Conductive and Ferromagnetic Syntactic Foam with Shape Memory and Self-Healing/Recycling Capabilities

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What is the outcome or accomplishment? (1-2 short sentences describing it and why it is transformative; 50-word maximum suggested)*

We introduced a multifunctional conductive and ferromagnetic syntactic foam with a shape memory effect and self-healing capabilities. This enables a series of additional potentials such as strain sensing, damage monitoring, Joule heating, and electromagnetic interference shielding. Despite its low density and outstanding mechanical properties, this foam exhibits shape memory behavior, which can be triggered by an electrical current, and damage healing capability due to its reversible dynamic covalent bonds. In particular, its recyclability makes recycling expensive silver-coated and nickel-coated HGMs feasible, making this foam cost-effective and environmentally sustainable.

The syntactic foam was prepared and characterized, and its thermomechanical properties were tested. In addition, many of its functionalities, including recyclability, shape memory, magnetism, and radio/electromagnetic shielding, were examined. The conductivity of this foam for triggering shape memory and strain sensing was also demonstrated.

What is the impact? (1-2 simple sentences describing the benefits for science, industry, society, the economy, national security, *etc.*; suggested 50-word maximum)

In recent years, multifunctional materials have emerged as a focal point of scientific interest, primarily for their capacity to integrate a variety of functions within a singular material framework. The syntactic foam being proposed stands at the forefront of this innovation, offering two key impacts. Firstly, it represents a breakthrough in material versatility, ingeniously combining an array of functionalities into a unified system. More crucially, this foam paves the way for a new era in material science by championing recyclability. This not only promotes sustainable manufacturing practices but also ensures economic feasibility, marking a significant stride towards eco-friendly and cost-effective material solutions.

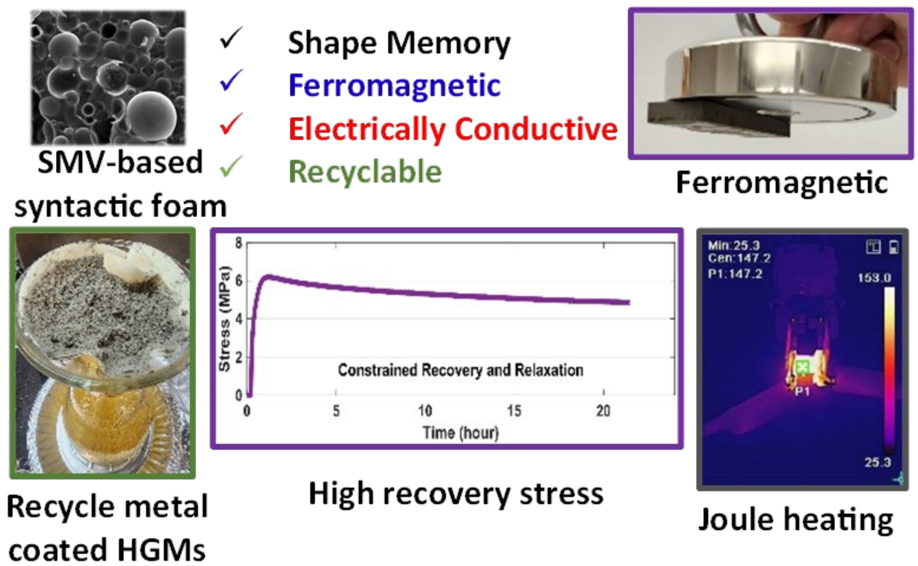
With its many features and economical manufacturability, this syntactic foam has the potential to be utilized in many applications, ranging from aerospace structures to biomedical devices to household items.

What explanation/background does the lay reader need to understand the significance of this outcome? (1-2 paragraphs that might include, for example, more on who, when, where; NSF's role; support from multiple directorates/offices; what makes this accomplishment unique; additional intellectual merits; or broader impacts such as education, outreach, or infrastructure improvement that are integral to this outcome; suggested 150-word maximum)

First, unlike traditional materials, multifunctional materials offer improved performance, reduced weight, better durability, and increased functionality, leading to more efficient systems. This new field holds the potential to revolutionize various industries, including electronics, aerospace, and biomedical. Second, shape memory polymers (SMPs) are a class of multifunctional materials that, in addition to their structural properties, can restore their original shape by an external trigger. Once they are programmed to a temporary geometry, they will return to their original form through different means, such as heat, moisture, pH, light, electricity, or magnetic fields. Therefore, they are highly regarded as actuators. A shape memory polymer turned into a syntactic foam has additional benefits and applications, which makes it extra beneficial for smart adaptable sandwich cores, sealants, lightweight actuators, and shock absorption, among other applications. Adding HGMs into SMVs not only makes them lightweight but also has the potential to enhance their functionalities by making them ferromagnetic and electrical conductors.

The addition of two-way actuation, which means the shape conversion can be reversible, improves the current use of these foams by allowing them to be tailored at will and suggests a great number of additional applications for SMP-based foams.

Dr. Li and his group have previously developed a novel shape memory vitrimer (SMV) that showed remarkable self-healing and recycling features. By incorporating nickel and silver-plated hollow glass microbubbles (HGMs) into this vitrimer, LAMDA researchers, supported by NSF proposed an SMV-based syntactic foam that supplements the multifunctionality of the SMV with electrical conductivity and ferromagnetism. This enables a series of additional potentials such as strain sensing, damage monitoring, Joule heating, and electromagnetic interference shielding. Despite its low density and outstanding mechanical properties, this foam exhibits shape memory behavior, which can be triggered by an electrical current, and damage healing capability due to its reversible dynamic covalent bonds. In particular, its recyclability makes recycling the expensive silver-coated and nickel-coated HGMs feasible, making this foam cost-effective and environmentally sustainable., fabricated a syntactic foam. Results obtained from a broad spectrum of tests performed on the fabricated foams with varying porosities can be used to engineer foams for different applications that may require particular properties.



SMV-based
syntactic foam
✓ Shape Memory
✓ Ferromagnetic
✓ Electrically Conductive
✓ Recyclable
Ferromagnetic
Recycle metal
coated HGMs
Stress (MPa)
Constrained Recovery and Relaxation
Time (hour)
High recovery stress
Min:25.3
Cen:147.2
P1:147.2
153.0
25.3
P1
Joule heating