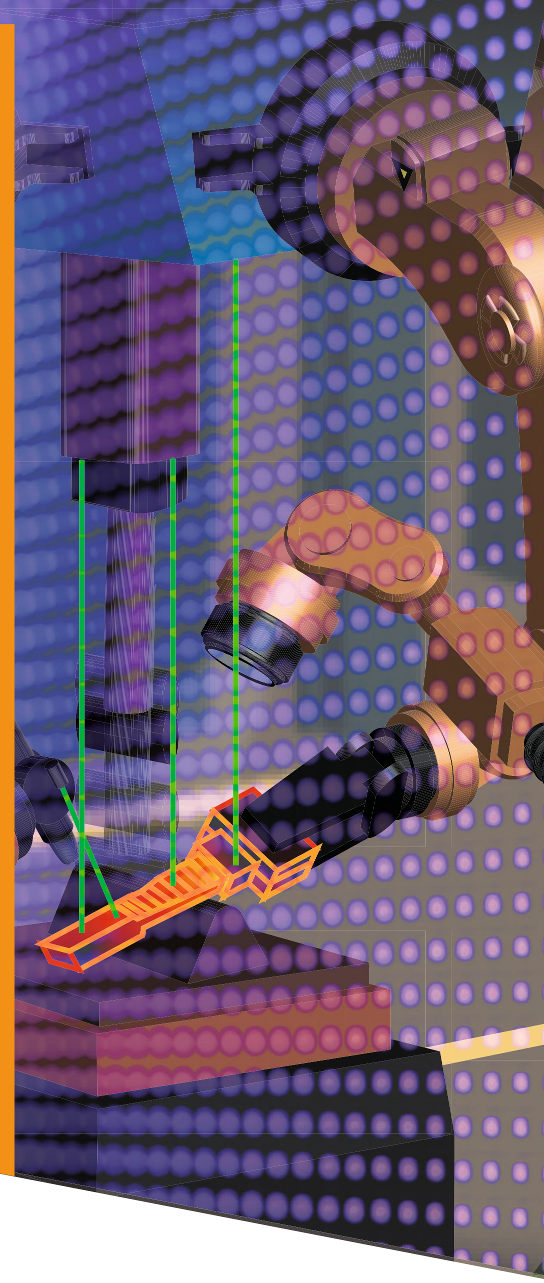
JOM, Vol. 75, No. 4, 2023
https://doi.org/10.1007/s11837-023-05765-y

INTRODUCING NSF'S HAMMER ENGINEERING RESEARCH CENTER: *HYBRID AUTONOMOUS MANUFACTURING MOVING FROM EVOLUTION TO REVOLUTION (HAMMER)*



BY GLENN S. DAEHN, JIAN CAO, JOHN LEWANDOWSKI, TONY SCHMITZ, JAG SANKAR

We are pleased to announce to the materials community that as of September 1, 2022, a coalition of universities was awarded a National Science Foundation (NSF) Engineering Research Center (ERC) with the title *Hybrid Autonomous Manufacturing—Moving from Evolution to Revolution* (HAMMER). With a successful renewal, this is planned as a 10-year project with $52 million in federal funding. The coalition was led by The Ohio State University, in collaboration with Case Western Reserve University, Northwestern University, North Carolina Agricultural and Technical State University, the University of Tennessee, Knoxville, and a network of societies and companies.

The center's title describes its core ideas quite well. *Hybrid Manufacturing* refers to using all appropriate tools to manufacture a part, and use them where they make sense, always with digital control. This follows the natural progression of digital manufacturing where numerically controlled machining started the revolution, while additive manufacturing used similar control processes to build materials. A central idea here is to add numerically controlled deformation to the mix. Deformation is, of course, excellent for shape making, and this community knows that thermomechanical processing is arguably our most powerful approach for optimizing microstructure and resulting properties.

Incidentally, the concept of numerically controlled deformation was detailed in a TMS report, *Metamorphic Manufacturing: Shaping the Future of On-Demand Components.* (See sidebar on

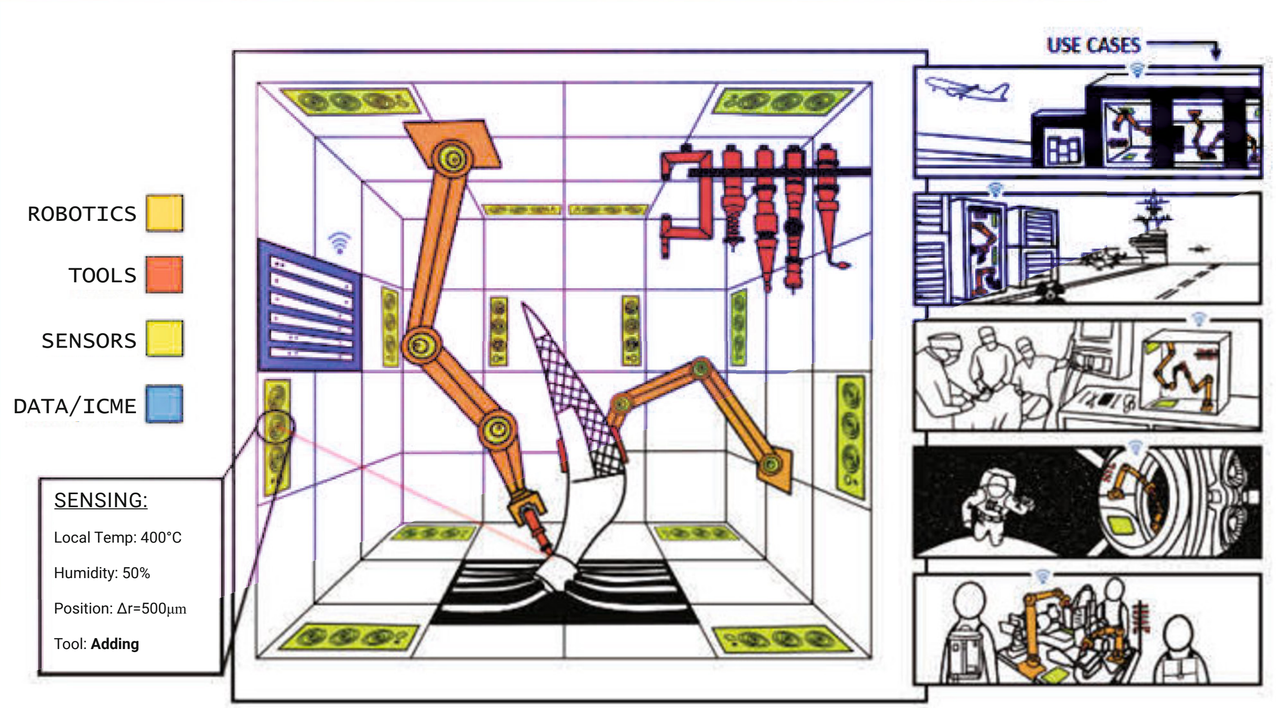


Figure 1: Schematic concept for the Auto-FAB—Autonomous Factory/Automaton Box—that is at the center of the NSF-HAMMER-ERC program. (Credit: HAMMER-ERC, hammer.osu.edu. Reproduced with permission.)

page 13.) This project is also significant in that four of the five principal investigators of the HAMMER program served on that TMS study team that led the development of the report.

Our next word, *Autonomous* describes that these will be automated systems that make decisions, learn, and store their learning in the cloud so that learning can be shared from one system to another. In this way, multiple tools for addition, subtraction, deformation, positioning, and inspection may be integrated, and control schemes will improve over time. The *Evolution* in foundational tools in sensing, robotics, integrated computational materials engineering (ICME), and even logistics will be harnessed to usher in a *Revolution* where quality-assured components will be manufactured in a distributed manner without long supply chains. A schematic figure for our approach is shown in Figure 1 and illustrates an Auto-FAB—an Autonomous Factory/Artisan Box. Multiple tools can act on a part in a suite of sensors recording operations, and this data stream may represent a digital thread for quality assurance. Several use cases are also indicated on the right of the figure.

We believe that this vision can fundamentally change manufacturing, but it requires many talents acting over many years. To advance this vision, the HAMMER-ERC has four primary research thrusts:

- **The *Design* thrust** will develop comprehensive system-level design methods that can concurrently design material, topology, and flexible manufacturing process sequences to meet social and economic needs. This will tackle the issue of the enormous design space that is developed by concurrently considering multiple product design options with multiple manufacturing sequences and varied material sources.

- **The *Tools and Process Convergence thrust*** will provide an extensible framework for design and control of "tools" to complete individual processes, sequence processes, measure results *in situ* and physically connect processes by part transfer without loss of dimensional or materials data.

- **The *Materials State Awareness* thrust** will develop fast-acting, reduced-order models, necessary to plan, execute and self-correct an Auto-FAB manufacturing sequence. The goal is to calculate and manage uncertainty in properties/performance of the manufactured part in such a manner that we might move the field towards model-based certification instead of the current paradigm of locking-down a process that has been proven by many destructive tests.

- **The last research thrust is *Control, Intelligence, and Autonomy*** which will develop manufacturing problem-centric artificial intelligence (AI) methods and integrate them with empirical knowledge, process physics, and high-fidelity simulations. This will be coupled with *in situ* sensing data to enable AI-enhanced control and intelligence for autonomous hybrid manufacturing processes.

The research is the foundation of the center and, in each case, fundamental technical questions are at the core. We also see four areas where we can move quickly to demonstrate and test outcomes from this approach. These are called testbeds in the language of the ERC program.

The first of these we refer to as *Numerical Forming*, which we define as manufacturing products with geometry and microstructure controlled by numerically controlled incremental open die forging with material-state aware. When successful, the numerical forming testbed will enable industrial collaborators to translate the research to manufacture forming with purposeful gradients in properties using smaller, more agile equipment integrating real time information about related manufacturing supply chains. Also, the evolution of this approach will largely decouple product and press size, allowing the rapid production of very large forgings without large dies or presses.

This approach is next coupled with preforms created by additive manufacturing, casting, or welding. We refer to this as *Additive Manufacturing + X*. Thermomechanical processing, (thermal processing with deformation) provides far more flexibility to create an optimal microstructure. Large grains can be refined and any porosity from solidification can be eliminated. This use of hybrid processing has special appeal in this area.

Our *Point of Care Manufacturing* testbed is focused in healthcare clinics on the use of bending, possibly hybridized with other processes. Use of dimensional data and multiple processes, including deformation, can create medical devices customized for a given patient. Personalized medical devices are already in wide use for joint replacements, fracture and graft fixation hardware, heart valves, surgical guides, limb prostheses, and dental implants. This has the potential to replace current practice where a surgeon may spend hours bending skeletal fixation plates to that model by hand, one at a time. Our approach will send computed tomography data to a bank of robots that would fabricate components quickly. One could envision gaining as much as a day, an advance that would quickly bring this technology to the clinic.

Our most outward and student-engaged testbed is in *Physical Exploration and Training—Factory Automaton Boxes (PET-FABs)*. These will provide inexpensive, short learning curve suites of equipment and software that can be used for student engagement, rapid innovation, teaching, and competition. HAMMER will develop standard equipment and training modules for many educational settings.

Possibly the most exciting and important part of this initiative is that the NSF-ERC program is focused on using the technical research as a base for positive social change. In the language of the Engineering Research Centers, this is captured in four foundational elements: Convergent Research (which we have already covered), Education and Workforce Development, Diversity and Culture of Inclusion, and an Innovation Ecosystem.

Do You Have Industry News to Share?

This article is the latest installment in an occasional *JOM: The Magazine* article series that features a case study or non-technical project overviews with strong industrial and/or manufacturing applications. To suggest an article idea, contact Kelly Zappas at kzappas@tms.org.

The HAMMER-ERC will establish robust programs in each of these areas. *Education and Workforce Development* will reach wide audiences through collaboration with other educational institutions, community colleges, societies, and makerspaces. Areas of special emphasis will include training trainers (high school, community college, industry) and the development of PET-FABs as educational platforms. Our *Diversity and Culture of Inclusion* Program will focus on including and promoting the participation of under-represented groups (minority, female, rural, economically disadvantaged) in advanced manufacturing programs. For instance, our partner, North Carolina A&T State University, the largest US educator of African American engineers, plans to initiate a Hybrid Autonomous Manufacturing Ph.D. program. The base of all this is the *Innovation Ecosystem* that will build community and use the results of HAMMER to start and enhance businesses.

We will try to adapt the cultural attributes that made Silicon Valley so successful to our HAMMER team. Those include trust, fairness, openness, and paying forward. External companies and researchers are welcome to participate in deep technical discussions by joining and executing a non-disclosure agreement so important concepts can be developed and protected. Intellectual property will be aggregated into a not-for-profit corporation that will be a catalyst for new ventures and systems.

We invite you to join us. We are just getting started but are thrilled about the opportunities that the HAMMER NSF-ERC provides. We believe that this is the kind of public-private partnership that can bring new technology and a larger, better trained and more diverse workforce forward. Visit hammer.osu.edu to learn more and contact us.

ABOUT THE AUTHORS

Glenn S. Daehn is the Mars. G Fontana Professor of Metallurgical Engineering in the Department of Materials Science and Engineering at The Ohio State University. He has wide interests in manufacturing, deformation processing, and university-society engagement. He is the principal investigator of the NSF-HAMMER-ERC and led the 2019 TMS Metamorphic Manufacturing study group.

Cardiss Collins Professor **Jian Cao** of Northwestern University specializes in innovative manufacturing processes and systems, particularly in the areas of deformation-based processes and laser additive manufacturing processes. She is the founding director of the university research center on Manufacturing Science and Innovation at Northwestern. Cao has been involved with TMS activities since 2001.

John Lewandowski is Distinguished University Professor at Case Western Reserve University. He served as the director of the Advanced Manufacturing and Mechanical Reliability Center (AMMRC) and the Nitinol Commercialization Accelerator Laboratory (NCAL) and is a 2022 TMS Fellow.

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Jag Sankar has developed high-profile, advanced, broad-based materials innovation centers, including, but not limited to, multiple NSF, Army, Department of Energy, and Navy programs at North Carolina A&T State University (NCAT). Under his leadership, from 2008-2022, NCAT was chosen as the lead to house the NSF's Gen 3 – ERC for Revolutionizing Metallic Biomaterials (RMB). Sankar's team received the 2023 TMS Light Metals Division Magnesium Technology Best Poster Award.