UNITED STATES AIR FORCE MATERIALS TECHNOLOGY HIGHLIGHTS

Air Force Research Laboratory

Materials & Manufacturing Directorate

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Researchers Partner With The Canadian Brass on Testing Composites

The Air Force Research Laboratory's Materials and Manufacturing Directorate (ML) is collaborating with the world renowned Canadian Brass quintet to better understand how advanced materials, which the directorate develops for air and space components, can be applied to musical instruments.

This activity resulted from the Brass' interest in these materials and the benefits they may provide to their instruments. The Brass' tuba player currently uses a carbon-fiber-reinforced polymer matrix composite (PMC) tuba bell, and the benefits he has experienced may also be applied to additional instruments such as trumpets, trombones, and French horns. The directorate expects that activities initiated by ML, while addressing musical components, will also lead to a better understanding of how these materials will perform in Air Force applications.

According to Dr. Allan Katz, chief of the directorate's Ceramics Branch, dialog between the Brass and the directorate was initiated by his wife, a member of the Dayton Philharmonic Orchestra (DPO). She observed the unusual PMC tuba bell when the Brass performed during a DPO concert and arranged a quick meeting between the Brass and Dr. Katz. It was clear from this initial, brief discussion that the members of the Brass were interested in learning about composites and other advanced materials that might be applied to their instruments.

A small group discussion between composites engineers from the directorate and the Brass was arranged in July 2002. Researchers were particularly interested in the demonstration of four PMC tuba bells, as well as a PMC trumpet mute. According to Katz, the best of the PMC bells provided a richness and clarity of sound that was very noticeable when compared to the other bells. The PMC bells had been custom made at the Brass' request, most of them by the Yamaha Band and Orchestra Division with whom the Brass has a close working relationship. The bells were of different thicknesses and composite constructions, which the researchers believe relate to the resulting differences in sound character.

The tuba player reported that the PMC bells (versus brass) produce sound that can be heard well at the ear while also projecting into the performance hall, and are more responsive. "The considerable weight difference between light advanced composites and brass is also of benefit for a musician toting a heavy tuba," Katz said.

The PMC trumpet mute was also of special interest to directorate scientists, Katz said. Unlike metallic mutes, the composite mute did not alter pitch or playing resistance with the degree of muting applied by the musician.

"The visit in December reinforced the notion that we can contribute to increased understanding of the role of advanced materials in traditional 'brass' instruments," Katz said. "The issues, in many ways, are similar to ones we face in aerospace applications."

"For example, though hot exhaust washed ducts and engine cowlings found on aircraft are not an exact match, the tuba bell does bear some resemblance," said Tia BensonTolle, chief of the directorate's Structural Materials Branch. "Aircraft components are often acoustically excited, and vibrational modes, resonances, and damping can be critical to performance of systems in an operational environment where excess vibration can cause material fatigue and unwanted noise levels in an aircraft. Understanding these parameters and how to control and apply them to materials selection and design, whether for aerospace components or musical instruments, bears a keen resemblance and importance to materials such as composites"

The collaboration between the directorate and the Canadian Brass will allow them to discover how advanced materials characteristics impact sound character. The directorate will use this understanding to help select and design materials that will sound better and will be more responsive for the musician while gaining important knowledge about vibration and damping properties of materials in Air Force structures.

As time and resources permit, ML personnel plan to fabricate small components in the lab, with varied materials design (for example, with different fiber reinforcement architecture), to assess the impact on musical sound character. These components may include PMC mouthpieces, lead pipes (the small transition piece between the mouthpiece and the body of the instrument), and mutes.

According to Dr. Mark Tudela, a directorate researcher who specializes in characterizing material behavior, they will initially focus on the French horn bell because it is small enough to be fabricated in-house, with varying PMC constructions. The French horn is configured to accept interchangeable bells, which will permit the direct comparison of audible sound character and the measurement of vibration characteristics in differing PMC bells. Tudela suggested that the directorate may also examine metal alternatives to

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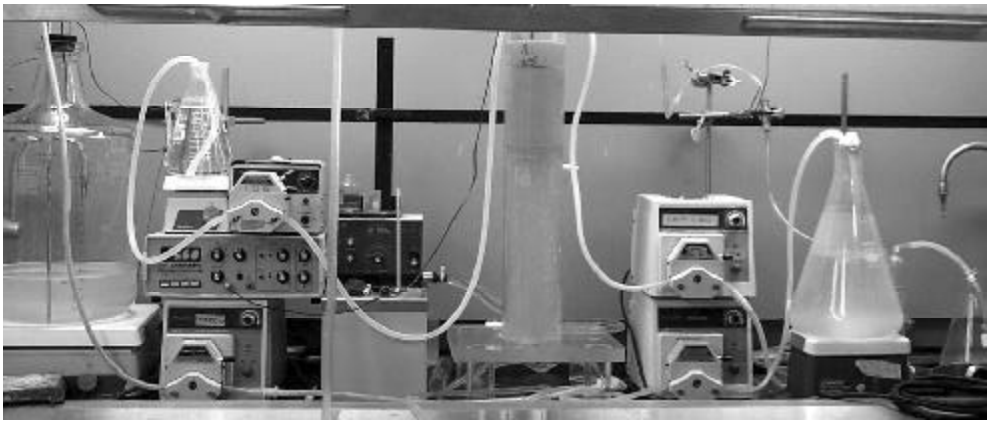
Researchers Explore Hydrogen Production as Energy Source

Scientists at the Air Force Research Laboratory's Materials and Manufacturing Directorate (ML) are developing a biological method of producing hydrogen from waste streams created by base dining halls, kitchens, latrines, hospitals, laundry facilities, and showers at bare base facilities.

When successful, researchers will have demonstrated that hydrogen production from bare base waste streams is a feasible alternative source of energy for fuel cells. Using hydrogen as an alternative energy source is an exciting option due to its high conversion efficiency and nonpolluting nature.



Conversion of a biological waste stream into hydrogen biogas through a microbial fermentative process using a fluidized bed reactor

Bare base facilities have as many as 1,100 military personnel who live in temporary housing. Their mission often requires the base to function for several years, with little or no services provided by the host nation. Currently, MEP-12 diesel generators produce the electrical power needs of the base. Generators supporting these energy needs require 4,000 gallons of diesel fuel per day that has to be transported to and stored at the facility.

A two-reactor system, currently being developed by researchers from ML's Weapons Systems Logistics Branch, is expected to reduce logistical burdens, pollution, and noise associated with using current diesel energy generators for energy production. Fuel cells driven by hydrogen will lower diesel fuel consumption, and minimize the use of fossil fuels for production of hydrogen.

Though hydrogen is the most abundant element on earth, it is bound to other elements and has to be separated before it can be used in energy generation. Microorganisms contain enzymes that can produce hydrogen from waste materials, providing a seemingly inexhaustible source of material for hydrogen production.

Many anaerobic organisms can produce hydrogen from organic substrates, converting carbohydrates to organic acids. For example, glucose can be converted to two acetate molecules, releasing four hydrogen molecules. The hydrogenase enzyme responsible for the reaction works very rapidly, but the process stops at the organic acid, which retains significant hydrogen energy.

In order to fully extract the hydrogen from organic molecules, ML experts have developed a two-stage process, a fermentative reactor with a photosynthetic bacterial hydrogen production process to yield the maximum hydrogen from organic carbon sources. The photosynthetic reaction uses the energy from sunlight to completely convert the organic acids to six molecules of carbon dioxide and ten to twelve hydrogen molecules.

By using microorganisms in hydrogen production, the production process would encourage additional waste recycling, reducing waste disposal and treatment needs of nations hosting the base. Also, no additional carbon dioxide is released during this process. The process is similar to biodegrading organic molecules at a wastewater treatment facility. However, at the wastewater facility the hydrogen is not collected or used.

While scientists have developed thermochemical and electrochemical methods for hydrogen generation, these processes are energy intensive and are not always environmentally friendly. Biological methods present a less energy intensive means of hydrogen production. These occur at ambient temperatures and pressures, which require very little energy and predominantly generate hydrogen and carbon dioxide.

Researchers from the directorate built an up-flow fixed bed anaerobic reactor to begin testing on biological hydrogen production. The reactor was filled with approximately, 2 kilograms of diatomaceous earth pellets. Diatomaceous earth pellets have a high surface area to mass ratio that provides abundant sites for the bacteria to attach and form biofilms. A large fixed biofilm optimizes hydrogen production and prevents loss of bacteria from the reactor during high flow rates. A sucrose solution and soil sample, which contained the bacteria, was introduced to the earth pellets. The reactor was operated at low flow rates, one milliliter per minute for two months to allow the bacteria to colonize the earth pellets. As bacteria degraded the sucrose, carbon dioxide and hydrogen were produced. The fixed bed reactor consistently produced 50 to 60 percent hydrogen in the resulting biogas waste stream.

Microbial hydrogen generation from biomass occurs at significant rates, however, the net production of hydrogen may be limited by the presence of competing bacteria, which consume hydrogen to produce methane. Methods to eliminate the competing methane production and hydrogen-consuming microbes can be accomplished by heat-treating a reactor when hydrogen production slows under normal operation. Because bacteria are fragile organisms, heat treatment kills and controls the competing methane producing bacteria. But, the "useful" bacteria may also be harmed as a result of heat-treatment. Previous studies demonstrated that a species of *Clostridium* were spore-forming. Bacteria that are capable of going into a spore phase are protected from the heat treatment. Thus, the bacteria survive and the competing organisms are removed. The spore-forming bacteria will also allow for a system to be shut down, with vegetative cells forming spores during down times, and converting back to vegetative cells when the process resumes.

Though researchers intended to use *Clostridium*, preliminary RNA characterization of bacteria from the reactor has demonstrated that *Bacillus* bacteria, another spore forming bacteria, rather than *Clostridium* is the active hydrogen producer in their reactor tests. Additional testing and characterization will provide scientists with additional insight about biological hydrogen production by bacteria.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 03-062.

"Kissing Bonds" Composites Test Discovered

A scientist at the Air Force Research Laboratory Materials and Manufacturing Directorate has discovered a way to test adhesive bonds for mechanical performance nondestructively during manufacturing and depot level repair. The technology employed in the new testing method works with both composite and metal as well as hybrid composite and metal structural components; wherever adhesive bonding, due to its many advantages, is used.

This new testing method is so effective at identifying weak and nonexistent bonds or "kissing bonds," it could easily make composites the material of choice for most high performance aircraft and civil structures. Other major areas of application for composite materials that could be affected by this technological advance are spacecraft, automobiles, prostheses and sports equipment.

A kissing bond refers to a condition in adhesive bonding where there is intimate contact between the adhesive and the structure or component but no adhesion between these two entities. A sizeable number of premature service failures have been traced to kissing bonds. Consequently, aircraft designers have been reluctant to use adhesive bonding in primary or flight critical structures, despite the advantages of this joining technique.

The nondestructive inspection (NDI) community within the United States has been searching intently since the 1950s to find *any* technique capable of predicting bond performance and detecting kissing bonds. Two challenges have stopped progress towards this goal. First, the most often used methods for detecting these defects are based on ultrasonic techniques, which are restricted to areas that carry little or no structural loads; hence, any correlation with mechanical performance has been happenstance. Second, from an ultrasonic inspection point of view, there is no difference between a kissing bond and a coherent one because both are in intimate contact and therefore not detectable with ultrasonic methods. Finally, even if a kissing bond could be detected, it is still possible for a "low-strength" bond to slip through the inspection process and result in unexpected structural failures.

A technician working with a first generation adhesive bond inspection system

Dr. Robert L. Crane, a scientist at the Air Force Research Laboratory Materials and Manufacturing Directorate, found a way to detect kissing bonds *and* low-strength bonds, while performing research on the detection of high cycle fatigue (HCF) damage in the first stage compressor blades of an F100 jet engine. The leading edges of these blades had been treated using a process known as laser shock peening (LSP), in which a high-energy laser pulse is focused on both surfaces of the blades. The pulse initiates high-level compression waves into the blade that produce near-surface compressive residual stresses, which prevent the growth of HCF cracks in service. After the compression waves traverse the blades they bounce off the opposing free surface as tensile waves. These waves approach each other and combine to produce a very large tensile load in the center of the blade. In the case of the F100 engine blades, these overlapping tensile waves were sufficient to fracture the very tough titanium blades during the shock peening treatment.

Dr. Crane realized that if LSP processing could fracture the titanium, then it would be possible to use this method to load an adhesive bond to a sufficient level to fail it, and thus test for the presence of both kissing bonds and low-strength bonds. Furthermore, it would be possible to vary the timing of the laser pulses so as to place the maximum tensile load at predetermined points in the bonded joint. Also, since the surfaces of the structures being subjected to the LSP process are monitored during the process, it would be relatively easy to detect bonded joint failures by way of surface displacements.

The research that validated this concept was conducted jointly with the Boeing Company, which is currently patenting the technology. This new capability will speed up certification of composite materials for widespread use in aircraft construction. If composite components can be assembled with adhesive bonding, then they can compete economically with traditional riveted aluminum structures. New design concepts will be lighter, stronger and more efficient because they will not be constrained by the traditional joining methodologies.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 02-306.

Canadian Brass member Ryan Anthony demonstrates a carbon-fiber-reinforced polymer matrix composite trumpet mute.

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brass for mouthpieces, and ceramics for valves.

"Ultimately, the goal of the Canadian Brass is to improve their instruments by use of advanced materials, to find suppliers who will employ these materials to make the musical components, and to educate the public so that the use of these materials for instruments becomes more widespread," Katz added. "These aims are fully consistent with the Air Force's technology transfer interests. We also expect to learn much during this collaboration about the behavior of a number of Air Force structural components and materials that will help us achieve the valuable properties and characteristics that we desire."

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 03-034.

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