Dr. M. Kumosa's Key Academic and Research Accomplishments
January 2026

Personal Information: Born on July 13, 1953, in Warsaw, Poland.

Key Research Interests: Physical Properties, Life Prediction, and Manufacturing of Advanced Materials and Structures for Extreme Applications, including High Voltage (HV), High Temperature (HT), High Strain/Stress (HSS), combined HVTS, and others.

Education: BS/MS (1978) and Ph.D. (1982) in Applied Mechanics and Materials Science at Wroclaw University of Science and Technology/Politechnika Wroclawska (PWR, http://pwr.edu.pl/en/) in Poland. Dr. Kumosa's Ph.D. program was jointly sponsored by PWR and the US National Science Foundation (NSF) through the Marie Curie Foundation, International Programs. His Polish academic advisor was Professor L. Golaski, and his American advisor was Professor K. Ono from the University of California, Los Angeles (UCLA). As part of Dr. Kumosa's Ph.D. program, he was invited by the NSF to visit UCLA and other research organizations in the USA for two months in 1981.

Current Employment

1. John Evans Professor (award for life) at the University of Denver (DU) and retired academic tenure Professor starting July 2024. Department of Mechanical and Materials Engineering, University of Denver, 2155 East Wesley Avenue, Denver, Colorado 80208 tel: (303) 871-3807, fax: (303) 871-4450; mkumosa@du.edu.
2. Center Director: National Science Foundation Industry/University Cooperative Research Center (I/UCRC) for Novel High Voltage/Temperature Materials and Structures ("HVT Center").

HVT Center Highlight (www.HVTCenter.org); see also Dr. Kumosa's CV and his HVT Phase I Report)

1. The Center was established on March 15, 2014, for an initial period of five years. The first Phase of the center was completed on September 30, 2024, after five no-cost extensions. The Center is one of about 80 I/UCRCs in Engineering in the US, and it is presently ready to move to Phase II in a new structure and location.

NATIONAL SCIENCE FOUNDATION CENTER FOR NOVEL HIGH VOLTAGE/TEMPERATURE MATERIALS AND STRUCTURES

2. The three original sites of the Center at its conception were: DU, Michigan Technological University (MTU), and the University of Illinois at Urbana-Champaign (UIUC). The University of Connecticut (UConn) was added in Feb 2016.
3. It was conceived by M. Kumosa following his HV and HT research experience and accomplishments (see below) with very significant help and contributions from Professor G. Odegard (MTU site director), Professor I. Jasiuk (UIUC site director), Professor Martin Ostoja-Starzewski (UIUC), and Professor Y. Cao (UConn site director).
4. According to NSF, Division of Industrial Innovation and Partnership (IIP), Directorate of Engineering, the HVT Center was in good standing for every year between 2014 and 2024
5. In Phase I, between March 14, 2014, and September 30, 2024, the Center graduated 42 Ph.D. and 15 MS students.
6. 202 journal papers in refereed int. journals were published in Phase I by the four sites.
7. Total funding since inception
    - $3.61 M in cash in private and federal fees (plus at least $1M in-kind)
    - $1.65M in NSF supporting grants
    - $11-12M in various leverage funds
8. The industries (21) supporting HVT from 2014 until September 2024 in Phase I were:
   ABB, Boeing, Bonneville Power Administration, BP, CTC Global, Composites Technology Development, DOE Headquarters; Electricity Office, Eversource, G&W, General Cable, General Electric, John Crane, Marmon Engineered Wire & Cable, Lockheed Martin Space Systems, New York Power Authority, Prysmian Group, Southwire, Tri-State Transmission and Distribution, USi, US Bureau of Reclamation, Western Area Power Administration.
   (Most are large multibillion-dollar corporations).
9. The Center was evaluated by its members for 2017. For the quality of its research, meetings, and management, the Center received 4.1/5, 4.2/5, and 4.2/5, respectively, all noticeably above the national averages. The evaluations for 2016 were very similar (for research, 4.8/5).
10. The following federal evaluation was provided to the HVT Center by Dr. Andrei Marshall, NSF I/UCRC program director, on Apr**il 11, 2018:** ***"After review of your annual report, I am writing to inform you that HVT has met NSF member requirements and is considered to be in good standing. The HVT Center has made significant research contributions during Phase I. We ask HVT to carefully consider a Phase II proposal submission."***
11. According to Dr. Lindsey McGowen in her NSF Evaluator’s Report, February 28, 2019

"This is the final year of Phase 1 for the Center for Novel High Voltage/Temperature Materials & Structures (HVT Center). During the award period, the Center has established policies and procedures necessary for the successful operation of an IUCRC. With the support and involvement of industry and government members, the Center has established an industrially relevant program of research in multiscale design and development, advanced manufacturing, environmental degradation, damage prevention, and the monitoring and diagnosis of HVT materials, structures, and equipment. Since its launch in 2014, the HVT Center has been supported by 19 member organizations, investing $2.7M in industrial funding for Center research, with an additional ~$3M in additional support from NSF and other federal grants. They have produced over 100 journal publications, 84 conference presentations, and graduated 14 MS and 20 PhDs. ***When compared to other Phase 1 IUCRCs, HVT Center is a leader in many respects: they are in the top 10 for the number of university sites, the number of IAB members, students trained, students graduated, and publications. And they are on par with their Phase 1 peers in terms of the total annual budget and membership support.***"

Dr. Kumosa's Memberships on Editorial Boards

1. Composites Science and Technology (#1 int. j. in composites; Impact Factor 9.9), since 2001; extended until 2025
2. Structural Durability & Health Monitoring (http://www.techscience.com/sdhm/)
3. Fibers (http://www.mdpi.com/journal/fibers)

Academic Awards

1. John Evans Professor, the highest recognition at DU for outstanding internationally recognized research or other creative, scholarly achievement, was awarded in April 2006. One of 20 recipients selected between 1990 and the present.

2. Distinguished Teaching Award, Oregon Graduate Institute (OGI), Portland, OR, 92-93; the highest recognition for research and graduate teaching at the Oregon Graduate Institute of Science and Technology (OGI), Portland, Oregon.

Completed Graduate Programs under Dr. Kumosa's advising

1. 25 PhDs
2. 20 MS projects

Most Accomplished Graduate Students Advised by M. Kumosa

1. Professor N. Sukumar, MS at OGI in 1992; presently Professor of Computational Mechanics, University of California, Davis
2. Dr. A. Bansal, Ph.D., at OGI in 1995; presently Senior Manager at Applied Materials Inc.
3. Professor G. Odegard, Ph.D., at DU in 2000; presently
    - Professor of Computational Mechanics at MTU
    - HVT Site Director at MTU since March 2014
    - Director of the NASA Institute for Ultra-Strong Composites by Computational Design; since August 2017, $15M grant from NASA for five years
4. Dr. K. Searles, Ph.D., at OGI in 2000; presently Senior Research Engineer at Exxon-Mobil Corporation – Upstream Research, Kingwood, TX
5. Dr. B. Benedikt, Ph.D., at DU in 2003; presently Senior Scientist at Los Alamos National Laboratory
6. Dr. P. Rupnowski, Ph.D., at DU in 2005; presently Senior Scientist at NREL in Golden, CO.
7. Dr. B. Burks, Ph.D., at DU in 2012; President at Hexagon Digital Wave, LLC, Englewood, CO
8. Dr. Z. Loftus, Ph.D., at DU in 2013; presently Lockheed Martin Technical Fellow, Denver, CO.
9. Dr. J. Middleton, Ph.D., at DU in 2014; presently Lead Mechanical Engineer, L3Harris Technologies, Alpharetta, Georgia.
10. Dr. J. Hoffman, Ph.D., at DU in 2015; presently Deputy Director of HVT Center and Research Associate Professor at DU.
11. Dr. E. Hakansson, Ph.D., at DU in 2016; initially a lecturer in Mechanical Engineering at the University of Auckland, Auckland, NZ. World's fastest female motorcycle rider https://en.wikipedia.org/wiki/Eva_H%C3%A5kansson, also a founder & CEO of KiwiFil 3D in NZ
12. Dr. C. Henderson, Ph.D., at DU in 2019, initially at the US Bureau of Reclamation in Denver, CO, presently Chief Corrosion Engineer at Carollo Engineers, Westminster, Colorado.

Recently Graduated Ph.D. Students

13. Dr. M. Bleszynski, Ph.D., at DU in 2018; presently founder and CEO of Greenshoot Materials, LLC, Colorado.
14. Dr. Tianyi Lu, Ph.D., at DU in 2019; presently with China National Electric Apparatus Research Institute in Guangzhou, China.
15. Dr. Daniel Waters, Ph.D., at DU in Fall 2021, Senior Engineer, Lunar Mobility Prog, Lockheed Martin, since April 2022, Denver, Colorado.
16. Dr. Sabuj Khadka, Ph.D. at DU, Research and Development Engineer, Johnson & Johnson Innovation Center, Boston, MA., starting April 2022.

17. Billy Grell, PhD at DU in 2023, Senior Engineer and Associate Technical Fellow, Lockheed Martin Corporation, Denver, Colorado.
18. Jide William, PhD, at DU in 2023, Non-Tenure Assistant Professor, Colorado State University, Fort Collins, Colorado
19. Matt Reil, PhD at DU in 2024, Chief Scientist at Field Propulsion Technologies, Denver, Colorado.

Other Highly Accomplished Students Involved in Dr. Kumosa's research

1. Dr. L. Kumosa (son); Ph.D. in Bioengineering from UCSD in 2011; presently Postdoctoral Fellow at Neuronano Research Center (NRC) at Lund in Sweden. Between 1999 and 2003, Dr. L. Kumosa worked with Dr. M. Kumosa as an undergraduate research assistant/associate at DU and published jointly 25 journal papers in materials science, composites, and electrical engineering. Dr. L. Kumosa has recently published several papers in leading neuroscience journals, including "Commonly Overlooked Factors in Biocompatibility Studies of Neural Implants," by Lucas Kumosa, Advanced Science, January 2023. https://doi.org/10.1002/advs.202205095

Dr. Kumosa's Total Competitive Research Funding between 1990 and 2024

Approximately $8.0M (both federal grants and private/federal contracts), including:

- Federal Grants: $2.750 M (5 NSF and 5 AFOSR grants, with M. Kumosa as PI
- Private/Federal Contracts: $5.3M (including multiple BPA, WAPA, NASA Glenn individual contracts and HVT memberships)

Average per Year: ~ $250 in 32 years (with continuous funding ranging from approx. $150k to $500k/year)

Publications

1. Approximately 150 published in international journals, including:
   a) 35 papers in Composites Science and Technology (#1 in composites)
   b) 25 in major IEEE journals (Transactions on Dielectrics and Electrical Insulation, Transactions on Power Delivery, Insulation Magazine, Transactions on Reliability, and Transactions on Instrumentation and Measurement)
   c) 75 papers in other composites, physics, materials science, mechanics, general science, and other journals
   d) 15 journal papers not listed under Web of Science; for example, Acoustic Emission (1982), Additive Manufacturing (2017), CIGRE journal (2016), Polish Technical Journals, and others
   e) Other papers in press (1), submitted (2), and to be submitted (4)

2. 60 papers at international conferences, nine articles in major engineering magazines, and others
3. At least 50 extensive federal and private industrial and scientific reports, including two EPRI final externally published reports ($20k per copy) and numerous HVT Center annual and semi-annual, monthly reports to NSF and HVT industrial members
4. Citations

54711 citations according to Google Scholar; h-index 44 and i10-index 109

Most Important Engineering and Scientific Accomplishments

Graduate Research at PWR, Poland, between 1975 and 1983

Master's Thesis (Materials Science, 1978); Dislocation Characteristics in Silicon-Iron Above and Below the Brittle–Ductile Transition Temperature

Using advanced electron microscopy (EM) techniques, the types, density, and distribution of dislocations in 3% silicon–iron were investigated. Samples were elongated to failure below and above the brittle–ductile transition temperature, electropolished, and examined using a Philips and a Tesla microscopes. Primary dislocation types as a function of temperature were identified, and their Burgers vectors were determined from bright- and dark-field imaging. It was found that both the dislocation density and the morphology of dislocation lines were strongly affected by elongation temperature, for both screw and edge dislocations. Mechanical twinning was also observed at 77 K and was identified as a key mechanism initiating brittle fracture. This discovery served as the basis for Dr. Kumosa's subsequent PhD research.

PhD Dissertation (Applied Mechanics, 1981); Mechanical Stress Concentrations Around Stationary Mechanical Twins and Their Relaxation Under Limited Plastic Conditions

Mechanical twins in 3% silicon–iron were investigated both numerically and experimentally to determine their role in fracture initiation and in stress relaxation through slip formation at the tips of arrested twins. A fully anisotropic model of elliptical twins was developed using Eshelby's inclusion theory and the Asaro–Barnett formulation. Numerical analyses showed that the stress concentrations at the tips of terminated twins were sufficiently high to initiate catastrophic brittle failure at very low temperatures, or to trigger extensive slip formation at higher temperatures. In addition, the preferred directions of mechanical twinning were determined by minimizing strain energy over the anisotropic crystallographic twinning systems.

Cambridge Years between 1984 and 1990

After graduating from WPR (one of the top engineering schools in Poland) in 1982, Dr. Kumosa was appointed an Assistant Professor of Applied Mechanics and Materials Science at WPR in 1983. In January 1984, primarily due to economic reasons, he left Poland and sought academic employment abroad. Initially, between January 1984 and December 1984, he worked as a Visiting Research Fellow at the University of Liverpool. Then, in December 1984, he moved to Cambridge, England, where he spent more than six very productive years. In the Department of Materials Science and Metallurgy at the University of Cambridge, working with Professor Derek Hull, FRS, Sir Alan Cottrell, FRS, and Professor John Knott, FRS, Dr. Kumosa was exposed to state-of-the-art material science research and advanced composites research. Dr. Kumosa's final title at Cambridge was Senior Research Associate, which is similar to an Associate Research Professor in the States. At Cambridge, Dr. Kumosa conducted research on:

(1) application of Finite Element Methods (FEM) to failure predictions of advanced composite structures subjected to multiaxial loading conditions,
(2) stress corrosion cracking (SCC) of Glass Reinforced Polymer (GRP) composites,
(3) mixed-mode failure and fracture of both GRP and Carbon Fiber Reinforced (CFRP) composites,
(4) environmental failures of HT polymers,
(5) application of Acoustic Emission (AE) for monitoring composite structures, and
(6) composite crashworthiness.

In particular, Dr. Kumosa made significant contributions to:

- development of the Iosipescu shear test showing how the test could be modeled by FEM, including the presence of axial splits and their effect on composite failure predictions, a highly unique approach. He also, jointly with W. Broughton, redesigned the test to include biaxial shear-dominated conditions (highly novel at that time).
- multiaxial testing of filament-wound composite tubes; evaluated by FEM with experimental verification of the presence of hoop cracks in thin-walled composite tubes (first time, not widely cited, however).
- crushing of composite structures; proposed the very first numerical model of a composite tube subjected to axial crushing (still widely cited internationally).
- monitoring of stress corrosion cracking in GRPs using acoustic emission (widely cited); showed how fractured fibers in SCC of GRPs can be precisely counted using AE.

Also at Cambridge, Dr. Kumosa extended his Ph.D. research, which he had already defended in 1982. At Cambridge, he finalized and submitted two international journal papers based on his PhD work, both of which were successful. At Cambridge, Dr. Kumosa published 14 papers in international journals and several papers at global conferences. According to Dr. J. Knott FRS and Sir Alan Cottrell FRS, Dr. Kumosa made significant contributions to science during his years at Cambridge, as stated in their recommendation letters (copies available).

GE90 Research between 1990 and 1995

In May 1990, due to family reasons, Dr. Kumosa moved to the Oregon Graduate Institute of Science and Technology in Portland, Oregon. The SCC and shear testing of composites projects moved with Dr. Kumosa to OGI. They subsequently became the nuclei of two extensive research programs at OGI and later at DU on (1) the biaxial failures of HT polyimide composites and (2) in-service failures of HV transmission composite insulators (the SCC research).

At OGI, between 1990 and 1995, Dr. Kumosa was involved, as a PI, in the failure analysis and design of advanced metallic alloys for jet engine applications as part of the GE90 project jointly supported by General Electric Aircraft Engines (GEAE), Precision Castparts Corporation, the State of Oregon, and the Federal Bureau of Mines. His first research group in the US investigated the resistance to HT fracture and fatigue of nickel-based superalloys and titanium aluminides used in the GE90 engine.

HT fracture and fatigue tests were performed between 1990 and 1993 on a nickel-based superalloy (Rene 220C) at room temperature and at 1200°F to evaluate the effects of hold times, frequencies, load amplitudes, creep, microstructure, and other variables on crack growth in the alloys, simulating in-service conditions in the GE90 jet engines, which were about to be installed on Boeing 777 aircraft. Then, after the first two years and the accomplishment of the original goals of the Rene 220C project, the efforts, still funded by the same sponsors, moved to improving the ductility of titanium aluminides, also for the GE90 project.

Dr. Kumosa's GE work was highly proprietary, and little was published except for one journal paper (Scripta Metallurgica, 29-5, Sept. 1993), **several successful technical reports (copies available)**

submitted to the sponsors, and one Ph.D. thesis (Dr. J. Ding, OGI, 1995). According to the sponsors at GEAE, Drs. Ken Wright, Ken Bain, and others, the superalloy and titanium aluminides projects managed by Dr. Kumosa at OGI were highly successful.

Transition to PMC Research between 1991 and 1996

Also, at OGI, while working on the GE90 project, Dr. Kumosa began developing new research programs in 1991/92 in the area of Polymer Matrix Composites (PMC), which was more consistent with his research experience at Cambridge. The PMC research programs were subsequently moved to the University of Denver. Dr. Kumosa's main research activities at DU between 1996 and 2014 were primarily related to

(1) the use of PMCs at temperatures as high as 350°C for aerospace applications and

(2) the use of PMCs in HV electric fields (up to 500kV) for power transmission applications. The successful programs were supported by three consortia of federal and private sponsors, all originally built by Dr. Kumosa at OGI and subsequently expanded at DU.

HV Transmission Line Insulator Research between 1992 and 2006. Between 1992 and 2006, Dr. Kumosa supervised major interdisciplinary research efforts on HV composite insulators, also known as Non-Ceramic Insulators (NCIs). The insulators are widely used in transmission lines and substation applications in the US and abroad. In service, the insulators are subjected to the combined action of extreme mechanical, electrical, and environmental stresses. Due to these stresses, catastrophic failures of insulators would occur quite frequently in service in many regions of the world. Because of his composite background, in 1992, the US Government (DOE) requested Dr. Kumosa's involvement in a major study leading to the comprehensive evaluation of the suitability of polymers and their glass fiber composites in HV transmission line applications. The request came from the Bonneville Power Administration (BPA) and the Western Area Power Administration (WAPA). For more information, please contact Mr. Mike Staats, Senior Manager at BPA (retired), and Mr. Ross Clark, VP for Engineering at WAPA (retired).

The primary goal of the HV insulator research was to understand the fundamental mechanisms underlying the premature mechanical and electrical failures of insulators in service and to improve their design to prevent such failures. This research was extensively funded through multiple contracts by the Electric Power Research Institute (EPRI) and a consortium of electric utilities and insulator manufacturers consisting of BPA, the Alabama Power Company (APC), WAPA, Pacific Gas & Electric (PG&E), the National Rural Electric Cooperative Association (NRECA), NGK-Japan and Glasforms, Inc. Thanks to the generous support of these sponsors, Dr. Kumosa's research groups, initially at OGI and then at DU, made critical contributions to the entire field of composite insulator technology. Dr. Kumosa's most important accomplishments in this area consist of:

- Satisfactory explanation of several devastating groups of large HV transmission line insulator failures by brittle fracture experienced by:
  - Western Area Power Administration; catastrophic 345 kV failures in 1991/92 on their very large Craig Bonanza line in Colorado, resulting in 14 energized line drops
  - Pacific Gas & Electric; 5 catastrophic 500 kV line drops on their Monterey Moss Landing Line in California in 1995/96
  - Several less severe but equally important international insulator failures.
- First identification of the type of acid responsible for the brittle fracture failures in CA, CO, and many other parts of the world.
- First simulation of brittle fracture in the insulator GRP composites with and without high voltage; a very unique accomplishment and absolutely critical for the entire HV insulator industry.
- First comprehensive model and explanation of insulator failures caused by improper crimping.
- First identification of several critical conditions leading to brittle fracture and other mechanical and electrical failures of NCIs, which was the first comprehensive approach of this type, leading to extensive insulator improvements across the globe.
- First ranking of the commonly used GRP rod materials for their resistance to HV brittle fracture and other HV failure modes (electrical, overcrimping, mishandling, etc.).
- Recommendation of numerous experimental and numerical procedures critical for insulator design.

Most of Dr. Kumosa's insulator research has been published in numerous major IEEE Transactions and composites journals (see his full Vitae). This research is still internationally cited, and the citation rates are steadily increasing. The HV composite insulator research had a significant international impact on the entire HV transmission industry (see 1-4 below). The 1992 and 1995 insulator failures at WAPA and PG&E had devastating effects on manufacturers and users of NCIs worldwide. The confidence in their suitability and, in many cases, their superiority

over the old porcelain designs was reestablished by Dr. Kumosa and his internationally recognized HV composite research, which was completed around 2006.

1. Interview with Maciej Kumosa of the University of Denver, Research of Brittle Fractures in Composite Insulators, Insulator News & Market Report, July/August 1997, pp. 47-51.

2. Research Program on Brittle Fracture Concludes at the University of Denver; Interview with Maciej Kumosa, Insulator News and Market Report, July/August 2005, pp. 78-83.

3. Composite Insulator Failures Lead to Improved Designs, Transmission and Distribution World, January 2006, pp. 42-48.

4. https://www.tdworld.com/safety-and-training/article/20957020/maciej-kumosa-pioneering-high-voltage-research

HT PMC Combustion Chamber Research between 1991 and 2004

The second area of Dr. Kumosa's research on PMCs, initially at OGI and later at DU, was the numerical and experimental failure analysis of advanced HT carbon fiber/epoxy and polyimide matrix systems for aerospace and space applications. The primary goal of this research was to understand the fundamental failure mechanisms in HT composites comprising medium- and high-stiffness carbon fibers and various HT polyimide resins. Particular attention was given to determining the effect of physical and chemical aging on the strength properties of the composites as a function of temperature and biaxial shear-dominated loading conditions. In collaboration with NASA Glenn, Boeing, and 24 other large US industrial organizations, Dr. Kumosa was involved in developing multidisciplinary technologies for affordable propulsion engine components that enable systems to operate at higher temperatures with reduced cooling requirements while maintaining performance and durability.

(http://www.grc.nasa.gov/WWW/RT2002/5000/5150sutter.html).

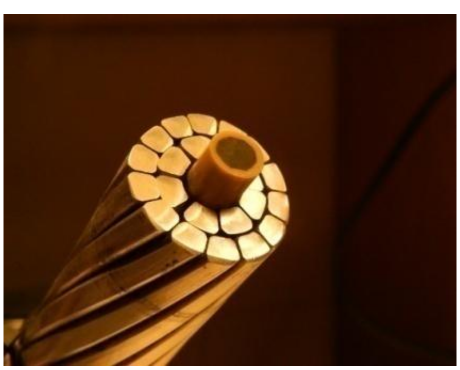
As part of the HT PMC efforts of the entire consortium, unique carbon/polyimide composites and fabrication technologies were developed, suitable for manifolds, thrust chamber supports, and attachments. The use of such composites enabled the replacement of heavy-metal engine components, thereby providing a high thrust-to-weight ratio. The combustion chamber, designed and manufactured (see left), was successfully tested by NASA Glenn for 5 days in 2004 under full-thrust conditions. Dr. Kumosa's portion of the study was jointly and extensively funded for 9 years by the National Science Foundation (3 consecutive grants), the Air Force Office of Scientific Research (5 consecutive grants), and NASA Glenn Research Center (3 contracts), with extensive interactions across the entire consortium. The work was supervised by Dr. Jim Sutter at NASA Glenn (for the entire consortium) and Drs. Tom Han, Ozden Ochoa, and Charles Lee at AFOSR. The work of Dr. Kumosa's group and his graduate students resulted in:

- the development of unique experimental/numerical techniques based on embedded Al inclusions, X-ray diffraction, and non-linear multiple inclusion Eshelby models for the prediction of residual manufacturing stresses in the HT PMC composites for unidirectional and woven laminates with various fabric architectures.
- predictions of failure properties of the composites at HT under multiaxial shear-dominated conditions.
- evaluation of aging resistance of the composites in nitrogen (physical aging) and in the air (chemical aging) at temperatures as high as 400°C, and many other significant but less critical accomplishments.

The HT combustion chamber composites were optimized by Dr. Kumosa and his graduate students at DU by selecting fibers and matrices based on their HT behavior. This subsequently resulted in the successful testing of the combustion chamber (see above).

Polymer Core Composite Conductor Research between 2008 and 2014 at DU and then in the HVT Center after March 2014

Starting in 2008, Dr. Kumosa and his graduate students investigated HT HV Polymer Core Composite Conductors (PCCC) for HV transmission line applications. This research was initially funded from 2008 to 2014 by BPA, WAPA, Tri-State, CTC Global, and NSF (GOALI), and then, in 2014, moved to the HVT Center.



Due to the rapidly increasing demand for electric power and the development of new energy sources, there is an urgent need in this country and abroad to transport more electrical power more efficiently using existing rights-of-way. However, the current designs of HV conductors, based on steel strands (for strength) and aluminum (for conduction), used in regional grids, are limited by their tendency to sag. One of the incidents involving sagging of a steel/aluminum conductor and a subsequent HV discharge to a tree occurred in Ohio in 2003 (https://en.wikipedia.org/wiki/Northeast_blackout_of_2003) affecting 55 million people in Canada and the US. Therefore, new conductors, so-called High Temperature Low Sag (HTLS) conductors with significantly better resistance to sagging, are being designed. One of them is the PCCC design (see upper left).

The PCCC conductors are based on a unidirectional PMC core with carbon and glass fibers for strength and stiffness, and aluminum strands for conduction. They can deliver up to three times the power of current designs based on steel and aluminum. In addition, the PCCC sag less than established overhead conductors (carbon fibers shrink on heating!). Since the conductors are designed with an expected life of 50 years, their structural deterioration with time needs to be well understood, considering in-service temperatures of up to 180°C, high concentrations of ozone, atomic oxygen, nitric acid, and other pollutants, as well as a variety of extreme dynamic mechanical and electrical loading conditions. The significant accomplishments of Dr. Kumosa's group to date in the HTLS conductor area are as follows:

- The critical bend radius of the most popular HT LS PCCC was determined numerically and verified experimentally by Dr. Kumosa and his students at DU in 2008-2010. This analysis subsequently explained three catastrophic international failures of the US-manufactured conductors in Poland in 2008. Dr. Kumosa’s involvement in the 2008 conductor failures was requested by the US government (WAPA, Mr. Ross Clark), and the explanations were reported to the international transmission line community in 2010 (IEEE PES, Minnesota, July 2010) and in several IEEE papers. Dr. Kumosa’s explanation of the Polish failures with this novel US transmission line technology helped rebuild the manufacturer's reputation and reestablish its international standing. It also reestablished trust in the PCCC technology.
- In 2011, Dr. Kumosa was asked again by DOE (Mr. Ross Clark) to explain another PCCC failure, this time in Salt Lake City, Utah, on a 230 kV line. The failure was caused by excessive bending under severe dynamic conditions. Like the Polish failures, the Utah failure was correctly explained and reported to the IEEE community.
- It was shown in 2009-2012 for the first time that PCCC rods could be sensitive to transverse loading under aeolian vibrations. It was also suggested that bearing stresses resulting from crimping the conductor at a dead-end connection in a transmission line could be considered for effective fatigue-life design. This effect was also evaluated for the first time for the PCCC rods at

various stages of environmental aging (a highly unique combined experimental/numerical approach).

- The same group performed life predictions of the PCCC conductors. They demonstrated that exposure to HT appears to be much more damaging to PCCC rods than exposure to highly concentrated ozone. Considering possible environmental conditions (HT, ozone pollution, etc.), it was predicted that the PCCC rods could survive in service for many years if the operating temperature did not exceed 120°C and the ozone concentration was no more than about 1%. This, however, should be further independently verified.
- Dr. Kumosa's group showed that the in-service life of the conductors could be significantly extended (by 75%) if special Teflon coatings were placed on the rods. Such coatings were subsequently developed at the HVT Center, and their feasibility was demonstrated internationally in 2015.
- The current PCCC design was evaluated for its resistance to corrosion on transmission lines (a major problem facing utilities using the traditional steel/aluminum design, especially in coastal environments). A new powerful analytical model of atmospheric galvanic corrosion of PCCC conductors was proposed and numerically and experimentally verified in 2016 (rapidly gaining international recognition; Hakansson et al., Corrosion Science, 2017).
- The PCCC conductors were studied by the HVT Center in 2014-2017, for the first time, for their resistance to low velocity excessive transverse impacts by using unique impact fixtures and by simulating the impact behavior by FEM (Waters et al, Int. J. Impact Engineering, 2017). In this area, the conductors also demonstrated their superiority over their Al/steel counterparts.
- Dr. Kumosa's research group also demonstrated that the PCCC conductors could be successfully monitored in service for a variety of static and dynamic loads using Fiber Bragg Grating sensors. The sensors could also be used to accurately monitor the conductors during installation and in service, including both small and large deformations. Such monitoring could identify potential damage to the PCCC rods, which might result in major catastrophic failures of the conductors in service, even several years after their installation, as happened in Poland. This critical development was published in two papers in the IEEE Transactions on Instrumentation and Measurement (Waters, Hoffman, and Kumosa, 2018, and Hoffman, Waters, and Kumosa, 2019).

Dr. Kumosa and his research teams have improved the understanding of the in-service performance of the next generation of HV HTLS Polymer Core Composite Conductors (similar to his previous HV composite insulator project) and suggested numerous potential improvements to their designs (see #1 below). No other research team has made similar contributions in this area,

which is critical to so many utilities worldwide. One of the reasons why the HVT Center was awarded to Dr. Kumosa and his research partners from MTU, UIUC, and UConn in 2014 was the exceptional progress of the PCCC research at DU between 2008 and 2014.

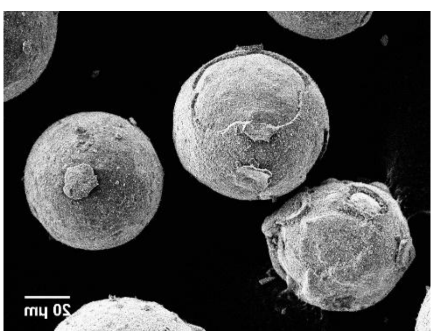
1. University of Denver Professor: New Transmission Line Product Would Save Lives, Denver Business Journal, May 24, 2013
http://www.bizjournals.com/denver/print-edition/2013/05/24/university-of-denver-professor-new.html?page=all

I/UCRC for Novel High Voltage Materials and Structures since 2014

It is beyond the scope of this document to adequately describe the size, complexity, and national/international importance of all research efforts in the HVT Center (see Dr. Kumosa's HVT Final Report for Phase I, December 2025). Four large research teams (60 mostly Ph.D. students, 12 faculty, and 4-6 postdocs) at some of the best engineering graduate schools in the country were solving major engineering problems and closely collaborating with numerous industrial partners. Between March 2014 and October 2024, the Center completed about 60 research projects concentrated in 5 major research areas (see Dr. Kumosa's HVT Final Report for Phase I, December 2025). The Center also held 12 major meetings, including a grant-planning meeting in 2012, five semi-annual meetings, and five annual meetings with industrial members, NSF representatives, the sites, and numerous guests.

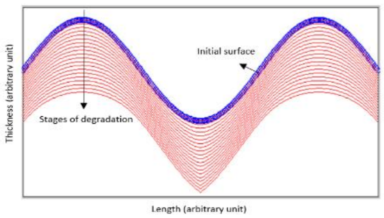
Below, some of the key accomplishments from the recently completed and active HVT projects at DU under Dr. Kumosa's advising and supervision between 2014 and 2024 are presented, highlighting their engineering/scientific complexity, importance, and relevance to HVT technologies globally.

1. Effect of Oxygen Aging on Ti/Al/V Powders used in Additive Manufacturing



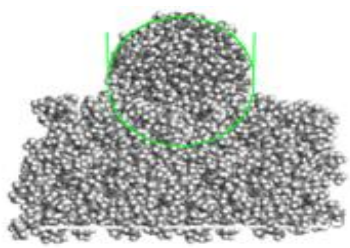
In collaboration with NIST and Lockheed Martin, the HVT Center has shown, for the first time, that the effect of oxygen on the toughness of aerospace Ti/Al/V parts made by additive manufacturing can be accurately determined using an entirely new approach proposed by Grell, Kumosa, Loftus, et al. (Additive Manufacturing, 2017). Ti/Al/V powders were first artificially oxidized in air and then used to make Charpy specimens with oxygen contents up to 0.5%. This resulted in a dramatic decrease in the alloy's toughness. Using such data, aerospace and other industries could, for the first time, relate oxygen content in their AM powders to the reduction in the resistance to fracture of their AM parts.

2. Synergistic Aging of Polymers and their Composites



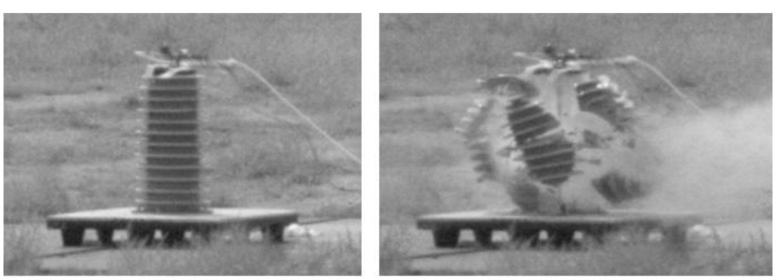
Synergistic aging of polymers and GRP composites exposed to UV, water (rain), temperature, and time was numerically simulated and experimentally verified. Unique numerical models of UV degradation of uneven polymer surfaces were constructed. Polymer micro-particles created by UV were then numerically removed from polymer and composite surfaces by slowly moving rainwater. The numerical simulation of water-based cleaning was supported by experimental verification. The work was published in Polymer Degradation and Stability (PDS) and in CST (Lu, Solis-Ramos, Yi, Kumosa, et al, 2017).

3. Prevention of HV Silicone Rubber Aging in Extreme Environments



Extreme aging of silicone rubbers used in HV voltage applications was investigated in this highly transformative research. New molecular dynamics (MD) models of aging of the rubbers were proposed. The models were used to design the next generation of HV rubbers with embedded titanium dioxide particles to improve their resistance to extreme oxidative aging. As a result, an HV silicone rubber was designed, manufactured, and tested, with its resistance to extreme aging improved by about 50%. This critical HV transmission technology work was published in PDS (Bleszynski and Kumosa, 2017) and in CST (Bleszynski and Kumosa, 2018). In addition, a new model of residual dielectric strength of rubbers under dry-band arcing and pollution was also proposed (Allen, Kumosa, et al., 2018).

4. Prevention of Ballistic Damage to HV Transformer Bushings

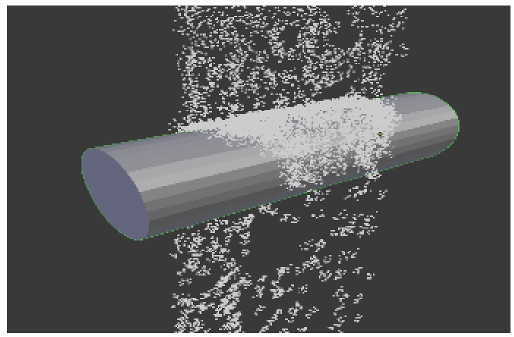


(a) (b)

In this unique study, conducted jointly by the HVT Center, the US Bureau of Reclamation, and the FBI, HV porcelain transformer bushings subjected to high-power rifle damage were experimentally modeled as pressurized glass cylinders subjected to air-gun impacts. The cylinders were tested with ballistic polymer coatings for damage initiation and fragmentation. In their subsequent work, the authors tested full-scale porcelain-transformed bushings under high-power rifle impact to demonstrate the effectiveness of the coatings for damage protection. It was shown for the first time that bushings could be protected when sufficient coating thicknesses were used, even under high-energy, high-velocity rifle-impact conditions.

The first part of this research, critical for electric utilities worldwide, was published in Int. J. Impact Engineering (Henderson, Kumosa, et al, 2018). The full-scale ballistic testing work on coated bushings was also published in the same journal (Henderson, Kumosa, et al., 2019). They also evaluated the efficiency of polymeric coatings for impact protection of brittle materials in drop-tower tests (Henderson et al., 2020, Int. J. Impact Engineering).

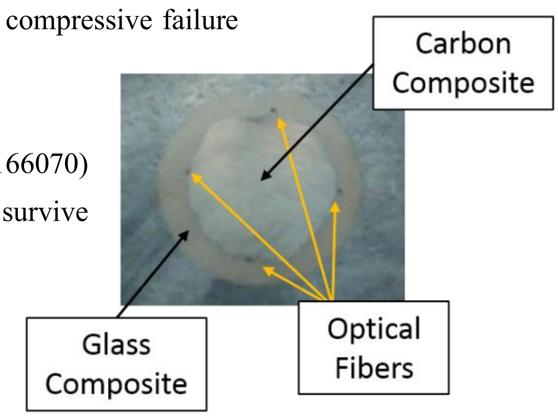
5. Design of Next Generation Icephobic Barriers



Ice adhesion to ultra-low energy surfaces, ice shedding, ice accumulation prevention, and aging of ice barriers were successfully studied by Bleszynski, Woll, Middleton, and Kumosa since 2016. The group reduced ice accumulation on HV PCCC by 50% by coating the conductors with a new icephobic barrier developed by the HVT Center. Ice adhesion to the barriers was also reduced to about 7kPa, which is very low compared with ice adhesion to Al (about 500kPa). Unique MD, FEM, and particle physics-based type models of ice adhesion, ice melting and accumulation, and ice prevention have also been recently proposed by Dr. Kumosa's graduate students in several papers: Polymer Degradation and Stability (Bleszynski et al, 2019), Materials & Design (Bleszynski and Kumosa, 2019), and Bleszynski et al, Int. J. Molecular Sciences, 2020.

6. Monitoring Next Generation PCC Conductors for in-Service Failures

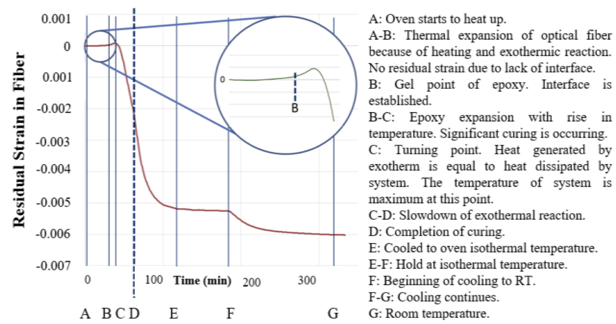
The application of FBG sensors for the monitoring of full-scale PCCC transmission lines by Waters, Hoffman, and Kumosa (IEEE TIM, 2018 and 2019) has been described above. We also determined the strength limits of their composite cores (Waters et al, Composites Part A, 2021). Both the effect of axial tension and the influence of fiber misalignment on the conductor's bending strength were investigated using a combined experimental, analytical, and numerical analysis. Using three and four-point bending experiments and a non-linear finite element model, the axial stresses and likely failure-initiating locations were identified in the rods. Damage modes included tensile failure and compressive failure due to fiber buckling and kink band formation.



We also demonstrated (Waters et al., IEEE, 10.1109/TPWRD.2022.3166070) for the first time that relatively inexpensive acrylate-coated FBGs can survive short exposure times to high temperatures during pultrusion and monitor relatively low-magnitude bending and axial tension strains in a composite material. The optimal placement of embedded optical fibers in the rods was determined based on the rods' limitations and the mechanical strength of the commercially available optical fibers.

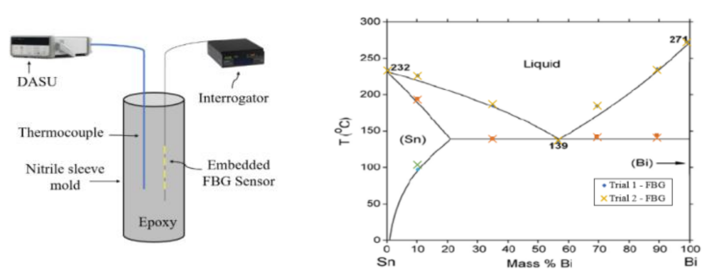
7. Monitoring Polymerization in Single Fiber Composites using FBG Sensors

A novel technique using FBG sensors was invented in the HVT Center to evaluate the responses of modeled polymer and metal composites to manufacturing conditions. For the polymers (epoxies), FBG sensors were used to identify the beginning and end of curing, the gel point, cooling strains, and stresses. Unique algorithms were developed to calculate the residual stress in the matrix using FBGs (Hoffman et al., Composites Science and Technology, CST, 2020, Khadka et al., CST, 2020, and Khadka et al, CST, 2022).



8. Monitoring Solidification of Metals using FBG Sensors

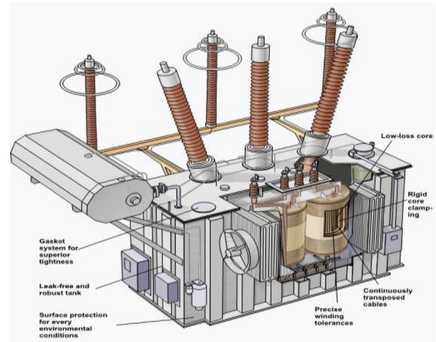
A new approach was also developed to determine phase diagrams of metals such as, for example, Sn/Bi alloys, and an algorithm was created to identify residual strains and stresses in the FBG fiber and the Sn/Bi alloys, all based on FBG measurements (Khadka et al, Materialia, 2022, and Hoffman et al, Materialia, 2022).



The above non-destructive FBG technology was also expanded in the HVT Center to monitor the extreme aging of polymers, including thermal and chemical decomposition, various manufacturing methods (including stresses during additive manufacturing), and the impact of many other stressors (Khadka, Ph.D. thesis, 2022, and several HVT Reports). The Center has also made significant advances in applying FBG sensors for monitoring full-scale transmission lines for ice deposition.

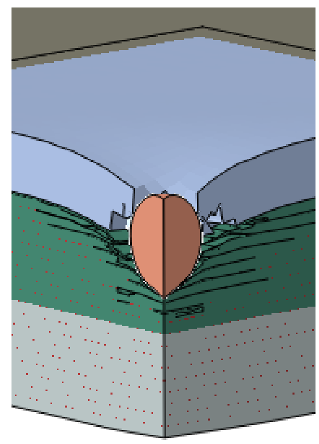
9. Modernization of the Large Power Transformer Tanks; funded by DOE Headquarters through HVT

Part A. <u>Application of polymer matrix composites in large power transformer tanks</u>. Large Power Transformers (LPT) are a key component of the electrical grid. A formalized approach has been developed at DU for the first time to identify substitute materials for LPT tanks. The ideal materials should be capable of maximizing reliability parameters, such as strength, stiffness, toughness, and resilience, while minimizing weight. In addition, the selection process was designed to incorporate the potential for self-healing and smart sensing. A preliminary selection stage followed by a TOPSIS optimization stage identified five advanced composite materials as potential replacements. The work has been published in the IEEE Transactions on Power Delivery, Williams et al., 37 (5), 2023, 4190-4201.

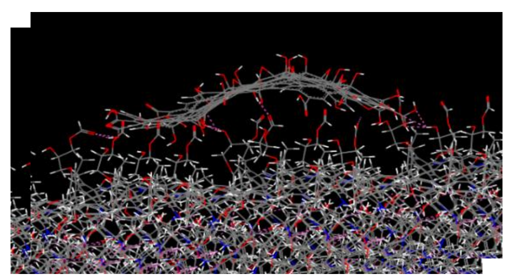


Part B. <u>Potential Impact Protection of Polymer Matrix Composite Panels Using Polyurea Coatings</u>

We developed a unique methodology to analyze the ballistic performance of steel and PMC materials for use in LPT tanks. Our numerical simulations of steel projectile impacts on LCS plates and on glass and/or carbon fiber polymer composite laminates showed that, with sufficient thickness, both could prevent projectile penetration. This prevention was especially effective when the plates were coated with a high-strain-rate-sensitive material, such as polyurea (PU), as reported by Williams et al. (Polymers 17 (3), 2025, 385.



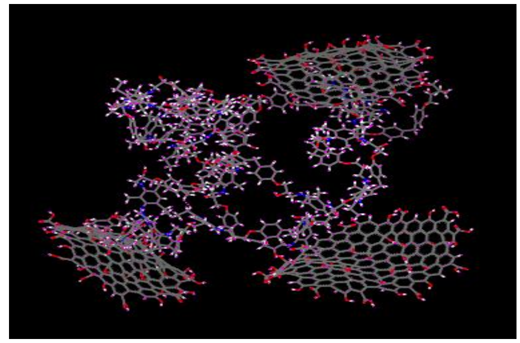
10. <u>Graphene (G) and Graphene Oxide (GO) Nano-Particle Interactions with Polymers</u>



Part A. Graphene and graphene oxide energetic interactions with polymers through molecular dynamics simulations,

Molecular dynamics simulations of graphene (G) or graphene oxide (GO) nanoplates with epoxy, PDMS, or ABS were performed separately to investigate plate/polymer interactions using both large and small MD models. The simulations independently demonstrated that polymer matrix plate composites (PMPCs) doped with GO resulted in stronger stabilizing interactions than those doped with G. Important conclusions were drawn regarding the ability of the G and GO nanoparticles to be evenly dispersed in the investigated polymers. by Reil et al., Computational Mat Sci, Vol 211 (2022) 111548.

Part B and C. Effects of G and GO Desperation on Polymers (B) and High Toughness Graphene Oxide/Epoxy Nanocomposites Under Compression (C)



The effect of G and GO agglomerates on epoxy was investigated by manufacturing G- or GO-doped epoxy nanocomposites without pre-exfoliation and by conducting mechanical property testing in tension, bending, and compression. The toughness of GO/epoxy nanocomposites was estimated, showing trace amounts of GO increased the tensile toughness under compression by approximately 1 to 2 orders of magnitude, M Reil., Composites Science and Technology 248, 110433 (B), and Reil et al., under review in CST, 2024/5 (C)

11. Recycling Carbon and Glass Fiber Polymer Matrix Composite Waste into Cementitious Materials

We investigated if hybrid carbon and glass FPMC waste could be recycled as an admixture for cementitious materials in order to improve their properties for seawater applications. We assessed the compression strength of ordinary Portland cement (OPC) with 6% wt of various FPMC admixtures before and after accelerated salt-water aging. The experimental part of this research was supported by molecular dynamics (MD) simulations to examine the effect of FPMC admixtures on moisture diffusion in OPC. " by Clark et al. in Resources, Conservation, and Recycling, 2020.

12. Visualizing Polymer Damage Using Hyperspectral Imaging

Hyperspectral imaging (HSI) and previously investigated aging methods were successfully used as a proof-of-concept to demonstrate how HSI can detect various types of aging damage in different SIR materials. The spectral signature changes in four different SIRs subjected to four different in-service aging environments all occurred between 400 and 650 nm. Bleszynski et al, in Polymers, 2020.