

**FINAL REPORT for  
GEOPOLYMER POROUS NANOCERAMICS FOR STRUCTURAL, FOR  
SMART AND THERMAL SHOCK RESISTANT APPLICATIONS  
AFOSR - Grant No. (FA9550-06-1-0221)**

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**Summary**

During the past five years, we have continued our work to understand and elucidate the microstructure of geopolymers and geopolymer composites, as fabricated and upon conversion to ceramics with heating. The microstructure consisted of nanoporous, nanoparticulate precipitates, and contains ~40% nanoporosity of average diameter 6.8 nm in the case of K-based geopolymer. The size of the precipitates increase with increasing ionic radius of the charge balancing cation, having diameters of the order of 5-10 nm for Na<sup>+</sup>, 10-20 nm for K<sup>+</sup> and 30-40 nm for Cs<sup>+</sup>. The room temperature compressive strengths were systematically investigated as a function of Group I charge balancing cations (Na, K, and Cs and mixtures of Na-K). Potential applications were explored in the area of refractory adhesives between metal, corrosion resistant coatings on steel, glass and ceramics, porous membranes and foams, ceramic armor composites, iron-based geopolymer analogues, geopolymer composites reinforced with chopped polypropylene or basalt fibers, and polycrystalline ceramics or glass-ceramics. The basic science of amorphous geopolymer structure was probed down to the Angstrom level by state of the art Pair Distribution Function analysis (PDF) of X-ray synchrotron data. It revealed that the building blocks of AlO<sub>4</sub><sup>-</sup> and SiO<sub>4</sub> units were formed from solution under ambient conditions, consistent with the hypothesis that geopolymerization occurs by the three steps of dissolution, polycondensation and precipitation. Stoichiometric composites corresponding to M<sub>2</sub>O•Al<sub>2</sub>O<sub>3</sub>•4SiO<sub>2</sub>•11H<sub>2</sub>O where M = Na, K, or Cs, were heated to form polycrystalline ceramics. The conversions were studied by a range of ceramic powder characterization and processing techniques including XRD, synchrotron, SEM, EDS, TEM, density measurements by the Archimedes method, pycnometry, specific surface area analysis (SSA), mercury intrusion porosimetry (MIP) and flexure strength measurements. As a result of this research we now have a much improved insight into the nature and properties of aluminosilicate geopolymers. We are now poised to continue this work into the area of evolution of high temperature microstructure and mechanical properties.

## Report Documentation Page

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14. ABSTRACT

**We have continued our work to understand and elucidate the microstructure of geopolymers and geopolymer composites, as fabricated and upon conversion to ceramics with heating. The microstructure consisted of nanoporous, nanoparticulate precipitates, and contains ~40% nanoporosity of average diameter 6.8 nm in the case of K-based geopolymer. The room temperature compressive strengths were systematically investigated as a function of Group I charge balancing cations (Na, K, and Cs and mixtures of Na-K). Potential applications were explored in the area of refractory adhesives between metal, corrosion resistant coatings on steel, glass and ceramics, porous membranes and foams, ceramic armor composites, iron-based geopolymer analogues, geopolymer composites reinforced with chopped polypropylene or basalt fibers, and polycrystalline ceramics or glass-ceramics. The basic science of amorphous geopolymer structure was probed down to the Angstrom level by state of the art Pair Distribution Function analysis (PDF) of X-ray synchrotron data. It revealed that the building blocks of AlO<sub>4</sub>- and SiO<sub>4</sub> units were formed from solution under ambient conditions. The conversions were studied by a range of ceramic powder characterization and processing techniques.**

15. SUBJECT TERMS

**Geopolymers; geopolymer composites; M<sub>2</sub>O·Al<sub>2</sub>O<sub>3</sub>·4SiO<sub>2</sub>·11H<sub>2</sub>O where M = Na, K, or Cs; microstructure; compressive and flexure strengths; pair distribution function analysis; X-ray synchrotron; ceramic formation.**

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## Research Publications on geopolymers resulting from this work

1. "Comparison of Naturally and Synthetically-Derived, Potassium-Based Geopolymers," M. Gordon, J. Bell and W. M. Kriven, *Ceramic Transactions*, vol. **165**. *Advances in Ceramic Matrix Composites X*, edited by J. P. Singh, N. P. Bansal and W. M. Kriven 95-106 (2005).
2. "Microstructural Characterization of Metakaolin-based Geopolymers," P. Duxson, G. C. Lukey, J. S. J. van Deventer, S. W. Mallicoat, W. M. Kriven *Ceramic Transactions*, vol. **165**. *Advances in Ceramic Matrix Composites X*, edited by J. P. Singh, N. P. Bansal and W. M. Kriven 71-85 (2005).
3. "Understanding the Relationship between Geopolymer Composition, Microstructure and Mechanical Properties," P. Duxson, J. L. Provis, G. C. Lukey, S. W. Mallicoat, W. M. Kriven and J. S. J. van Deventer, *Colloids and Surfaces A – Physicochemical and Engineering Aspects*, **269** [1-3] 47-58 (2005).
4. "Use of Geopolymeric Cements as a Refractory Adhesive for Metal and Ceramic Joins," J. L. Bell, M. Gordon and W. M. Kriven, *Ceramic Engineering and Science Proceedings*. Edited by D.-M. Zhu, K. Plucknett and W. M. Kriven, vol **26**, [3] 407-413 (2005).
5. "Novel Alkali-Bonded Ceramic Filtration Membranes," S. Mallicoat, P. Sarin and W. M. Kriven, *Ceramic Engineering and Science Proceedings*. Edited by M. E. Brito, P. Filip, C. Lewinsohn, A. Sayir, M. Opeka, W. M. Mullins, D.-M. Zhu and W. M. Kriven, vol **26**, [8] 37-44 (2005).
6. "Modeling Speciation in Highly Concentrated Alkaline Silicate Solutions," John L. Provis, Peter Duxson, Grant C. Lukey, Frances Separovic, Waltraud M. Kriven and Jannie S. J. van Deventer, *Industrial and Engineering Chemistry Research*, **44** [23], 8899-8908 (2005).
7. "Thermal Conversion and Microstructural Evaluation of Geopolymers or "Alkali Bonded Ceramics" (ABCs)," M. Gordon, J. Bell and W. M. Kriven. *Ceramic Transactions*, vol. **175**. *Advances in Ceramic Matrix Composites XI*. Edited by N. P. Bansal, J. P. Singh and W. M. Kriven, 225-236 (2005).
8. "Intrinsic Microstructure of Geopolymers and Geopolymer-based Materials," W. M. Kriven, J. Bell, M. Gordon and Gianguo Wen, pp 179-183 in Geopolymer, Green Chemistry and Sustainable Development Solutions, edited by Joseph Davidovits. Proc. World Congress Geopolymer, 2005, St. Quentin, France. Published by the Geopolymer Institute, St. Quentin, France (2005).
9. "Microstructure and Nanoporosity in As-set Geopolymers," W. M. Kriven, J. L. Bell and M. Gordon. Mechanical Properties and Performance of Engineering Ceramics II, *Ceramic Engineering and Science Proceedings*, Cocoa Beach, Vol. **27**, Issue 2, 313-324 (2006).

10. "Effect of Alkali and Si/Al Ratio on the Development of Mechanical Properties of Metakaolin-based Geopolymers," P. Duxson, S. W. Mallicoat G. C. Lukey, W. M. Kriven and J. S. J. van Deventer, *Colloids and Surfaces A-Physicochemical and Engineering Aspects*, **292** 8-20 (2007).
11. "Intrinsic Microstructure and Properties of Metakaolin-Based Geopolymers," W. M. Kriven, J. L. Bell, S. W. Mallicoat and M. Gordon, contributed chapter to Proc. of Int. Workshop on Geopolymer Binders – Interdependence of Composition, Structure and Properties, Weimar, Germany, 71-86 (2007).
12. "Corrosion Protection Assessment of Concrete Reinforcing Bars with a Geopolymer Coating," W. M. Kriven, M. Gordon, B. L. Ervin and H. Reis. *Cer. Eng. and Sci. Proc.*, **28** [9] 373-381 (2007). In Developments in Porous, Biological and Geopolymer Ceramics, edited by Manuel Brito, Eldon Case, W. M. Kriven, volume editors Jonathan Salem and Dongming Zhu, published by the American Ceramic Society.
13. "Concepts for Energy Absorption and Dissipation in Ceramic Armor," D. K. Kim, J. L. Bell, W. M. Kriven and V. Kelsey," *Cer. Eng. Sci. Proc.* **28** issue [5] 57-70 (2007). Advances in Ceramic Armor III, edited by Jonathan Salem and Dongming Zhu, (series editors); Lisa Prokurat Franks, (editor).
14. "Atomic Structure of a Cesium Aluminosilicate Geopolymer: A Pair Distribution Function Study," J. L. Bell, P. Sarin, J. L. Provis, R. P. Haggerty, P. E. Driemeyer, P. J. Chupas, J. S. J. van Deventer and W. M. Kriven, *Chemistry of Materials*, **20** [14] 4768-4776 (2008).
15. "Preparation of Ceramic Foams from Metakaolin-based Geopolymer Gels," J. L. Bell and W. M. Kriven, *Cer. Eng. and Sci Proc.*, vol **29** (2008). In Developments in Strategic Materials. Edited by Hua-Tay Lin, Kunihito Koumoto, Waltraud M. Kriven, David P. Norton, Edwin Garcia and Ivar Reimanis, Vol **29** issue 10 pp 97-112 (2008).
16. "X-ray Pair Distribution Function Analysis of Potassium Based Geopolymer," J. L. Bell, P. Sarin, P. E. Driemeyer, R. P. Haggerty, P. J. Chupas and W. M. Kriven, *Journal of Materials Chemistry, J. Mater. Chem.*, **18** [48], 5974 - 5981 (2008).
17. "Formation of Ceramics from Metakaolin-based Geopolymers: Part I. Cs-based Geopolymer," J. L. Bell, P. E. Driemeyer and W. M. Kriven, *J. Amer. Ceram. Soc.*, **92** [1] 1551-2916 (2009).
18. "Formation of Ceramics from Metakaolin-based Geopolymers: Part II. K-based Geopolymer," J. L. Bell, P. E. Driemeyer and W. M. Kriven, *J. Amer. Ceram. Soc.*, **92** [3] 607-615 (2009).
19. "Formation of an Iron-Based Geopolymer Analogue," J. L. Bell and W. M. Kriven, *Cer. Eng. and Sci. Proceedings Vol 30*, issue 2, pp x-x. "Mechanical Properties and

Performance of Engineering Ceramics and Composites IV. Edited by Dileep Singh and Waltraud M. Kriven, Ceramic Engineering and Science Proceedings, Vol **30**, issue [2] 301-312 (2009).

20. "The Ageing Process of Alkali Activated Metakaolin," C. H. Rüscher, E. Mielcarek, W. Lutz, A. Ritzmann and W. M. Kriven, Microporous Mesoporous Materials, Proc. of Pacrim 09, **215** 315-324 (2010).
21. "Weakening of Alkali-Activated Metakaolin during Aging Investigated by the Molybdate Method and Infrared Absorption Spectroscopy," C. H. Rüscher, E. Mielcarek, W. Lutz, A. Ritzmann and W. M. Kriven, J. Amer. Ceramic Society, **93** [9] 2585-2590 (2010).
22. "Fabrication of Structural, Leucite Glass-Ceramics from Potassium-Based Geopolymer Precursors," N. Xie, J. L. Bell and W. M. Kriven, J. Amer. Ceram. Soc., **93** [9] 2644-2649 (2010).
23. "Inorganic Polysialates or "Geopolymers", W. M. Kriven, (invited paper), American Ceramic Society Bulletin, **89** [4] 31-34 (2010).
24. "Effect of High Tensile Strength Polypropylene Chopped Fiber Reinforcements on the Mechanical Properties of Sodium Based Geopolymer Systems," D. R. Lowry and W. M. Kriven, in Strategic Materials and Computational Design, edited by Waltraud M. Kriven, Yanchun Zhou and Miladin Radovic. Cer. Eng. Sci. Proc. **31** [10] 47-56 (2010).
25. "Properties of Basalt Fiber Reinforced Geopolymer Composites," E. Rill, D. Lowry and W. M. Kriven, in Strategic Materials and Computational Design, edited by Waltraud M. Kriven, Yanchun Zhou and Miladin Radovic. Cer. Eng. Sci. Proc. **31** [10] 57-69 (2010).

#### **Books edited by the PI since 2005 and containing research on geopolymers**

1. Advances in Ceramic-Matrix Composites-X. Edited by J. P. Singh, N. P. Bansal and W. M. Kriven, Ceramic Transactions, vol. **165**, (2005). Published by the American Ceramic Society, Westerville, OH, USA.
2. Developments in Advanced Ceramic and Composites. Edited by Manuel E. Brito, Peter Filip, Charles Lewinsohn, Ali Sayir, Mark Opeka, William M. Mullins, Dongming Zhu and Waltraud M. Kriven. Ceramic Engineering and Science Proceedings, vol **26**, issue 8 (2005) (43 papers).
3. Advances in Ceramic-Matrix Composites-XI. Edited by J. P. Singh, N. P. Bansal and W. M. Kriven, Ceramic Transactions, vol. **175**, (2005). Published by the American Ceramic Society, Westerville, Ohio, USA.
4. Developments in Porous, Biological and Geopolymer Ceramics. Edited by Jonathan Salem and Dongming Zhu, General Editors; Manuel Brito, Eldon Case and Waltraud Kriven. Ceramic Engineering and Science Proceedings, Volume **28**, Issue 9 (2007).

5. Developments in Strategic Materials. Edited by Hua-Tay Lin, Kunihiro Koumoto, Waltraud M. Kriven, David P. Norton, Edwin Garcia and Ivar Reimanis, Ceramic Engineering and Science Proceedings, Vol **29** issue 10 (2008).
6. “Mechanical Properties and Performance of Engineering Ceramics and Composites IV. Edited by Dileep Singh and Waltraud M. Kriven. Volume editors - Dileep Singh and Jonathan Salem. Ceramic Engineering and Science Proceedings, Vol **30**, issue 2 (2009).
7. Strategic Materials and Computational Design, Editors Waltraud M. Kriven, Yanchun Zhou and Miladin Radovic, Vol. **31**, issue 10 (2010).

### **Honors and Awards**

- Elected to become a Fellow of the Australian Ceramic Society
- Became an Affiliate Professor in the Department of Mechanical Science and Engineering at the University of Illinois at U-C
- Became an Affiliate Professor in the Department of Bioengineering at the University of Illinois at Urbana-Champaign

### **Keynote/Plenary Lectures - 9**

1. “Geopolymers: More than just a Cement,” W. M. Kriven (Plenary lecture). Presented at Geopolymer 2005, Int. Conf. on Geopolymers, held in St. Quentin, June 29<sup>th</sup> – June 30<sup>th</sup>, (2005) in St. Quentin, France.
2. “Microstructure of Geopolymers and Geopolymer-based Materials,” Geopolymers as Ceramic Matrix Composites, W. M. Kriven. Plenary lecture presented at Int. Conf. and Workshop on Geopolymers and Geopolymer Concrete in Civil Engineering, Perth, Western Australia, Australia, Sept 28<sup>th</sup> – 29<sup>th</sup> (2005).
3. “From Geopolymers to Ceramics,” W. M. Kriven, J. L. Bell and P. Sarin. Invited keynote lecture presented at 3<sup>rd</sup> International Conference on Alkali Activated Materials, - Research, Production and Utilization. Presented in Prague, Czech Republic, Jun 21-22<sup>nd</sup> (2007).
4. “From Geopolymers to Ceramics,” W. M. Kriven, J. Bell and P. Sarin. Invited keynote lecture presented at 4<sup>th</sup> Int. Conf. on Advanced Materials (ICAMP-4), held in Sydney, Australia, July 4<sup>th</sup> – 6<sup>th</sup> (2007).
5. Invited lecture at Honorary Colloquium for Dr. Nils Claussen, Technische Universität Hamburg-Harburg, part of the Deutsche Keramische Gesellschaft (DKG) and Deutsche Gesellschaft für Materialkunde (DGM) Feb 25<sup>th</sup> (2008).
6. “Ceramics Without Sintering: Inorganic Polymers,” W. M. Kriven,\* J. Bell, P. Sarin and P. E. Driemeyer,” Invited Keynote Lecture presented at FORUM 2008, of the World Academy of Ceramics, Siena, Italy July 5<sup>th</sup> – 8<sup>th</sup> (2008).

7. "Atomic Structure and Microstructure of Geopolymer and Crystallized Geopolymer Ceramics," W. M. Kriven. Invited lecture to be presented at Conferences Internationales Materiaux et Technologies (CIMTEC) 2010. Held in Montecatini Terme, Tuscany, Italy, June 6 – 11 (2010).
8. "Microstructure and Properties of Metakaolin-based Geopolymers," W. M. Kriven,\* presented at Annual Meeting of the Cements Division of the American Ceramic Society, Purdue, IN, July 11<sup>th</sup>- 13<sup>th</sup> (2010) and at Int. Conf. of Cements Microscopy Soc. Held in New Orleans, March 29, New Orleans
9. "Geopolymers and Environmental Stability," W. M. Kriven,\* presented at the Gordon Conference on Solid State Studies in Ceramics, Colby Sawyer College, New Hampshire, Aug 16<sup>th</sup> -20<sup>th</sup> (2010).

### **Invited Lectures on Geopolymers and Geopolymer Composites - 32**

1. "Geopolymers: More than Just a Cements," W. M. Kriven (Plenary Lecture). Presented at *Geopolymer 2005*. Int. Conf. on Geopolymers, held in St. Quentin, June 29<sup>th</sup> – July 1<sup>st</sup> 2005.
2. "Microstructure and Nanoporosity of As-set and Heat-Treated Geopolymers," W. M. Kriven, J. L. Bell, M. Gordon and J. Wen. Presented at 30<sup>th</sup> Int. Cocoa Beach Conf. and Exposition on Advanced Ceramics and Composites, Jan 22-27<sup>th</sup> (2006), Florida, USA.
3. "Microstructure and Nanoporosity of As-set and Heat-Treated Geopolymers," W. M. Kriven, J. L. Bell, M. Gordon and J. Wen. Presented at 30<sup>th</sup> Int. Cocoa Beach Conf. and Exposition on Advanced Ceramics and Composites, Jan 22-27<sup>th</sup> 2006, Florida, USA.
4. Processing of Ceramics via the Geopolymer Route," International Conference on Novel and Emerging Ceramics and Composites, held in Kona, Hawaii, July 10-15<sup>th</sup> (2006).
5. "Microstructure and Effect of Heat Treatment on Geopolymers" W. M. Kriven,\* J. L. Bell and M. Gordon (invited lecture) to be presented at International Workshop on Geopolymer Binders – Interdependence of Composition, Structure and Properties, Sept 18-19<sup>th</sup> 2006 in Weimar, Germany.
6. "Crystallization of Leucite and Pollucite from Geopolymer Gels," W. M, Kriven,\* J. L. Bell, M. Gordon, and P. Sarin Abstract [#ICACC-FS3-007-2007] presented at 31<sup>st</sup> International Cocoa Beach Conference and Exposition on Advanced Ceramics and Composites held at Daytona Beach on Jan 21<sup>st</sup> - 26<sup>th</sup> 2007.
7. "Geopolymers," W. M. Kriven, presented at Pittsburgh Plate and Glass Company (PPG) Coatings Division, Pittsburgh PA, on April 20<sup>th</sup> (2007).

8. "The Complex Structure of Geopolymers," W. M. Kriven, \* J. L. Bell and P. Sarin, (invited lecture) presented at 7<sup>th</sup> Understanding Complex Systems Conference held at The University of Illinois at Urbana-Champaign, Department of Physics, May 14-17<sup>th</sup> (2007).
9. "From Geopolymers to Ceramics," W. M. Kriven, J. L. Bell and P. Sarin. Presented at the Annual Meeting of the European Ceramic Society, held in Berlin, Germany, June 17<sup>th</sup>-21<sup>st</sup> (2007).
10. "Geopolymers and Geopolymer Concretes," W. M. Kriven,\* J. L. Bell, P. Sarin, R. P. Haggerty and P. Driemeyer. Presented at Tyndall Air Force Base, Panama City, FL Aug. 7<sup>th</sup> (2007).
11. "Geopolymer-derived Ceramics based on Less Contaminated, Synthetic Analogues of Fly-Ash," W. M. Kriven\*, P. E. Driemeyer, J. L. Bell. Presented at the 109<sup>th</sup> Annual Meeting of the American Ceramic Society, in conjunction with Materials Science and Technology 2007 Conference and Exhibition (MS &T '07), held in Detroit, Sept 16-20 (2007).
12. "From Geopolymers to Ceramics," W. M. Kriven, J. L. Bell and P. Sarin. Presented at Composites at Lake Louise, Canada, Oct 28<sup>th</sup> –Nov 2<sup>nd</sup> (2007).
13. "Recent Advances in Thermally-induced Evolution of Geopolymers into Ceramics," W. M. Kriven,\* J. L. Bell, R. P. Haggerty, P. E. Driemeyer. Presented at the 32<sup>nd</sup> Int. Conf. and Exposition on Advanced Ceramics and Composites, Daytona Beach, Florida, Jan 27<sup>th</sup> – Feb 1<sup>st</sup> (2008).
14. "*In situ*, in Air, High Temperature (2000°C) Studies of Oxide Ceramics," W. M. Kriven. Presented in the Institut für Kristallographie at the University of Cologne, Cologne, Germany Feb 22<sup>nd</sup> 2008. At the invitation of Prof. Hartmut Schneider.
15. "From Zirconia Toughening to the Design of Advanced Composites," W. M. Kriven.\* Presented at the Ehren Kolloquium (Colloquium in honor of) of Nils Claussen and Symposium on Hochleistungskeramik 2008 (High Durability Ceramics) held at the University of Hamburg-Harburg, Germany Feb 25-28<sup>th</sup> (2008).
16. "Pair Distribution Function Analysis of Metakaolin-Based Geopolymers," J. L. Bell, \*, P. Sarin, R. P. Haggerty, P. E. Driemeyer and W. M. Kriven Brookhaven National Laboratory, National Synchrotron Light Source (NSLS), Seminar Series, March 7<sup>th</sup>, (2008).
17. "In Situ Synchrotron Studies of Oxide Ceramics to 2000°C in Air," W. M. Kriven, P. Sarin, J. L. Bell, \*, R. P. Haggerty and P. E. Driemeyer. Presented in the Department of Mechanical Engineering, Texas A&M University, College Station, Texas, April 24<sup>th</sup> 2008.
18. "Geopolymer Porous Nanoceramics for Structural, Smart and Thermal Shock Resistant Applications," W. M. Kriven, J. L. Bell and P. E. Driemeyer. Presented at AFOSR review at Dayton Air Force Base, Dayton, OH, May 5<sup>th</sup> 2008.

19. "From Geopolymers to Ceramics," presented at the University of Trento, (per Prof. G. D. Sororu), in Trento, Italy, July 3<sup>rd</sup> (2008).
20. "High Tech Ceramics and Refractories without Sintering," W. M. Kriven\*. Presented at 2<sup>nd</sup> International Congress on Ceramics (2nd ICC2), held in Verona, Italy, June 29<sup>th</sup> – July 4<sup>th</sup> (2008).
21. "Geopolymers" W. M. Kriven (an intensive two day lecture course on geopolymers, at the invitation of Dr. Alek Pyzik, presented at the Corporate R & D section of Dow Chemical Company in Midland, MI, on Sept. 2<sup>nd</sup> - 5<sup>th</sup> (2008).
22. "Microstructure and Short Range Order in Aluminosilicate Geopolymers," J. L. Bell, P. Sarin and W. M. Kriven, presented at 33<sup>rd</sup> International Conference on Advanced Ceramics and Composites held at Daytona Beach, FL, Jan 18<sup>th</sup> -23<sup>rd</sup> (2009).
23. "In Situ Synchrotron Studies of Ceramics to 2000°C in Air," W. M. Kriven\*, presented as the Physics Department Colloquium of Eastern Illinois University, Bloomington, IL, Feb 24<sup>th</sup> (2009).
24. "Microstructure and Mechanical Properties of Leucite Glass-Ceramics Converted from Potassium-based Geopolymer," N. Xie, J. L. Bell and W. M. Kriven, 8<sup>th</sup> Pacific Rim Conference on Ceramics and Glass Technology, (PACRIM8), held in Vancouver, British Columbia, Canada, (May 31<sup>st</sup> – June 5<sup>th</sup> (2009).
25. "In-situ Synchrotron Studies of Ceramics to 2000°C in Air," W. M. Kriven, Departmental Seminar presented in the Department of Materials Science and Engineering, Boise State University, Idaho, Oct 9<sup>th</sup> 2009.
26. "Formation of Ceramics from Metakaolin-based Geopolymers," W. M. Kriven, N. Xie and J. L. Bell. Presented at Materials Science and Technology 2009 Conference and Exhibition (MS&T'09) including the ACERS 111<sup>th</sup> Annual Meeting, held in Pittsburgh PA, Oct 25<sup>th</sup> -29<sup>th</sup> (2009).
27. "In situ Synchrotron Studies of Ceramics to 2000°C in Air," W. M. Kriven, P. Sarin, R. P. Haggerty and Z. D. Apostolov. Presented at the Lunchtime seminar series at the National Synchrotron Light Source at Brookhaven National Laboratory, Brookhaven, Nov 10<sup>th</sup> (2009).
28. "Mechanical Properties and Thermal Behavior of Geopolymer Composites," W. M. Kriven, B. Andress, B. Choragwicki, D. Lowry, E. Rill, B. C. Wagoner. Presented at the 34<sup>th</sup> Int. Conf. and Exposition on Advanced Ceramics and Composites, held in Daytona Beach, FL, Jan 24<sup>th</sup> – 29<sup>th</sup> (2010).
29. "Microstructure and Properties of Metakaolin-based Geopolymers," W. M. Kriven,\* J. L. Bell, P. E. Driemeyer, P. Sarin, R. P. Haggerty, M. Gordon, S. Mallicoat, P. Duxson, N.

Xie, D. R. Lowry and E. Rill. Presented at 32<sup>nd</sup> Int. Conf. on Cement Microscopy, held in New Orleans, USA, March 28<sup>th</sup>-April 1<sup>st</sup> (2010).

30. "Atomic Structure and Microstructure of Geopolymer and Crystallized Geopolymer Ceramics," W. M. Kriven,\* J. L. Bell, P. E. Driemeyer, P. Sarin, R. P. Haggerty, N. Xie. To be presented at 12<sup>th</sup> International Ceramics Congress, Montecatini Terme, Tuscany, Italy, June 6<sup>th</sup> - 11<sup>th</sup> (2010).
31. "Microstructure and Properties of Metakaolin-based Geopolymers," W. M. Kriven.\* Presented at Annual Meeting of the Cements Division of the American Ceramic Society, Purdue, IN, July 11<sup>th</sup>- 13<sup>th</sup> (2010).
32. "Mechanical Properties of Chopped Fiber Reinforced Composites as a Function of Temperature," T. P. Dietz and W. M. Kriven\*, presented at 35<sup>th</sup> Int. Conf. on Advanced Ceramics and Composites, Jan 23<sup>rd</sup> – 28<sup>th</sup> (2011).

#### **Contributed Talks on Geopolymers - 14**

1. "Thermal Shock Resistant, Graphite Fiber-reinforced, Geopolymer Composites for Near-net Shape Solidification of Fe<sub>2</sub>Si," D. Comrie, J. L. Bell,\* M. Gordon and W. M. Kriven. Presented at Int. Conf. and Workshop on Geopolymers and Geopolymer Concrete in Civil Engineering, Perth, Western Australia, Australia, Sept 28<sup>th</sup>-29<sup>th</sup> (2005).
2. "In-situ High Temperature Synchrotron X-ray Diffraction Studies of Pollucite (CaAlSi<sub>2</sub>O<sub>6</sub>) and Pollucite-based Compounds," M. Gordon, P. Sarin, D. K. Kim and W. M. Kriven\*. Presented at 30<sup>th</sup> Int. Cocoa Beach Conf. and Exposition on Advanced Ceramics and Composites, Jan 22-27<sup>th</sup> 2006, Florida, USA.
3. "Nanoporosity and Microporosity in Geopolymer Gels" J. L. Bell, M. Gordon and W. M. Kriven\*. Presented at Microscopy and Microanalysis 2006, Held in Chicago, IL USA, July 30<sup>th</sup> – Aug 3<sup>rd</sup> 2006.
4. "Formation of Nanocrystalline Zeolites in Geopolymer Gels," J. L. Bell\*, P. Sarin and W. M. Kriven. Presented at Microscopy and Microanalysis 2006. Held in Chicago, IL USA, July 30<sup>th</sup> – Aug 3<sup>rd</sup> 2006.
5. "Crystallization of Pollucite (CsAlSi<sub>2</sub>O<sub>6</sub>) from Cs-based Geopolymer Precursor," J. L. Bell, P. Sarin, R. P. Haggerty, M. Gordon, J. L. Provis, and W. M. Kriven. Presented at 64<sup>th</sup> Pittsburgh Diffraction Conference, Duquesne University, Pittsburgh, PA, Oct 26<sup>th</sup>-28<sup>th</sup> 2006.
6. "Preparation of Ceramic Foams from Geopolymer Gels," J. L. Bell, S. Mallicoat and W. M. Kriven. Abstract [#ICACC-FS3-011-2007], presented at 31<sup>st</sup> Int. Cocoa Beach Conf. and Exposition on Advanced Ceramics and Composites, Daytona Beach, FL, Jan 21<sup>st</sup> -26<sup>th</sup> (2007).

7. "XPS Study of Metakaolin-based Geopolymers," S. Mallicoat, P. Sarin and W. M. Kriven. Abstract [#ICACC-FS3-012-2007], presented at 31<sup>st</sup> Int. Cocoa Beach Conf. and Exposition on Advanced Ceramics and Composites, Daytona Beach, FL, Jan 21<sup>st</sup> -26<sup>th</sup> (2007).
8. "Corrosion Protection of Concrete Reinforcing Rebars using Geopolymers," W. M. Kriven, M. Gordan and B. Erwin and H. Reis. Abstract [#ICACC-FS3-018-2007], presented at 31<sup>st</sup> Int. Cocoa Beach Conf. and Ezposition on Advanced Ceramics and Composites, Daytona Beach, FL, Jan 21<sup>st</sup> -26<sup>th</sup> (2007).
9. "Pair Distribution Function Analysis of Metakaolin Based Geopolymers," J. L. Bell, P. Sarin, R. P. Haggerty, P. E. Driemeyer and W. M. Kriven. Presented at the 32<sup>nd</sup> Int. Conf. and Exposition on Advanced Ceramics and Composites, Daytona Beach, Florida, Jan 27<sup>th</sup> – Feb 1<sup>st</sup> (2008).
10. "Short to Medium range structural Order in Amorphous, Pre-zeolitic Geopolymers of Composition  $M_2O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 11H_2O$ ," W. M. Kriven, J. L. Bell, P. Sarin, R. P. Haggerty, P. E. Driemeyer. Presented at 2<sup>nd</sup> International Congress on Ceramic (CC2) held in Verona, Italy June 29<sup>th</sup> – July 4<sup>th</sup> (2008).
11. "Formation of Iron-based Inorganic Polymer (Geopolymer)," J. L. Bell and W. M. Kriven, presented at 33<sup>rd</sup> International Conference on Advanced Ceramics and Composites held at Daytona Beach, FL, Jan 18<sup>th</sup> -23<sup>rd</sup> (2009).
12. "The Aging Process of Alkali Activated Metakaolin," C. H. Rüscher, E. Mielcarek, W. Lutz; A. Ritzmann and W. M. Kriven. Presented at 8<sup>th</sup> Pacific Rim Conference on Ceramics and Glass Technology, (PACRIM8), held in Vancouver, British Columbia, Canada, (May 31<sup>st</sup> – June 5<sup>th</sup> (2009).
13. "Effect of PVA Chopped Fiber Reinforcements on the Mechanical Properties of Potassium-based Geopolymer Systems," E. Lowry\* and W. M. Kriven. Presented at the 34<sup>th</sup> Int. Conf. and Exposition on Advanced Ceramics and Composites, held in Daytona Beach, FL, Jan 24<sup>th</sup> – 29<sup>th</sup> (2010).
14. "Properties of Basalt Fiber Reinforced Geopolymer Composites," E. Rill and W. M. Kriven\*. Presented at the 34<sup>th</sup> Int. Conf. and Exposition on Advanced Ceramics and Composites, held in Daytona Beach, FL, Jan 24<sup>th</sup> – 29<sup>th</sup> (2010).