®
borax.com/dehybor
U.S. Borax Inc I Rio Tinto IL
See ad on page 73

Chromite
Prince Minerals Inc (Prince International Corporation) TX

Clays, Ball
Fusion Ceramics Inc OH
Imerys GA
Old Hickory Clay Co KY
Sheffield Pottery MA
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX
Unimin Corp CT

Clays, China
Fusion Ceramics Inc OH
Imerys GA
Old Hickory Clay Co KY
Sheffield Pottery MA
Sibelco Benelux Belgium
Vanderbilt Minerals LLC CT

Clays, Enamel
Old Hickory Clay Co KY
RISE Research Institutes of Sweden RISE Glass Sweden
Sibelco Benelux Belgium
Vanderbilt Minerals LLC CT

Clays, Engobe
Imerys GA
Old Hickory Clay Co KY
Sheffield Pottery MA
Sibelco Benelux Belgium
Vanderbilt Minerals LLC CT

Clays, Fire or Refractory
Alsey Refractories Co MO
Christy Minerals LLC MO

Endiccott Clay Products Company NE
Furnace Products & Services Inc PA
Imerys Refractory Minerals GA
Maryland Refractories Co OH
Old Hickory Clay Co KY
Peter Pugger Mfg Inc CA
Riverside Refractories Inc--Allied Mineral Products AL
Sheffield Pottery MA
Sibelco Benelux Belgium

Clays, Glaze
Imerys GA
Old Hickory Clay Co KY
Peter Pugger Mfg Inc CA
Sheffield Pottery MA
Sibelco Benelux Belgium
Vanderbilt Minerals LLC CT

Clays, Stoneware
Christy Minerals LLC MO
Old Hickory Clay Co KY
Peter Pugger Mfg Inc CA
Sheffield Pottery MA
Sibelco Benelux Belgium

Cordierite
Maryland Ceramic & Steatite Co Inc MD
Mason Color Works Inc OH
Reade Advanced Materials RI
Refratechnik Ceramics GmbH Germany
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Diatomateous Earth
Reade Advanced Materials RI

Dolomite
Fusion Ceramics Inc OH
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX

Feldspar
Avalon Advanced Materials Inc Canada
Fusion Ceramics Inc OH
Imerys GA
Prince Minerals Inc (Prince International Corporation) TX
Sheffield Pottery MA
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX

Flint
Christy Minerals LLC MO
Fusion Ceramics Inc OH
Sheffield Pottery MA

Forsterite
Du-Co Ceramics Company PA
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Kaolin
Arkema Inc PA
Bosai Minerals Group Co Ltd China
CARBO Texas
Christy Minerals LLC MO
Fusion Ceramics Inc OH
Imerys GA
Imerys Refractory Minerals GA
M&M Clays Inc GA
Old Hickory Clay Co KY
RE Carroll Inc PA
Reade Advanced Materials RI
Sheffield Pottery MA
Trinity Ceramic Supply Inc TX
U.S. Silica Co MD
Vanderbilt Minerals LLC CT

Kyanite
Kyanite Mining Corp VA

Lime & Limestone
Prince Minerals Inc (Prince International Corporation) TX
RE Carroll Inc PA

Lithium Minerals
Avalon Advanced Materials Inc Canada
Fusion Ceramics Inc OH

Magnesite
APF Recycling Inc OH
Bosai Minerals Group Co Ltd China
Fluid Energy Processing & Equipment Co PA
Imerys Refractory Minerals GA

Mica
Imerys GA

Montmorillonite
Reade Advanced Materials RI
Vanderbilt Minerals LLC CT

Mullite
Christy Minerals LLC MO
Imerys Refractory Minerals GA
International Ceramic Engineering MA
Kyanite Mining Corp VA
Pred Materials International Inc NY
Reade Advanced Materials RI
Texers Technical Ceramics Inc Canada
Washington Mills Electro Minerals Co NY

Nepheline Syenite
Fusion Ceramics Inc OH
Sheffield Pottery MA
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX

Olivine
Prince Minerals Inc (Prince International Corporation) TX
Sibelco Benelux Belgium

Pyrite
Kyanite Mining Corp VA
Washington Mills Electro Minerals Co NY

Pyrophyllite
Maryland Ceramic & Steatite Co Inc MD
Vanderbilt Minerals LLC CT

Quartz
Applied Ceramics Inc CA
Fusion Ceramics Inc OH
Goodfellow Corp PA
Imerys GA
International Ceramic Engineering MA
Momentive Performance Materials Inc NY
Multi Lab UK
Prince Minerals Inc (Prince International Corporation) TX
Sibelco Benelux Belgium
Technical Glass Products Inc Ohio

Rutile
Fusion Ceramics Inc OH
Prince Minerals Inc (Prince International Corporation) TX

Sapphire
Applied Ceramics Inc CA
Centerline Technologies MA
Goodfellow Corp PA
International Ceramic Engineering MA
MSE Supplies AZ

Silica
APF Recycling Inc OH
Centerline Technologies MA
Imerys GA
Imerys Refractory Minerals GA
Maryland Refractories Co OH
Prince Minerals Inc (Prince International Corporation) TX
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX
U.S. Silica Co MD

Soda Ash
Fusion Ceramics Inc OH
RE Carroll Inc PA

Spinels
Almatis Inc PA
Baikowski Malakoff Inc NC
Fluid Energy Processing & Equipment Co PA
GrainBound LLC PA
Pred Materials International Inc NY
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**
Washington Mills Electro Minerals Co NY

Spodumene
Avalon Advanced Materials Inc Canada
Fusion Ceramics Inc OH
Prince Minerals Inc (Prince International Corporation) TX
Trinity Ceramic Supply Inc TX

Steatite
Du-Co Ceramics Company PA
International Ceramic Engineering MA

Steatite
Maryland Ceramic & Steatite Co Inc MD

Talc
Custom Processing Services PA
Fusion Ceramics Inc OH
Trinity Ceramic Supply Inc TX

Wollastonite
Bosai Minerals Group Co Ltd China
Fusion Ceramics Inc OH
Reade Advanced Materials RI
Trinity Ceramic Supply Inc TX
Vanderbilt Minerals LLC CT

Zircon
AluChem Inc OH
APF Recycling Inc OH
Fusion Ceramics Inc OH
Lithoz GmbH NY
Prince Minerals Inc (Prince International Corporation) TX
Reade Advanced Materials RI
TAM Ceramics NY

CONSTRUCTION CERAMICS

Brick
Belden Brick Co OH
Brick Industry Assn VA
Cancarb Limited Canada
Endicott Clay Products Company NE
Niokem Inc NC
Zibo Guangtong Chemical Co Ltd China

Brick & Paving
Belden Brick Co OH
Brick Industry Assn VA
Cancarb Limited Canada
Endicott Clay Products Company NE
Niokem Inc NC

Pipe, Ceramic-Lined
CerCo LLC OH

Sanitaryware
Roca Sanitario SA Spain
Zibo Guangtong Chemical Co LtdChina

Tile, Floor & Pavers
Endicott Clay Products Company NE
Foundation Floors FL
Heartland Wood Flooring FL
Somany Ceramics Ltd India

Tile, Wall
Comtrust Architectural Mesh Co Ltd China
Endicott Clay Products Company NE
Peter Pugger Mfg Inc CA
Somany Ceramics Ltd India

CONSULTANTS & SERVICES

Advanced Coatings
Activation Laboratories Ltd Canada
Advanced Materials Associates CO
Bharat Heavy Electricals Ltd India
Cerakote Ceramic Coatings OR
CoorsTek CO
Delkic & Associates FL
Gwent Electronic Materials Ltd UK
New Tech Ceramics Inc IA
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**
Viridis3D LLC MA

Analytical Services
Activation Laboratories Ltd Canada

Alfred University NY **See ad on page 40**
AVEKA MN
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
CMC Laboratories Inc AZ
CoorsTek CO
Edward Orton Jr Ceramic Foundation OH
Geller Microanalytical Laboratory Inc MA
GrainBound LLC PA
H&M Analytical Services Inc NJ
Hindalco Industries Limited India
Hitech Materials Pty Ltd NSW
Israel Ceramic & Silicate Inst Israel
JTF Microscopy Services LLC NY
Micromeritics Instrument Corp GA
Micron Inc DE
NSL Analytical Services Inc OH
OPF Enterprises TX
Particle Technology Labs IL
Quantachrome Instruments FL
Refractory Consulting Services OH
RISE Research Institutes of Sweden RISE Glass Sweden
SEMTech Solutions Inc MA

Spectrochemical Laboratories PA
TA InstrumentsDE

Brick & Structural Clay Processing
Ceramitec Germany
Lucideon UK
Niokem Inc NC
OPF Enterprises TX
Peter Pugger Mfg Inc CA
Verity Technical Consultants LLC OH

Ceramic Materials

Activation Laboratories Ltd Canada
Advanced Materials Associates CO
Alfred University NY **See ad on page 40**
AVEKA MN
Bharat Heavy Electricals Ltd India

Bomas Machine Specialties Inc MA **See ad on page 83**
Cancarb Limited Canada
CelSian Glass & Solar BV The Netherlands
Cerakote Ceramic Coatings OR
Ceralink Inc NY
Cerion Nanomaterials NY
Elan Technology GA
Elcon Precision LLC CA
GrainBound LLC PA
H&M Analytical Services Inc NJ
Hitech Materials Pty Ltd NSW
Imerys GA
Inst for Applied Materials-Ceramics in Mechanical Engineering Karlsruhe Inst of Technology Germany
International Ceramic Engineering MA
Lithoz GmbH NY
Lucideon UK
MemPro Materials Corp
North American Hoganas PA
NSL Analytical Services Inc OH
O'Keefe Ceramics Inc CO
OPF Enterprises TX
Piezo by Graco OH
P-Ker Engineering NY
Rauschert Industries Inc GA
Refrac Systems AZ
Rensselaer Polytechnic Inst NY
Schott North America Inc NY
Silicon Carbide Products Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
Texers Technical Ceramics Inc Canada
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**
Verity Technical Consultants LLC OH
Viridis3D LLC MA

Chemistry

Activation Laboratories Ltd Canada
CelSian Glass & Solar BV The Netherlands
Cerion Nanomaterials NY
Chemical Abstracts Service OH
CHEMIR - A Division of Evans Analytical Group MO
H&M Analytical Services Inc NJ
Hitech Materials Pty Ltd NSW
NSL Analytical Services Inc OH
Polymer Innovations Inc CA

Combustion Systems

Air Products PA
CelSian Glass & Solar BV The Netherlands
Ceramic Services Inc PA

Harrop Industries Inc OH **See ad on page 58**

Compositions

Activation Laboratories Ltd Canada
Advanced Materials Associates CO
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
Gwent Electronic Materials Ltd UK
Hitech Materials Pty Ltd NSW
NSL Analytical Services Inc OH

Decorating Processes & Materials

Cerlase France
Lucideon UK
OPF Enterprises TX

Design

Air Force Civil Engineer Center FL
CoorsTek CO
Deltech Kiln and Furnace Design LLC CO **See ad on page 75**
General Glass Equipment Co NJ
I Squared R Element Co NY **See ad on page 85**
Ingredient Masters Inc OH **See ad on page 101**
Jenike & Johanson Inc MA
OPF Enterprises TX
RocCera LLC NY
Tethon 3D NE
Viridis3D LLC MA

Electronics & Electrical Materials

Advanced Energy CO
APC International Ltd PA
AVEKA MN
Centerline Technologies MA
Elan Technology GA
Electrosciences Ltd UK
Gwent Electronic Materials Ltd UK
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL

Harrop Industries Inc OH **See ad on page 58**

I Squared R Element Co NY **See ad on page 85**
Powder Processing & Technology LLC IN
Semiconductor Energy Laboratory Co Ltd Japan

Energy

A123 Systems Inc MI
Advanced Energy CO
Air Force Civil Engineer Center FL
CelSian Glass & Solar BV The Netherlands
Ceralink Inc NY
FCT Systeme GmbH Germany
Lucideon UK
Semiconductor Energy Laboratory Co Ltd Japan
Texers Technical Ceramics Inc Canada

Engineering

Advanced Materials Associates CO
Air Force Civil Engineer Center FL
CelSian Glass & Solar BV The Netherlands
Cerinnov France
Ceritherm France
Cyclonaire Corp NE
Deltech Kiln and Furnace Design LLC CO **See ad on page 75**
FCT Systeme GmbH Germany
General Glass Equipment Co NJ
Hitech Materials Pty Ltd NSW
Ingredient Masters Inc OH **See ad on page 101**
International Ceramic Engineering MA
Jenike & Johanson Inc MA
Lithoz GmbH NY
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY
Teeter Marketing Services LLC FL
Verity Technical Consultants LLC OH
Wistra GmbH Germany

Environmental

Activation Laboratories Ltd Canada
Air Force Civil Engineer Center FL
CelSian Glass & Solar BV The Netherlands
Lucideon UK
SEMTech Solutions Inc MA
Texers Technical Ceramics Inc Canada
Tri-Mer Corp MI

Expert Witness

Advanced Materials Associates CO
CHEMIR - A Division of Evans Analytical Group MO
H&M Analytical Services Inc NJ
Hitech Materials Pty Ltd NSW
JTF Microscopy Services LLC NY
Lucideon UK
Particle Technology Labs IL
Refrac Systems AZ
Refractory Consulting Services OH
Spontaneous Materials CO
Verity Technical Consultants LLC OH

Fabrication

Accuratus Corp NJ
Advanced Materials Associates CO
Bullen OH
Ingredient Masters Inc OH **See ad on page 101**
Lithoz GmbH NY
O'Keefe Ceramics Inc CO
PremaTech Advanced Ceramics MA
Refrac Systems AZ
RocCera LLC NY
Technology Assessment and Transfer Inc (TA&T) MD
Thermal Products Co Inc GA
Verity Technical Consultants LLC OH

Furnaces

Advanced Materials Associates CO
American Isostatic Presses OH
CelSian Glass & Solar BV The Netherlands
Centorr Vacuum Industries NH

Deltech Kiln and Furnace Design LLC CO **See ad on page 75**
Fosbel Inc OH
General Glass Equipment Co NJ

Harper International NY **See ad on page 77**
I Squared R Element Co NY **See ad on page 85**
JTF Microscopy Services LLC NY
Refrac Systems AZ
Technology Assessment and Transfer Inc (TA&T) MD
The Furnace Source LLC CT
Trent Inc PA
Winner Technology Korea

Glass Processes & Materials

Alfred University NY **See ad on page 40**
CelSian Glass & Solar BV The Netherlands
Ceradyne Inc a 3M Co KY

Diversified Controls & Systems NY
Elan Technology GA
JTF Microscopy Services LLC NY
NSL Analytical Services Inc OH
Optimation - Klug Systems NY
Rensselaer Polytechnic Inst NY
RISE Research Institutes of Sweden RISE Glass Sweden
Saxon Glass Technologies Inc NY
Schott North America Inc NY
Specialty Glass Inc FL
Tri-Mer Corp MI
Verity Technical Consultants LLC OH
Vesuvius SC

Glazes/Colorants

Cancarb Limited Canada
Ceradyne Inc a 3M Co KY
Laguna Clay Co CA
Lucideon UK
NSL Analytical Services Inc OH
OPF Enterprises TX
RISE Research Institutes of Sweden RISE Glass Sweden

High-Technology Ceramics

Advanced Materials Associates CO
APC International Ltd PA
ARBURG GmbH + Co KG Germany
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd India
Ceramitec Germany
CHEMIR - A Division of Evans Analytical Group MO
Elcon Precision LLC CA
Gwent Electronic Materials Ltd UK
Hitech Materials Pty Ltd NSW
Lucideon UK
NSL Analytical Services Inc OH
OPF Enterprises TX
Piezo by Graco OH
P-Ker Engineering NY
Silicon Carbide Products Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
Viridis3D LLC MA
Wistra GmbH Germany
Zircoa Inc OH

Kilns

Ceritherm France

Deltech Kiln and Furnace Design LLC CO **See ad on page 75**
FCT Systeme GmbH Germany
Lucideon UK
Nabertherm Inc DE
OPF EnterprisesTX

Litigation

H&M Analytical Services Inc NJ
Lucideon UK
Particle Technology Labs IL
Refractory Consulting Services OH
Spontaneous Materials CO
Verity Technical Consultants LLC OH

Maintenance & Repairs, After Sales
Cerinnov France
Optimation - Klug Systems NY

Management
OPF Enterprises TX
Teeter Marketing Services LLC FL

Manufacturing
Advanced Materials Associates CO
AVEKA MN
Ceramco Inc NH
CeramTec North America Corp SC
Cerinnov France
CoorsTek CO
Custom Processing Services PA
Cyclonaire Corp NE
Endiccott Clay Products Company NE
Ingredient Masters Inc OH **See ad on page 101**
Jenike & Johanson Inc MA
Laserage Technology Corp IL
Lucideon UK
Maryland Ceramic & Steatite Co Inc MD
O'Keefe Ceramics Inc CO
OPF Enterprises TX
P-Ker Engineering NY
Refrac Systems AZ
Semiconductor Energy Laboratory Co Ltd Japan
Technology Assessment and Transfer Inc (TA&T) MD
Verity Technical Consultants LLC OH
Wistra GmbH Germany

Markets
Advanced Materials Associates CO
Matmatch Germany
OPF Enterprises TX
Teeter Marketing Services LLC FL
Texers Technical Ceramics Inc Canada

Materials Testing & Characterization
Advanced Materials Associates CO
Alfred University NY **See ad on page 40**
ARBURG GmbH + Co KG Germany
AVEKA MN
Bharat Heavy Electricals Ltd India
BuzzMac Intl LLC ME
Ceramitec Germany
CHEMIR - A Division of Evans Analytical Group MO
CSC Force Measurement Inc MA
Cyclonaire Corp NE
Edward Orton Jr Ceramic Foundation OH
Elan Technology GA
Fluid Energy Processing & Equipment Co PA
Geller Microanalytical Laboratory Inc MA
GrainBound LLC PA
H&M Analytical Services Inc NJ
Hindalco Industries Limited India
Hitachi High-Tech America Inc MD
Hitech Materials Pty Ltd NSW
Hysitron Inc MN
Inst for Applied Materials-Ceramics in Mechanical Engineering Karlsruhe Inst of Technology Germany
Jenike & Johanson Inc MA
JTF Microscopy Services LLC NY
Lucideon UK
Micromeritics Instrument Corp GA
Nol-Tec Systems Inc MN
NorECs AS Norway
NSL Analytical Services Inc OH
OPF Enterprises TX
Particle Technology Labs IL
P-Ker Engineering NY
Refractory Consulting Services OH
Semiconductor Energy Laboratory Co Ltd Japan

Spectrochemical Laboratories PA
Taber Industries NY
Washington Mills Electro Minerals Co NY

Modeling
CelSian Glass & Solar BV The Netherlands
CoorsTek CO
Lucideon UK
Ram Products Inc OH
Spontaneous Materials CO
Tethon 3D NE

Nuclear Materials
Advanced Materials Associates CO
Dunhua Zhengxing Abrasive Co Ltd China
NSL Analytical Services Inc OH

Patents
Modern Times Legal MA
Refrac Systems AZ
Spontaneous Materials CO
Teeter Marketing Services LLC FL

Professional Engineer
NSL Analytical Services Inc OH
Optimation - Klug Systems NY
Spontaneous Materials CO
Texers Technical Ceramics Inc Canada
Verity Technical Consultants LLC OH

Quality Management/ISO 9000
Elcon Precision LLC CA
Lucideon UK

Refractories
CelSian Glass & Solar BV The Netherlands
Ceramitec Germany
Dunhua Zhengxing Abrasive Co Ltd China
Edward Orton Jr Ceramic Foundation OH
Fluid Energy Processing & Equipment Co PA
Fosbel Inc OH
Hitech Materials Pty Ltd NSW
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
JTF Microscopy Services LLC NY
Laguna Clay Co CA
Lucideon UK
Maryland Refractories Co OH
NSL Analytical Services Inc OH
Refractory Consulting Services OH
Silicon Carbide Products Inc NY
Teeter Marketing Services LLC FL
Texers Technical Ceramics Inc Canada
Viridis3D LLC MA
Wistra GmbH Germany

Research
Advanced Materials Associates CO
Alfred University NY **See ad on page 40**
ARBURG GmbH + Co KG Germany
AVEKA MN
CelSian Glass & Solar BV The Netherlands
Ceralink Inc NY
Cerion Nanomaterials NY
Cerlase France
CHEMIR - A Division of Evans Analytical Group MO
Inst for Applied Materials-Ceramics in Mechanical Engineering Karlsruhe Inst of Technology Germany
Laeis GmbH Luxembourg
Lithoz GmbH NY
Lucideon UK
OPF Enterprises TX
Refrac SystemsAZ
RISE Research Institutes of Sweden RISE Glass Sweden
Technology Assessment and Transfer Inc (TA&T) MD
Viridis3D LLC MA
Wistra GmbH Germany

Semiconductors (Consultants)
Semiconductor Energy Laboratory Co Ltd Japan
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Software
Chemical Abstracts Service OH
General Glass Equipment Co NJ
Outotec Research Oy Finland
Rockwell Automation Inc WI
Throughput Bluestreak WI

Structural Ceramics
Advanced Materials Associates CO
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd India
Ceramitec Germany
CeramTec North America Corp SC
FCT Ingenieurkeramik GmbH Germany
Hitech Materials Pty Ltd NSW
OPF Enterprises TX
Rauschert Industries Inc GA
Silicon Carbide Products Inc NY
Technology Assessment and Transfer Inc (TA&T) MD

Superconductors
NSL Analytical Services Inc OH
Advanced Materials Associates CO
Bharat Heavy Electricals Ltd India
CelSian Glass & Solar BV The Netherlands
Hitech Materials Pty Ltd NSW
JTF Microscopy Services LLC NY
Spontaneous Materials CO
Teeter Marketing Services LLC FL

Technology Transfer
CelSian Glass & Solar BV The Netherlands
Ceralink Inc NY
Cerlase France
Gwent Electronic Materials Ltd UK
Lucideon UK
Particle Technology Labs IL
Spontaneous Materials, CO
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
Viridis3D LLC MA

CUSTOM CERAMICS FABRICATION & ENGINEERING SERVICES

Advanced Ceramics, Structural

Accuratus Corp NJ
Actech Precision Ceramic (HK) Limited China
AdTech Ceramics TN
AdValue Technology LLC AZ **See ad on page 51**
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Astro Met Advanced Ceramics Inc OH

Bomas Machine Specialties Inc MA **See ad on page 83**
Bullen OH
CeramTec North America Corp SC
CeraNova Corp MA
CerCo LLC OH
CiDRA Precision Services LLC CT
CoorsTek CO
Custom Processing Services PA
Dunhua Zhengxing Abrasive Co Ltd China
Exothermics Inc NH
FCT Ingenieurkeramik GmbH Germany
FELDCO Intl CA
Ferro Ceramic Grinding Inc MA
GE Global Research NY
Induceramic Canada
Innovnano - Advanced Materials SA Portugal
Israel Ceramic & Silicate Inst Israel
Lithoz GmbH NY
Machined Ceramics Inc KY
Maryland Ceramic & Steatite Co Inc MD
McDanel Advanced Ceramic Technologies LLC PA
MemPro Materials Corp
Morgan Technical Ceramics Auburn CA
Petro Mold Company PA
P-Ker Engineering NY
Precision Ceramics FL
Precision Ferrites and Ceramics Inc CA

PremaTech Advanced Ceramics MA
Progressive Technology Inc CA

Rauschert Industries Inc GA
Refrac Systems AZ
Refractron Technologies Corp NY
RocCera LLC NY
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
Silicon Carbide Products Inc NY
Starfire Systems Inc NY
Superior Technical Ceramics Corp VT
Technical Products Inc WI
Tethon 3D NE
Toto Ltd Japan
Zircoa Inc OH

Calcining, Custom

CerPoTech AS Norway
Christy Minerals LLC MO
OPF Enterprises TX

Powder Processing & Technology LLC IN

Classification, Custom

AVEKA MN

Bomas Machine Specialties Inc MA **See ad on page 83**
Christy Minerals LLC MO
Du-Co Ceramics Company PA
Fluid Energy Processing & Equipment Co PA

Coatings, Corrosion-Resistant

Aremco Products Inc NY
Cerakote Ceramic Coatings OR
CoorsTek CO
ESL ElectroScience PA
Hexion Inc OH
Induceramic Canada
Master Bond Inc NJ
Starfire Systems Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
TevTech LLC MA **See ad on page 89**
Verity Technical Consultants LLC OH

Coatings, Thermal-Resistant

Aremco Products Inc NY
Cancarb Limited Canada
Cerakote Ceramic Coatings OR
Delkic & Associates FL
ESL ElectroScience PA
Induceramic Canada
New Tech Ceramics Inc IA
Sigma Advanced Materials NY
Starfire Systems Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**
Unifrax I LLC NY
Verity Technical Consultants LLC OH
ZYP Coatings Inc TN

Coatings, Wear-Resistant

Cerakote Ceramic Coatings OR
CeramTec-ETEC Germany
CoorsTek CO
ESL ElectroScience PA
Master Bond Inc NJ
New Tech Ceramics Inc IA
Starfire Systems Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
TevTech LLC MA **See ad on page 89**

Crushing, Custom

AVEKA MN
Bekeson Glass LLC MS **See ad on page 96**
Christy Minerals LLC MO
Fluid Energy Processing & Equipment Co PA
Reade Advanced Materials RI
Stedman Machine Co IN

Dielectrics

Accuratus Corp NJ
AdTech Ceramics TN
Advanced Ceramic Technology CA
CerPoTech AS Norway
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Sigma Advanced Materials NY
Starfire Systems Inc NY
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Drying, Custom

AVEKA MN
Fluid Energy Processing & Equipment Co PA
General Spray Drying Service Inc NJ
Ipsen Ceramics IL
Reade Advanced Materials RI

Films, Thick

CoorsTek CO
ESL ElectroScience PA
Gwent Electronic Materials Ltd UK
New Tech Ceramics Inc IA
P-Ker Engineering NY
Sigma Advanced Materials NY
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Films, Thin

Advanced Energy CO
Cerakote Ceramic Coatings OR
CoorsTek CO
Industrial Hard Carbon LLC NC
Morgan Technical Ceramics Auburn CA
New Tech Ceramics Inc IA
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
Verity Technical Consultants LLC OH

Furnace Rebuilds

Cancarb Limited Canada
Fosbel Inc OH
Materials Research Furnaces Inc NH
Oxy-Gon Industries Inc NH **See ad on page 85**
TevTech LLC MA **See ad on page 89**

Grinding, Custom

Advanced Ceramic Technology CA
Astro Met Advanced Ceramics Inc OH

Bekeson Glass LLC MS See ad on page 96

Bomas Machine Specialties Inc MA See ad on page 83

Bullen OH
Christy Minerals LLC MO
CiDRA Precision Services LLC CT
CoorsTek CO
Du-Co Ceramics Company PA
FCT Ingenieurkeramik GmbH Germany
Ferro Ceramic Grinding Inc MA
Fluid Energy Processing & Equipment Co PA
International Ceramic Engineering MA
Machined Ceramics Inc KY
McDanel Advanced Ceramic Technologies LLC PA
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
PremaTech Advanced Ceramics MA
Reade Advanced Materials RI
Refractory Machining Services PA
Refractory Minerals Co Inc PA
Refractron Technologies Corp NY
RocCera LLC NY
Stedman Machine Co IN
Union Process OH
Valley Design Corp MA
Washington Mills Electro Minerals Co NY
Zibo Guangtong Chemical Co Ltd China

Hot Repair

Fosbel IncOH

Joining

Advanced Ceramic Technology CA
CeramTec North America Corp SC
Fosbel Inc OH
Fuse Tech/Hot Tech Group OH
Induceramic Canada
Morgan Technical Ceramics Auburn CA
P-Ker Engineering NY
Precision Ferrites and Ceramics Inc CA
Refrac Systems AZ
RocCera LLC NY
Sigma Advanced Materials NY
Starfire Systems Inc NY

Lapping & Polishing

Advanced Ceramic Technology CA
Astro Met Advanced Ceramics Inc OH
Bullen OH
CoorsTek CO
Du-Co Ceramics Company PA
Dunhua Zhengxing Abrasive Co Ltd China
International Ceramic Engineering MA
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
PremaTech Advanced Ceramics MA
Superior Technical Ceramics Corp VT
Technical Products Inc WI
Texers Technical Ceramics Inc Canada
Valley Design Corp MA

Laser Cutting & Scribing Services

Cerlase France
CoorsTek CO
Laserage Technology Corp IL
Ortech Inc CA

Machining

Accuratus Corp NJ

Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Aremco Products Inc NY
Astro Met Advanced Ceramics Inc OH

Bomas Machine Specialties Inc MA See ad on page 83

Bullen OH
CerCo LLC OH
CiDRA Precision Services LLC CT

Du-Co Ceramics Company PA
Elan Technology GA
FCT Ingenieurkeramik GmbH Germany
FELDCO Intl CA
Ferro Ceramic Grinding Inc MA
Fosbel Inc OH
International Ceramic Engineering MA
Laserage Technology Corp IL
Machined Ceramics Inc KY
Maryland Ceramic & Steatite Co Inc MD
McDanel Advanced Ceramic Technologies LLC PA

Mitsubishi Materials Corporation Japan
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
Precision Ceramics FL

PremaTech Advanced Ceramics MA
Progressive Technology Inc CA
Ram Products Inc OH
Refractory Machining Services PA
RocCera LLC NY
Stahli USA Inc WI
Superior Technical Ceramics Corp VT
Technical Products Inc WI
Valley Design Corp MA

Milling, Custom

Advanced Ceramic Technology CA
AVEKA MN

Bekeson Glass LLC MS **See ad on page 96**
Bullen OH
CiDRA Precision Services LLC CT
Custom Processing Services PA
Ferro Ceramic Grinding Inc MA
Fluid Energy Processing & Equipment Co PA
International Ceramic Engineering MA
MSE Supplies AZ
Powder Processing & Technology LLC IN
Precision Ceramics FL
PremaTech Advanced Ceramics MA
Reade Advanced Materials RI
Refractory Machining Services PA
RocCera LLC NY
Stedman Machine Co IN
Union Process OH
Valley Design Corp MA
Washington Mills Electro Minerals Co NY

Nuclear Materials

Dunhua Zhengxing Abrasive Co Ltd China
Free Form Fibers NY
Morgan Technical Ceramics Auburn CA
Peter Pugger Mfg Inc CA
Refrac Systems AZ
Verity Technical Consultants LLC OH

Piezoelectrics

APC International Ltd PA
CerPoTech AS Norway
Electrosciences Ltd UK
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Meggitt Piezo Technologies IN
Piezo by Graco OH
Sparkler Ceramics Pvt Ltd India

Powder Synthesis

CerPoTech AS Norway

Prototypes

Accuratus Corp NJ
Advanced Ceramic Technology CA
Astro Met Advanced Ceramics Inc OH
Bullen OH
CeramTec North America Corp SC
CerCo LLC OH
CoorsTek CO
Du-Co Ceramics Company PA
ESL ElectroScience PA
FCT Ingenieurkeramik GmbH Germany
Ferro Ceramic Grinding Inc MA
Goceram AB Sweden
Industrial Ceramic Products Inc OH
International Ceramic Engineering MA
Lithoz GmbH NY
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
P-Ker Engineering NY
Precision Ceramics FL

PremaTech Advanced Ceramics MA
Progressive Technology Inc CA
Ram Products Inc OH
Refrac Systems AZ
Robocasting Enterprises LLC NM
RocCera LLC NY
Silicon Carbide Products Inc NY
Technical Products Inc WI
Technology Assessment and Transfer Inc (TA&T) MD
Tethon 3D NE

Refractory Installation

Diamorph AB UK
Fosbel Inc OH
Refractory Consulting Services OH
Riverside Refractories Inc--Allied Mineral Products AL
Wistra GmbH Germany

Screen Printing

Aremco Products Inc NY
Gwent Electronic Materials Ltd UK
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL

Screening, Custom

AVEKA MN
Bekeson Glass LLC MS **See ad on page 96**
CerPoTech AS Norway
Fluid Energy Processing & Equipment Co PA
General Spray Drying Service Inc NJ
Reade Advanced Materials RI

Seals

Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd India
CerCo LLC OH
Dunhua Zhengxing Abrasive Co Ltd China
Elan Technology GA
Ferro Ceramic Grinding Inc MA
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
P-Ker Engineering NY
Precision Ceramics FL
Refrac Systems AZ
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
Texers Technical Ceramics Inc Canada

Spray Drying

Arch Maintenance Services GA
AVEKA MN
CeramTec North America Corp SC
CerPoTech AS Norway
Dorst America Inc PA
Elan Technology GA
General Spray Drying Service Inc NJ

Powder Processing & Technology LLC IN

Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**
Verity Technical Consultants LLC OH

Superconductors

Precision Ceramics FL

Toll Blending, Processing

AVEKA MN
CerPoTech AS Norway
Custom Processing Services PA
Euro Support Advanced Materials The Netherlands
Fluid Energy Processing & Equipment Co PA
Fusion Ceramics Inc OH
General Spray Drying Service Inc NJ
Gwent Electronic Materials Ltd UK
Peter Pugger Mfg Inc CA
Powder Processing & Technology LLC IN
Reade Advanced Materials RI
Refrac Systems AZ
TAM Ceramics NY

Toll Firing, Contract
ACCCO Inc/Burley Clay Products Co OH
Advanced Ceramics Manufacturing AZ
Astro Met Advanced Ceramics Inc OH
CeramTec North America Corp SC
Christy Minerals LLC MO
FCT Ingenieurkeramik GmbH Germany
FCT Systeme GmbH Germany

Harrop Industries Inc OH **See ad on page 58**
Ipsen Ceramics IL
Oxy-Gon Industries Inc NH **See ad on page 85**
Refrac Systems AZ
Sunrock Ceramics Co IL
TAM Ceramics NY
TevTech LLC MA **See ad on page 89**

Ultrasonic Machining
Ferro-Ceramic Grinding Inc MA
PremaTech Advanced Ceramics MA

■ DECORATING

Coating Equipment
Cerakote Ceramic Coatings OR
Cerinnov France
Haiku Tech Europe BV The Netherlands
Industrial Hard Carbon LLC NC
Laguna Clay Co CA

Colors
Arlimin Industries CO
Ceramic Color & Chemical Mfg Co PA
Cerlase France
Fusion Ceramics Inc OH
Mason Color Works Inc OH

Decal Equipment
Art On Ceramic NY
Cerinnov France

Decals
Cerlase France
IPS Ceramics LTD UK
Milestone Decal Art LLC NY

Decorating Equipment
Cerinnov France

Decorating Supplies
Ceramic Color & Chemical Mfg Co PA

Enamels
Ceramic Color & Chemical Mfg Co PA
Cerinnov France
Cerlase France
Fusion Ceramics Inc OH
RISE Research Institutes of Sweden RISE Glass Sweden

Engobes
American Art Clay Co Inc IN
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Mason Color Works Inc OH

Frits
Bekeson Glass LLC MS **See ad on page 96**
Ceradyne Inc a 3M Co KY
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
RISE Research Institutes of Sweden RISE Glass Sweden
Trinity Ceramic Supply Inc TX

Glazes
American Art Clay Co Inc IN
Ceramic Color & Chemical Mfg Co PA
Cerlase France
Fusion Ceramics Inc OH
Laguna Clay Co CA
Mason Color Works Inc OH
RISE Research Institutes of Sweden RISE Glass Sweden
Sheffield Pottery MA

Glazing Equipment
Arlimin Industries CO
Cerinnov France
Du-Co Ceramics Company PA
HED INtl Inc NJ

Inks
American Art Clay Co Inc IN
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Gwent Electronic Materials Ltd UK
Zibo Guangtong Chemical Co Ltd China

Lehrs
Nabertherm Inc DE
Recco Furnaces CA

Pigments
Arlimin Industries CO
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Mason Color Works Inc OH

Porcelain Enamels
Cerlase France
Fusion Ceramics Inc OH
RISE Research Institutes of Sweden RISE Glass Sweden

Precious Metals
FELDCO Intl CA
Fusion Ceramics Inc OH
Gwent Electronic Materials Ltd UK

Screen Printing Equipment
Aremco Products Inc NY
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL

Silver Pastes, Conducting
Master Bond Inc NJ

Spray Booths
American Art Clay Co Inc IN
Laguna Clay Co CA

Stains
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Mason Color Works Inc OH
Sheffield Pottery MA
Trinity Ceramic Supply Inc TX

Used Equipment

Mohr Corp MI **See ad on page 79**

■ DINNERWARE

China, Fine

Cerinnov France
StudioLX - Home Decor IL

Earthenware

Petro Mold Company PA
Sheffield Pottery MA
Tethon 3D NE

Porcelain

Akron Porcelain & Plastics Co OH
Art On Ceramic NY
Cerinnov France
Sheffield Pottery MA
StudioLX - Home Decor IL
Tethon 3D NE
Wistra GmbH Germany

Stoneware

ACCCO Inc/Burley Clay Products Co OH
Petro Mold Company PA
Sheffield Pottery MA
Tethon 3D NE

Tableware, Glass

RISE Research Institutes of Sweden RISE Glass Sweden
StudioLX - Home Decor IL

■ DRYING, FIRING & MELTING

Blowers

Zenith China

Burners

Air Products PA
Ceritherm France
Furnace Products & Services Inc PA
HED INtl Inc NJ
Swindell Dressler Intl Co PA
Zenith China

Calciners

Applied Test Systems Inc PA
Euro Support Advanced Materials The Netherlands
Fluid Energy Processing & Equipment Co PA
Harper International NY **See ad on page 77**
HED INtl Inc NJ
Keith Co CA
Nabertherm Inc DE
Raymond Bartlett Snow-Schneck Processing IL
Recco Furnaces CA
Thermcraft Inc NC
Wistra GmbH Germany
Wyssmont Co NJ
Zenith China

Cars, Dryer

Zenith China

Cars, Kiln

Basic Machinery Co Inc NC
Ceritherm France
Deltech Inc (Deltech Furnaces) CO **Inside front cover**
Harrop Industries Inc OH **See ad on page 58**
Keith Co CA
Magneco Metrel Inc IL
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Wistra GmbH Germany
Zenith China

Cars, Transfer

Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan

Controllers

Applied Test Systems Inc PA
Carbolite Gero UK
General Glass Equipment Co NJ
HED INtl Inc NJ
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Zenith China

Controllers, Combustion

Air Products PA
Fives North American Combustion Inc OH

Controllers, Furnace

Carbolite Gero UK
Nabertherm Inc DE
Verder Scientific Inc PA **See ad on page 87**

Controllers, Temperature

Applied Test Systems Inc PA
Datapaq Inc NH
Edward Orton Jr Ceramic Foundation OH
Nabertherm Inc DE
Optocon AG Germany
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Verder Scientific Inc PA **See ad on page 87**

Data Acquisition Systems

Applied Test Systems Inc PA
Datapaq Inc NH
HED INtl Inc NJ
Nabertherm Inc DE

Dryers

Aadvanced Machinery Inc MI
Applied Test Systems Inc PA
B&P Littleford MI
Basic Machinery Co Inc NC
Ceramic Services Inc PA
Cerlase France
Cober Muegge LLC CT
Fives North American Combustion Inc OH
Fluid Energy Processing & Equipment Co PA
Furnace Products & Services Inc PA
Goceram AB Sweden
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
Laeis GmbH Luxembourg
Nabertherm Inc DE
Raymond Bartlett Snow-Schneck Processing IL
Spray Drying Systems Inc MD
Swindell Dressler Intl Co PA
Wyssmont Co NJ
Zibo Guangtong Chemical Co Ltd China

Electrodes

Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
I Squared R Element Co NY **See ad on page 85**

Environmental Control Systems

Air Products PA
Applied Test Systems Inc PA
Control Instruments Corp NJ

Furnaces

American Isostatic Presses OH
Applied Test Systems Inc PA
Carbolite Gero UK
CM Furnaces Inc NJ
Cober Muegge LLC CT

Deltech Inc (Deltech Furnaces) CO **Inside front cover**
FCT Systeme GmbH Germany
Furnace Products & Services Inc PA
Gasbarre Products Inc PA **See ad on page 93**
Goceram AB Sweden
Harper International NY **See ad on page 77**

Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ

L&L Kiln Mfg Inc NJ

L&L Special Furnace Co Inc PA — See ad on page 87
Materials Research Furnaces Inc NH
Mohr Corp MI — See ad on page 79
Nabertherm Inc DE
Oxy-Gon Industries Inc NH — See ad on page 85
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Quintus Technologies LLC OH
RD Webb Company Inc MA
Seco/Warwick Corp PA
Swindell Dressler Intl Co PA

TevTech LLC MA — See ad on page 89
The Furnace Source LLC CT
Thermcraft Inc NC
Trent Inc PA
Verder Scientific Inc PA — See ad on page 87
Wyssmont Co NJ

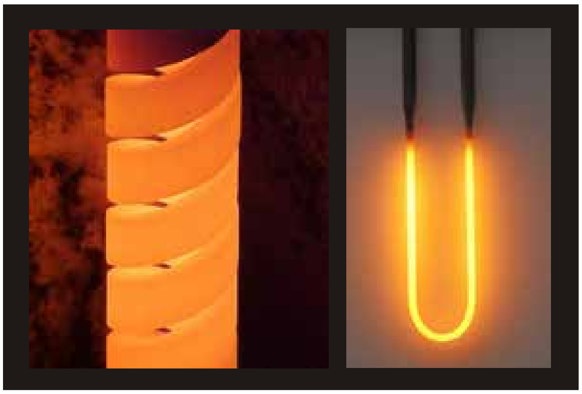
Furnaces, Alternative Fuels

Ceritherm France
Harper International NY — See ad on page 77
Harrop Industries Inc OH — See ad on page 58
Keith Co CA
Recco Furnaces CA
Swindell Dressler Intl Co PA
Thermcraft Inc NC
Verder Scientific Inc PA — See ad on page 87

Furnaces, Electric

Aadvanced Machinery Inc MI
American Isostatic Presses OH
Applied Test Systems Inc PA
Aremco Products Inc NY
Carbolite Gero UK

Centorr Vacuum Industries NH
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ



Deltech Inc (Deltech Furnaces) CO Inside front cover
Deltech Kiln and Furnace Design LLC CO See ad on page 75
FCT Systeme GmbH Germany
Gasbarre Products Inc PA See ad on page 93
Harper International NY See ad on page 77
Harrop Industries Inc OH See ad on page 58
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA See ad on page 87
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Oxy-Gon Industries Inc NH See ad on page 85
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
RD Webb Company Inc MA
Recco Furnaces CA
Seco/Warwick Corp PA
The Furnace Source LLC CT
Thermcraft Inc NC
Trent Inc PA
Verder Scientific Inc PA See ad on page 87
Winner Technology Korea
Wyssmont Co NJ

Furnaces, Gas

Aadvanced Machinery Inc MI
Ceramic Services Inc PA
Ceritherm France
Harper International NY See ad on page 77
Harrop Industries Inc OH See ad on page 58
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA See ad on page 87
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Recco Furnaces CA
Seco/Warwick Corp PA
Swindell Dressler Intl Co PA
The Furnace Source LLC CT
Thermcraft Inc NC
Wyssmont Co NJ

Furnaces, Glass-Melting

Applied Test Systems Inc PA
Carbolite Gero UK
Ceradyne Inc a 3M Co KY
CM Furnaces Inc NJ

Deltech Inc (Deltech Furnaces) CO Inside front cover
Deltech Kiln and Furnace Design LLC CO See ad on page 75
Furnace Products & Services Inc PA
General Glass Equipment Co NJ
Magneco Metrel Inc IL
Nabertherm Inc DE
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
RISE Research Institutes of Sweden RISE Glass Sweden
Verder Scientific Inc PA See ad on page 87

Furnaces, High-Temperature

Applied Test Systems Inc PA
Cancarb Limited Canada
Carbolite Gero UK
Centorr Vacuum Industries NH
Ceritherm France
CM Furnaces Inc NJ
Cober Muegge LLC CT
Dalmia Inst of Scientific & Industrial Research India
Deltech Inc (Deltech Furnaces) CO Inside front cover
Detroit Process Machinery MI
FCT Systeme GmbH Germany
Furnace Products & Services Inc PA
Gasbarre Products Inc PA See ad on page 93
Harper International NY See ad on page 77
Harrop Industries Inc OH See ad on page 58
HED INtl Inc NJ
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Nabertherm Inc DE

Oxy-Gon Industries Inc NH See ad on page 85
Plansee SE MA
PSH Kilns & Furnaces Canada
Quintus Technologies LLC OH
RD Webb Company Inc MA
Seco/Warwick Corp PA
Swindell Dressler Intl Co PA
The Furnace Source LLC CT
Verder Scientific Inc PA See ad on page 87
Winner Technology Korea

Furnaces, Laboratory

Carbolite Gero UK

Centorr Vacuum Industries NH
CM Furnaces Inc NJ
Cober Muegge LLC CT
Deltech Inc (Deltech Furnaces) CO Inside front cover
Deltech Kiln and Furnace Design LLC CO See ad on page 75
FCT Systeme GmbH Germany
Harper International NY See ad on page 77
L&L Special Furnace Co Inc PA See ad on page 87
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Oxy-Gon Industries Inc NH See ad on page 85
RD Webb Company Inc MA
RocCera LLC NY
The Furnace Source LLC CT

Verder Scientific Inc PA See ad on page 87
Winner Technology Korea

Furnaces, Vacuum

Applied Test Systems Inc PA
AVS Inc MA
Centorr Vacuum Industries NH
Cober Muegge LLC CT
FCT Systeme GmbH Germany
Gasbarre Products Inc PA See ad on page 93
Goceram AB Sweden
Materials Research Furnaces Inc NH
Nabertherm Inc DE

Oxy-Gon Industries Inc NH See ad on page 85
RocCera LLC NY
Seco/Warwick Corp PA
The Furnace Source LLC CT
Verder Scientific Inc PA See ad on page 87

Heating Elements

Applied Test Systems Inc PA
CM Furnaces Inc NJ
Hotek Alliance Ltd China

I Squared R Element Co NY See ad on page 85
Keith Co CA
L&L Kiln Mfg Inc NJ
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Oxy-Gon Industries Inc NH See ad on page 85
Plansee SE MA
PSH Kilns & Furnaces Canada
Recco Furnaces CA
Seco/Warwick Corp PA
Thermal Products Co Inc GA
Thermcraft Inc NC
Trent Inc PA
Verder Scientific Inc PA See ad on page 87
Winner Technology Korea

Humidification Systems

CM Furnaces Inc NJ

Kilns
Applied Test Systems Inc PA
Carbolite Gero UK
Ceramic Services Inc PA
Ceritherm France
Detroit Process Machinery MI
FCT Systeme GmbH Germany
Fives North American Combustion Inc OH
Furnace Products & Services Inc PA

Harper International NY — **See ad on page 77**
Harrop Industries Inc OH — **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ

L&L Special Furnace Co Inc PA — **See ad on page 87**
Laeis GmbH Luxembourg
Laguna Clay Co CA
Lucifer Furnaces Inc PA
Mohr Corp MI — **See ad on page 79**
Nutec Bickley Mexico
PSH Kilns & Furnaces Canada
RD Webb Company Inc MA
Recco Furnaces CA
RocCera LLC NY
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC
Wistra GmbH Germany

Kilns, Bell
Carbolite Gero UK
Ceramic Services Inc PA
Ceritherm France
Harper International NY — **See ad on page 77**
Harrop Industries Inc OH — **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA — **See ad on page 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
PSH Kilns & Furnaces Canada
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC

Kilns, Box
Aadvanced Machinery Inc MI
American Art Clay Co Inc IN
Applied Test Systems Inc PA
Carbolite Gero UK
Ceramic Services Inc PA
Ceritherm France

CM Furnaces Inc NJ
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on page 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC
Verder Scientific Inc PA **See ad on page 87**

Kilns, Chamber
Carbolite Gero UK
Ceritherm France
Harrop Industries Inc OH **See ad on page 58**
L&L Kiln Mfg Inc NJ
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Takasago Industry Co Ltd Japan
Thermcraft Inc NC
Verder Scientific Inc PA **See ad on page 87**

Kilns, Conveyor
Ceramic Services Inc PA
Ceritherm France
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Recco Furnaces CA

Kilns, Elevator
Aadvanced Machinery Inc MI
Applied Test Systems Inc PA
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Euro Support Advanced Materials The Netherlands
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on page 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan

Kilns, Envelope
Ceritherm France
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on page 87**
Nabertherm Inc DE
PSH Kilns & Furnaces Canada
Recco Furnaces CA
Swindell Dressler Intl Co PA

Kilns, Periodic (Batch)
Aadvanced Machinery Inc MI
Carbolite Gero UK
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Cober Muegge LLC CT
FCT Systeme GmbH Germany
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on page 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
RD Webb Company Inc MA
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC

Kilns, Pusher Plate
Ceritherm France
CM Furnaces Inc NJ
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Ipsen Ceramics IL
Keith Co CA
Lucifer Furnaces Inc PA
Recco Furnaces CA

Kilns, Roller Hearth
Ceramic Services Inc PA
Ceritherm France
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
Lucifer Furnaces Inc PA
Nutec Bickley Mexico
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Wistra GmbH Germany

Kilns, Rotary
Ceritherm France
CM Furnaces Inc NJ

Deltech Inc (Deltech Furnaces) CO **Inside front cover**
Fives North American Combustion Inc OH
Furnace Products & Services Inc PA
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Lucifer Furnaces Inc PA
Nutec Bickley Mexico
Raymond Bartlett Snow-Schneck Processing IL
Thermcraft Inc NC
Verder Scientific Inc PA **See ad on page 87**

Kilns, Shuttle
Basic Machinery Co Inc NC
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on page 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC
Wistra GmbH Germany

Kilns, Test/Lab
American Art Clay Co Inc IN
Applied Test Systems Inc PA
Carbolite Gero UK
Ceramic Services Inc PA
CM Furnaces Inc NJ
Cober Muegge LLC CT
FCT Systeme GmbH Germany
Harper International NY **See ad on page 77**
Harrop Industries Inc OH **See ad on page 58**
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on page 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
RD Webb Company Inc MA
Recco Furnaces CA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC
Verder Scientific Inc PA **See ad on page 87**

Kilns, Tunnel (Continuous)
Applied Test Systems Inc PA
Basic Machinery Co Inc NC
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Cober Muegge LLC CT
Deltech Inc (Deltech Furnaces) CO **Inside front cover**
Euro Support Advanced Materials The Netherlands
Harper International NY **See ad on page 77**

Harrop Industries Inc OH **See ad on page 58**
Keith Co CA
Nutec Bickley Mexico
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Wistra GmbH Germany

Lehrs
Ceramic Services Inc PA
Harrop Industries Inc OH **See ad on page 58**
Keith Co CA
Recco Furnaces CA

Microwave Systems
- Bharat Heavy Electricals Ltd India
- Ceralink Inc NY
- Ceritherm France
- CM Furnaces Inc NJ
- Cober Muegge LLC CT
- Gerling Applied Engineering Inc CA
- **Harper International NY** **See ad on page 77**

- **Harrop Industries Inc OH** **See ad on page 58**
- RocCera LLC NY
- Takasago Industry Co Ltd Japan

Oxygen Supply
- Air Products PA

Process/Quality Control Systems
- Applied Test Systems Inc PA
- Datapaq Inc NH
- General Glass Equipment Co NJ
- Materials Research Furnaces Inc NH

Pyrometric Cones/Plaques
- American Art Clay Co Inc IN
- Edward Orton Jr Ceramic Foundation OH
- Industrial Ceramic Products Inc OH
- PSH Kilns & Furnaces Canada
- Trinity Ceramic Supply Inc TX

Sensors, Temperature
- Datapaq Inc NH
- Penn Tool Co NJ
- Zibo Guangtong Chemical Co Ltd China

Thermocouples & Accessories
- **AdValue Technology LLC AZ** **See ad on page 51**
- American Art Clay Co Inc IN
- American Isostatic Presses OH
- CM Furnaces Inc NJ
- Datapaq Inc NH
- **Gasbarre Products Inc PA** **See ad on page 93**
- **Harrop Industries Inc OH** **See ad on page 58**
- Keith Co CA
- Leico Industries Inc NJ
- Materials Research Furnaces Inc NH
- McDanel Advanced Ceramic Technologies LLC PA
- PSH Kilns & Furnaces Canada
- Quintus Technologies LLC OH
- Recco Furnaces CA
- **Verder Scientific Inc PA** **See ad on page 87**

■ EDUCATION & RESOURCES

Associations & Societies
- Assoc of American Ceramic Component Manufacturers (AACCM) OH
- Brick Industry Assn VA
- Glass Mfg Industry Council OH
- Indian Ceramic Society India
- International Centre for Diffraction Data PA
- Journal of the American Ceramic Society OH
- SAMPE CA
- The American Ceramic Society OH

Books
- APC International Ltd PA
- Bharat Heavy Electricals Ltd India
- Journal of the American Ceramic Society OH
- SAMPE CA
- Sheffield Pottery MA

Continuing Education
- **Alfred University NY** **See ad on page 40**
- Arizona State University AZ
- CelSian Glass & Solar BV The Netherlands
- Fraunhofer Institute for Ceramic Technologies and Systems IKTS Germany
- International Centre for Diffraction Data PA
- Jenike & Johanson Inc MA
- JTF Microscopy Services LLC NY
- Spontaneous Materials CO
- Tethon 3D NE

Degree Programs, ABET Accredited

- **Alfred University NY** **See ad on page 40**

Case Western Reserve University OH
Massachusetts Inst of Technology MA
Missouri University of Science and Technology MO
Rensselaer Polytechnic Inst NY

Degree Programs, Ceramic

Alfred University NY **See ad on page 40**
Fraunhofer Institute for Ceramic Technologies and Systems IKTS Germany
Massachusetts Inst of Technology MA
Missouri University of Science and Technology MO

Degree Programs, Glass Engrg Science

Alfred University NY **See ad on page 40**
Fraunhofer Institute for Ceramic Technologies and Systems IKTS Germany

Degree Programs, Materials Science

Alfred University NY **See ad on page 40**
Arizona State University AZ
Case Western Reserve University OH
Fraunhofer Institute for Ceramic Technologies and Systems IKTS Germany
Massachusetts Inst of Technology MA
Missouri University of Science and Technology MO
Rensselaer Polytechnic InstNY

Employment Services

SAMPE CA

Publications

American Ceramic Society Bulletin OH
American Scientific Publishers CA
Chemical Abstracts Service OH
GrainBound LLC PA
Indian Ceramic Society India
Journal of the American Ceramic Society OH

Ultrasonic Transducers

Piezo by Graco OH

■ ELECTRICAL/ELECTRONIC CERAMICS

Antennas, Dielectric

Euro Support Advanced Materials The Netherlands
O'Keefe Ceramics Inc CO
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Capacitors

Associated Ceramics & Technology Inc PA
AVX Corp SC
Euro Support Advanced Materials The Netherlands
Induceramic Canada
Murata Manufacturing Co Ltd Japan

Ceramic-Brazed Assemblies

AdTech Ceramics TN
CeramTec North America Corp SC
Induceramic Canada
Morgan Technical Ceramics Auburn CA
Precision Ferrites and Ceramics Inc CA

Conductors

AdTech Ceramics TN
CerPoTech AS Norway
ESL ElectroScience PA
Master Bond Inc NJ
NorECs AS Norway

Crystals

Induceramic Canada
Kyocera International Inc CA
Momentive Performance Materials Inc NY
MSE Supplies AZ
TevTech LLC MA **See ad on page 89**

Dielectrics

AVX Corp SC
Centerline Technologies MA
CerPoTech AS Norway
ENrG Inc NY
ESL ElectroScience PA
Euro Support Advanced Materials The Netherlands
Gwent Electronic Materials Ltd UK
Morgan Advanced Materials CA
NGK Spark Plug Co Ltd Japan
Pacific Ceramics Inc CA
Advanced Ceramic Technology CA

Ferrites & Ferromagnetics

Ferro Ceramic Grinding Inc MA
Pacific Ceramics Inc CA
Precision Ferrites and Ceramics Inc CA
Spontaneous Materials CO

Filters, Dielectric

CerPoTech AS Norway
Euro Support Advanced Materials The Netherlands
Murata Manufacturing Co Ltd Japan
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Fuel Cells, Solid Oxide

AdTech Ceramics TN
Associated Ceramics & Technology Inc PA
Bharat Heavy Electricals Ltd India
Cancarb Limited Canada
CerPoTech AS Norway
ENrG Inc NY
ESL ElectroScience PA
Euro Support Advanced Materials The Netherlands
Gwent Electronic Materials Ltd UK
Morgan Technical Ceramics Auburn CA
Nexceris LLC OH
NorECs AS Norway
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

High-Voltage Insulators

Akron Porcelain & Plastics Co OH
Bharat Heavy Electricals Ltd India
Ceramco Inc NH
CeramTec North America Corp SC
Du-Co Ceramics Company PA
Elcon Precision LLC CA
Morgan Technical Ceramics Auburn CA
Precision Ferrites and Ceramics Inc CA
Xiamen Innovacera Advanced Materials Co Ltd China

Hybrid Circuits & Packages

AdTech Ceramics TN
AVX Corp SC
Precision Ferrites and Ceramics Inc CA
Xiamen Innovacera Advanced Materials Co Ltd China

IC Packages

AdTech Ceramics TN
Kyocera International Inc CA
NGK Spark Plug Co Ltd Japan

Insulators, Electrical/Electronic

Accuratus Corp NJ
AdTech CeramicsTN
AdValue Technology LLC AZ **See ad on page 51**
Akron Porcelain & Plastics Co OH
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CeramTec North America Corp SC
CerCo LLC OH
Du-Co Ceramics Company PA
ER Advanced Ceramics Inc OH
ESL ElectroScience PA
Federal-Mogul MI
Ferro Ceramic Grinding Inc MA
Maryland Ceramic & Steatite Co Inc MD
Materion Ceramics AZ
Morgan Technical Ceramics Auburn CA
NEVZ-Ceramics Close JSC Russia
P-Ker Engineering NY
Precision Ferrites and Ceramics Inc CA
Sonya Ceramics (Export Division) India
Superior Technical Ceramics Corp VT
Toto Ltd Japan
Xiamen Innovacera Advanced Materials Co Ltd China
Zircoa Inc OH

Magnets

Spontaneous Materials CO

Microwave Packages

AdTech Ceramics TN
Kyocera International Inc CA
Precision Ferrites and Ceramics Inc CA

Multilayer Ceramic Capacitors

Euro Support Advanced Materials The Netherlands
Murata Manufacturing Co Ltd Japan

Multilayer Ceramics, AlN

AdTech Ceramics TN
NEVZ-Ceramics Close JSC Russia
Xiamen Innovacera Advanced Materials Co Ltd China

Multilayer Ceramics, Custom

AdTech Ceramics TN
EBL Products Inc CT

ENrG Inc NY
Euro Support Advanced Materials The Netherlands
Piezo by Graco OH
Xiamen Innovacera Advanced Materials Co Ltd China

Piezoelectrics
APC International Ltd PA
AVX Corp SC
EBL Products Inc CT
Meggitt Piezo Technologies IN
Morgan Advanced Materials CA
Sparkler Ceramics Pvt Ltd India

Resistors, Thick-Film
ESL ElectroScience PA
Murata Manufacturing Co Ltd Japan

Resonators
AVX Corp SC
Murata Manufacturing Co Ltd Japan
NGK Spark Plug Co Ltd Japan
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

RF Components
AdTech Ceramics TN
Advanced Ceramic Technology CA
Advanced Energy CO
Murata Manufacturing Co Ltd Japan
Precision Ferrites and Ceramics Inc CA
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Semiconductors
Cancarb Limited Canada
Elcon Precision LLC CA
Momentive Performance Materials Inc NY
NEVZ-Ceramics Close JSC Russia
Semiconductor Energy Laboratory Co Ltd Japan
Toto Ltd Japan

Sensors
AdTech Ceramics TN
AVX Corp SC
Bullen OH
CeramTec North America Corp SC
EBL Products Inc CT
ENrG Inc NY
Gwent Electronic Materials Ltd UK
Murata Manufacturing Co Ltd Japan
Neoptix Canada
Optocon AG Germany
Piezo by Graco OH
Quality Thermistor Inc ID
Sparkler Ceramics Pvt Ltd India
Technisonic Research Inc CT

Spark Plugs
Associated Ceramics & Technology Inc PA
CerCo LLC OH
Federal-Mogul MI
Gwent Electronic Materials Ltd UK
NGK Spark Plug Co Ltd Japan

Substrates, Alumina
Accuratus Corp NJ

Substrates, Alumina
Actech Precision Ceramic (HK) Limited China
AdTech Ceramics TN
Bullen OH
Centerline Technologies MA
CeramTec North America Corp SC
CoorsTek CO
Du-Co Ceramics Company PA
Ferro Ceramic Grinding Inc MA
Laserage Technology Corp IL
NEVZ-Ceramics Close JSC Russia
NGK Spark Plug Co Ltd Japan
Ortech Inc CA
Saint-Gobain NorPro OH
Toto Ltd Japan
Valley Design Corp MA
Xiamen Innovacera Advanced Materials Co Ltd China

Substrates, Aluminum Nitride
Accuratus Corp NJ
Actech Precision Ceramic (HK) Limited China
AdTech Ceramics TN
Bullen OH
Centerline Technologies MA
CoorsTek CO
Laserage Technology Corp IL
MSE Supplies AZ
NEVZ-Ceramics Close JSC Russia
Ortech Inc CA
Starfire Systems Inc NY
Valley Design Corp MA
Xiamen Innovacera Advanced Materials Co Ltd China

Substrates, Glass
Accuratus Corp NJ
Bullen OH
Centerline Technologies MA
Laserage Technology Corp IL
RISE Research Institutes of Sweden RISE Glass Sweden
Saint-Gobain Recherche France
Valley Design Corp MA

Substrates, Other
Accuratus Corp NJ
Akron Porcelain & Plastics Co OH
Bullen OH
Centerline Technologies MA
CoorsTek CO
Du-Co Ceramics Company PA
ENrG Inc NY
Materion Ceramics AZ
MSE Supplies AZ
NGK Spark Plug Co Ltd Japan
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**
Valley Design Corp MA

Substrates, Silicon Carbide
Bullen OH
Centerline Technologies MA
Ferro Ceramic Grinding Inc MA
Ortech Inc CA
Toto Ltd Japan
Valley Design Corp MA

Superconductors, High-Temperature
ENrG Inc NY
Xiamen Innovacera Advanced Materials Co Ltd China

Tapes
Du-Co Ceramics Company PA
ESL ElectroScience PA
Euro Support Advanced Materials The Netherlands
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Maryland Ceramic & Steatite Co Inc MD

Thermistors
AVX Corp SC
Gwent Electronic Materials Ltd UK
Murata Manufacturing Co Ltd Japan
Quality Thermistor Inc ID

Transducers
APC International Ltd PA
CSC Force Measurement Inc MA
EBL Products Inc CT
Meggitt Piezo Technologies IN
Neoptix Canada
Piezo by Graco OH
Sparkler Ceramics Pvt Ltd India
Technisonic Research Inc CT

Transformers
Grand Power Systems formally Warner Power LLC MI
RoMan Manufacturing MI

Ultrasonic Ceramics
APC International Ltd PA
EBL Products Inc CT
Meggitt Piezo Technologies IN
Piezo by Graco OH

Varistors
AVX Corp SC
Kyocera International Inc CA

■ FABRICATING & FINISHING

Abrasives
Allied High Tech Products Inc CA
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Dunhua Zhengxing Abrasive Co Ltd China
Dynacut Inc PA
Electro Abrasives Corp NY
Engis Corp IL
FELDCO Intl CA
Jet Edge Waterjet Systems MN
Reade Advanced Materials RI
Saint-Gobain Abrasives MA
Sigmadiamant Spain
Stahli USA Inc WI
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Washington Mills Electro Minerals Co NY

Brickmaking Equipment
Basic Machinery Co Inc NC
EZG Manufacturing Inc OH
Laeis GmbH Luxembourg
Stedman Machine Co IN

Casting Equipment, Pressure
American Isostatic Presses OH
Cerinnov France
Cerlase France
Dorst America Inc PA
HED INtl Inc NJ
Laguna Clay Co CA
Maryland Ceramic & Steatite Co Inc MD

Casting Equipment, Tape
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
HED INtl Inc NJ

CNC Mills
Elcon Precision LLC CA
Liberty Machinery Co IL
OptiPro Systems LLC NY **See ad on page 93**
Penn Tool Co NJ
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Coating Equipment
Allied High Tech Products Inc CA
Cerakote Ceramic Coatings OR

Dynacut Inc PA
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Liberty Machinery Co IL

Cold-End Coatings, Glass
RISE Research Institutes of Sweden RISE Glass Sweden

Controllers
Dorst America Inc PA
General Glass Equipment Co NJ
Laguna Clay Co CA
Rockwell Automation Inc WI

Cutting Equipment
Basic Machinery Co Inc NC
Diamond Industrial Tools Inc IL
General Glass Equipment Co NJ
Haiku Tech Inc FL
Jet Edge Waterjet Systems MN
Liberty Machinery Co IL
OptiPro Systems LLC NY **See ad on page 93**
Penn Tool Co NJ
Sigmadiamant Spain
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Cutting Tools
Diacut Inc CO
Dynacut Inc PA
Engis Corp IL
Jet Edge Waterjet Systems MN
New Tech Ceramics Inc IA
Penn Tool Co NJ
Sigmadiamant Spain

CVD Equipment
Advanced Energy CO
Centorr Vacuum Industries NH
Liberty Machinery Co IL

Deburring Equipment
Engis Corp IL
Liberty Machinery Co IL
Mohr Corp MI **See ad on page 79**
Penn Tool Co NJ

Diamond Drills
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Greenlee Diamond Tool Co IL

Mitsubishi Materials Corporation Japan

Diamond Hones
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Engis Corp IL
Greenlee Diamond Tool Co IL
Saint-Gobain Abrasives MA
Stahli USA Inc WI

Diamond Saw Blades
Allied High Tech Products Inc CA
Aremco Products Inc NY
Comtrust Architectural Mesh Co Ltd China
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
LECO Corp MI
Liberty Machinery Co IL
Saint-Gobain Abrasives MA
Texers Technical Ceramics Inc Canada

Diamond Saws
Allied High Tech Products Inc CA
Aremco Products Inc NY
Diacut Inc CO
Dynacut Inc PA
Greenlee Diamond Tool Co IL
Liberty Machinery Co IL

Diamond Tools
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Engis Corp IL
Greenlee Diamond Tool Co IL
LECO Corp MI

Mitsubishi Materials Corporation Japan
Penn Tool Co NJ
Saint-Gobain Abrasives MA
Sigmadiamant Spain

Dicing Equipment
Aremco Products Inc NY
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Liberty Machinery Co IL

Dies
Gasbarre Products Inc PA **See ad on page 93**
Ram Products Inc OH

Dressing Wheels, Diamond
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL

Electroplating Equipment
Haiku Tech Inc FL
Liberty Machinery Co IL
Penn Tool Co NJ

Extruders
Aadvanced Machinery Inc MI
American Art Clay Co Inc IN
Basic Machinery Co Inc NC
Detroit Process Machinery MI
Dorst America Inc PA
Ipsen Ceramics IL
Laguna Clay Co CA
Mohr Corp MI **See ad on page 79**
North Star Equipment Inc WA
Peter Pugger Mfg Inc CA

Feeders
Ingredient Masters Inc OH **See ad on page 101**
Isoform Ltd UK
Mohr Corp MI **See ad on page 79**
Wyssmont Co NJ

Forming Equipment
American Isostatic Presses OH
ARBURG GmbH + Co KG Germany
Dorst America Inc PA
HED INtl Inc NJ
Ipsen Ceramics IL
Isoform Ltd UK
Lithoz GmbH NY
Mohr Corp MI **See ad on page 79**
Quintus Technologies LLC OH
Ram Products Inc OH

Glass Finishing Equipment
General Glass Equipment Co NJ
Liberty Machinery Co IL
Lithoz GmbH NY

OptiPro Systems LLC NY **See ad on page 93**

Glass Forming Equipment
General Glass Equipment Co NJ

Glass Shear Spray
RISE Research Institutes of Sweden RISE Glass Sweden

Glass Supplies
Ipsen Ceramics IL

Grinders, Centerless
Diamond Industrial Tools Inc IL
Liberty Machinery Co IL
Precision Ferrites and Ceramics Inc CA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Grinders, Cylindrical
Diamond Industrial Tools Inc IL
Liberty Machinery Co IL
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Grinders, Finished Product
DCM Tech MN
Ipsen Ceramics IL
Liberty Machinery Co IL
OptiPro Systems LLC NY **See ad on page 93**
Stahli USA Inc WI

Grinding Wheels
Allied High Tech Products Inc CA
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
Penn Tool Co NJ
Sigmadiamant Spain
Stahli USA Inc WI

Hydraulic Systems
Isoform Ltd UK
Ram Products Inc OH

Injection-Molding Equipment
ARBURG GmbH + Co KG Germany
Goceram AB Sweden
Mohr Corp MI See ad on page 79
Rockwell Automation Inc WI
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Jiggering Equipment
Cerinnov France
Ram Products Inc OH

Lapping Equipment
Allied High Tech Products Inc CA
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Liberty Machinery Co IL
OptiPro Systems LLC NY See ad on page 93
Sigmadiamant Spain
Stahli USA Inc WI

Lapping Supplies
Allied High Tech Products Inc CA
Diamond Industrial Tools Inc IL
Dunhua Zhengxing Abrasive Co Ltd China
Engis Corp IL
FELDCO Intl CA
Stahli USA Inc WI

Laser Scribers
Centerline Technologies MA
Cerlase France
Laserage Technology Corp IL

Machining Equipment
Dynacut Inc PA
Ferro Ceramic Grinding Inc MA
International Ceramic Engineering MA
Liberty Machinery Co IL
OptiPro Systems LLC NY See ad on page 93
Penn Tool Co NJ
Stahli USA Inc WI

Mandrels, Diamond
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Engis Corp IL
Greenlee Diamond Tool Co IL

Molds, Case
Petro Mold Company PA
Ram Products Inc OH

Molds, Ceramic-Forming
Akron Porcelain & Plastics Co OH
Cerinnov France
Cerlase France
Goceram AB Sweden
Ipsen Ceramics IL
Isoform Ltd UK
Laeis GmbH Luxembourg
Laguna Clay Co CA
Petro Mold Company PA
Ram Products Inc OH
Viridis3D LLC MA

Molds, Models
Petro Mold Company PA
Ram Products Inc OH
Viridis3D LLC MA

Plasma Etching Systems
Advanced Energy CO
Liberty Machinery Co IL

Pneumatic Systems
Cyclonaire Corp NE
Ingredient Masters Inc OH See ad on page 101
Ram Products Inc OH
Young Industries Inc PA

Polishing Equipment
Allied High Tech Products Inc CA
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
LECO Corp MI
Liberty Machinery Co IL
OptiPro Systems LLC NY See ad on page 93
Penn Tool Co NJ
Sigmadiamant Spain
Stahli USA Inc WI

Polishing Powder & Supplies
Baikowski Malakoff Inc NC
C&L Development Corp CA
Dianamic Abrasive Products Inc MI
Engis Corp IL
Sigmadiamant Spain
Stahli USA Inc WI

Presses, Compacting
Detroit Process Machinery MI
Digital Press Inc PA
Dorst America Inc PA
Gasbarre Products (PTX Pentronix) PA See ad on page 93

Gasbarre Products Inc PA See ad on page 93
Mohr Corp MI See ad on page 79
Quintus Technologies LLC OH

Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD See ad on page 81

Presses, Dry
Aadvanced Machinery Inc MI
Dorst America Inc PA
Gasbarre Products Inc PA See ad on page 93
Maryland Ceramic & Steatite Co Inc MD
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Presses, Extrusion
Dorst America Inc PA
Maryland Ceramic & Steatite Co Inc MD
Mohr Corp MI See ad on page 79
Peter Pugger Mfg Inc CA

Presses, Hot
American Isostatic Presses OH
Centorr Vacuum Industries NH
FCT Ingenieurkeramik GmbH Germany
FCT Systeme GmbH Germany
Materials Research Furnaces Inc NH
Oxy-Gon Industries Inc NH See ad on page 85
Refrac Systems AZ

Presses, Hot Isostatic
American Isostatic Presses OH
AVS Inc MA
FCT Ingenieurkeramik GmbH Germany
Quintus Technologies LLC OH

Presses, Hydraulic
Aadvanced Machinery Inc MI
ARBURG GmbH + Co KG Germany
AVS Inc MA
Digital Press Inc PA
Dorst America Inc PA
Gasbarre Products Inc PA See ad on page 93
Laeis GmbH Luxembourg
Materials Research Furnaces Inc NH
Mohr Corp MI See ad on page 79
Ram Products Inc OH

Presses, Isostatic
Aadvanced Machinery Inc MI
American Isostatic Presses OH
Cerinnov France
Cerlase France
Detroit Process Machinery MI
Dorst America Inc PA
Gasbarre Products (PTX Pentronix) PA See ad on page 93

Gasbarre Products Inc PA See ad on page 93
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Isoform Ltd UK
Mohr Corp MI See ad on page 79
Quintus Technologies LLC OH
RocCera LLC NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Presses, Other
ARBURG GmbH + Co KG Germany
Isoform Ltd UK

Presses, Pressure Casting
Cerlase France
Dorst America Inc PA
Peter Pugger Mfg Inc CA
Ram Products Inc OH

Presses, Refractory Shapes
Laeis GmbH Luxembourg

Presses, Rotary
Aadvanced Machinery Inc MI

Presses, Rotary
Materials Research Furnaces Inc NH

Presses, Tile (Ceramic)
Laeis GmbH Luxembourg
Peter Pugger Mfg Inc CA

Pug Mills
Aadvanced Machinery Inc MI
Basic Machinery Co Inc NC
Dorst America Inc PA
Mohr Corp MI See ad on page 79
Peter Pugger Mfg Inc CA
Sheffield Pottery MA
Young Industries Inc PA

PVD Equipment
Liberty Machinery Co IL
Teeter Marketing Services LLC FL

Roofing Tile Machinery
Laeis GmbH Luxembourg

Setting Equipment
Basic Machinery Co Inc NC

Slab Rollers
North Star Equipment Inc WA

Spray Booths
Treibacher Industrie AG Austria

Sputtering Equipment
Advanced Energy CO
FCT Ingenieurkeramik GmbH Germany

Superabrasives
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
Liberty Machinery Co IL
Teeter Marketing Services LLC FL

Surface Modification Systems
Teeter Marketing Services LLC FL

Tilemaking Equipment
Basic Machinery Co Inc NC
Peter Pugger Mfg Inc CA
Ram Products Inc OH

Tools, Modeling
Sheffield Pottery MA
Viridis3D LLC MA

Turning Machines, Insulator
Liberty Machinery Co IL

Ultrasonic Machining Equipment
Bullen OH
International Ceramic Engineering MA
Liberty Machinery Co IL

OptiPro Systems LLC NY See ad on page 93

Used Equipment
Aadvanced Machinery Inc MI
Basic Machinery Co Inc NC
Cerinnov France
Diamond Industrial Tools Inc IL
Dorst America Inc PA
Dynacut Inc PA

Liberty Machinery Co IL
Mohr Corp MI See ad on page 79
Ram Products Inc OH
Viridis3D LLC MA

Vibratory Finishing Equipment
Liberty Machinery Co IL
Penn Tool Co NJ
Rockwell Automation Inc WI

Weighing/Scales
Optimation - Klug Systems NY

Wheels, Cutoff & Grinding
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
LECO Corp MI
Liberty Machinery Co IL
Penn Tool Co NJ

Wheels, Diamond
Aremco Products Inc NY
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dianamic Abrasive Products Inc MI
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
LECO Corp MI
Sigmadiamant Spain
Stahli USA Inc WI

■ GLASS PRODUCTS

Automotive Glass
Arkema Inc PA
RISE Research Institutes of Sweden RISE Glass Sweden
Saint-Gobain Recherche France
Schott North America Inc NY

Beads/Spheres
Bekeson Glass LLC MS See ad on page 96
Ceradyne Inc a 3M Co KY
Maryland Ceramic & Steatite Co Inc MD

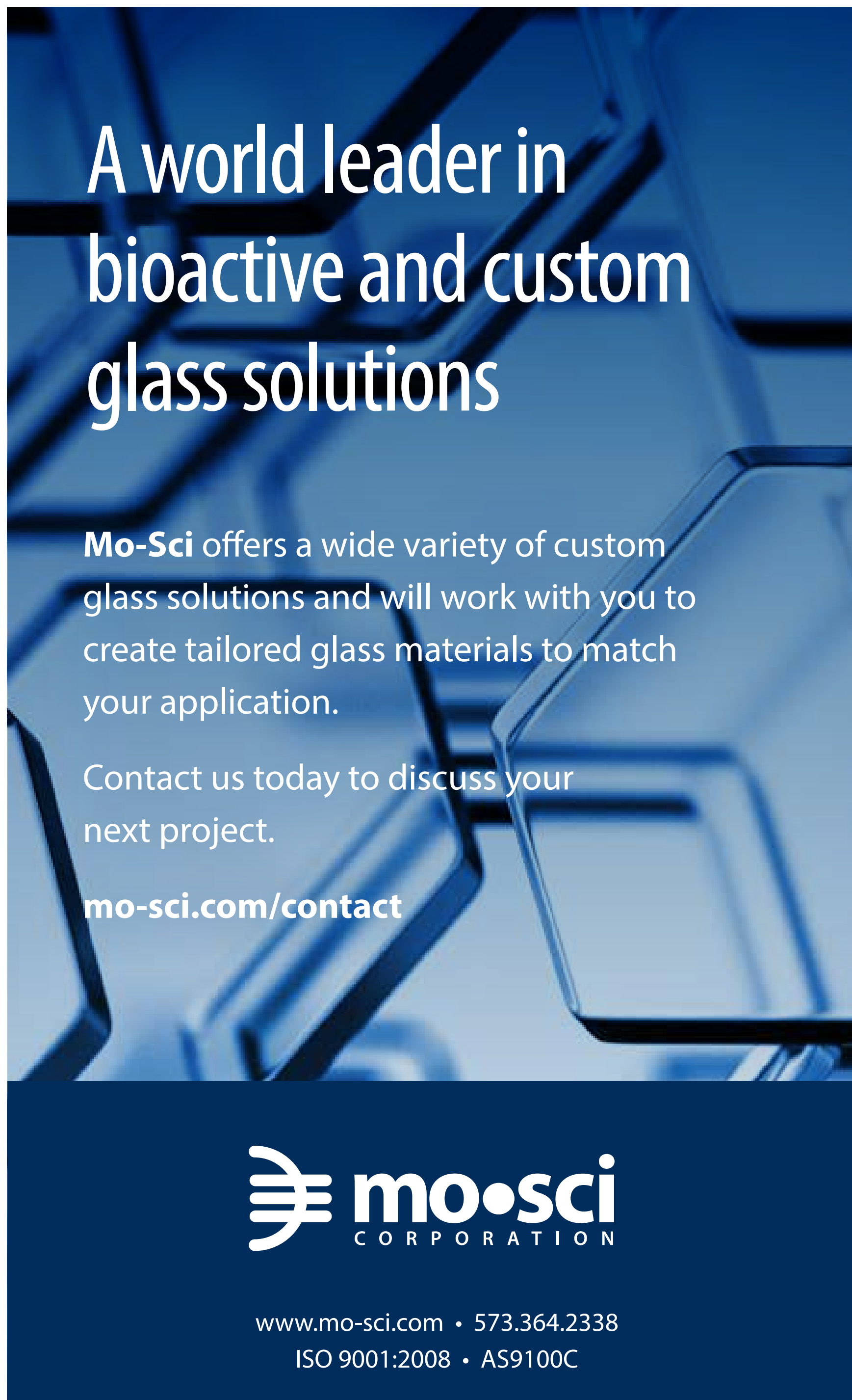
Mo-Sci Corp MO See ad on page 95

Bioglass
Ceradyne Inc a 3M CoKY

Mo-Sci Corp MO See ad on page 95
RISE Research Institutes of Sweden RISE Glass Sweden
Specialty Glass Inc FL

Borosilicate Glass
Bekeson Glass LLC MS See ad on page 96
Bullen OH
Elan Technology GA
Garg Process Glass India Pvt Ltd India
RISE Research Institutes of Sweden RISE Glass Sweden
Schott North America Inc NY

Specialty Glass Inc FL
Valley Design Corp MA



Chemically Strengthened Glass
Arkema Inc PA
Garg Process Glass India Pvt Ltd India
RISE Research Institutes of Sweden RISE Glass Sweden
Saint-Gobain Recherche France
Saxon Glass Technologies Inc NY
Schott North America Inc NY
Vesuvius SC

Container Glass
Arkema Inc PA
Cerinnov France
Owens-Illinois Inc OH
RISE Research Institutes of Sweden RISE Glass Sweden
Saint-Gobain Recherche France
Vesuvius SC

Fibers, Continuous
Saint-Gobain Recherche France
Verity Technical Consultants LLC OH

Fibers, Optical
Adamant Co Ltd Japan
Corning Incorporated NY **Inside back cover**
Optocon AG Germany
Schott North America Inc NY

Flat & Safety Glass
Arkema Inc PA
RISE Research Institutes of Sweden RISE Glass Sweden
Saint-Gobain Recherche France
Vesuvius SC

Fused Silica Glass
Accuratus Corp NJ
Arkema Inc PA
Bullen OH
Ferro Ceramic Grinding Inc MA
Imerys Refractory Minerals GA
RISE Research Institutes of Sweden RISE Glass Sweden
Valley Design Corp MA

Glass-Ceramics
Accuratus Corp NJ
Advanced Ceramic Technology CA
Arkema Inc PA
Bekeson Glass LLC MS **See ad on page 96**
Bullen OH
Cerlase France
Elan Technology GA
Ivoclar Vivadent Inc Principality of Liechtensteinen
Petro Mold Company PA
PremaTech Advanced Ceramics MA
Schott North America Inc NY
Specialty Glass Inc FL
StudioLX - Home Decor IL
TevTech LLC MA **See ad on page 89**
Texers Technical Ceramics Inc Canada
Valley Design Corp MA
Xiamen Innovacera Advanced Materials Co Ltd China

Glass-to-Metal Seals
Bekeson Glass LLC MS **See ad on page 96**
Elan Technology GA
ESL ElectroScience PA
RISE Research Institutes of Sweden RISE Glass Sweden
Schott North America Inc NY
Specialty Glass Inc FL

Laboratory & Technical Glass
Arkema Inc PA
Garg Process Glass India Pvt Ltd India
LECO Corp MI
RISE Research Institutes of Sweden RISE Glass Sweden
Saxon Glass Technologies Inc NY
Schott North America Inc NY
Specialty Glass Inc FL
TevTech LLC MA **See ad on page 89**

Laminated Glass
Arkema Inc PA
RISE Research Institutes of Sweden RISE Glass Sweden
Vesuvius SC

Laser Glasses
Cerinnov France
Israel Ceramic & Silicate Inst Israel
RISE Research Institutes of Sweden RISE Glass Sweden

Lenses
TevTech LLC MA **See ad on page 89**

Lighting
Osram Sylvania Inc MA

Manufacturing
Bekeson Glass LLC MS **See ad on page 96**

Mirrors
Valley Design Corp MA

Optical & Optoelectronic Ceramics
NEVZ-Ceramics Close JSC Russia
Specialty Glass Inc FL
TevTech LLC MA **See ad on page 89**
Vesuvius SC

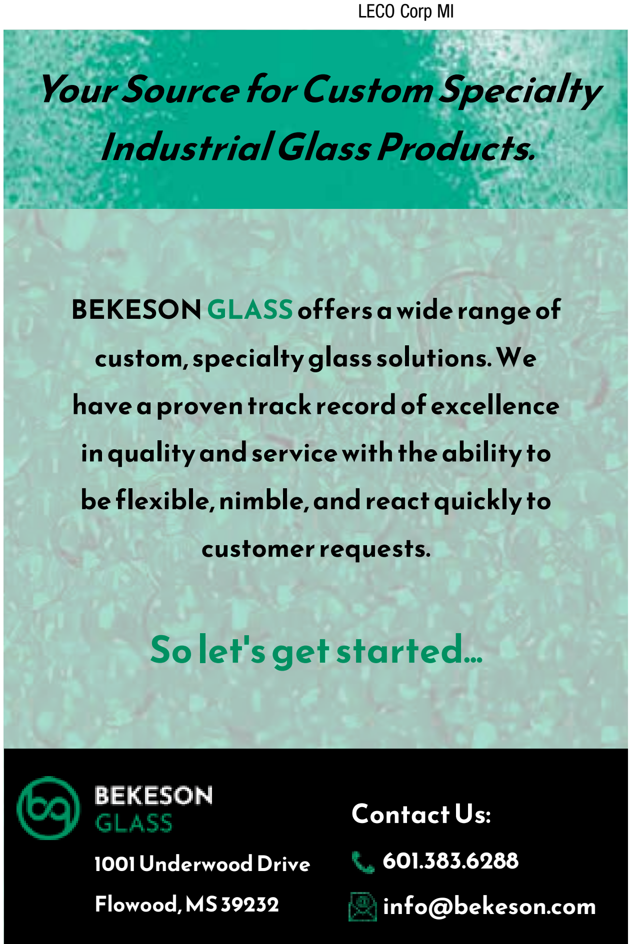
Optical Substrates
Bullen OH
FELDCO Intl CA
Schott North America Inc NY
Specialty Glass Inc FL
Valley Design Corp MA
Vesuvius SC

Optical Thin Films
FELDCO Intl CA
Schott North America Inc NY
TevTech LLC MA **See ad on page 89**

Solar
Ceradyne Inc a 3M Co KY
FELDCO Intl CA
TevTech LLC MA **See ad on page 89**
Texers Technical Ceramics Inc Canada
Vesuvius SC

Specialty Glass


Bekeson Glass LLC MS **See ad on page 96**
Ceradyne Inc a 3M Co KY
Corning Incorporated NY **Inside back cover**
Fusion Ceramics Inc OH
Garg Process Glass India Pvt Ltd India
Israel Ceramic & Silicate Inst Israel
Keeling & Walker Ltd UK
Refrac Systems AZ
RISE Research Institutes of Sweden RISE Glass Sweden
Saint-Gobain Recherche France
Saxon Glass Technologies Inc NY
Schott North America Inc NY



Specialty Glass Inc FL
Vesuvius SC

Technical Glass

Bekeson Glass LLC MS — **See ad on page 96**
Ceradyne Inc a 3M Co KY
Elan Technology GA
RISE Research Institutes of Sweden RISE Glass Sweden
Saxon Glass Technologies Inc NY
Schott North America Inc NY

Specialty Glass Inc FL
Vesuvius SC

Tubing & Rod

AdValue Technology LLC AZ — **See ad on page 51**
Garg Process Glass India Pvt Ltd India
Morgan Advanced Materials CA
Specialty Glass Inc FL

■ LABORATORY EQUIPMENT & SUPPLIES

Chemicals

Arkema Inc PA
Bayville Chemical Supply Co Inc NY
Lubrizol Performance Coating OH
Nanofilm OH
RocCera LLC NY

Colorimeters

HunterLab VA

Density Measurement Instruments

Hitachi High-Tech America Inc MD
Micromeritics Instrument Corp GA
Particle Technology Labs IL
Penn Tool Co NJ
Quantachrome Instruments FL
RocCera LLC NY

Detectors

Control Instruments Corp NJ
Penn Tool Co NJ
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA

Dimension Measurement Instruments

CSC Force Measurement Inc MA
Penn Tool Co NJ

Dryers

Applied Test Systems Inc PA
B&P Littleford MI
Ceramic Services Inc PA
Cober Muegge LLC CT
Detroit Process Machinery MI
EIRICH Machines Inc IL
Goceram AB Sweden
Recco Furnaces CA
Wyssmont Co NJ

Fiberoptic Illuminators

Carl Zeiss MircoImaging Inc NY

Glass Testing Instruments

Mo-Sci Corp MO — **See ad on page 95**
RISE Research Institutes of Sweden RISE Glass Sweden
Taber Industries NY

Glassware

AdValue Technology LLC AZ — **See ad on page 51**
Garg Process Glass India Pvt Ltd India
RISE Research Institutes of Sweden RISE Glass Sweden

Glossimeters

Horiba Instruments Inc CA

Hardness Measurement Instruments

Allied High Tech Products Inc CA
Buehler Ltd IL
Carl Zeiss MircoImaging Inc NY
LECO Corp MI
Nanoscience Instruments AZ
Penn Tool Co NJ
Taber Industries NY

Hot Plates

RocCera LLC NY
Zhengzhou Mission Ceramic Products Co Ltd China

Lab Crucibles

AdValue Technology LLC AZ — **See ad on page 51**
Ceramco Inc NH
CoorsTek CO
Materion Ceramics AZ
McDanel Advanced Ceramic Technologies LLC PA
Robocasting Enterprises LLC NM
Xiamen Innovacera Advanced Materials Co Ltd China
Zhengzhou Mission Ceramic Products Co Ltd China

Lab Furnace Tubes

AdValue Technology LLC AZ — **See ad on page 51**
Carbolite Gero UK
McDanel Advanced Ceramic Technologies LLC PA
Nabertherm Inc DE
Xiamen Innovacera Advanced Materials Co Ltd China
Zhengzhou Mission Ceramic Products Co Ltd China

Lab Furnaces

Aadvanced Machinery Inc MI
American Isostatic Presses OH
Applied Test Systems Inc PA
AVS Inc MA
Carbolite Gero UK

Centorr Vacuum Industries NH
Ceramic Services Inc PA
CM Furnaces Inc NJ
CSC Force Measurement Inc MA
Deltech Inc (Deltech Furnaces) CO — **Inside front cover**
Detroit Process Machinery MI
L&L Special Furnace Co Inc PA — **See ad on page 87**
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Oxy-Gon Industries Inc NH — **See ad on page 85**
Paragon Industries LP TX
RD Webb Company Inc MA

TevTech LLC MA — **See ad on page 89**
The Furnace Source LLC CT
Thermcraft Inc NC
Trent Inc PA
Verder Scientific Inc PA — **See ad on page 87**
Zhengzhou Mission Ceramic Products Co Ltd China

Light Sources

Allied High Tech Products Inc CA
Carl Zeiss MircoImaging Inc NY
Spectronics Corp NY

Mechanical Property Measurement Instruments

Applied Test Systems Inc PA
Buehler Ltd IL
BuzzMac Intl LLC ME
CSC Force Measurement Inc MA
Nanoscience Instruments AZ
TA Instruments DE
Taber Industries NY

Microscopes, Hot Stages

Carl Zeiss MircoImaging Inc NY
Dalmia Inst of Scientific & Industrial Research India
TA Instruments DE

Microscopes, Interference

Buehler Ltd IL
Carl Zeiss MircoImaging Inc NY

Microscopes, Other

AdValue Technology LLC AZ — **See ad on page 51**
Allied High Tech Products Inc CA
Carl Zeiss MircoImaging Inc NY
Nanoscience InstrumentsAZ
TA Instruments DE

Microscopes, Polarizing

Buehler Ltd IL
Carl Zeiss MircoImaging Inc NY
JTF Microscopy Services LLC NY

Microscopes, Reflected Light

Allied High Tech Products Inc CA
Buehler Ltd IL
Carl Zeiss MircoImaging Inc NY
LECO Corp MI

Microscopes, Scanning Electron

Hitachi High-Tech America Inc MD
Nanoscience Instruments AZ
SEMTech Solutions Inc MA

Microscopes, Transmission Electron

Hitachi High-Tech America Inc MD
Horiba Instruments Inc CA

Mills, Laboratory
Advanced Ceramics Manufacturing AZ
Custom Processing Services PA
Detroit Process Machinery MI
Fluid Energy Processing & Equipment Co PA
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Ivoclar Vivadent Inc Principality of Liechtensteinen
MSE Supplies AZ
Stedman Machine Co IN
Union Process OH

Mixers, Laboratory
B&P Littleford MI
Custom Processing Services PA
Detroit Process Machinery MI
EIRICH Machines Inc IL
Fritsch GmbH - Milling and Sizing Germany
Lancaster Products PA
Peter Pugger Mfg Inc CA
Ram Products Inc OH
Verder Scientific Inc PA **See ad on page 87**

Moisture Testing
LECO Corp MI
Micromeritics Instrument Corp GA

Optical Comparitors
Penn Tool Co NJ

Optical Property Measurement Instruments
Fritsch GmbH - Milling and Sizing Germany

pH Meters
Horiba Instruments Inc CA
Mettler-Toledo Inc OH
Ocean Optics Inc FL

Porosimeters
Micromeritics Instrument Corp GA
Particle Technology Labs IL
Quantachrome Instruments FL

Powders Samplers
Fritsch Milling & Sizing Inc NC
Quantachrome Instruments FL

Recorders
CSC Force Measurement Inc MA
Datapaq Inc NH
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA

Rheometers
Particle Technology Labs IL
TA InstrumentsDE

Sample Preparation Equipment
Allied High Tech Products Inc CA
Buehler Ltd IL
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Micromeritics Instrument Corp GA
Ram Products Inc OH

Verder Scientific Inc PA **See ad on page 87**

Thermometers
Optocon AG Germany
Penn Tool Co NJ
Xiamen Innovacera Advanced Materials Co Ltd China

Viscosity Measurement Instruments
Carl Zeiss MircoImaging Inc NY
Norcross Viscosity Controls MI
RISE Research Institutes of Sweden RISE Glass Sweden
Rockwell Automation Inc WI
TA Instruments DE

Visual Inspection Instruments
Buehler Ltd IL
Haiku Tech Inc FL
Penn Tool Co NJ
Taber Industries NY

Weighing/Scales
CSC Force Measurement Inc MA
Mettler-Toledo Inc OH
Penn Tool Co NJ
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA

LABORATORY SERVICES

Atomic Adsorption
Spectrochemical Laboratories PA

Auger Analysis
Evans Analytical Group LLC CA
High Temperature Materials Lab TN
Micron Inc DE

Chemical Analysis
Activation Laboratories Ltd Canada
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
Dalmia Inst of Scientific & Industrial Research India
Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
Geller Microanalytical Laboratory Inc MA
H&M Analytical Services Inc NJ
Hindalco Industries Limited India
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Lucideon UK
NSL Analytical Services Inc OH
RISE Research Institutes of Sweden RISE Glass Sweden
Setaram Instrumentation France
Technology of Materials CA
Washington Mills Electro Minerals Co NY

Clay Testing
Activation Laboratories Ltd Canada
Edward Orton Jr Ceramic Foundation OH
Imerys GA
Laguna Clay Co CA
Technology of Materials CA

Composition
Activation Laboratories Ltd Canada
Alfred University NY **See ad on page 40**
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
Dalmia Inst of Scientific & Industrial Research India
Edward Orton Jr Ceramic Foundation OH
Japan Fine Ceramics Center Japan
P-Ker Engineering NY
Rauschert Industries Inc GA
Viridis3D LLC MA

Corrosion Testing
Activation Laboratories Ltd Canada
All Waste Matters UK
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
Dalmia Inst of Scientific & Industrial Research India
Edward Orton Jr Ceramic Foundation OH
P-Ker Engineering NY
SEMTech Solutions Inc MA

Density Determination
Activation Laboratories Ltd Canada
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
Cyclonaire Corp NE
Edward Orton Jr Ceramic Foundation OH
GrainBound LLC PA
Hindalco Industries Limited India
Hysitron Inc MN
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Micromeritics Instrument Corp GA
NSL Analytical Services Inc OH
Particle Technology Labs IL
Quantachrome Instruments FL

Differential Thermal Analysis

Activation Laboratories Ltd Canada
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
High Temperature Materials Lab TN
Hindalco Industries Limited India
Japan Fine Ceramics Center Japan
Micron Inc DE
Netzsch Instruments NA LLC MA **See ad on page 109**
RISE Research Institutes of Sweden RISE Glass Sweden
Setaram Instrumentation France
TA Instruments DE
Technology of Materials CA

Electron Microprobe Analysis

Activation Laboratories Ltd Canada
GrainBound LLC PA
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
Micron Inc DE
Rensselaer Polytechnic Inst NY
Technology of Materials CA

Failure Analysis

CHEMIR - A Division of Evans Analytical Group MO
CMC Laboratories Inc AZ
CoorsTek CO
Edward Orton Jr Ceramic Foundation OH
Geller Microanalytical Laboratory Inc MA
H&M Analytical Services Inc NJ
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
JTF Microscopy Services LLC NY
Micron Inc DE
NSL Analytical Services Inc OH
Rensselaer Polytechnic Inst NY
RISE Research Institutes of Sweden RISE Glass Sweden
SEMTech Solutions Inc MA
Technology of Materials CA

Fracture Analysis

CHEMIR - A Division of Evans Analytical Group MO
CoorsTek CO
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
JTF Microscopy Services LLC NY
Micron Inc DE
NSL Analytical Services Inc OH
Rensselaer Polytechnic Inst NY
RISE Research Institutes of Sweden RISE Glass Sweden
SEMTech Solutions Inc MA
Spectrochemical Laboratories PA

Materials Analysis

Activation Laboratories Ltd Canada
Alfred University NY **See ad on page 40**
CHEMIR - A Division of Evans Analytical Group MO
CSC Force Measurement Inc MA

Edward Orton Jr Ceramic Foundation OH
Elan Technology GA
Evans Analytical Group LLC CA
Geller Microanalytical Laboratory Inc MA
GrainBound LLC PA
H&M Analytical Services Inc NJ
Harper International NY **See ad on page 77**

Harrop Industries Inc OH **See ad on page 58**
High Temperature Materials Lab TN
Hysitron Inc MN
Japan Fine Ceramics Center Japan
Jenike & Johanson Inc MA
JTF Microscopy Services LLC NY
Micromeritics Instrument Corp GA
Micron Inc DE
Monofrax LLC NY
NSL Analytical Services Inc OH
Particle Technology Labs IL
RISE Research Institutes of Sweden RISE Glass Sweden
SEMTech Solutions Inc MA
Setaram Instrumentation France
Spectrochemical Laboratories PA
Technology of Materials CA
Washington Mills Electro Minerals Co NY

Mechanical Properties

Activation Laboratories Ltd Canada
Advanced Ceramics Manufacturing AZ
Alfred University NY **See ad on page 40**
BuzzMac Intl LLC ME
CHEMIR - A Division of Evans Analytical Group MO
CSC Force Measurement Inc MA
Edward Orton Jr Ceramic Foundation OH
High Temperature Materials Lab TN
Hysitron Inc MN
Japan Fine Ceramics Center Japan
TA Instruments DE
Taber Industries NY

Nondestructive Testing

SEMTech Solutions Inc MA
Activation Laboratories Ltd Canada
CHEMIR - A Division of Evans Analytical Group MO
Rensselaer Polytechnic Inst NY

Particle-Size Analysis

Activation Laboratories Ltd Canada
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
Custom Processing Services PA
Cyclonaire Corp NE
Geller Microanalytical Laboratory Inc MA
H&M Analytical Services Inc NJ
Harper International NY **See ad on page 77**
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Micromeritics Instrument Corp GA
Micron Inc DE
NSL Analytical Services Inc OH
Particle Technology Labs IL
P-Ker Engineering NY
SEMTech Solutions Inc MA
Technology Assessment and Transfer Inc (TA&T) MD
Technology of Materials CA
Washington Mills Electro Minerals Co NY

Pore Structure Analysis

GrainBound LLC PA
Japan Fine Ceramics Center Japan
Micromeritics Instrument Corp GA
Particle Technology Labs IL
P-Ker Engineering NY
Quantachrome Instruments FL
SEMTech Solutions Inc MA

Residual Stress Analysis

American Stress Technologies Inc PA
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
RISE Research Institutes of Sweden RISE Glass Sweden
TA Instruments DE

Scanning Electron Microscopy

Activation Laboratories Ltd Canada
Alfred University NY **See ad on page 40**
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
CoorsTek CO
Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
GrainBound LLC PA
H&M Analytical Services Inc NJ
High Temperature Materials Lab TN
Hindalco Industries Limited India
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
JTF Microscopy Services LLC NY
Micron Inc DE
NSL Analytical Services Inc OH
Particle Technology Labs IL
SEMTech Solutions Inc MA
Technology of Materials CA
Washington Mills Electro Minerals Co NY

Spectroscopy

Activation Laboratories Ltd Canada
CHEMIR - A Division of Evans Analytical Group MO
CoorsTek CO
Evans Analytical Group LLC CA
GrainBound LLC PA
Japan Fine Ceramics Center Japan
Micron Inc DE
NSL Analytical Services Inc OH
Spectrochemical Laboratories PA

Surface-Area Analysis

AVEKA MN
Harper International NY **See ad on page 77**
Hindalco Industries Limited India
Japan Fine Ceramics Center Japan
Micromeritics Instrument Corp GA
NSL Analytical Services Inc OH
Particle Technology Labs IL
Quantachrome Instruments FL
RISE Research Institutes of Sweden RISE Glass Sweden
SEMTech Solutions Inc MA
Technology Assessment and Transfer Inc (TA&T) MD

Thermal Analysis

Activation Laboratories Ltd Canada
Alfred University NY **See ad on page 40**
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
Datapaq Inc NH

Edward Orton Jr Ceramic Foundation OH

Evans Analytical Group LLC CA
Harper International NY — See ad on page 77

Harrop Industries Inc OH — See ad on page 58
High Temperature Materials Lab TN
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Mettler-Toledo Inc OH
Micron Inc DE
Netzsch Instruments NA LLC MA — See ad on page 109
Particle Technology Labs IL
P-Ker Engineering NY
Setaram Instrumentation France
TA Instruments DE
Technology Assessment and Transfer Inc (TA&T) MD

Transmission Electron Microscopy
Evans Analytical Group LLC CA
GrainBound LLC PA
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
Micron Inc DE
NSL Analytical Services Inc OH

Tribological Studies
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
Micron Inc DE
Taber Industries NY

X-Ray Diffraction
Activation Laboratories Ltd Canada
Alfred University NY — See ad on page 40
American Stress Technologies Inc PA
CHEMIR - A Division of Evans Analytical Group MO
Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
GrainBound LLC PA
H&M Analytical Services Inc NJ
High Temperature Materials Lab TN
Hindalco Industries Limited India
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Micron Inc DE
NSL Analytical Services Inc OH
Technology of Materials CA
Washington Mills Electro Minerals Co NY

X-Ray Fluorescence
CHEMIR - A Division of Evans Analytical Group MO
Euro Support Advanced Materials The Netherlands
H&M Analytical Services Inc NJ
Spectrochemical Laboratories PA

Markets
Matmatch Germany

■ MATERIALS PREPARATION, HANDLING & PACKAGING

Agglomerators
Applicon Co IN
B&P Littleford MI
Lancaster Products PA

Bagging Equipment
Applicon Co IN
Cyclonaire Corp NE
Ingredient Masters Inc OH — See ad on page 101
Lancaster Products PA
Nol-Tec Systems Inc MN

Barcode Labels
Rockwell Automation Inc WI

Batching Equipment
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
General Glass Equipment Co NJ

Ingredient Masters Inc OH — See ad on page 101
Laguna Clay Co CA
Lancaster Products PA
Mohr Corp MI — See ad on page 79
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA
Young Industries Inc PA

Batching Plants & Systems
Applicon Co IN
Cyclonaire Corp NE
EIRICH Machines Inc IL

Ingredient Masters Inc OH — See ad on page 101
Lancaster Products PA
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA

Belts, Elevator
Carolina Material Technologies NC
Optimation - Klug Systems NY

Bin Activators
Carolina Material Technologies NC
Optimation - Klug Systems NY

Bin Dischargers
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY

Bins, Storage
Ingredient Masters Inc OH — See ad on page 101
Jenike & Johanson Inc MA
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY
Penn Tool Co NJ
Tempo Plastic CA

Blenders
Aadvanced Machinery Inc MI
Applicon Co IN
B&P Littleford MI
Cyclonaire Corp NE
Detroit Process Machinery MI
EIRICH Machines Inc IL
Gasbarre Products Inc PA — See ad on page 93
Glen Mills Inc NJ — See ad on page 103
Laguna Clay Co CA
Lancaster Products PA
Mohr Corp MI — See ad on page 79
Netzsch Premier Technologies LLC PA
Nol-Tec Systems Inc MN
Young Industries Inc PA

Briquetting & Tableting Equipment
Aadvanced Machinery Inc MI
Applicon Co IN
Mohr Corp MI — See ad on page 79

Buckets, Elevator
Optimation - Klug Systems NY

Classifiers
Applicon Co IN
AVEKA MN
Fluid Energy Processing & Equipment Co PA
Netzsch Premier Technologies LLC PA
Raymond Bartlett Snow-Schneck Processing IL
Young Industries Inc PA

Conveyors
Basic Machinery Co Inc NC
Carolina Material Technologies NC
General Glass Equipment Co NJ
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA
Velco GmbH Germany
Young Industries Inc PA

Conveyors, Belt
Applicon Co IN
Carolina Material Technologies NC
Ingredient Masters Inc OH — See ad on page 101
Mixer Systems Inc WI

Conveyors, Bucket
Applicon Co IN
Ingredient Masters Inc OH — See ad on page 101

Conveyors, Pneumatic
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE

Ingredient Masters Inc OH **See ad on page 101**
Nol-Tec Systems Inc MN
Velco GmbH Germany

Conveyors, Screw
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
Ingredient Masters Inc OH **See ad on page 101**
Mixer Systems Inc WI

Conveyors, Vibrating
Applicon Co IN
Carolina Material Technologies NC
Cleveland Vibrator Co OH

Crushers
Aadvanced Machinery Inc MI
AVEKA MN
Basic Machinery Co Inc NC
Detroit Process Machinery MI
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on page 103**
Lancaster Products PA
Mohr Corp MI **See ad on page 79**
Optimation - Klug Systems NY
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Crushers, Hammermill
AVEKA MN
Glen Mills Inc NJ **See ad on page 103**
Mixer Systems Inc WI
Stedman Machine Co IN
Verder Scientific Inc PA **See ad on page 87**
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Crushers, Impact
Applicon Co IN
Glen Mills Inc NJ **See ad on page 103**
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Crushers, Jaw
Applicon Co IN
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on page 103**
Verder Scientific Inc PA **See ad on page 87**

Crushers, Primary
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO

Crushers, Roll
Applicon Co IN
Lancaster Products PA
Williams Patent Crusher & Pulverizer Co Inc MO

Cullet-Handling Equipment
Applicon Co IN
General Glass Equipment Co NJ
Optimation - Klug Systems NY

Drum Tumblers
Glen Mills Inc NJ **See ad on page 103**

Dryers, Fluid Bed
Applicon Co IN
AVEKA MN
Williams Patent Crusher & Pulverizer Co Inc MO

Dryers, Rotating Tray
Raymond Bartlett Snow-Schneck Processing IL
Wyssmont Co NJ

Dust Collectors
Cyclonaire Corp NE
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY
RoboVent MI

Dust Control Equipment
Carolina Material Technologies NC
Mixer Systems Inc WI
Optimation - Klug Systems NY
Penn Tool Co NJ
RoboVent MI
Young Industries Inc PA

Edge Protectors
Tempo Plastic CA

Electric Screen Heating
Midwestern Industries Inc OH

Environmental/Waste Treatment Equipment
Carolina Material Technologies NC
Cober Muegge LLC CT
Control Instruments Corp NJ
Fritsch GmbH - Milling and Sizing Germany
Mixer Systems Inc WI
OPF Enterprises TX
Oxy-Gon Industries Inc NH **See ad on page 85**
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA
Young Industries Inc PA

Feeders
Basic Machinery Co Inc NC
Carolina Material Technologies NC
Cleveland Vibrator Co OH
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
General Glass Equipment Co NJ
Jenike & Johanson Inc MA
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY
Young Industries Inc PA

Feeders, Batch
Applicon Co IN
Carolina Material Technologies NC
Ingredient Masters Inc OH **See ad on page 101**
Merkle International Inc IL
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
Siemens Process Industries and Drives GA

Feeders, Gravimetric
Applicon Co IN
Carolina Material Technologies NC

Feeders, Pneumatic
Carolina Material Technologies NC
Cyclonaire Corp NE
Nol-Tec Systems Inc MN

Filters
Texers Technical Ceramics Inc Canada

Granulators
Aadvanced Machinery Inc MI
Applicon Co IN
B&P Littleford MI
Fritsch GmbH - Milling and Sizing Germany
Mohr Corp MI **See ad on page 79**
Netzsch Premier Technologies LLC PA
Wyssmont Co NJ

Grinders
Buehler Ltd IL
Diamond Industrial Tools Inc IL
Fluid Energy Processing & Equipment Co PA
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on page 103**
Mohr Corp MI **See ad on page 79**
Netzsch Premier Technologies LLC PA
Stedman Machine Co IN
Verder Scientific Inc PA **See ad on page 87**
Wyssmont Co NJ

Grinding Media
CerCo LLC OH
CoorsTek CO
Dunhua Zhengxing Abrasive Co Ltd China
ER Advanced Ceramics Inc OH
Federal-Mogul MI
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on page 103**
Jyoti Ceramic Industries Pvt Ltd India
MSE Supplies AZ
Netzsch Premier Technologies LLC PA
Texers Technical Ceramics Inc Canada
Union Process OH
Verder Scientific Inc PA **See ad on page 87**
Zibo Guangtong Chemical Co Ltd China
Zircoa Inc OH

Grinding Mills, Vibratory
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC

Gunning Equipment, Refractory
Reed Gunite & Shotcrete Equipment CA
Velco GmbH Germany

Hoppers
Basic Machinery Co Inc NC
Carolina Material Technologies NC
Ingredient Masters Inc OH **See ad on page 101**
Jenike & Johanson Inc MA
Mixer Systems Inc WI
Optimation - Klug Systems NY
Reed Gunite & Shotcrete Equipment CA

Hydraulic Systems
Basic Machinery Co Inc NC
Ram Products Inc OH

Impeller, Mixing
Lancaster Products PA
Mixer Systems Inc WI

Materials Handling Equipment
Basic Machinery Co Inc NC
Carolina Material Technologies NC
Cyclonaire Corp NE
Gasbarre Products Inc PA **See ad on page 93**
Lancaster Products PA
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
North Star Equipment Inc WA
Optimation - Klug Systems NY
Penn Tool Co NJ
Reed Gunite & Shotcrete Equipment CA
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA
Tempo Plastic CA
Young Industries Inc PA

Mill Linings
CerCo LLC OH
ER Advanced Ceramics Inc OH
Jyoti Ceramic Industries Pvt Ltd India

Mills
Custom Processing Services PA
ER Advanced Ceramics Inc OH
Euro Support Advanced Materials The Netherlands
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on page 103**
Hockmeyer Equipment Corp NC
Netzsch Premier Technologies LLC PA
Raymond Bartlett Snow-Schneck Processing IL
Stedman Machine Co IN
Union Process OH

Mills, Attritor
Aadvanced Machinery Inc MI
Custom Processing Services PA
Detroit Process Machinery MI
Glen Mills Inc NJ **See ad on page 103**
Netzsch Premier Technologies LLC PA
Union Process OH
Wyssmont Co NJ

Mills, Ball & Pebble
Aadvanced Machinery Inc MI
Advanced Ceramics Manufacturing AZ
Detroit Process Machinery MI
ER Advanced Ceramics Inc OH
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on page 103**
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Mohr Corp MI **See ad on page 79**
MSE Supplies AZ
Netzsch Premier Technologies LLC PA
Raymond Bartlett Snow-Schneck Processing IL
Union Process OH

Mills, Centrifugal
Fritsch GmbH - Milling and Sizing Germany
Glen Mills Inc NJ **See ad on page 103**
Verder Scientific Inc PA **See ad on page 87**

Mills, Hammer
AVEKA MN
Glen Mills Inc NJ **See ad on page 103**
Stedman Machine Co IN
Verder Scientific Inc PA **See ad on page 87**
Williams Patent Crusher & Pulverizer Co Inc MO

Mills, Jar
Detroit Process Machinery MI
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC

Mills, Jet
AVEKA MN
Fluid Energy Processing & Equipment Co PA
Netzsch Premier Technologies LLC PA

Mills, Planetary
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Hockmeyer Equipment Corp NC
MSE Supplies AZ
Verder Scientific Inc PA **See ad on page 87**

Mills, Rod
Wyssmont Co NJ

Mills, Roll
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
MSE Supplies AZ
Raymond Bartlett Snow-Schneck Processing IL
Williams Patent Crusher & Pulverizer Co Inc MO

Mills, Vibratory
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC

Mining & Beneficiation Equipment
Netzsch Premier Technologies LLC PA
Reed Gunite & Shotcrete Equipment CA
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA

Mixers, Batch
Carolina Material Technologies NC
Custom Processing Services PA
EIRICH Machines Inc IL

Glen Mills Inc NJ **See ad on page 103**
Goceram AB Sweden
Lancaster Products PA
Mixer Systems Inc WI
Mohr Corp MI **See ad on page 79**
Netzsch Premier Technologies LLC PA
Nol-Tec Systems Inc MN
OPF Enterprises TX
Optimation - Klug Systems NY
Peter Pugger Mfg Inc CA

Mixers, Drum
Glen Mills Inc NJ **See ad on page 103**
Hockmeyer Equipment Corp NC

Mixers, Pneumatic
Carolina Material Technologies NC
EIRICH Machines Inc IL
Nol-Tec Systems Inc MN

Mixers, Portable
Jiffy Mixer Co Inc CA
Mixer Systems Inc WI
Peter Pugger Mfg Inc CA

Mixers, Refractory
Applicon Co IN
B&P Littleford MI
EIRICH Machines Inc IL

EZG Manufacturing Inc OH
Laeis GmbH Luxembourg
Lancaster Products PA
Mixer Systems Inc WI
Netzsch Premier Technologies LLC PA
Peter Pugger Mfg Inc CA
Reed Gunite & Shotcrete Equipment CA

Mixers, Vacuum

Applicon Co IN
EIRICH Machines Inc IL
Netzsch Premier Technologies LLC PA
Peter Pugger Mfg Inc CA

Mixing Equipment

Aadvanced Machinery Inc MI
B&P Littleford MI
Carolina Material Technologies NC
Custom Processing Services PA
Detroit Process Machinery MI
EIRICH Machines Inc IL
ER Advanced Ceramics Inc OH
General Glass Equipment Co NJ

Glen Mills Inc NJ **See ad on page 103**
Goceram AB Sweden
Hockmeyer Equipment Corp NC
Laguna Clay Co CA
Lancaster Products PA
Mixer Systems Inc WI
Mohr Corp MI **See ad on page 79**
Netzsch Premier Technologies LLC PA
OPF Enterprises TX
Peter Pugger Mfg Inc CA
Resodyn Acoustic Mixers Inc MT
Young Industries Inc PA

Nozzles

CerCo LLC OH
Dunhua Zhengxing Abrasive Co Ltd China
Maryland Ceramic & Steatite Co Inc MD

Packaging

Tempo Plastic CA

Packaging Equipment

Basic Machinery Co Inc NC

Pneumatic Systems

Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
Nol-Tec Systems Inc MN
Reed Gunite & Shotcrete Equipment CA
Velco GmbH Germany
Young Industries Inc PA

Process Control Equipment

Control Instruments Corp NJ
Datapaq Inc NH
General Glass Equipment Co NJ
Ingredient Masters Inc OH **See ad on page 101**
Nol-Tec Systems Inc MN
Norcross Viscosity Controls MI
Optimation - Klug Systems NY
Ram Products Inc OH
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA

Pulverizers

Aadvanced Machinery Inc MI
Applicon Co IN
Basic Machinery Co Inc NC
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on page 103**
Mixer Systems Inc WI
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Pumps

ER Advanced Ceramics Inc OH
Ram Products Inc OH
Reed Gunite & Shotcrete Equipment CA

Pumps, Concrete

Reed Gunite & Shotcrete Equipment CA

Scale Systems

CSC Force Measurement Inc MA
Mettler-Toledo Inc OH
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY

Screens & Screening Equipment

Aadvanced Machinery Inc MI
Basic Machinery Co Inc NC
Cleveland Vibrator Co OH
Control Instruments Corp NJ
Detroit Process Machinery MI
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on page 103**
Midwestern Industries Inc OH
Mohr Corp MI **See ad on page 79**
Sicco Engineering Works India

Separators

Fritsch GmbH - Milling and Sizing Germany
Midwestern Industries Inc OH
Williams Patent Crusher & Pulverizer Co Inc MO

Shredders

Basic Machinery Co Inc NC
Fritsch GmbH - Milling and Sizing Germany
Glen Mills Inc NJ **See ad on page 103**
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO

Single-Wafer Packs

Tempo Plastic CA

Size Reduction Equipment

AVEKA MN
Basic Machinery Co Inc NC
Custom Processing Services PA
EIRICH Machines Inc IL
ER Advanced Ceramics Inc OH
Fluid Energy Processing & Equipment Co PA
Fritsch GmbH - Milling and Sizing Germany
Glen Mills Inc NJ **See ad on page 103**
Lancaster Products PA
Netzsch Premier Technologies LLC PA
Raymond Bartlett Snow-Schneck Processing IL
Stedman Machine Co IN
Union Process OH
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Spray Dryers
Aadvanced Machinery Inc MI
Arch Maintenance Services GA
AVEKA MN
Detroit Process Machinery MI
Dorst America Inc PA
Elan Technology GA
Euro Support Advanced Materials The Netherlands
Mohr Corp MI **See ad on page 79**
Spray Drying Systems Inc MD

Storage Equipment
Basic Machinery Co Inc NC

Storage Equipment
Cyclonaire Corp NE

Substrate Wafer Trays
Tempo Plastic CA

Used Equipment
Aadvanced Machinery Inc MI
American Isostatic Presses OH
Detroit Process Machinery MI
Dorst America Inc PA

Mohr Corp MI **See ad on page 79**
Reed Gunite & Shotcrete Equipment CA

Vacuum Cleaning Systems
Carolina Material Technologies NC

Ventilating Equipment
American Art Clay Co Inc IN

Vibrators
Carolina Material Technologies NC
Cleveland Vibrator Co OH
Optimation - Klug Systems NY
Rockwell Automation Inc WI

Vibrators, Bin
Carolina Material Technologies NC
Cleveland Vibrator Co OH
Cyclonaire Corp NE

Weighing Equipment
Carolina Material Technologies NC
CSC Force Measurement Inc MA
Cyclonaire Corp NE
Mettler-Toledo Inc OH
Nol-Tec Systems Inc MN
Optimation - Klug Systems NY
Rockwell Automation IncWI
Siemens Process Industries and Drives GA

Weighing/Scales
Optimation - Klug Systems NY

Wire Cloth
Midwestern Industries Inc OH

PLANT CONSTRUCTION, DESIGN & ENGINEERING

Brick Production
Basic Machinery Co Inc NC
Laeis GmbH Luxembourg
Swindell Dressler Intl Co PA

Casting Plants
Dorst America Inc PA
ER Advanced Ceramics Inc OH

Ceramic Production
Cerinnov France
Cerlase France
GrainBound LLC PA
Lucideon UK
Maryland Ceramic & Steatite Co Inc MD
Riedhammer GmbH Germany
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**
Viridis3D LLC MA

Combustion Systems
Air Products PA
Swindell Dressler Intl Co PA

Decals & Decorating
Cerinnov France
Cerlase France
Gwent Electronic Materials Ltd UK

Drying & Firing
Basic Machinery Co Inc NC
Ceramic Services Inc PA

Harrop Industries Inc OH **See ad on page 58**
Swindell Dressler Intl Co PA
Wistra GmbH Germany

Electronic Materials Production
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**

Environmental Control
Cyclonaire Corp NE
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
RoboVent MI
Rockwell Automation Inc WI
Saint-Gobain NorPro OH
Tri-Mer Corp MI

Fabrication Shops
Maryland Ceramic & Steatite Co Inc MD

Glass Production
CelSian Glass & Solar BV The Netherlands
General Glass Equipment Co NJ
Optimation - Klug Systems NY
RISE Research Institutes of Sweden RISE Glass Sweden
Schott North America Inc NY
Tri-Mer Corp MI

Inspection Systems
CSC Force Measurement Inc MA
Fosbel Inc OH
Rockwell Automation Inc WI
Siemens Process Industries and Drives GA

Laboratories
Activation Laboratories Ltd Canada

Optical-Fiber Production
Ocean Optics Inc FL

Refractory Production
ER Advanced Ceramics Inc OH
Fosbel Inc OH
Laeis GmbH Luxembourg
Laguna Clay Co CA
Swindell Dressler Intl Co PA

Structural Ceramics Production
CerCo LLC OH
Maryland Ceramic & Steatite Co Inc MD
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
TevTech LLC MA **See ad on page 89**

Tile Production
Laeis GmbH Luxembourg
LIXIL Corporation Japan
Peter Pugger Mfg Inc CA

Whiteware Production
LIXIL Corporation Japan
Ram Products Inc OH
Swindell Dressler Intl Co PA

PORCELAIN ENAMEL

Appliances
Roca Sanitario SA Spain
Zenith China

Architectural Units
Roca Sanitario SA Spain
Zenith China

Ceramic Coatings, Thermal Protection
Cerinnov France
Cerlase France
Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD **See ad on page 81**
Zenith China

Porcelain
Riedhammer GmbH Germany

REFRACTORIES

Acid
Allied Mineral Products Inc OH
Magneco Metrel Inc IL
Pacific Refractories Ltd India
Vitcas Ltd UK

Aggregate
Christy Minerals LLC MO
Furnace Products & Services Inc PA
Magneco Metrel Inc IL
Maryland Refractories Co OH

Alumina
Advanced Ceramic Technology CA
Allied Mineral Products Inc OH
Associated Ceramics & Technology Inc PA
Astral Material Industrial Co Ltd China
Baikowski Malakoff Inc NC
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Dalmia Inst of Scientific & Industrial Research India
Du-Co Ceramics Company PA
Elcon Precision LLC CA
ER Advanced Ceramics Inc OH
Fosbel Inc OH
General Material Industrial Co China
GrainBound LLC PA
IPS Ceramics LTD UK
Ipsen Ceramics IL
Magneco Metrel Inc IL
Maryland Refractories Co OH
Materion Ceramics AZ
Pacific Refractories Ltd India
Plibrico Company IL **See ad on page 105**
Precision Ferrites and Ceramics Inc CA
Rath Inc DE
Refractory Minerals Co Inc PA
RHI US Ltd NY
Riverside Refractories Inc–Allied Mineral Products AL
Selee Corp NC
Sunrock Ceramics Co IL
Texers Technical Ceramics Inc Canada
Wistra GmbH Germany
Xiamen Innovacera Advanced Materials Co Ltd China
Zircar Refractory Composites Inc NY

Zircar Zirconia Inc NY

Anchors
Associated Ceramics & Technology Inc PA
Magneco Metrel Inc IL

Arches, Suspended
Fosbel Inc OH
Ipsen Ceramics IL
Merkle International Inc IL

AZS
Bucher Emhart Glass SA Switzerland
Fosbel Inc OH
Magneco Metrel Inc IL
Monofrax LLC NY
RHI US Ltd NY

Backwalls
Fosbel Inc OH
Merkle International Inc IL

Basic
Allied Mineral Products Inc OH
Furnace Products & Services Inc PA
Magneco Metrel Inc IL
RHI US Ltd NY

Blankets
Associated Ceramics & Technology Inc PA
Morgan Thermal Ceramics GA
RHI US Ltd NY
Thermal Products Co Inc GA
Unifrax I LLC NY
Zircar Refractory Composites Inc NY

Boards
Agni Fiber Boards Pvt Ltd India
Morgan Thermal Ceramics GA
RHI US Ltd NY
Saint-Gobain Ceramics & Plastics MA
Thermal Products Co Inc NY
Unifrax I LLC NY

Zircar Ceramics Inc NY
Zircar Refractory Composites Inc NY

Brick
APF Recycling Inc OH
Cancarb Limited Canada
General Material Industrial Co China
HarbisonWalker Intl PA
IFB Insulating Firebrick Inc PA
Morgan Thermal Ceramics GA
Pacific Refractories Ltd India
RHI US Ltd NY
Sunrock Ceramics Co IL
Wistra GmbH Germany

Brick, Acid-Resisting
Pacific Refractories Ltd India
Vitcas Ltd UK

Brick, Fireclay
Allied Mineral Products Inc OH
Alsey Refractories Co MO
Pacific Refractories Ltd India
RHI US Ltd NY
Vitcas Ltd UK

Carbon
Astral Material Industrial Co Ltd China
Cancarb Limited Canada
Pacific Refractories Ltd India
Riedhammer GmbH Germany

Castable
Allied Mineral Products Inc OH
Alsey Refractories Co MO
Aremco Products Inc NY
Cancarb Limited Canada
Capital Refractories Ltd UK
Furnace Products & Services Inc PA

HarbisonWalker Intl PA
Industrial Ceramic Products Inc OH
Magneco Metrel Inc IL
Pacific Refractories Ltd India

Plibrico Company IL **See ad on page 105**
Plibrico Japan Co Ltd Japan
Reno Refractories Inc AL
RHI US Ltd NY
Riverside Refractories Inc–Allied Mineral Products AL
Selee Corp NC
Vitcas Ltd UK
Zircar Refractory Composites Inc NY

Cements
Allied Mineral Products Inc OH
Aremco Products Inc NY
Capital Refractories Ltd UK
Dalmia Inst of Scientific & Industrial Research India
Furnace Products & Services Inc PA

Gorka Cement Poland **See ad on page 71**
Kerneos Inc VA
Plibrico Company IL **See ad on page 105**
Reno Refractories Inc AL
Unifrax I LLC NY
Vitcas Ltd UK

Clay Flux
Furnace Products & Services Inc PA
Peter Pugger Mfg Inc CA
RHI US Ltd NY

Coatings
Allied Mineral Products Inc OH
Aremco Products Inc NY
Elcon Precision LLC CA
Fosbel Inc OH
Furnace Products & Services Inc PA
Fusion Ceramics Inc OH
Gwent Electronic Materials Ltd UK
Induceramic Canada
Magneco Metrel Inc IL
Plibrico Japan Co Ltd Japan
Rath Inc DE
Riverside Refractories Inc--Allied Mineral Products AL
Starfire Systems Inc NY
Thermal Products Co Inc GA
Unifrax I LLC NY
Vitcas Ltd UK
Zibo Guangtong Chemical Co Ltd China
Zircar Refractory Composites Inc NY
ZYP Coatings Inc TN

Cordierite
Advanced Ceramic Technology CA
Akron Porcelain & Plastics Co OH
Astral Material Industrial Co Ltd China

CoorsTek CO
Du-Co Ceramics Company PA
ER Advanced Ceramics Inc OH
Industrial Ceramic Products Inc OH
IPS Ceramics LTD UK
Maryland Refractories Co OH
Rauschert Industries Inc GA
Saint-Gobain Ceramics & Plastics MA

Crucibles
AdValue Technology LLC AZ **See ad on page 51**
Allied Mineral Products Inc OH
APC International Ltd PA
Aremco Products Inc NY
Blasch Precision Ceramics Inc NY
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Furnace Products & Services Inc PA
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
LECO Corp MI
Magneco Metrel Inc IL
Materion Ceramics AZ
McDanel Advanced Ceramic Technologies LLC PA
Progressive Technology Inc CA
Selee Corp NC
Silicon Carbide Products Inc NY
Zhengzhou Mission Ceramic Products Co Ltd China
Zircoa Inc OH

Dead-Burned
Fluid Energy Processing & Equipment Co PA

Fiber Products
Allied Mineral Products Inc OH
Furnace Products & Services Inc PA
LECO Corp MI
Thermal Products Co Inc GA
Unifrax I LLC NY
Vitcas Ltd UK

Zircar Ceramics Inc NY

Filters, Molten Metal
Akron Porcelain & Plastics Co OH
Induceramic Canada
Industrial Ceramic Products Inc OH
Selee Corp NC

Foundry
Allied Mineral Products Inc OH
Blasch Precision Ceramics Inc NY
Capital Refractories Ltd UK
Fosbel Inc OH
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
LECO Corp MI
Magneco Metrel Inc IL
Plibrico Company IL **See ad on page 105**
Riverside Refractories Inc--Allied Mineral Products AL
Selee Corp NC
Silicon Carbide Products Inc NY
Zircar Refractory Composites Inc NY

Fused Cast
Fosbel Inc OH
Furnace Products & Services Inc PA
Monofrax LLC NY
Saint-Gobain Ceramics & Plastics MA

Fused Spinel Refractories
Dalmia Inst of Scientific & Industrial Research India

Glass Furnace
Deltech Inc (Deltech Furnaces) CO **Inside front cover**

Diversified Controls & Systems NY
Fosbel Inc OH
Furnace Products & Services Inc PA
HarbisonWalker Intl PA
Ipsen Ceramics IL
Magneco Metrel Inc IL
RHI US Ltd NY
RISE Research Institutes of Sweden RISE Glass Sweden
Vesuvius SC

Graphite
Applied Ceramics Inc CA
Furnace Products & Services Inc PA
Riedhammer GmbH Germany

Grog
Alsey Refractories Co MO
Maryland Refractories Co OH

Gunning
Allied Mineral Products Inc OH
Blastcrete Equipment Co AL
Capital Refractories Ltd UK
Fosbel Inc OH
Plibrico Company IL **See ad on page 105**
Plibrico Japan Co Ltd Japan
Reno Refractories Inc AL
Riverside Refractories Inc--Allied Mineral Products AL
Unifrax I LLC NY
Velco GmbH Germany

High-Alumina
Advanced Ceramic Technology CA
Allied Mineral Products Inc OH
Applied Ceramics Inc CA
Astral Material Industrial Co Ltd China
Blasch Precision Ceramics Inc NY
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Custom Processing Services PA
Dalmia Inst of Scientific & Industrial Research India
ER Advanced Ceramics Inc OH
Fosbel Inc OH
IPS Ceramics LTD UK
Ipsen Ceramics IL
LECO Corp MI
Magneco Metrel IncIL
Maryland Refractories Co OH
Monofrax LLC NY
Plibrico Company IL **See ad on page 105**
Plibrico Japan Co Ltd Japan
Precision Ferrites and Ceramics Inc CA
Rath Inc DE
RHI US Ltd NY

Riedhammer GmbH Germany
Riverside Refractories Inc–Allied Mineral Products AL
Selee Corp NC
Sunrock Ceramics Co IL
Tethon 3D NE
Xiamen Innovacera Advanced Materials Co Ltd China
Zhengzhou Mission Ceramic Products Co Ltd China
Zircar Refractory Composites Inc NY

Insulating Brick

Dalmia Inst of Scientific & Industrial Research India
Furnace Products & Services Inc PA
General Material Industrial CoChina
IFB Insulating Firebrick Inc PA
Laguna Clay Co CA
PSH Kilns & Furnaces Canada
RHI US LtdNY
Riedhammer GmbH Germany
Zircoa Inc OH

Insulation

Agni Fiber Boards Pvt Ltd India
Capital Refractories Ltd UK
Du-Co Ceramics Company PA
Furnace Products & Services Inc PA
General Material Industrial Co China
HarbisonWalker Intl PA
Induceramic Canada
Plibrico Company IL **See ad on page 105**
Plibrico Japan Co Ltd Japan
PSH Kilns & Furnaces Canada
Rath Inc DE
Reno Refractories Inc AL
RHI US Ltd NY
Thermal Products Co Inc GA
Unifrax I LLC NY
Vesuvius SC
Wistra GmbH Germany

Zircar Ceramics Inc NY
Zircar Refractory Composites Inc NY

Zircar Zirconia Inc NY

Insulation Board

Agni Fiber Boards Pvt Ltd India
Thermal Products Co Inc GA
Unifrax I LLC NY
Zircar Refractory Composites Inc NY

Insulation Slabs, Calcium Silicate

Furnace Products & Services Inc PA
Zircar Refractory Composites Inc NY

Insulation Slabs, Vermiculite

IFB Insulating Firebrick Inc PA

Insulation, Microporous

Furnace Products & Services Inc PA
Thermal Products Co Inc GA
Unifrax I LLC NY

Kiln Car Insulation

Thermal Products Co Inc GA

Kiln Furniture

Advanced Ceramic Technology CA
American Art Clay Co Inc IN
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
Induceramic Canada
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
L&L Kiln Mfg Inc NJ
Laguna Clay Co CA
Magneco Metrel Inc IL
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
RHI US Ltd NY
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
Selee Corp NC
Silicon Carbide Products Inc NY
Sunrock Ceramics Co IL
Texers Technical Ceramics Inc Canada
Zircar Refractory Composites Inc NY
Zircoa Inc OH

Magnesite

Allied Mineral Products Inc OH
Astral Material Industrial Co Ltd China
Dalmia Inst of Scientific & Industrial Research India
Fluid Energy Processing & Equipment Co PA
Furnace Products & Services Inc PA
RHI US Ltd NY
Riedhammer GmbH Germany

Monolithic

Allied Mineral Products Inc OH
Blasch Precision Ceramics Inc NY
Cancarb Limited Canada
Ceramco Inc NH
Furnace Products & Services Inc PA
Magneco Metrel Inc IL
Plibrico Company IL **See ad on page 105**
Plibrico Japan Co Ltd Japan
RHI US Ltd NY
Riverside Refractories Inc–Allied Mineral Products AL
Saint-Gobain Ceramics & Plastics MA
Selee Corp NC
Zili USA LLC PA

Mortars

Allied Mineral Products Inc OH
Alsey Refractories Co MO
CoorsTek CO
Monofrax LLC NY
Pacific Refractories Ltd India
Plibrico Company IL **See ad on page 105**
Plibrico Japan Co Ltd Japan
Refratechnik Ceramics GmbH Germany
Reno Refractories Inc AL
RHI US Ltd NY
Riverside Refractories Inc–Allied Mineral Products AL
Vitcas Ltd UK

Mullite

Advanced Ceramic Technology CA
Akron Porcelain & Plastics Co OH
Allied Mineral Products Inc OH
Astral Material Industrial Co Ltd China
Atlantic Equipment Engineers NJ
Bharat Heavy Electricals Ltd India
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Dalmia Inst of Scientific & Industrial Research India
ER Advanced Ceramics Inc OH
Fosbel IncOH
General Material Industrial Co China
Industrial Ceramic Products Inc OH
IPS Ceramics LTD UK
Magneco Metrel Inc IL
McDanel Advanced Ceramic Technologies LLC PA
Reade Advanced Materials RI
RHI US Ltd NY
Robocasting Enterprises LLC NM
Unifrax I LLC NY

Nozzles

Advanced Ceramic Technology CA
Blasch Precision Ceramics Inc NY
Blastcrete Equipment Co AL
CeramTec-ETEC Germany
FELDCO Intl CA
Industrial Ceramic Products Inc OH
Jyoti Ceramic Industries Pvt Ltd India
LECO Corp MI
Magneco Metrel Inc IL
Reed Gunite & Shotcrete Equipment CA
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
Silicon Carbide Products Inc NY
Xiamen Innovacera Advanced Materials Co Ltd China
Zircoa Inc OH

Paper

Thermal Products Co Inc GA
Unifrax I LLC NY

Plastic

Allied Mineral Products Inc OH
Capital Refractories Ltd UK
Maryland Ceramic & Steatite Co Inc MD
Plibrico Company IL **See ad on page 105**
Plibrico Japan Co Ltd Japan
RHI US Ltd NY
Riverside Refractories Inc–Allied Mineral Products AL

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Fosbel Inc OH
Industrial Ceramic Products Inc OH
Magneco Metrel Inc IL

Plibrico Company IL **See ad on page 105**
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RHI US Ltd NY
Riverside Refractories Inc–Allied Mineral Products AL
Selee Corp NC
Silicon Carbide Products Inc NY
Zircar Refractory Composites Inc NY

Ramming Mixes
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Monofrax LLC NY
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Selee Corp NC

Rods
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AdValue Technology LLC AZ **See ad on page 51**
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CerCo LLC OH
Du-Co Ceramics Company PA
Industrial Ceramic Products Inc OH
LECO Corp MI
McDanel Advanced Ceramic Technologies LLC PA
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA
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Keith Co CA
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Saggers
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IPS Ceramics LTD UK
Ipsen Ceramics IL
LECO Corp MI
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Selee Corp NC
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Industrial Ceramic Products Inc OH
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Thermal Products Co Inc GA

Tubes
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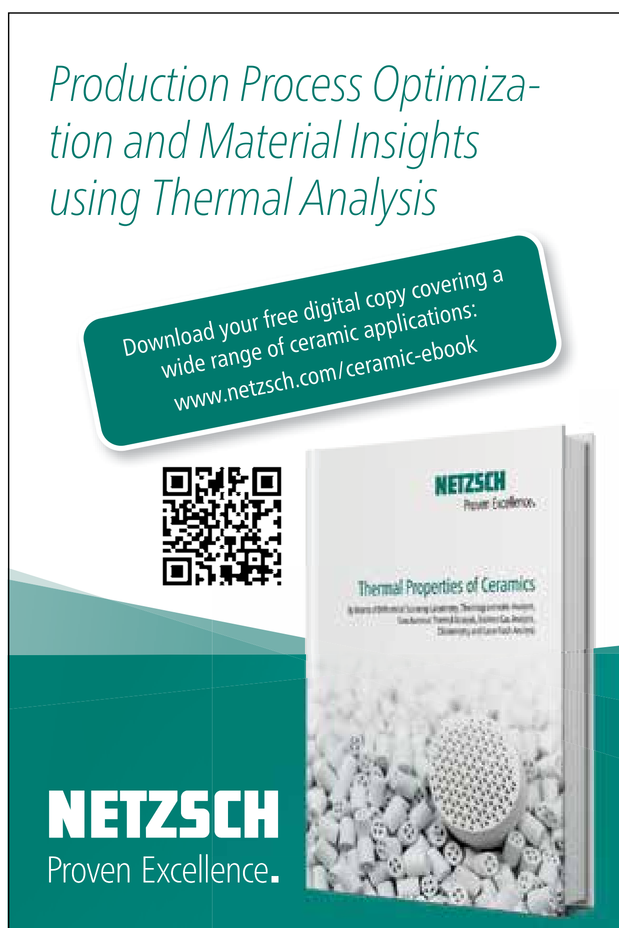

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ARBURG is a PIM pioneer with more than 50 years of experience in the industry and one of the world's leading manufacturers of plastic processing machines. The portfolio includes ALLROUNDER injection moulding machines with clamping forces between 125 and 6,500 kN, the freeformer for industrial additive manufacturing, robotic systems, customer- as well as sector-specific turnkey solutions, and further peripherals. ARBURG offers also application consulting, training, and a well-equipped PIM laboratory for all relevant production steps.

An international sales and service network guarantees first-class, local customer support. ARBURG has its own organizations at 34 locations in 26 different countries; together with its trading partners, it is present in more than 100 countries. The machines are produced exclusively at the parent factory in Lossburg, Germany. From a total of around 3,000 employees, around 2,500 work in Germany. About 500 further employees work in ARBURG's organizations worldwide.

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AACCM's member companies manufacture components from ceramic powders at U.S. operating facilities. Its purpose is to expand the market for U.S.-manufactured components by enhancing processes and quality and to increase awareness of ceramic applications.

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Associated Ceramics & Technology Inc is a custom manufacturer of ceramics composed of alumina, steatite, cordierite, spinel, wollastonite, mullite, and high performance materials such as zirconia and yttria-stabilized zirconia. Its engineers' knowledge of the physical and chemical properties of a finished product allow the company to provide excellent quality in applications pertaining to chemical, electrical, wear-resistant, automotive, appliances, and many others. The expansive production capabilities at ACT include more than 155 dry and isostatic presses, seven extrusion presses, 10 kilns, and pre- and post-sintered machining capabilities that are sure to satisfy a customer's every need.

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Produces customized components made of silicon nitride-based ceramics, sintered silicon carbide, C/C-SiC composites, and zirconia. Major applications are in light-metal casting, wear protection, chemical and mechanical process engineering, electronics, precision optics, testing equipment, metal forming, and brake pads.

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http://www.vesuvius.com
Marcus.Bancroft@vesuvius.com

Vesuvius is a worldwide leader in advanced ceramics for the solar, glass-tempering, and glass-forming industry.

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http://www.washingtonmills.com
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http://www.unipretec.com
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Unipretec is a professional manufacturer for advanced ceramics. Our materials include alumina ceramic, zirconia ceramic, boron nitride, and machinable glass ceramic. We aim to provide high quality products and solutions for our customers.

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ZILI USA LLC
149 Nichol Ave No 2
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http://www.zilialutech.com
jsum@ziliref.com

Zili USA is a subsidiary of Zhejiang Zili Alumina Materials Co Ltd, specializing in high-purity alumina materials development and manufacturing. Its products include tabular alumina, low sodium alumina, reactive alumina, and calcined alumina. With warehouses situated in the states, Zili has fully stocked inventories ready for shipment.

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http://zrci.com
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ZIRCAR Refractory Composites, Inc., produces a comprehensive line of advanced high performance ceramic-ceramic composite materials and related products. Our materials are used around the world in the most demanding thermal, structural and electrical insulating applications ranging in temperatures from 600°C (1,112°F) to 2,200°C (3,992°F). For over thirty years, we have been a problem-solver working with our customers to resolve their thermal management problems. We have developed products that have become industry standards for induction melting, forging and heat treating applications, investment casting, glass processing, hot pressing, and high temperature electrical applications.

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