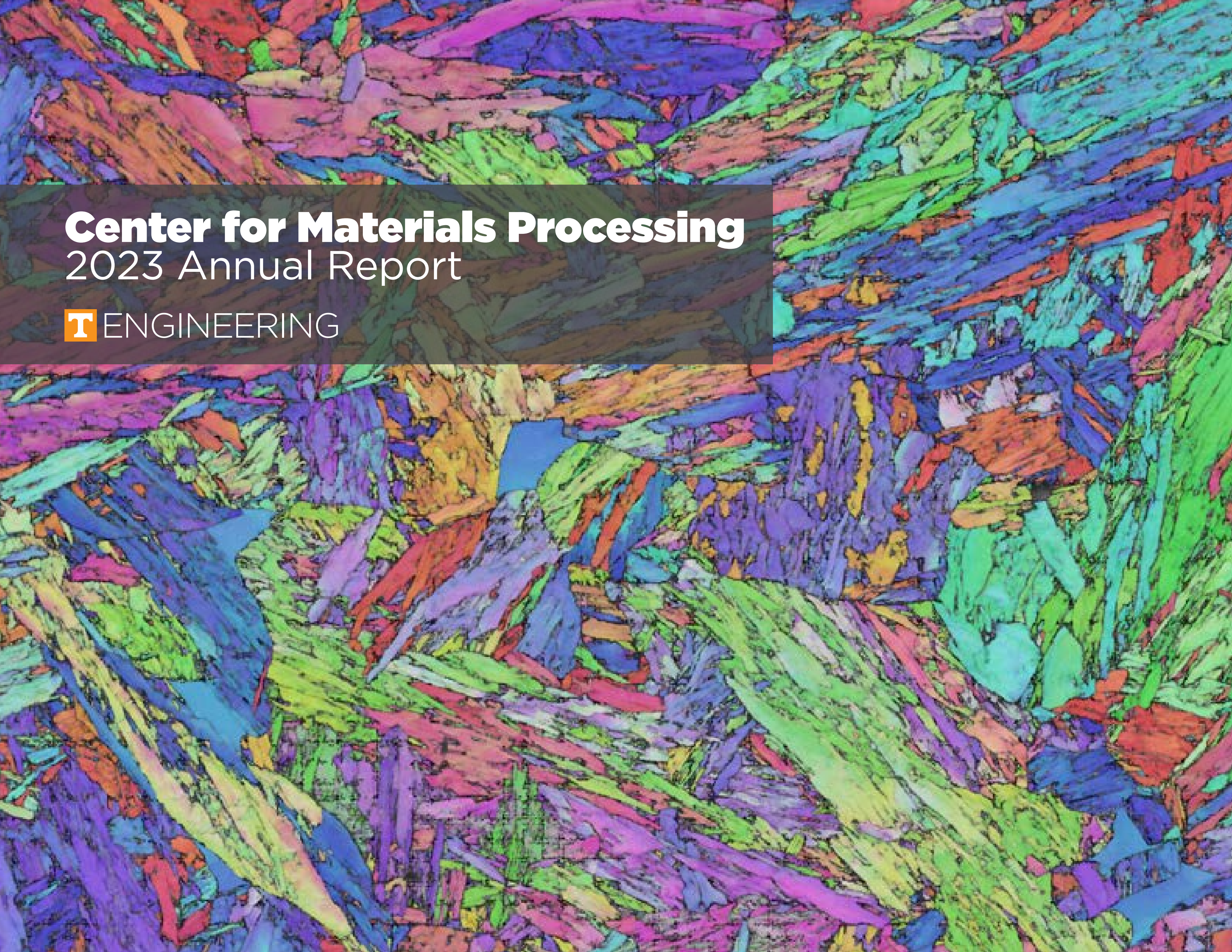

Center for Materials Processing
2023 Annual Report

T ENGINEERING

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Project Manager: Carin Medford | Designer: Wes Baldwin

On the Cover: Inverse pole figure of martensitic laths and microstructural features of additively manufactured Grade 91 steel | Photo Credit: Emily Proehl

Advisory Committee

Established in early 2014, the CMP Advisory Committee works with the CMP director and associate director for industrial partnerships regarding various areas of research that the CMP can advocate for and invest in for the future. The CMP leadership and the Advisory Committee work together with the goal of bringing positive recognition to the CMP, the Tickle College of Engineering, and the University of Tennessee in areas related to materials processing.

William Dunne
Associate Dean, Research and Facilities
Tickle College of Engineering
University of Tennessee, Knoxville

Veerle Keppens
Professor and Head, Materials Science and Engineering
Tickle College of Engineering
University of Tennessee, Knoxville

Danny Norman
Advanced Manufacturing Consultant
Center for Industrial Services
University of Tennessee

Tom Rogers
President and CEO
Cherokee Farm Development Corporation

Jon Phipps
Director, Institute for Advanced Materials and Manufacturing
University of Tennessee

Mission Statement

The Center for Materials Processing supports teaching and conducting basic and applied research emphasizing relationships between processing, structure on various scales, and properties of all classes of materials. This support improves existing processing and synthesis techniques, develops new materials and technologies, transfers improvements to the applied sector, and equips students to thrive in the broad field of materials science and engineering. The center fosters interdisciplinary activities and establishes partnerships with industries and other institutions as appropriate.

Executive Summary

In FY23, the Center for Materials Processing (CMP) supported twelve graduate students and 90 undergraduates, resulting in 30 publications and seven dissertations. Ten percent of the undergraduate students participated in CMP-supported research with early-stage entrepreneurial Spark Incubator companies. Holocene Climate Corporation, Safire Technology Group, Inc., and SkyNano Technologies are all Spark Incubator companies hosting students and/or having facility memberships with the CMP. Students working with the Spark companies are introduced to developing technologies related to end applications, including fuel cells, batteries, and CO_2 conversion. The majority of the Spark companies are housed at the Institute for Advanced Materials and Manufacuturing (IAMM) on the Cherokee Farm campus or in the Zeanah Engineering Complex (ZEC) on the main campus. Research topics undertaken by students and their mentors in FY23 include lowering the CO_2 emissions in concrete, composite materials for lightweighting vehicles, quantum magnets, developing structural materials for use in extreme environments (e.g., nuclear and aerospace industries), 3D printing of polymer composites, additive manufacturing of metals, high entropy oxide synthesis, and converting abundant and inexpensive plant-based feedstocks into materials with end applications in the areas of batteries, supercapacitors, environmental remediation, and light-emitting-diodes. To disseminate CMP-supported research to a larger community, the CMP annually sponsors two poster sessions at IAMM. These poster sessions provide a local venue for graduate and undergraduate students to present their research to judges from Oak Ridge National Laboratory, research staff from Spark Innovation companies and local industry, and faculty from various departments. The top posters are awarded with travel support that enables students to participate in events with a larger audience and allows the larger community to experience first-hand the exceptional work of UT students. In addition to supporting students with stipends and hourly wages, the CMP contributes to their research efforts by (1) maintaining and operating smaller equipment vital to understanding structure-processing-property relationships and (2) supporting the IAMM Diffraction Facility, which is heavily used by many CMP students.

CMP Staff

Claudia Rawn
Director

Claudia Rawn has been director of the Center for Materials Processing since July 1, 2012. She is a Professor in the Department of Materials Science and Engineering at the University. In addition to being the director of the CMP, Rawn is the UT site director of the Manufacturing and Materials Joining Innovation Center (Ma2JIC), funded by the National Science Foundation Division of Industrial Innovations and Partnerships (IIP) and individual industrial memberships. Ma2JIC, now in Phase III, has additional university sites at The Ohio State University (lead site), Colorado School of Mines, Penn State University, and an international site at the University of Waterloo in Canada. Her research interests include investigations of crystal structures, phase transitions, and thermophysical properties of a variety of materials using in-situ X-ray and neutron scattering methods. She received her bachelor's degree in materials engineering from Virginia Tech, her master's degree in chemistry from George Mason University, and her PhD in materials science and engineering from the University of Arizona.

Gerald Egeland
Student Supervisor

Gerald Egeland is the CMP laboratory manager and supervises the undergraduate students that perform work on CMP Industrial Facility Membership sponsored research. He has a joint appointment between the CMP and MSE serving as the undergraduate laboratory manager and the departmental safety officer. Egeland has degrees in materials science and engineering from New Mexico Institute of Mining and Technology. Prior to joining UT, he had appointments at both Los Alamos National Laboratory and Idaho National Laboratory focusing on radiation damage of alloys, ceramic powder processing for advanced fuel, and fuel-cladding interactions.

Karen Boyce
Business Manager

Karen Boyce is the business manager for the CMP, the Scintillation Materials Research Center, and the Ma2JIC University of Tennessee, Knoxville, site; she also assists the Tickle College of Engineering Finance Office. She has been working within various university systems since 1995 and joined UT in June 2011.

Amber White
Administrative Specialist

Amber White has served as the administrative specialist for the CMP and the and the Reliability and Maintainability Center since November 2016. Amber served as the inaugural TCE Staff Advisory Council chairperson from 2019–2022, was a member of the TCE Strategic Vision Planning Committee, and participates in other college and university initiatives. This year, Amber was the recipient of the TCE Inspirational Leadership Staff Award.

Andy Sarles
Associate Director for Industrial Relations

Andy Sarles started as the CMP Associate Director for Industrial Relations on May 1, 2023. Andy joined the University of Tennessee in 2011 and is currently the James Conklin Fellow and an associate professor in the Department of Mechanical, Aerospace, and Biomedical Engineering. His research is focused on the assembly, characterization, and application of biologically inspired and biomolecular material systems for engineered devices. Andy received his bachelor's degree in mechanical engineering from UT and his master's degree and PhD in mechanical engineering from Virginia Tech.

Domes Day

Written by Claudia Rawn.

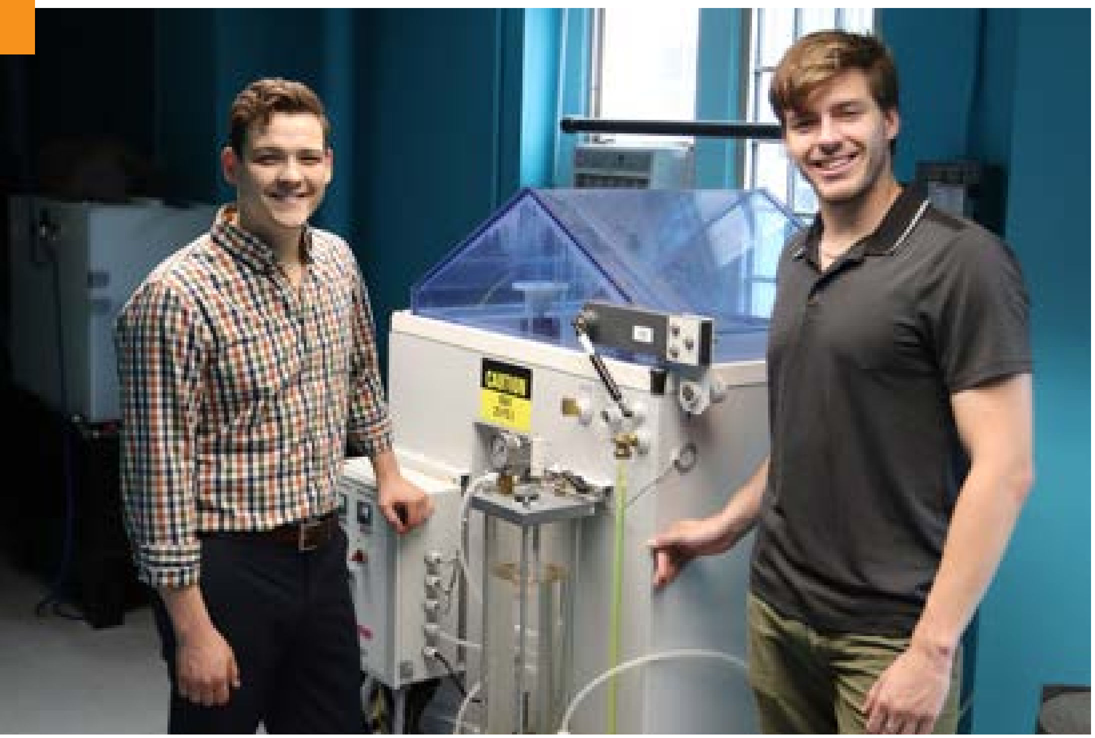
From left: Cole Franz, Marlena Alexander, Jack Fredrick, and Raymond Wysmierski

DomesDay is a geodesic dome design competition sponsored annually by ASM International. The event was established in 2014 and has a multifold purpose, including involving students in a materials design and selection competition along with familiarizing Materials Advantage students with a piece of ASM culture, the world's largest open air geodesic dome that spans ASM International Headquarters in Ohio. Every year, the rules are modified to keep the competition interesting. In September of 2022, the University of Tennessee Chapter of Materials Advantage (an academic student organization supported by the professional societies ASM International, the American Ceramic Society, TMS, and the Association for Iron & Steel Technology) sent its first team to the DomesDay Competition at the International Materials Applications & Technology (IMAT) conference in New Orleans, Louisiana. The UT student team consisted of Marlena Alexander, Cole Franz, Jack Fredrick, and Raymond Wysmierski and was advised by Jerry Egeland and Claudia Rawn. The team created a design for the dome mold using the CAD software package Fusion 360. Once the mold was ready, several attempts were required for a successful casting of the A356 aluminum alloy. The as-cast dome was subsequently heat treated to promote precipitation hardening and anodized to create an aesthetic finish. A finite element analysis predicted the compressive force the dome could withstand when fabricated from A356 aluminum.

There were seven domes competing from university teams across the US and Mexico. Judging criteria included points for (1) design, assessed based upon student presentations and a Q&A session regarding the design and fabrication of the dome, and (2) structural integrity, assessed by the dome's structural performance in compression testing. The UT team impressed the judges by demonstrating their knowledge, having the only metal casted dome, and proving that their dome was up to the task by resisting more than 2000 lbs of compressive force. The UT team, sponsored in part by the Center of Materials Processing, won two of the four awards (second place and the most impressive destruction). The students had an extraordinary experience, both participating in the conference and competing at DomesDay, and are already designing and casting a dome for the 2023 competition.

Alex Greenhalgh, Undergraduate Researcher of the Year and So Much More

Written by David Keffer. Photography by Randall Brown.



Left: Dayton Kizzire , Right: Alex Greenhalgh

Alex Greenhalgh displayed an early interest in participating in undergraduate research, joining the research group of Professor David Keffer in October 2019 when he had been enrolled at the University of Tennessee for scarcely two months. His interest in using computational tools to solve materials problems quickly became evident. Before he had taken a single materials science class, he was able to bring himself up to speed on the use of radial distribution functions, crystallography, and atomic probe tomography (APT) to characterize the atomic-scale structure of materials. He developed a computational method to statistically characterize chemical ordering in APT data sets of high entropy alloys (HEA) and applied them to an APT experiment of an HEA from the group of John Fisher Professor Peter Liaw. As a freshman, Greenhalgh presented this work to collaborators in the Department of Mathematics from UT's College of Arts and Science and the Min H. Kao Department of Electrical Engineerign and Computer Science as well as to staff scientists at Oak Ridge National Laboratory. This work led to the interdisciplinary publication of a first author paper co-authored with Keffer, Professor Vasileios Maroulas (Math), and Research Associate Professor Piotr Luszczek (EECS), and others.

Along the way, Greenhalgh developed a mastery of classical molecular dynamics simulation using the LAMMPS software from Sandia National Laboratories. He has used molecular simulation to measure thermodynamic, mechanical, structural, and transport properties of aluminum and aluminum alloys. While at UT, in addition to majoring in materials science and engineering, he pursued a minor in mathematics and computer science, resulting in him becoming a fluent programmer in C++ and Python and developing a deep understanding of machine learning.

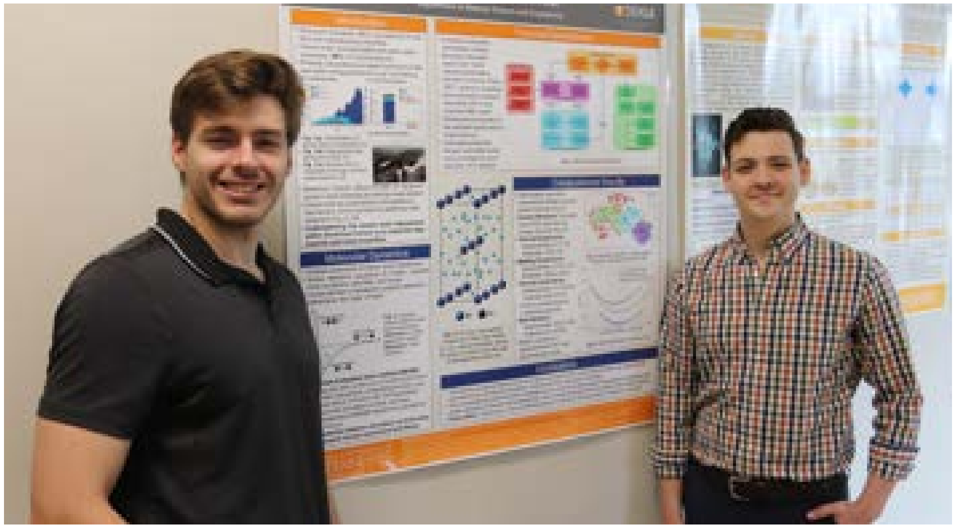
Greenhalgh combined these skills in the summer of 2021 when he participated in a Summer Undergraduate Laboratory Internship (SULI) in the Spallation Neutron Source (SNS) at ORNL, the world’s premier facility for using neutrons to characterize the atomic structure of materials. Under the advising of Yuanpeng Zhang, Greenhalgh worked on interfaces to better enable SNS users to extract the most insight from the data that they generated at the site.

In his last two years, Greenhalgh collaborated with Dayton Kizzire, a post-doctoral researcher in MSE, developing interaction potentials for cerium, an emerging candidate for new light-weight, high-temperature aluminum-based alloys. Because a viable interaction potential did not exist, molecular simulation could not be used for new alloy discovery. Greenhalgh and Kizzire's goal was to restore simulation as the third pillar of research, complementing theory and simulation of AlCe alloys. Their work required the combination of density functional theory (DFT), machine learning and classical molecular dynamics (MD), which resulted in an interaction potential for Ce capable of reproducing cohesive energy, bulk modulus, elastic coefficients, thermal expansivity, thermal conductivity, and many other material properties. At the time of writing, their manuscript is in the review process. Of his relationship with Kizzire, Greenhalgh says, "He has provided guidance on integrating materials science and machine learning in an interdisciplinary space. Conversations with him about his research experiences have cemented my desire to pursue a PhD."

The caliber of Greenhalgh's work has been recognized through many national competitions, including (i) the Consortium for Enabling Technologies & Innovation, managed by the Georgia Institute of Technology underwritten by the Department of Energy (DOE) and the National Nuclear Security Administration (NNSA); (ii) selection by the Science, Mathematics, and Research for Transformation (SMART) Scholarship-for-Service Program, funded by the Department of Defense (DoD); and (iii) the prestigious Barry Goldwater scholarship in March 2022. In spring of 2023, he was named Undergraduate Researcher of the Year by UT. Keffer also earned recognition as Undergraduate Research Mentor of the Year.

Greenhalgh is an Eagle Scout and exemplifies the maturity and traits to which Eagles Scouts aspire. Throughout his time at UT, he has interacted with many professionals both inside and outside the university. His commitment to collegiality and his internal standard of excellence coupled with his technical expertise and work ethic have earned him high praise from all those with whom he has worked. Greenhalgh is off to fulfill his obligations to the DoD through the SMART Scholarship-for-Service Program. He plans to pursue a master's degree in computer science during this service period and then return to graduate school to earn his doctorate in the broad field of computational science.

Having shared Greenhalgh's story, it is important to note that it was the financial support from the Center for Materials Processing (CMP) for undergraduate research when Alex was a first-year student that set him on this path to success. Through the financial support of so many undergraduates like him, the CMP continues to plant the seeds of success in the amazing, young materials scientists and engineers at the University of Tennessee.



CMP Spotlight on Professor David Harper

Written by David Keffer.

Lu Yu (center), PhD MSE May 2022, co-advised by David Keffer (left) and David Harper (Right

Professor David Harper exemplifies the value of successful interdisciplinary research at the University of Tennessee. A physicist (BS) and civil engineer (PhD) by training, Harper joined the faculty in the Department of Forestry, Wildlife, and Fisheries within the Herbert College of Agriculture in 2004 and quickly became an integral part of the research endeavor in the Center for Renewable Carbon (CRC), the Materials Science and Technology Unit on the campus of the University of Tennessee Institute of Agriculture.

Harper's approach to research embodies the quintessential blending of many elements, including fundamental science, industry input, emphasis on student education, and collaboration with many stakeholders, including chemical, civil, and materials engineers in the Tickle College of Engineering, techno-economists, and members of the Tennessee agricultural community.

His relationship with the Center for Materials Processing is a natural one: much of his research involves developing processing-structure-property-performance (PSPP) relationships for materials sourced from renewable feedstocks. In a nutshell, a PSPP relationship describes how the processing of a raw material influences its structure from the nanoscale through the macroscale. This structure, in turn, dictates the material properties that ultimately determine how a device made from those materials performs in service.

Harper's expertise involves converting abundant and cheap plant-based feedstocks into high-value nano-structured materials targeted for diverse applications, including battery anodes, supercapacitor electrodes, ion capture for environmental remediation, light-emitting-diodes for electronic displays, and membranes for carbon sequestration.

Harper has a keen interest in the sustainability of materials. He keeps an eye on all aspects of sustainability: people, prosperity, and the planet. Environmentally, his group looks to replace fossil-fuel based plastics with plant-derived plastics for applications as wide-ranging as the 100% recyclable automobile to a new generation of non-toxic and fully biodegradable plastic fishing lures. Economically, he strives for scalable and inexpensive processing so that the materials emerging from his lab are viable to industry. Societally, for the past two decades, he has been training young scientists and engineers to develop sustainable materials before sending them out to work toward material solutions to some of the world's toughest challenges in the areas of renewable energy and climate change.

Harper is a firm believer in engaging both graduate and undergraduate students in the research endeavor. At any given time, he may have half a dozen or more undergraduate students embedded in research at the CRC, many receiving support from CMP. The students are drawn to opportunities to satisfy their desire to participate in work that addresses sustainability while expanding their repertoire of technical skills. Many of these students present their work at poster sessions and co-author papers published in technical journals. Having discovered their zeal for research at the CRC, some of these students head off to graduate school after graduation.

Graduate students also thrive under Harper's mentorship. One example of a student who received support from the CMP during her dissertation work is Lu Yu. Her research converted lignin, a waste stream from the pulp and paper industry, into nanostructured activated carbon with uses in energy storage and environmental remediation. For her research, Yu was recognized in 2022 as an outstanding wood scientist by the International Academy of Wood Science, an award that would have been impossible without Harper's guidance.

At CRC, Harper continues to blend university research with the needs of industry. His work with Volkswagen is an on-going collaboration. MSE PhD student Cece Grubb is developing new materials for plastic automobile components that are plant-based and fully recyclable, an essential step to Volkswagen's goal of the carbon neutral and 100% recyclable automobile.

Prof. Harper and MSE graduate students formed a team for the MSE Halloween Trivia Contest in October 2021. (Students left to right: Bert Rodriquez, Cece Grubb & Lu Yu).

While the technical accomplishments of Harper's research are impressive, he also has created a culture in the CRC where everyone—graduate students, undergraduate researchers, staff, and collaborating faculty—can reach their full potential, not only as researchers but as human beings. Students want to work with Harper. They are comfortable being themselves as they discover not only new materials but also find their unique path toward using materials to make the world a better place.

UT MSE PhD student Cece Grubb explains her dissertation work on bio-based paneling for automobiles to help Volkswagen meet their goals of a 100% recyclable vehicle to Pablo Di Si, President and CEO of Volkswagen Group of America. Cece's advisor, Prof. David Harper of the Center for Renewable Carbon, looks on.

The members of the Harper-Keffer Research Group gathered in April 2023 in the University of Tennessee gardens for a group photo on a beautiful spring afternoon. Pictured from left to right: Chris Webb (MSE, senior); David Keffer (MSE, professor) Kendhl; Seabright (CRC, lab manager extraordinaire); Michael Broud (MSE, junior); Matthew Valderrama (MSE, senior); Jakob Scroggins (MSE, sophomore); Emma Howard (MSE, junior); Bert Rodriguez (CRC, post-Masters researcher); Amy Kurr (ESE, PhD student); Jacob Morton (MSE, MS student); Cece Grubb (MSE, PhD student); Cotton Pekol (MSE, PhD student); Mohsen Samandari (MSE, PhD student); Eli Christoph (MSE, MS student); David Harper (CRC, professor); Jonah Brown (CBE, PhD student)

CMP Supported and Associated Graduate Students

In FY23, through its competitive application process, the CMP continued supporting graduate students working in areas of materials processing research. Current students, featured below, are from a variety of disciplines including civil and environmental engineering, materials science and engineering, nuclear engineering, and physics. These students along with CMP supported graduate students that have graduated in the last year are the force behind the publications and dissertations listed in this report.

Pradip Adhikari, Physics

What is your thesis topic? I am studying selective area growth (SAG) of advanced superconductor-semiconductor hybrid nanowires for quantum devices.

How is materials processing involved in your research? My research focuses on the SAG of III-V semiconductors and in-situ deposition of superconductors to form superconductor-semiconductor heterostructures. To grow nanowires using the SAG technique, the substrate should be prefabricated with the nanowire patterns using an oxide mask. This process includes a series of material processing steps, including oxide deposition, electron-beam patterning, and dry/wet etching. The nanowire is then grown under ultra-high vacuum using molecular beam epitaxy (MBE) at a selected thermodynamic condition followed by in-situ superconductor deposition. Further material processing is required to pattern and deposit metals and dielectrics to prepare contacts and gates for transport studies.

Provide an example of where the material, process, or properties you are studying might find an application. Semiconductor nanowires have applications in diverse fields of electronics, renewable energy, and photonics. Engineering these hybrid nanowires as quantum point contacts and quantum dots allows us to make a device that gives quantized conductance. Furthermore, superconductor-semiconductor heterostructures have shown great potential to be host platforms for quantum computing.

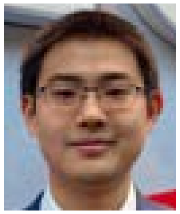
Ty Austin, NE

What is your thesis topic? Using laser directed energy deposition additive manufacturing of oxide dispersion strengthened (ODS) FeCrAl under a reactive atmosphere.

How is materials processing involved in your research? Conventional powder metallurgy manufacturing techniques are used to produce ODS alloys. These techniques are energy intensive and time consuming. Here I use a novel approach combining additive manufacturing and a reactive atmosphere (oxygen-rich) to reduce the number of manufacturing steps, allow for increased geometric complexity of parts, and potentially improve microstructural control.

Provide an example of where the material, process, or properties you are studying might find an application. ODS FeCrAl has been shown to have excellent corrosion resistance and high-temperature, strength making it an ideal candidate for heat exchangers. Coupled with the improved radiation tolerance provided by the oxide precipitates, ODS FeCrAl could serve as a promising nuclear fuel cladding material in current generation nuclear reactors or structural support materials in advanced nuclear fission and fusion reactor designs.

Xuesong Fan, MSE



What is your thesis topic? My thesis work focuses on the mechanical properties of high-entropy alloys (HEAs), including improving the ductility of body centered cubic (BCC) HEAs and enhancing the strength of face centered cubic (FCC) HEAs. The first part involves utilizing the concept of phase-transformation-induced plasticity (TRIP) to improve the tensile ductility in compositions with the TiZrHfNb refractory HEA system with BCC structures. The second part of my thesis work focuses on designing and developing new FCC HEAs that are enhanced by introducing nano-precipitates.

How is materials processing involved in your research? To design and develop new HEAs, synthesis of metallic samples is first and foremost. Fabrication methods such as arc-melting, drop-casting, and suction-casting are usually used to combine four or more metallic elements to form a single phase solid-solution. Additionally, thermomechanical processes (e.g., rolling, homogenization, annealing, and aging) are generally performed to further improve mechanical properties. By combining different processing methods, the aim is to develop advanced structural materials and understand the relationship among processing-structure-properties.

Provide an example of where the material, process, or properties you are studying might find an application. Similar to commercial Ni-based superalloys, HEAs with FCC structures are considered promising alternatives for high-temperature applications due to their lower cost and better mechanical performance in a wide temperature range. By introducing ordered precipitates as the strengthening phase, the strength of the FCC-based HEAs can be potentially improved due to dislocation-precipitate interactions, which hinder dislocation movements.

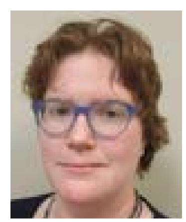
Yao Li, NE

What is your thesis topic? My thesis project focuses on dislocation loops created by ion irradiation in BCC Fe-Cr model alloys. The main characterization techniques to study these dislocation loops include state-of-the-art electron backscatter diffraction (EBSD), focused ion beam (FIB) sample preparation, energy dispersive x-ray spectroscopy (EDXS), atom probe tomography (APT), and transmission electron microscopy (TEM).

How is materials processing involved in your research? To simulate the irradiation effects on the resulting microstructures and bulk properties of various structural materials used in a reactor, we varied the temperature and ion fluence during heavy ion beam. We took full advantage of the newly commissioned TEM Spectra 300 in the IAMM Core Microscopy Facility to study ion irradiated pure Fe, Fe-3Cr, Fe-5Cr, and Fe-8Cr alloys (wt% Cr). The effects of damage rate, damage level, temperature, and Cr concentration on dislocation loop formation were investigated.

Provide an example of where the material, process, or properties you are studying might find an application. Ferritic-martensitic (FM) steels are extensively deployed in engineering systems, such as large-scale fossil and nuclear energy systems. However, FM steels face challenges including undesirably high irradiation-induced hardening and embrittlement at low to intermediate temperatures. These issues arise due to the abundant formation of dislocation loops and Cr-rich α' precipitates. Although numerous experiments have been conducted on FM alloys over the past decades, the interpretation and quantification of these previous results were limited by the resolution of earlier scientific instruments. By applying multiple techniques, the dislocation loop formation mechanism(s) were tested. The damage level and damage rate effect on dislocation loop formation were explored, and a more comprehensive understanding of the physics revealed that these effects are imperative for designing next generation Fe-Cr based advanced alloys for extreme engineering environments. These results in turn will be used to improve the ion beam processing conditions on similar alloys in future.

Hannah Maeser, CEE



What is your thesis topic? Fiber alignment and mesostructure play a key role in tailoring the anisotropic properties of carbon fiber reinforced polymer composites (CFRC) for use in automotive applications. My dissertation topic focus is to develop novel non-invasive methods for characterizing the effect of composite manufacturing processes on micro/meso structure and to relate the resulting structure to mechanical properties.

How is materials processing involved in your research? Discontinuous CFRCs are susceptible to fiber misalignment during high-throughput molding and manufacturing methods, such as the compression molding technique using sheet molding compounds. Aspects such as how the partially cured material is placed into the mold or the length of the molding time can affect how the fibers flow and orient around the part geometry. I am developing a novel non-destructive evaluation (NDE) method called thermal digital image correlation (TDIC) to determine the preferred fiber orientation that results in the part during manufacturing. I seek to develop a set of guidelines, confirming against TDIC, on how to process the uncured composite material during molding to reduce or control fiber misalignment. I am also exploring the use of thermography for identifying defects such as pores or resin rich regions.

Provide an example of where the material, process, or properties you are studying might find an application. A good example of where my research might find an application in the field is in quality control of composite automotive parts. Discontinuous composites offer a low-cost composite solution for light-weighting for fuel efficiency, corrosion resistance, and energy absorption through crushing.

CMP Supported and Associated Graduate Students Cont.

Shashi Pandey, Physics

What is your thesis topic? Integrating epitaxial and in situ anisotropic strain for magnetoelastic control of a Jeff = 1⁄2 antiferromagnet (AF).

How is materials processing involved in your research? My research is focused on applying strain as an external perturbation to complex oxides and studying its effect on the magnetic behavior and other transport properties. We perform layer by layer thin film growth of complex oxide materials using pulsed laser deposition (PLD) on a substrate that is chosen with a deliberate lattice mismatch, which ultimately induces epitaxial strain on the film. In situ strain are then applied with the help of strain cells on such epitaxially strained thin films, which enables us to fine tune the applied strain on the system. The materials processing is involved not only in the growth process of the thin films but also its characterization, study of the transport properties, and x-ray diffraction study.

Provide an example of where the material, process, or properties you are studying might find an application. One example would be Sr_2IrO_4, a 5d iridate system with Jeff = ½ AFM Mott insulating behavior. Studying the strain effect on magnetic behavior of this material, we found that a metamagnetic transition can be significantly driven with the application of in situ strain. Conversely, such a strain can do robust switching between two different magnetic phases, i.e., AF and FM. The study might find an application where the magnetic behavior of a material needs to be fine-tuned without applying external field.

"Shashi is truly a comeback student through a journey of graduate study full of ups and downs. Shashi is now well trained to tackle a challenging project of engineering quantum materials with a large and tunable strain, which is crucial for controlling functional properties, such as quantum magnetism, metal-insulator transition, and unconventional superconductivity."

Jian Liu – Physics

Anjali Rathore, Physics

What is your thesis topic? My thesis topic is "Manipulating Topological and Superconducting Phases of Sn Thin Films." The goal of my research work is to understand properties of distinct phases of Sn thin films and to further utilize them for topological superconductivity studies.

How is materials processing involved in your research? Sn is a unique group IV element that has recently drawn attention due to its ability to exhibit both topological and superconducting phases. My research is focused on synthesizing high quality Sn thin films using molecular beam epitaxy and studying different phases of Sn. To achieve this goal, we grow Sn thin films with varying lattice parameters by growing them on closely lattice-matched buffer layers and then perform a systematic study of a broad range of Sn phases in the presence of different compressive and tensile strains. Later, this study will be utilized to prepare hybrid structures for topological superconductivity studies, including superconducting Sn–semiconductor hybrids and topological Sn-superconductor hybrids. Further material processing will be required in thin film characterization, transport studies, and device fabrication.

Provide an example of where the material, process, or properties you are studying might find an application. Sn thin film material processing is not only important to characterize interesting properties of various Sn phases to study novel physics but also to synthesize hybrid structures to realize topological superconductivity. Among different topological phases of matter, topological superconductors are unique as they can host Majorana bound states (MBS) that can act as quantum bits and have potential applications for fault-tolerant quantum computing. Theoretically, it is proposed that p-wave spinless superconductivity is necessary to realize topological superconductivity, which poses a materials science challenge. To solve this challenge, it is proposed that MBS can be realized in laboratory at the interface between a conventional s-wave superconductor and topological materials or semiconductors with strong spin orbit coupling.

Chengkun Xing , Physics

What is your thesis topic? My research focuses on unveiling quantum magnetism via anomalous transport phenomena by designing an epitaxial heterostructure of a nonmagnetic metal film on an insulating quantum magnet.

How is materials processing involved in your research? The epitaxial $Bi_2Ir_2O_7/Yb_2Ti_2O_7$ heterostructure was designed to probe the quantum spin fluctuation in a $Yb_2Ti_2O_7$ crystal by detecting anomalous transport on a $Bi_2Ir_2O_7$ conductive film. In this process, the traveling solvent floating zone (TSFZ) technique is employed to obtain high-quality, ultrapure $Yb_2Ti_2O_7$ crystals. Substrates of $Yb_2Ti_2O_7$ are then prepared by polishing the crystal surface into atomic-level flatness. Finally, pulsed laser deposition (PLD) is performed to epitaxially grow $Bi_2Ir_2O_7$ film on $Yb_2Ti_2O_7$ substrates. The material processing was not only involved in the synthesis process but also its characterization through use of atomic force microscope (AFM), X-ray diffraction (XRD), and physical properties measurement.

Provide an example of where the material, process, or properties you are studying might find an application. Quantum spin fluctuations in quantum magnets lead to unique magnetic excitations that could be useful for spintronic applications. However, due to the deficiency of free charge carriers in most quantum magnets, incorporating them into spintronic devices is especially challenging. Our design opens a new channel to tune the transport properties of itinerant electrons using localized quantum spin degrees of freedom, indicating the functional possibilities of insulating quantum magnets in spintronic devices.

"While his dissertation project is extremely challenging, Chengkun successfully achieved the goals by hard, patient, and intelligent work. During the process, he mastered a broad range of techniques, including both the bulk crystal growth and Pulsed Laser Deposition thin film growth, and various of characterization techniques. This makes him a 'unicorn' in the quantum materials research field, such as Shohei Ohtani in MLB, who is great at both the pitching and hitting ends. We are very confident that Chengkun will have a promising professional future."

Haidong Zhou – Physics

Thesis/Dissertation Titles

James Bracket, PhD (ESE)
"Analyzing Blended Material Transitions Produced by a Dual Hopper Large Format Additive Manufacturing System"

ADVISOR: Chad Duty

Clifton Sluss, PhD (MSE)
"Direct Calculation of Configurational Entropy: Pair Correlation Functions and Disorder"

ADVISOR: David Keffer
CURRENT EMPLOYER: Senior Technical Specialist, Y12

Debalina Ghosh, PhD (Civil)
"A Study on Early Age Properties of Concrete for Precast and 3D Printing"

ADVISOR: John Z. Ma
CURRENT EMPLOYER: Sr. Design Engineer, Integrated Design Engineers, Seattle, Washington

Subhadeep Koner, PhD (Mechanical)
"Brain Inspired Organic Electroic Devices and Systems for Adaptive Signal Processing, Memory, and Learning"

ADVISOR: Andrew Sarles
CURRENT EMPLOYER: Process Engineer 3, Lam Research, Tualatin, Oregon

Zongyang Lyu, PhD (MSE)
"Synergistic Fatigue Performance in High Entropy Alloys with Novel Precipitates and Metastable Phases"

ADVISOR: Peter Liaw

Yajie Zhao, PhD (MSE)
"Kinetics and Phase Stability of Nano-scale Precipitates in Fe-based Binary Alloys During Ion Irradiations"

ADVISOR: Steven Zinkle
CURRENT EMPLOYER: Postdoctoral Researcher, Center for Nanophase Materials, Oak Ridge National Laboratory

Pengcheng Zhu, PhD (NE)
"Microstructure Evolution and Mechanical Response of Thermally Aged and Irradiated Fe-Cr Alloys"

ADVISOR: Shradha Agarwal and Steven Zinkle
CURRENT EMPLOYER: Postdoctoral Researcher, Los Alamos National Laboratory

Program Accomplishments and Overview

Accomplishments

- Strengthened the relationship with the Spark Incubator companies by having undergraduate students partially supported by the CMP participate in research within the companies
    - One student graduated and is now an employee of SkyNano Technologies
- One full- and eleven facility-level memberships supporting industry, including two with Spark Incubator companies and more being processed
- Continued synergy between the NSF funded Industry/University Cooperative Research Center (I/UCRC), the Materials and Manufacturing Joining Innovation Center (Ma2JIC) now in Phase III, focused on welding and additive manufacturing technologies
- Twelve graduate students partially supported through CMP graduate student support packages
- 90 undergraduate students participated in research activities supported by the CMP
- 30 publications and seven dissertations generated with CMP support
- Two poster sessions showcasing and promoting CMP-funded student research at both the graduate and undergraduate level
- Co-sponsorship of the International Conference on High Entropy Materials (ICHEM)

The strength of the Center for Materials Processing, a Tennessee Higher Education Commission (THEC) Center of Excellence, lies in the graduate students, undergraduate students, and (by extension) the faculty that mentor these students.

In FY23, the CMP provided partial support to twelve graduate students via the CMP graduate student support packages that focused on graduate students who were in their last year or two before graduation and were performing discrete projects related to materials processing. These students came from a variety of disciplines and departments, including civil and environmental engineering, materials science and engineering, mechanical, aerospace, and biomedical engineering, nuclear engineering, and physics. Just some of the projects involved lowering the CO_2 emissions in concrete, composite materials for light weighting vehicles, quantum magnets, and structural materials for use in extreme environments such as the nuclear industry and space.

The CMP support of undergraduate students started as a way to recruit and retain students in MSE. Over the years, it has expanded due to both the bright and talented undergraduate students keen to be involved in undergraduate research and the mentors who value the efforts that these students bring to their research portfolios in areas of materials processing. This year, the CMP helped to support 90 undergraduates who participated in research involving 3D printing of both polymer composites and metals, high entropy oxide synthesis for detector applications, and a wide variety of battery materials for various components (to name a few). About 10% of the undergraduates supported by the CMP were embedded in Spark Incubator companies, getting first-hand experience in research with a focus on

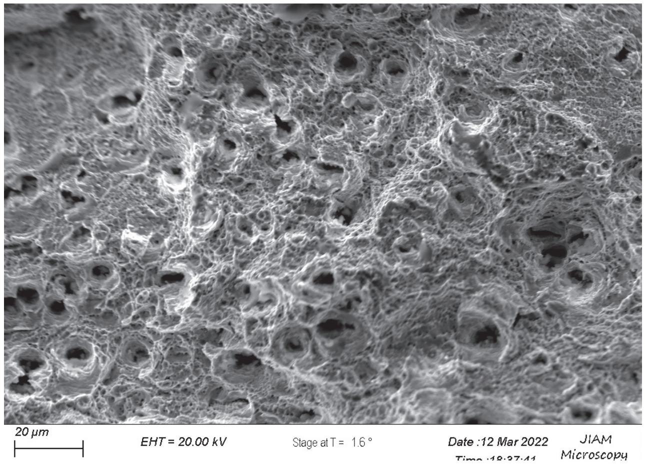


Photo Credit: Syeda Bushra Haider
Microstructure of Ni-Ce-Al alloy, precipitation aged for 192 hours at 800°C.

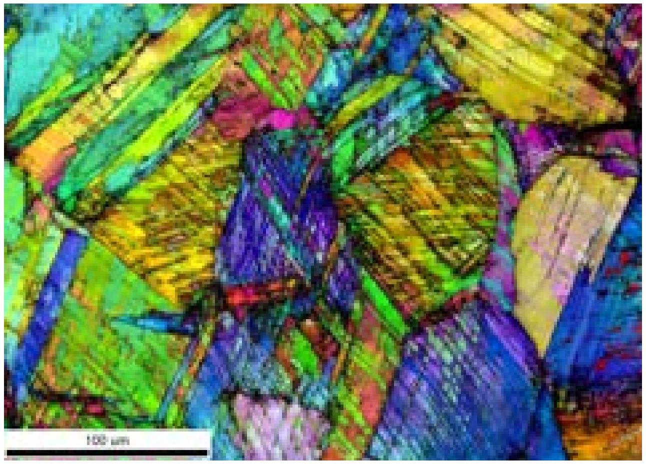


Photo Credit: Joshua Cicotte
Electron Backscattered Diffraction (EBSD) image of a CoCrNi alloy consisting of both hexagonal close packed (HCP) and face center close packed (FCC) phases.

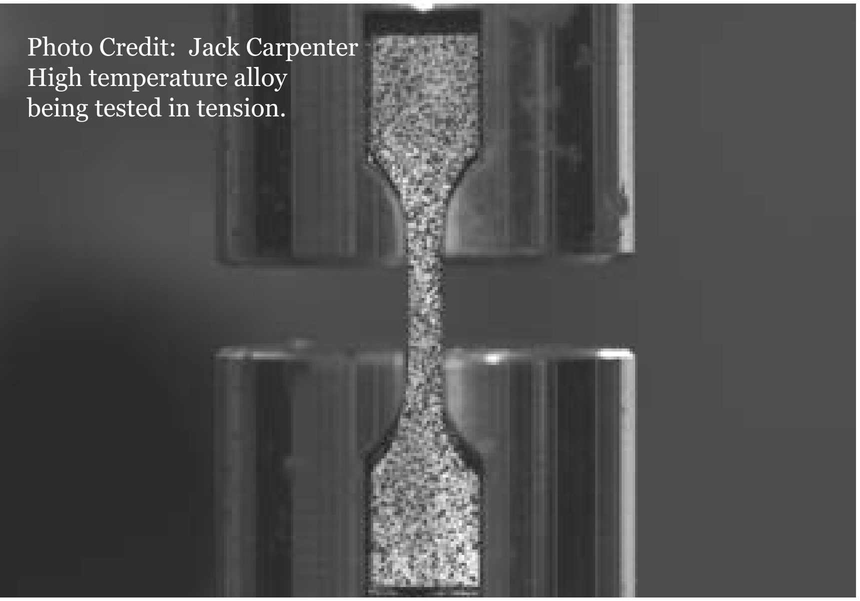


Photo Credit: Jack Carpenter
High temperature alloy being tested in tension.

commercialization of in-demand technologies. The three feature articles in the FY23 annual report highlight the accomplishments of students and mentors that make the CMP support of undergraduate research successful (see pages 4-7).

Each fall, the CMP hosts the End of Summer Poster Session at the Institute for Advanced Materials and Manufacturing (IAMM). The event serves as a welcome back activity and brings together graduate and undergraduate students eager to present on the research they performed over the summer. The CMP also co-hosts a second poster session annually with the Oak Ridge Chapter of ASM International (ORCASMI) in February at the start of the spring semester. Judges for both events are recruited from Oak Ridge National Laboratory (ORNL), Spark Innovation companies, industry, and faculty from several departments. Included as judges are alumni working locally in industry and at ORNL, many previously supported by the CMP when they were students. The top posters are recognized with travel support from the CMP that allows students to present their research at venues such as the American Chemical Society (ACS) Fall Meeting, the AIChE Annual Student Conference, and the TMS annual meeting. Internal to UT, many CMP-supported undergraduate students participate in the annual Exhibition of Undergraduate Research and Creative Achievement (EURēCA). This year, CMP student Marlena Alexander was recognized within the engineering category with an Award of Merit for her research on high entropy oxides. In September of 2022, the CMP supported a group of students from UT to participate for the first time in the DomesDay competition that is held annually at the IMAT conference (see page 3 for full recap).

The CMP continues to support IAMM activities by providing partial support to IAMM Diffraction (XRD) Facility Laboratory Manager Michael Koehler, who is in charge of the day-to-day operations of the laboratory, which includes helping students and industry members collect and analyze X-ray diffraction data. Many of the CMP supported graduate and undergraduate students access the instrumentation at the IAMM Core facilities, specifically the X-ray Diffraction Facility and the Electron Microscopy Center. Covering the instrumental charges for these core facilities is a popular part of the graduate student support packages. The CMP continues to maintain and operate a collection of smaller-scale instruments (e.g., particle size analyzers and a gas pycnometer for measuring density) in the Science and Engineering Research Facility (SERF) under the supervision of Jerry Egeland. This year, the CMP added a new Hitachi tabletop SEM that was debuted at the Engineering Fundamentals Departmental Fair. These instruments are available to students supported jointly by faculty sponsored research and CMP industrial membership research. In FY23, the CMP contributed to cost sharing the purchase of two accessories designed to characterize the electrical and optical properties of functional viscoelastic materials, thereby expanding the capabilities of the existing ARES-G2 rheometer.

The CMP co-sponsored the International Conference on High Entropy Materials (ICHEM), along with the Tickle College of Engineering (TCE) Department of Materials Science and Engineering (MSE) and Quantum Design. ICHEM took place in Knoxville in June of 2023 and featured renowned speakers in the area of high entropy materials, including William Curtin (Brown University), Jon-Paul Maria (Penn State University), Brian Cantor (Oxford), and Robert Cava (Princeton). In attendance were many current UT MSE students and faculty as well as several alumni previously supported by the CMP, including Brianna Musico (BS and PhD UT MSE, now at Los Alamos National Laboratory) and Jackson Spurling (BS UT MSE, now a PhD student at Penn State University).

*"My CMP students are absolutely incredible. Nicole made a particularly great impression during the NSF Director Visit" – **Philip Stuckey**, founder FC Renew*

Sethuraman Panchanathan, director of the National Science Foundation, talks with Nicole Liu while touring the FC Renew Lab inside the Institute for Advanced Materials and Manufacturing (IAMM).

Goals and Future Plans

While the Center for Materials Processing will continue its mission of supporting students involved in research and industry engagement in materials processing during 2024, it will experience a complete change in its leadership. In the spring of 2023, CMP Associate Director Chad Duty (focused on industrial relations) left to become the Chief Operating Officer for IACMI, a DoE-supported composites institute. Andy Sarles, James Conklin Fellow and Associate Professor in the Department of Mechanical, Aerospace, and Biomedical Engineering (MABE), joined later in the spring. As the new CMP Associate Director of Industrial Relations, Sarles worked to not only continue the momentum with the Center for Industrial Services (CIS) and the Spark Innovation companies but also recruit new companies and students. As UT continued to expand its research portfolio, the university was notified that it was being awarded a prestigious NSF-funded Materials Research and Science Engineering Center (MRSEC). CMP Director Claudia Rawn was part of the Center for Advanced Materials and Manufacturing (CAMM) team and has significant responsibilities as the CAMM Deputy Director and Director of Education and Diversity initiatives, which began on September 1, 2023. As a result, Rawn will step down as the CMP Director, after almost twelve years in that position. Philip Rack joined the CMP as an Associate Director starting on August 1, 2023 and will succeed Rawn as the Director on January 1, 2024.

While FY 23/24 will bring a transition in the leadership team, all agree that the current foci will remain largely the same for this year. Rack and Sarles will work together to strategize and seek to optimize the impact of THEC resources for the Center for Materials Processing. While undergraduate and graduate support will continue to be a large investment of the CMP resources, we will explore new partnerships and consider new strategies for graduate investments. Furthermore, we will develop a strategic plan for equipment investments as CMP has a strong legacy in infrastructure development on the University of Tennessee campus. Finally, leadership is considering a new direction, namely seed funding teams to stimulate new materials processing collaborations to enhance UT's reputation and competitiveness in new research frontiers. The CMP will be in good hands with Rack and Sarles as they move the CMP forward with continued support from Rawn, the CMP Advisory Committee, the Tickle College of Engineering, and the dedicated CMP staff members.

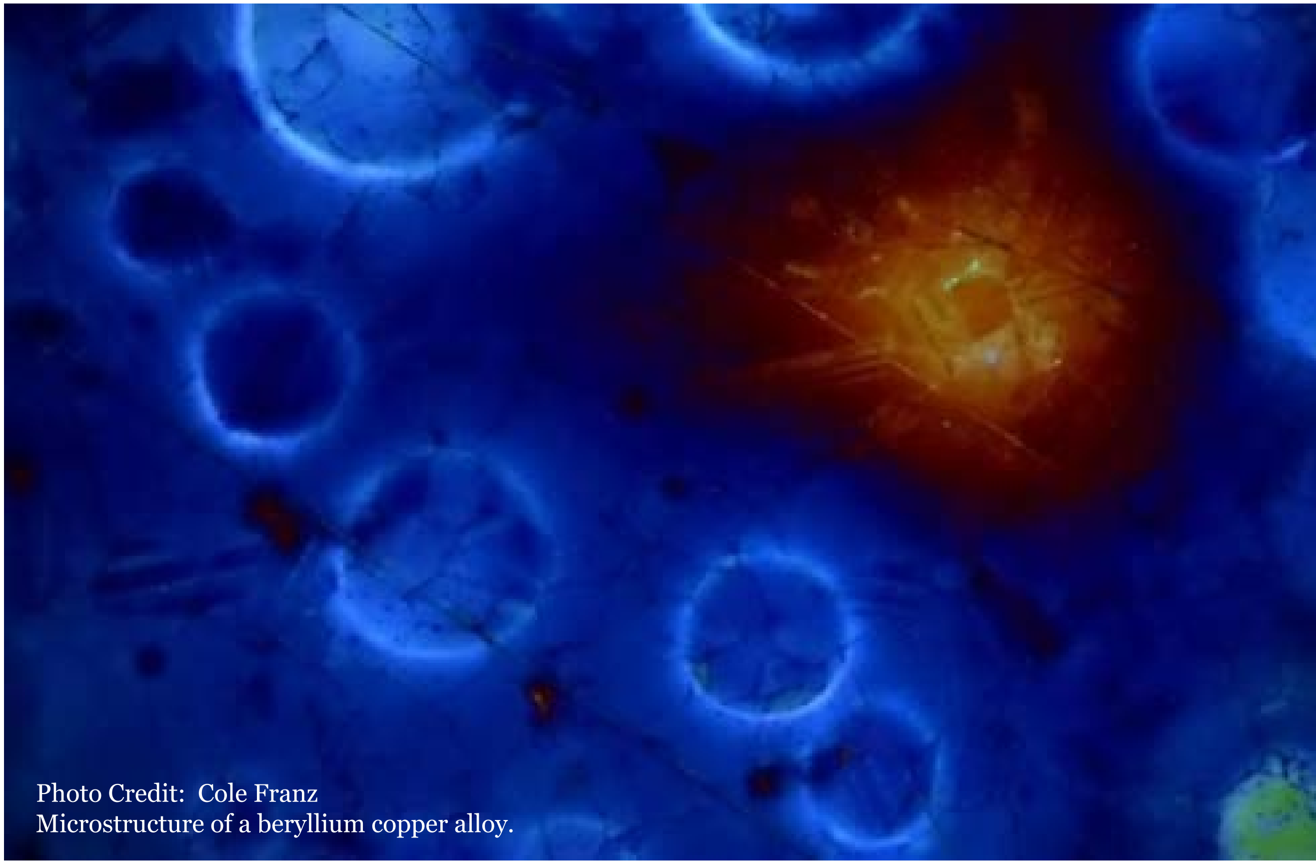


Photo Credit: Cole Franz
Microstructure of a beryllium copper alloy.

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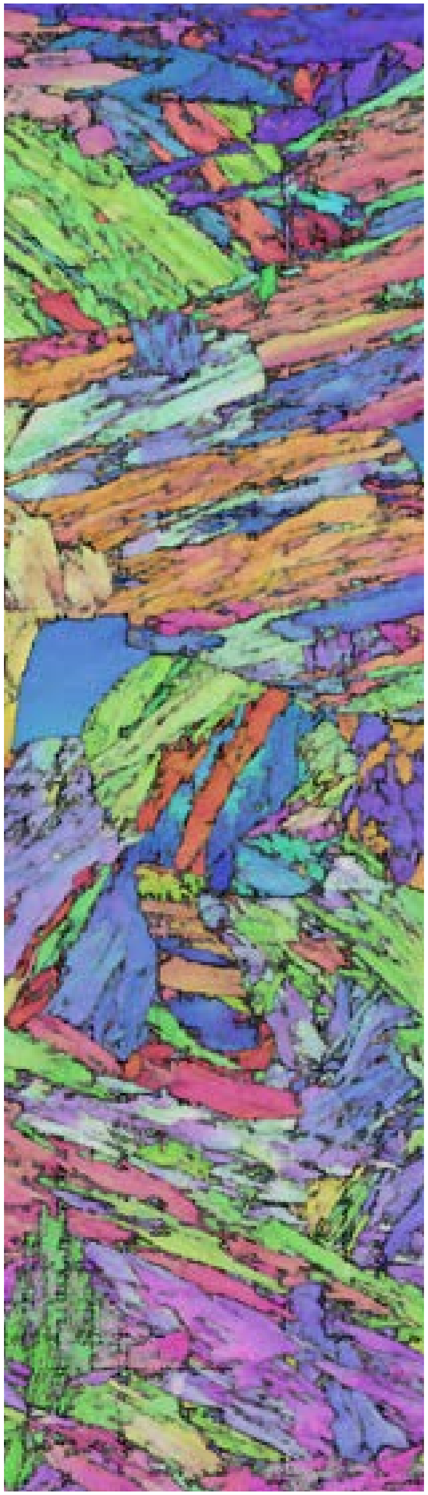

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