Composite Materials Research Set To Eliminate Weak Spots in Aerospace

Steel and aluminum are both strong and inexpensive materials, but when it comes to designing more environmentally-friendly and fuel efficient modes of transportation, their weight can become an issue. Polymers are lightweight materials, but weaker than metals. Combine them with carbon or glass fibers then you have the best of both worlds: lightweight and strong fiber-reinforced polymers.

There has been a steady increase in the use of lightweight composites in the aerospace and automotive industries. For example, the Boeing 787 Dreamliner and 777X, and Airbus A350, contain up to 50% composites by mass, while most other components are made of metals. Carbon fiber can reduce weight by 20% to 60% which greatly reduces fuel consumption. For instance, during an international flight from Boston to Tokyo, airlines can save at least $10,000 in fuel with some of the newest composites airplanes.

While the demand for composite materials is growing, many scientific challenges remain. One of the biggest issues is their assembly at joints, which are the weakest points and could fail under high load. Common joining methods include rivets and glue, neither of which are ideal, due to increased weight, stress points, and surface preparation. Louisiana researchers are investigating ways to improve joint strength through several projects.

Thermoplastic polymers can be joined through fusion bonding, otherwise known as “welding,” that eliminates the use of rivets or glue. For this purpose, ultrasonic welding is a promising joining technique owing to high-speed and energy-efficient cycles.

In addition, thermoplastic polymers can be formed again when heated up above a certain temperature. This makes thermoplastic composites (TPC) more sustainable, as they can be reused and recycled.

Welded metal TPC joint strength depends on mechanical, chemical and physical surface treatments of the metal substrate. For example, a rough metallic surface will lead to stronger joints compared to a smooth surface because the polymer will lock itself around the uneven surface areas.

Improving joint strength with 3D printing

A team of researchers, led by Dr. Genevieve Palardy, is developing a way to improve joint strength by 3D printing composite materials with continuous carbon fibers.

This research is by the NSF EPSCoR-funded Consortium for Innovation in Manufacturing & Materials (CIMM) with which Dr. Palardy is a recent new hire.

It is expected that fiber layup and orientation will have an effect on the mechanical performance of hybrid metal TPC joints when using microscopic surface texturing on the metal substrate.

Manufacturing composite substrates through 3D printing allows experimenters to easily vary fiber layup while minimizing fabrication time. The additive manufacturing and testing of these materials is occurring at the Advanced Manufacturing and Machining Facility at Louisiana State University, a part of the CIMM Core User Facilities.

In-depth research will include the thermomechanical behavior of 3D printed samples, plasma treatment and quality assessment through microstructural analysis and comparison with traditional manufacturing methods like compression molding.
In Summer 2018, preliminary experiments were carried out by undergraduate students on Dr. Palardy’s team who were able to start addressing key questions regarding this particular project. Surface texture created on metal substrates through additive manufacturing showed the most promising results in shear loading. Their findings will help improve the design of the surface modification on the metal substrates and help develop a finite element model to simulate the joining process.

**Composite joint-repair research**

Ultrasonic welding of thermoplastic composites has been successfully demonstrated on lab-scale and medium-sized components. However, there is still a lack of confidence in the fundamental prediction of failure behavior. In order for welded composite joints to be considered in industrial applications—especially for high-performance sectors such as the aerospace industry—it is imperative to find innovative ways to enable structural health monitoring and repair.

Funding awarded to Dr. Palardy from the Louisiana Board of Regents Research Competitiveness Subprogram is enabling research on the development of multifunctional thin films that could fulfill three purposes: Heat concentration at the interface during welding, strain sensing for structural integrity monitoring, and repair after failure or disassembly.

**New bonding technique research**

Currently, composites with a thermoset matrix, such as epoxy, are preferred by NASA. During the manufacturing process, they undergo an irreversible chemical reaction and cannot be melted, making them unsuitable for direct fusion bonding.

Dr. Palardy is leading a research collaboration investigating repair and bonding techniques of thermoset composites with funding from a NASA EPSCoR Research Award Program. The collaboration includes researchers from the NASA Johnson Space Center, Drs. Mark McElroy and Daniel Kim.

This project’s main goal is to assess the possibility of using high-speed ultrasonic welding, a common technique for thermoplastics, as an approach for structural repair and bonding of thermoset composites. Traditionally, structural repair of thermoset composites involves the application of a patch with adhesive and fibers, and external pressure and temperature, usually through autoclave or vacuum-bagging/heated blanket. These repair technologies are too time-consuming, leading to cost increase.

This ultrasonic process would greatly simplify structural repair/bonding by eliminating the vacuum-bagging step, and promoting time, cost, and weight reduction. This method also shows promise for use with thermoplastic composites manufacturing.