Developing a U.S. Roadmap for Advanced Joining and Forming Technologies

Tom McGaughy, Director of Technology
EWI

EWI recently led the development of the first comprehensive U.S. Advanced Joining and Forming Technology Roadmap under a two-year program funded by The National Institute of Standards and Technology (NIST) through the Advanced Manufacturing Technology Consortia (AMTech) program. EWI was supported by an external steering committee of joining and forming experts who assisted in data gathering and analysis, as well as ranking of roadmap priorities. The roadmap was developed by extensive canvassing of leading U.S. manufacturers, academia, industry and professional associations, and other stakeholders to identify and rank current joining and forming challenges and to develop a list of prioritized research and development topics that will lead to differentiating competitive advantages and produce substantive economic impact.

Information to support the roadmap was collected by performing a state-of-art review of global technology trends, conducting surveys and interviews with selected industry and research leaders, and holding expert focus group meetings across many manufacturing sectors. Industry-canvassing activities were designed to determine current limitations in joining and forming applications for today's manufacturing requirements. Key gaps and needs were identified by evaluating their impact on U.S. manufacturing competitiveness with respect to joining and forming operations. An additional goal of the roadmap was to leverage existing funding sources and regional economic development structures to develop and implement tangible solutions for manufacturers of all sizes.

The roadmap presents a national perspective on the technical and economic needs of the materials joining and metal forming industries within the U.S. manufacturing economy. While other broad reviews and forward-looking reports on the state of these technologies have been published by various organizations over the years, it is believed that this roadmap represents the most comprehensive review and assessment carried out to date within the U.S. It is the culmination of more than two years of industry canvassing across every major manufacturing segment in the U.S. economy, incorporating input from more than 400 companies, from small family-run businesses to large multi-national conglomerates.

The automotive industry increasingly relies on robotics to improve manufacturing processes.

The Importance of Materials Joining and Forming

Materials joining and forming are essential cross-cutting manufacturing technologies, contributing around $200B in value to U.S. manufactured products annually, and are closely related in terms of their applications, users, technical fundamentals, and emerging challenges. These operations are pervasive throughout manufacturers of all sizes in every sector of the economy. Production lines often include both forming and joining processes, and design optimization often involves assessing trade-offs between forming and joining options, as the approach used to form a component can have a significant impact on subsequent joining processes and vice versa. The two areas also require similar technical understanding of materials science, heat transfer, elasticity/plasticity behavior, and control of process equipment.

Today, there is a new wave of regulatory, economic, and technical forces impacting U.S. manufacturers' ability to meet rapidly changing consumer demands, achieve higher levels of productivity in the face of a dwindling technical labor force, compete against lower-cost global manufacturers, and meet new and more stringent government regulatory requirements. It is clear that the U.S. needs a renewed focus on advancing materials joining and forming technologies to address these emerging challenges and revive a critical part of the U.S. manufacturing base. Doing so would not only fundamentally improve the global competitiveness of U.S. manufacturers, but would bolster the middle class and reduce the trade balance deficit that has been steadily rising for more than two decades.

Friction stir welding increases the ability to produce products with a wider array of alloys.

The Current State of the Art and Existing Gaps

While the volume of joining and forming operations has declined in the U.S. over the past two or three decades, significant advancements have been made in metals forming and materials joining technologies that have reduced manufacturing costs, increased performance, and improved the quality and reliability of many of our manufactured products. However, these improvements have not been significant enough to slow the offshoring of many of these operations. Growing use of automation has partially offset a shrinking skilled labor force and increased quality while reducing costs. Development and maturation of new joining processes such as friction stir welding and laser-based brazing have dramatically improved the ability to produce products with a wider array of metal alloys that enhance performance of aircraft, spacecraft, automobiles, and many consumer products, to name but a few. The advancement of microjoining processes has revolutionized the electronics and medical device industries. Advanced brazing techniques allow use of specialized ceramics, metal matrix composites, and difficult-to-weld alloys that improve performance and reliability of critical components - such as jet engines - allowing them to operate more efficiently at higher temperatures and pressures.

Regardless, many technical and business challenges impacting U.S. industry remain, and new ones are emerging on the horizon. Today, the U.S. is experiencing a materials revolution on a scale not seen in several decades. New ultra-high-strength steels, aluminum alloys, and polymeric and composite materials are being developed to produce dramatic performance improvements in automobiles and aircraft, fossil fuel and advanced energy infrastructures, and power generation. New materials used in the construction of buildings ranging from homes to high-rise commercial office spaces to advanced clean-room-style automated factories are designed to improve energy efficiency and withstand natural forces from earthquakes and severe weather events. The advancement of additive manufacturing, also known as 3D printing, is opening the door to manufacturing hybrid material or multi-material products that allow the combination of a variety of metals or plastics in a single component or structure to take advantage of the economics and engineering performance of each material.

The increasing use of advanced materials creates significant challenges regarding joining and forming, particularly with hybrid or mixed-material systems. In some cases, methods of joining have not been fully developed for advanced materials, forcing industry to use older, less efficient techniques, such as mechanical fastening. In some cases, manufacturers are simply unable to take advantage of these new materials until joining technology catches up. Likewise, difficulties exist in the forming of ultra-high-strength steels and certain aluminum alloys now gaining greater use in the automotive industry. Current metal-forming technology can often result in high scrap and re-work rates that impede broader application of these emerging materials.

Key Gaps and Needs

Assessment of industry feedback during the roadmap development process identified the following overriding needs, most of which were broadly voiced across nearly all manufacturing sectors:

- Implementation of emerging materials to optimize product performance and cost, as well as new manufacturing processes, to form and join a wide range of high-performance materials and material combinations
- Increased access to advanced computer-simulation methods to optimize design and better predict product performance to satisfy increasing design requirements, reduce the need for physical prototypes, and reduce material or product qualification costs
- Reduced manufacturing costs and increased product reliability by ensuring 100% first time quality, requiring more robust manufacturing processes in combination with new real-time process monitoring and control approaches to detect and correct non-conformances
- Development of new test methods, baseline data, and standards for many new manufacturing process variations to ensure robust and consistent manufacturability
- Development of more agile, highly automated manufacturing operations that can efficiently and economically produce a wide variety of components in small batches (high mix, low volume)
- Development of near-net-shape processes to produce complex parts with fewer operations, requiring new design tools, cost models, and process parameter maps to help manufacturing engineers select and implement processes that will shorten production cycle time and potentially reduce material costs
- Expansion and maintenance of a skilled work force capable of developing and applying advanced forming and joining technologies

EWI automated robotics test lab.

Roadmap Recommendations

Analysis of the data obtained from extensive industry canvassing efforts led to the series of recommendations outlined below. Successful completion of these recommended actions would measurably advance the state of the art in materials-joining and forming technologies, provide U.S. manufacturers with critical capabilities that address today's and tomorrow's challenges, and enhance U.S. manufacturing competiveness. These recommendations are listed in no particular order, and details of each recommendation are discussed in the complete roadmap document.

- Workforce skills development encompassing the emerging and incumbent labor force, including technician, skilled trades, and professional staff
- Development of advanced weld distortion control methods (adaptive welding)
- Development of next-generation prediction tools, including automated materials exploration and optimization for joining processes
- Development of advanced high-productivity fusion processes
- Development of joining processes for hybrid materials and mixed metals

- Implementation of real-time advanced measurement, prediction, and control technologies for forming and joining processes
- Development of practical warm/hot forming technology for aluminum, titanium, nickel, and steel alloys
- Development of advanced technologies for producing lightweight high-strength forgings

U.S. manufacturers will gain differentiating capabilities if progress can be made on these priorities and technology advancements are delivered to the manufacturing floor. These advancements have the potential to reduce waste and rework, increase productivity of joining and forming operations, shorten product development cycles, and allow the manufacture of products with material combinations and performance characteristics currently not feasible with existing technology. If the U.S. leads the development of these technical advancements, U.S. manufacturers will reduce or eliminate current gaps in production costs and create opportunities to be first to market with goods that would otherwise be difficult to manufacture elsewhere.

Next Steps

In response to the needs identified and vetted through this roadmapping effort, EWI has created a series of Grand Challenge technical teams to develop multi-disciplinary solutions that will bridge these gaps across broad manufacturing sectors. Specific scopes and targeted outcomes will be developed in close consultation with industry and government stakeholders to identify funding opportunities and to ensure that technology advancements have a pathway to implementation. EWI will closely collaborate with industry as developments progress and refine scopes and approaches as needed to be responsive to industry feedback and maintain focus on targeted outcomes. The current Grand Challenge focus areas include:

- Ensuring first-time quality
- Enabling greater use of automation
- Developing and optimizing technologies for vehicle lightweighting
- Maturing additive manufacturing to produce end-use goods

The First-Time Quality team is aiming to advance development of in-process monitoring and control technology with closed-loop feedback to allow real time adjustment of multi-process manufacturing operations. The Advanced Automation team is seeking to develop technology that increases flexibility and adaptability of complex, skills-based manufacturing operations that are difficult to widely replicate. The Lightweight Vehicles team is seeking advancements that allow improved processing and fabrication with advanced lightweight materials or combinations of advanced materials. The Additive Manufacturing team is working to move AM from a predominantly prototyping technology to a more mature capability that manufacturers of all sizes can readily implement for the production of a wide array of end-use products. The specific activities undertaken by these Grand Challenge teams will be the subject of future papers.

Tom McGaughy *is the Director of Technology at EWI, where he chairs EWI's industry advisory board, leads EWI's senior technical staff, and manages EWI's research portfolio. He is also the Technology Leader of Structural Integrity and Modeling, providing technical oversight of the materials testing area and developing programs specializing in fracture mechanics and materials technologies. Tom is intricately involved in developing client relationships and technology development strategies, principally with the oil, gas, and petrochemical industries.*