University of Massachusetts Lowell Introduces Self-Healing, Sustainable Combat Boots. **By Kathlyn Swantko**

UPDATING THE UNIFORM

James Reuther, Associate Professor of Chemistry at UMass Lowell (UML), highlights sustainability as the critical factor for its "Self-Healing Combat Boot" research, currently being conducted at UML's Fabric Discovery Center (FDC). Supported by the U.S. Department of Defense (DoD) and AFFOA (Advanced Functional Fabrics of America), this UML FDC study is one of three American University FDCs, established by the AFFOA to spur innovation for advanced fibers and fabrics.

According to Reuther, 20 billion pairs of shoes are currently being produced annually, and 100% of this footwear contains polyurethane (PU), which is non-recyclable and the vast majority is non-biodegradable. This leads to large accumulations of footwear in landfills that impacts the environment.

Reuther adds, "My main motivation for this project is to develop sustainable PU material alternatives to facilitate other recyclable and up-scalable products that can potentially lead to reintegrating PU byproducts for a variety of other applications."

The initial phase of the project (HEROES SWIFT I - The Supporting Warfighters through Innovative Footwear Technologies) began in August 2023 as a collaboration between UML and Poly Laboratories & Solutions LLC, a polyurethane processing company in Lewiston, ME to advance footwear technologies for U.S. Warfighters. AFFOA's mission for this project focuses on developing next generation PU alternative combat boot outsoles as a replacement for the conventional rubber outsoles currently being used.

Synthesized PU outsoles with 0%, 1%, 5%, and 10% (left to right) dynamic monomer integrated are used to compare mechanical properties, recyclability and degradability between PU-vitrimers and controls incapable of reprocessing.

The team's goals include: 1) Demonstrate that PU outsoles can meet the Army's physical specifications, while lowering the weight and break-in time, compared to conventional rubber; 2) demonstrate that the incorporation of novel, dynamic monomer units into PU formulations can introduce self-healing properties, recyclability, and controlled-degradability without sacrificing performance, and 3) create the potential for other end-of-life applications for these components.

The second phase of the project (HEROES SWIFT II), began in April 2024. In this stage, UML collaborated with the Haartz Corporation, a world leader in synthetic leather production, to assess the potential replacement of the cattle-hide leather (currently in use for the upper components of the combat boots) with synthetic leather derivatives.

According to Reuther, the goals of Phase II are similar to the first, to demonstrate that synthetic leathers can meet the Army's specs, while improving the break-in properties, production sustainability and costs. The approach involves introducing key (diol) monomers into different "syn-leather" components to establish recyclability, self-healing, and degradability. Reuther says, "The synthesis of the diol monomer--UML's 'Secret Sauce'--is simple, efficient, responsive, and can be easily scaled-up industrially and produced domestically within the US market."

Once synthesized, the monomer can be introduced into resin formulations of PU (typically consisting of polyols, catalysts, foaming agents, etc.) to impart sustainable properties into the material. The recyclability and degradability are fully controlled by the dynamic bond integrated into the system. Reuther explains, "This leads the PUs to be classified as a unique, emerging class of materials called 'PU-vitrimers' which can then be reprocessed after curing, via compression molding or extrusion, to form new materials without degradation for reuse."

According to Reuther, the process of creating the new materials can be easily adapted through traditional manufacturing procedures, without requiring a major investment in new equipment. He says, "One of the key benefits of our designed chemistry is that our 'vitrimers' are considered 'drop-in' monomer alternatives. They are compatible with any (or most) PU synthesis applications, and don't require changes to existing commercial infrastructures."

The new material also enables self-healing capabilities that can repair cracks and damages in the outsole material. Reuther adds, "Enabled by the dynamic bonds we introduce into the materials, the damaged areas can be repaired using heat. Similarly, the dynamic bonds can be exchanged at higher temperatures to impart flowability and reprocessing qualities, using techniques otherwise impossible for PU thermosets."

Reuther says the team's short-term goal is to fully characterize the materials as prepared, and attempt a variety of different recycling procedures (i.e. compression molding, twin-screw extrusion, 3-D printing); and upcycling processes (i.e. reintegration into PU resins, re-crosslinking, 3-D printing) to demonstrate new end-of-life applications. Ultimately, the team hopes to expand the scope of the chemistry into other PU applications beyond combat boots, for new end-use products.

"The true impact of our work will not be realized until we understand which PU applications our technology will impact the most, and what our client base may be," states Reuther. "Footwear and furniture represent two markets with the highest potential, due to the environmental challenges and disposal similarities of both industries." ■

SPOTLIGHT ON AFFOA'S FABRIC DISCOVERY CENTER AT UMASS LOWELL

Through joint strategies with American Universities, Advanced Functional Fabrics of America's (AFFOA) Fabric Discovery Centers (FDCs) serve as start-up incubation space, and provide workforce development activities necessary for the true advancement of innovative functional fabrics. "AFFOA's mission is to revitalize textiles in the U.S. through innovation," explains Sasha Stolyarov, AFFOA's CEO. "This relies heavily on a domestic end-to-end U.S. innovation ecosystem with active regional nodes. AFFOA established its FDCs to focus its mission in regions with hotbeds of advanced fiber and fabric innovations."

AFFOA currently has four Fabric Discovery Centers: 1) AFFOA's Fabric Discovery Center (FDC) Headquarters, located in Cambridge, MA; 2) MIT's Defense Fabric Discovery Center (DFDC) and the U.S. Army Natick Soldier Research Development and Engineering Center (NSRDEC), located in MIT's Lincoln Laboratory; 3) Drexel University's Center for Functional Fabrics in Philadelphia, PA; and 4) UMASS Lowell's (UML) FDC. "

The FDCs provide advanced R&D for exceptional prototyping to create new manufacturing expertise and processes, along with critical engineering to support both the Department of Defense (DoD) and potential future commercial needs. Funded through partnerships among federal and state governments, along with its participating textile universities, AFFOA's FDCs create a network to connect, share, and advance textile fiber and fabric technologies, and move innovative cutting-edge capabilities forward.

The UML FDC site is the only USA location that brings together opportunities from three U.S. Manufacturing Innovation Institutes under one high-tech environment: 1) AFFOA; 2) Nextflex (a group devoted to manufacturing advancements in 'Flexible Hybrid Electronics'); and 3) ARM (Advanced Robotics Manufacturing). UML's FDC is responsible for driving research in both product- and process-developments to launch automated-manufacturing for the advanced commercialization of functional fabrics.

"Lowell has a rich history of textile and technology development," notes Stolyarov, and the UMass Lowell FDC has continued to do great work to ensure this history continues through R&D, education, and workforce development."

Besides impacting the USA's regional/national economies and national security, UML's FDC serves to provide the next-generation employees for wearable electronics and medical textile technologies. UML's FDC assists both academic and industry researchers by transforming product concepts into functional prototypes for other industries. ■