

## **CHRISTOPHER RUDOLF**

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### **Education**

- Ph.D Mechanical Engineering, Florida International University** Aug 5, 2016  
Research Areas: Ultra-high temperature ceramic composites; Spark plasma sintering;  
In-situ mechanical testing; Graphene based composites  
Awarded the Dissertation Year Fellowship (DYF) from FIU University Graduate School
- M.S. Mechanical Engineering, Florida International University** Dec 14, 2013  
Specialization in Mechanics and Materials
- B.S. Mechanical Engineering, Florida State University** April 28, 2012  
Minors in Math, Physics

### **Research Skills**

#### **Material Processing**

- Composite formation by wet chemistry including ball milling, ultrasonication, high-throughput tip-sonication for grain refinement and nano-particle dispersion followed by drying in a vacuum oven.
- Laser engraving and cutting: Proficient in the use of the Epilog CO<sub>2</sub> Laser for raster engraving and vector cutting of various materials including the programming of the path and speed/power optimization. Specifically used for the scoring of Si wafers for use as anodes in Li-ion batteries.
- Spark plasma sintering (SPS) of various materials. During my graduate studies, I was the SPS equipment custodian and in charge of processing parameter development (for desired densities and microstructures) for materials including metals, ceramics, and composites.
- Plasma spray coatings (thermal spray) using a Praxair SG 100 gun mounted on a 3-axis robotic scaffold. Materials sprayed include high temperature ceramics with multifunctional electromechanical properties.
- Additive manufacturing (3D printing). Lead in charge of the 3D printing laboratory during graduate school (2 semesters). Skills include part design using CAD programs and optimization of print parameters

#### **Material Characterization and Testing**

- Scanning Electron Microscopy (SEM) with Energy-Dispersive X-Ray Spectroscopy (EDS) and Electron Backscatter Diffraction (EBSD) for elemental analysis and chemical characterization of a sample. Extensively used for grain size characterization, analysis of wet chemistry dispersion of nanoparticles in a matrix, analysis of ceramic reinforcement phase alignment, and crack length measurements for post fracture analysis as a measure of material toughness.
- Focused Ion Beam (FIB). Underwent a two-week training during graduate school to be certified as an independent user on a Jeol MultiBeam SEM-FIB. Performed imaging using both the electron and ion beam for increased contrast. Performed deposition of Ga and Pt ions. Used milling and a serial slicing technique for a 3D morphology analysis.
- Optical Microscopy including digital imaging and photography of samples.
- X-Ray Diffraction (XRD). Utilized a Bruker D5000 using Cu K $\alpha$  radiation for post sintering characterization of ceramic composites to identify possible secondary phase formations.
- Static, Dynamic, and Fatigue Testing using an Instron ElectroPuls for mesoscale mechanical property evaluation in response to strain rate as well as extreme temperatures using an environmental chamber. Proficient in the use of Console, Bluehill, and WaveMatrix software for controlling and programming the system.
- In-Situ (inside SEM/FIB) Microscale Material Testing using an MTI SEMTester micro-load frame for tension, compression, microhardness, 3- and 4-point bend, adhesion layer, and splat-sliding testing. By combining load-displacement measurements with real time, high resolution imaging at the micro/nano scale, a new perspective on fracture mechanics is achieved. Additional experience using a Hysitron PI-89 SEM Picoindenter for nanomechanical testing.

- Forward Looking Infrared (FLIR) Camera System. Utilized for temperature characterization during electrically assisted deformation experimentation to monitor temperature through the gauge section of the metal wires as a function of applied electric current. Performed post-process analysis for determining the appropriate temperature profile to be run during Instron testing in the environmental chamber.
- Digital Image Correlation (DIC) using an MTS Video Extensometer (AVX) to accurately measure extension, strain, and strain rate, and rotation as well as post process analysis to monitor for slipping and formation of the necking region.
- Data Acquisition using National Instruments PXI Platform to allow synchronization of multiple modules into LabView.
- Electrochemistry of Li-ion batteries. This includes use of a glovebox for formulation of ionic liquid electrolytes and the fabrication of coin cell batteries. The batteries are then tested over a number of lithiation/delithiation cycles to analyze their stability.

### Software

- Origin, SolidWorks, Pro Engineer, ImageJ, Mathcad, Matlab, MS office, Adobe Illustrator, BlueHill, WaveMatrix

### Relevant Graduate Level Materials Coursework

- Experimental Stress Analysis; Computational and Advanced Computational Engineering Analysis; Analytical Techniques; Physical Properties of Materials; Principles of Composites; Intro to Ceramic Materials; Nanomechanics and Nanotribology; Finite Element Methods in Mechanical Engineering and Nonlinear Finite Element Analysis

### Research Experience

**U.S. Naval Research Laboratory, Washington, DC**

Feb 13, 2017 – Present

*Mechanical Engineer*

*Multifunctional Materials Branch of the Material Science and Technology Division – Code 6354*

- Lead investigator of electrically assisted deformation of metals (EADM) at the microscale. An MTI micro-load frame has been custom retrofitted to allow the passage of electric current through a 1 mm diameter metal wire while performing tensile experiments. By externally cooling the wire, high constant currents can be achieved while maintaining a safe working temperature range. The effect of electric current on deformation is isolated by subsequently performing tensile experiments in the environmental chamber of the Instron ElectroPuls at matching temperature profiles. A combination of analytical sensors (FLIR camera, AVX video extensometer, load cell) feed the information into a NI data acquisition system where it is synchronized using a LabView program.
- Lead investigator of fracture-free Si lithiation for next generation batteries. Examining the effect of size and temperature on deformation and fracture in the Li-Si system. Equipment setup is complete and initial proof of concept testing is underway.
- Performed pressure wave characterization as a result of blast testing to modernize the PPE testing standard for combat helmets. Spent a week at Chesapeake Testing performing helmet backface deformation characterization and how it relates to pressures picked up by sensors in a surrogate headform.
- Co-investigator of graphene growth on micro-scale wires. Examining the multifunctional properties of continuous graphene growth. A patent has been filed for a novel micro-mechanical testing device for tensile testing of these small-scale samples.
- Awarded the Karles Fellowship to invent a new method of measuring strain and pressures inside soft bio-surrogate materials. Developed and patented prototype liquid-metal – elastomer sensors for quantification of high-rate impact and shock events.
- Lead investigator of material-systems intelligence via neuromorphic computing (MINC). Utilizing lamb waves and an automated experimental platform, large datasets of damage to metal plates is being generated for training artificial neural networks.

**Florida International University, Miami, FL**

Jan 6, 2014 – Aug 5, 2016

*Graduate Research Assistant*

- Principal researcher on a grant from the Air Force Research Laboratory: Ultrahigh Temperature Ceramic (UHTC) Materials with Nano-Reinforcement
- Developed processing parameters and troubleshoot all issues as lead on the spark plasma sintering machine in our laboratory
- Performed material processing including composite formation by wet chemistry, spark plasma sintering, plasma spray coatings (thermal spray), and 3D printing
- Advanced novel material characterization techniques by performing in situ mechanical testing of many material systems with nano-filler reinforcement including ceramics, metals, polymers, and adhesive layers for micro/nano-scale observation

### **Teaching Experience**

**Florida International University, Miami, FL**

Jan 9, 2013 – April 26, 2014

*Graduate Teaching Assistant*

- Taught over 100 students in Mechanical Design (2 semesters), Mechanics and Material Science (2 semesters), and Dynamic Systems (1 semester)
- Led a weekly problem solving laboratory in dynamic systems (1 semester).
- Held office hours twice a week for individual tutoring
- Graded homework, quizzes, and exams

### **Field Based Engineering Experience**

**Bauer Foundations, Canal Point, FL**

Apr 29 – Jul 29, 2011

*Operations Engineer (Intern)*

- Surveyed the Lake Okeechobee dike for the placement of a cutoff wall
- Performed quality control analysis on samples taken from the newly injected cutoff wall
- Diagnosed the causes of broken machines
- Wrote and filed reports with the US Army Corp of Engineers

**City of Deerfield Beach, Deerfield Beach, FL**

May 10 – Aug 13, 2010

*Public Works and Environmental Services (Intern)*

- Generated a working model of the city's sewer system using H2OMAP Water software
- Calculated water flows and velocities
- Performed on-site inspections of the pump stations

### **Journal Publications**

1. M. Lefler, J. Yeom, **C. Rudolf**, R. Carter, C. Love. Structural and morphological analysis of the first alloy/dealloy of a bulk Si-Li system at elevated temperature. *ACS Omega*. *Accepted*
2. W.J. Choi, M.J. Kulak, C. Kim, E.J. Payton, **C. Rudolf**, W. Kang. Electro-thermo-mechanical characterization of microscale Ti-6Al-4V wires using an innovative experimental method. *Materials Characterization* 188 (2022) 111927.
3. H. Kashani, C. Kim, **C. Rudolf**, F.K. Perkins, E. Cleveland, W. Kang. An axially continuous graphene-copper wire for high-power transmission: Thermoelectrical Characterization and Mechanisms. *Adv. Mater.* 33 (2021) 2104208.
4. **C. Rudolf**, R. Goswami, W. Kang, J. Thomas. Effects of Electric Current on the Plastic Deformation Behavior of Pure Copper, Iron, and Titanium. *Acta Materialia* 209 (2021) 116776.
5. A. Loganathan, A. Sahu, **C. Rudolf**, C. Zhang, S. Rengifo, T. Laha, B. Boesl, A. Agarwal. Multi-scale tribological and nanomechanical behavior of cold sprayed Ti<sub>2</sub>AlC MAX phase coating. *Surf. Coat. Technol.* 334(25) (2018) 384-393.
6. **C. Rudolf**, B. Eranezhuth, B. Boesl, A. Agarwal. (Ta,Nb)C composites formed with graphene nanoplatelets by spark plasma sintering. *J. Eur. Ceram. Soc.*, 37 (12) (2017) 3781-3790.
7. A. Loganathan, A. Sharma, **C. Rudolf**, C. Zhang, P. Nautiyal, S. Suwas, B. Boesl, A. Agarwal. In-Situ Deformation Mechanism and Orientation Effects in Sintered 2D Boron Nitride Nanosheets. *Mater. Sci. Eng. A*, 708 (2017), pp. 440-450.

8. M. Asadikiya, C. Zhang, **C. Rudolf**, B. Boesl, A. Agarwal, Y. Zhong. "The effect of sintering parameters on spark plasma sintering of B<sub>4</sub>C". *Ceramics International* 43(14): 11182-11188, October 2017.
9. M. Asadikiya, **C. Rudolf**, C. Zhang, B. Boesl, A. Agarwal, Y. Zhong. "Thermodynamic modeling and investigation of the oxygen effect on the sintering of B<sub>4</sub>C". *Journal of Alloys and Compounds* 699:1022-1029, March 2017.
10. **C. Rudolf**, B. Boesl, A. Agarwal. TaC-NbC Formed by Spark Plasma Sintering with the Addition of Sintering Additives. *J. Ceram. Soc. Japan* 124 (4) (2016) 381-387.
11. **C. Rudolf**, B. Boesl, A. Agarwal. In Situ Mechanical Testing Techniques for Real-Time Materials Deformation Characterization. *JOM* 68(1) (2016) 136-142.
12. P. Nautiyal, **C. Rudolf**, A. Loganathan, C. Zhang, B. Boesl, A. Agarwal. Directionally Aligned Ultra-long Boron Nitride Nanotube Induced Strengthening of Aluminum based Sandwich Composite. *Adv. Eng. Mater.* 18(10) (2016) 1747-1754.
13. **C. Rudolf**, B. Boesl, A. Agarwal. In situ indentation behavior of bulk multi-layer graphene flakes with respect to orientation. *Carbon* 94 (2015) 872-878.

### Conference and Other Publications

1. **C. Rudolf**, Y.C. Chen, T. O'Shaughnessy. Bio-fidelic, Soft Deformation Sensing under Dynamic Loading, In Proceedings of the Society for Experimental Mechanics Annual Meeting, June, 2021
2. **C. Rudolf**, D. Wilbur, W. Kang. 3D Printed Mechanical Testing Device for Micro-Scale Material Systems, In Proceedings of the Society for Experimental Mechanics Annual Meeting, June, 2021.
3. **C. Rudolf**, C. Love, M. Merrill. Investigation of an Ionic Liquid as a High-Temperature Electrolyte for Silicon-Lithium Systems, In Proceedings of the ASME 2020 International Mechanical Engineering Congress and Exposition. November, 2020.
4. **C. Rudolf**, W. Kang, J. Thomas. "Method for Characterizing Electric Current Effects on the Deformation of Metals". In: Lamberson L. (eds) *Dynamic Behavior of Materials, Volume 1*. Conference Proceedings of the Society for Experimental Mechanics Series. Springer, Cham. November, 2019.
5. **C. Rudolf**. "Deformation Sensing in Soft Bio-Surrogate Materials". NRL Memo Report 6350-19-9885, 36 pages, May 2019. Distribution A.
6. **C. Rudolf**, W. Kang, C. Kindle, S. Qidwai, C. Pande, J. Thomas. "Influence of Electric Current on the Mechanical Deformation of Metals". NRL Memo Report 6350-19-9827, 46 pages, February 2019. Distribution A.
7. J.P. Thomas, M.H. Merrill, C.J. Kindle, **C. Rudolf**. "Pressure Sensing in Clay: Potential New Helmet Testing Metric for Backface Impact". In Proceedings of 2018 Personal Armour Systems Symposium, October 2018.
8. R.M. Sebdani, J. Gale, **C. Rudolf**, W. Kang, A. Achuthan. "Real-time layer-by-layer ultrasonic treatment of additively manufactured metallic materials". In: Proceedings of 2017 Annual International Solid Freeform Fabrication Symposium.
9. M. Asadikiya, **C. Rudolf**, C. Zhang, B. Boesl, Y. Zhong. The Role of CALPHAD Approach in the Sintering of B<sub>4</sub>C with SiC as a Sintering Aid by Spark Plasma Sintering Technique. 11<sup>th</sup> International Conference on Ceramic Materials & Components for Energy & Environmental Applications, February 2016.

### Presentations

1. C. Rudolf. 3D Printed Mechanical Testing Device for Micro-Scale Material Systems, 2021 International Mechanical Engineering Conference and Exposition (IMECE). **Invited Keynote**. November, 2021 Virtual.
2. C. Rudolf. Effects of Electric Current on the Plastic Deformation Behavior of Pure Copper, Iron, and Titanium, 2021 International Mechanical Engineering Conference and Exposition (IMECE). November, 2021 Virtual.
3. C. Rudolf, D. Wilbur, W. Kang. 3D Printed Mechanical Testing Device for Micro-Scale Material Systems, 2021 Society for Experimental Mechanics Annual Meeting, June, 2021 Virtual.
4. C. Rudolf, Y.C. Chen, T. O'Shaughnessy. Bio-fidelic, Soft Deformation Sensing under Dynamic Loading, 2021 Society for Experimental Mechanics Annual Meeting, June, 2021 Virtual.
5. C. Rudolf. Letting Research Guide the Way, **Invited Keynote** for FIU Undergraduate Research Symposium, February 26, 2021 Virtual.

6. C. Rudolf, C. Love, M. Merrill. Investigation of an Ionic Liquid as a High-Temperature Electrolyte for Silicon-Lithium Systems, 2020 ASME International Mechanical Engineering Congress and Exposition. November, 2020 Virtual.
7. C. Rudolf, W. Kang, J. Thomas. Method for Characterizing Electric Current Effects on the Deformation of Metals. 2019 Society of Experimental Mechanics Annual Meeting. Reno, NV. June 5<sup>th</sup>, 2019
8. C. Rudolf. TaCNbC Formed by Spark Plasma Sintering with the Addition of Sintering Additives. Presented in the Sintering and Related Powder Processing Science and Technologies symposium at the Materials Science & Technology 2015 conference, Columbus, OH, Oct. 4<sup>th</sup>-8<sup>th</sup>, 2015.
9. C. Rudolf. Ultrahigh Temperature Ceramics (UHTC) Materials with Nano-Reinforcement. Presented at the 2015 AFRL Research Collaboration Program Review, Dayton, OH, Sept. 17<sup>th</sup>, 2015.

### **Patents**

1. Aluminum-Boron Nitride Nanotube Composites and Method for Making the Same. (Serial No. 15/182,042) Patent No.: US 11,148,201 B2
2. 3D Printed Mechanical Testing Device for Micro-Scale Material Specimens. (Navy Case #112456) Patent Pub. No.: US 2021/0262783 A1
3. Force Sensing Strains in Soft Materials for Millisecond-scale Blast and Impact Characterization. (Navy Case #112519) Patent Pub. No.: US 2021/0262909 A1

### **Professional Affiliations**

American Society of Mechanical Engineers (ASME); The Mineral, Metals, and Materials Society (TMS); The American Ceramic Society (ACerS)