ADVANCED MATERIALS FOR THE

AUTOMOTIVE INDUSTRY

The CU-ICAR research campus features programs to develop advanced materials for the automotive market.

Clemson University
Clemson, South Carolina

The Clemson University International Center for Automotive Research (CU-ICAR) brings together two industry sectors – Automotive and Advanced Materials, which also are two of Clemson University's critical emphasis areas, pairing university expertise with the needs of South Carolina's economy.

Established in 2003, CU-ICAR is a 250-acre advanced-technology research campus in Greenville, S.C., 45 minutes from the main Clemson campus, where university, industry, and government organizations collaborate to fill the gap between basic research and commercial application of automotive technologies.

The Carroll A. Campbell Jr. Graduate Engineering Center (CGEC) (Fig. 1) at CU-ICAR houses master's and doctoral programs in automotive engineering, including the nation's only automotive engineering Ph.D. program. It is focused on the concept of systems integration, especially design and development, manufacturing, and the growing field of vehicle electronics systems. The Center is equipped with exceptional laboratory and test cell facilities for collaborative research projects for private clients and partners as well as strictly academic research. To date more than $220 million has been invested by public and private partners from various industries, including advanced materials.

This article describes CU-ICAR research in titanium alloys, metamaterials, and an automotive suspension development program, and overviews the Clemson University Advanced Materials Center.

Titanium development

Most recently, in November 2008, American Titanium Works announced it will locate its applications development and engineering technical center at CU-ICAR in connection with a $422-million titanium mini-mill facility the company plans to locate in nearby Laurens County, S.C.

ATW's manufacturing processes will include raw material preparation and blending equipment, plasma arc-melting and vacuum arc-melting furnaces, and a best-in-class four-high rolling mill designed and purpose-built for rolling of alloyed and commercially pure titanium plate. A wide range of titanium conditioning, finishing, nondestructive testing, and laboratory equipment will also be on site to ensure quality.

The company's proximity to and collaboration with CU-ICAR provides ATW staff daily interaction with an academic program that is focused on the future, looking at new ways to incorporate materials and processes in all aspects of the automotive and motorsports industries and others that have natural ties, such as aerospace and other transportation-related fields. At the same time, the relationship provides students and faculty critical access to real-world engineering problems and exposure to the everyday work environment of practicing engineers, a plus for students as they pursue career options.

Clemson researchers are looking at ways to develop a seamless interface with ATW to provide a "turnkey" R&D environment in which the Clemson research program will augment and enhance ATW's

Fig. 1 — The Carroll A. Campbell Jr. Graduate Engineering Center of Clemson University.

Fig. 2 — These diagrams show the shear bands of the Michelin Tweel, and the NASA lunar rover wheel. Research is under way to develop meta-materials that will enable more efficient performance than the current polyurethane material.

development programs.

Demand for titanium has historically exceeded the global industrial capacity, resulting in long lead times. This has constrained development of other promising applications for titanium, such as force protection for soldiers in combat. Expanding the commercial applications of titanium may result in greater industry investment in capacity, shortening lead times and leading to innovations in other titanium applications. The commercial automotive sector is a good candidate for additional titanium investment as lighter-weight materials may improve vehicle performance and corrosion resistance. Research will be completed in the areas of

- Titanium applications in the commercial automotive industry
- Structural integrity study of vehicle components replaced by titanium
- Factors affecting the machinability and formability of titanium

Clemson research expertise and facilities offer the unique ability to explore processing controls in the manufacture of titanium, particularly with regard to cost optimization.

Machining research will be carried out in partnership with Okuma America, which recently consigned state-of-the-art equipment for the CGEC lab. Assistant Professor Laine Mears says the Okuma collaboration was the final piece in the puzzle that allows CU-ICAR researchers to take a project from raw materials through design, machining, and testing. The CGEC full-vehicle and engine/powertrain testing facilities, which include a seven-post shaker and a chassis dynamometer, provide the all-important final step to verify results in-house.

Among the beneficiaries are commercial original equipment manufacturers and suppliers and military ground vehicle development teams who want to reduce energy use by making structural components of titanium.

Fig. 3 — The Michelin Tweel is being considered for the wheels of the new NASA Lunar Rover.

Meta-materials

Under a $1.9-million, three-year NIST/ATP contract, Clemson professors are working with engineers at Michelin and Milliken to develop a shear band of meta-materials to achieve 5% fuel saving for Michelin's non-pneumatic tire known as the Tweel (Fig. 2). The properties of a meta-material depend on its structure rather than its composition. The shear band, the key element of the Michelin Tweel, is a sandwich of an inner inextensible band, a shear module with low shear modulus, and an outer inextensible band. The shear band transmits the load of the Tweel to a uniformly distributed contact patch.

This material was initially investigated to create a structure with a negative refractive index, which is not found in any naturally occurring materials. The negative refractive index causes light to bend around a meta-material object, rendering it invisible.

In the mechanical sense, meta-materials have also been investigated to create a structure having negative Poisson's ratio, which also are not found in nature. Effectively, the meta-material with negative Poisson's ratio will dimensionally increase in length and breadth when pulled, essentially increasing in volume as tensile loading is applied.

Those concepts became the basis for the idea of changing meso-structural geometries. With proper selection of base materials, this could enable engineers to meet a material design criterion not possible with materials in nature.

As a first application, Clemson engineers have applied the meta-material concept to the development of a next-generation fuel-efficient tire, the Michelin Tweel. Mechanical Engineering associate professor Joshua D. Summers says the main goal of the project is the development of a shear band for replacing polyurethane with metallic meta-materials having both elastomer-like properties and low-energy hysteresis loss while rolling.

The advantage of meta-materials is that optimum properties can be created for both optimum structure and optimum flexure. This is because meta-materials can address both base materials and cell geometries, which means that the meta-material's design space is much larger than that of conventional materials.

Theoretically, any material can be tailored to have a target property with the meta-material design as long as manufacturability is not a concern. For example, polycarbonate and low carbon steel can be tailored to be meta-materials having the same target shear modulus as that of elastomers (6 to 8 MPa) by changing structural geometries. These two different kinds of meta-materials can be used for different purposes: Low hysteresis loss metals are preferred as base materials for a tire shear band on paved roads.

On the other hand, high-damping polymers are preferred as base materials for high impact absorption in the NASA lunar wheel application (Fig. 3). At the present time, the Clemson meta-material design is limited to the meso-scale, but its application is able to be extended to micro- and nano-scales.

Design development

The application of advanced materials to the automotive industry played a major role in a recent project conducted by students in Clemson's unique automotive engineering graduate program located at CU-ICAR.

The students collaborated with DiMora Motorcar company to design an automotive suspension system that can handle speeds in excess of 240 mph. DiMora Motorcar challenged a team of students to evaluate suspension technology options for the Natalia SLS 2 sport luxury sedan (Fig. 4), guided by associate professor of mechanical engineering and team faculty leader Steve Hung.

Based in Palm Springs, Calif., DiMora Motorcar crafts automobiles designed to exceed expectations for safety, performance, technology, ecology, beauty, comfort, and luxury. It reveals the design, production, and testing of its automobiles via the Internet so that people around the world can learn from and participate in the process. The DiMora Motorcar collaboration typifies the CU-ICAR model for partnership.

"DiMora is about showcasing new technologies," says Carl Flesher, CU-ICAR director of Global Business Development. "CU-ICAR is about developing the methods and people to make showcase technologies ready for the automotive original-equipment manufacturer market."

Suspension is obviously crucial to a safe and smooth ride. An effective suspension system will maximize the mechanical grip between the tires and the road, enhance steering stability, and provide a comfortable ride. The Natalia sedan has to thrive in all road environments, so the suspension must be compatible with all-wheel drive and have the ability to clear common road obstacles. The vehicle also must be controllable at speeds above 240 mph, so body response to driver input and road excitations must be well controlled across a broad speed range. A unique design-driven requirement is the use of 275/40R24 tires.

Fig. 4 — Graduate students at CU-ICAR collaborated with DiMora Motorcar company to design an automotive suspension system that can handle speeds in excess of 240 mph for its Natalia model.

After numerous advanced digital design and verification processes, preliminary DiMora Motorcar vehicle parameters, and computer-aided-design for the Natalia, the Clemson graduate team generated a solution that includes short-long arm architectures for both front and rear suspensions, titanium control arms and wheel carriers, and combination air spring and damper units.

The concept design services the requirement for all-wheel drive, minimizes suspension weight, and

Clemson's automotive-related advanced materials research is not limited to the CU-ICAR facilities.

allows for rear-wheel steering to enhance directional stability at high speeds as well as maneuverability at low speeds. The concept design also will help DiMora Motorcar package other vehicle systems that yield the right levels of performance without significant changes to the suspension system.

Broader advanced materials

Clemson's automotive-related advanced materials research is not limited to the CU-ICAR facilities. Just 30 minutes south on Interstate 85, the Clemson University Advanced Materials Center (CU-AMC) offers a similar campus environment. While CU-ICAR is focused primarily on the automotive industry, the CU-AMC facilities are dedicated to comprehensive materials research, which comprises 30% of the University's sponsored research program. The two campuses work collaboratively.

For example, Clemson's Timken Chair in Automotive Design and Development, John Ziegert, who is a member of the faculty located at CU-ICAR, has used the facilities of Clemson's Center for Optical Materials and Science Engineering Technology (COMSET), housed in the CU-AMC's Advanced Materials Research Laboratory, for a project on predictive molding of precision glass optics. As the need for smaller lenses rises, so does the need to have a molding process capable of predicting the lens final form, given a shape and set of processing parameters.

The automotive industry also receives analytical services for the development of new materials from Clemson's Electron Microscopy Facility, located in the Advanced Materials Center and considered one of the finest in the nation. The EM program offers remote access to some of its instruments so that clients can view and control images from anywhere in the world using only a PC. This saves clients both time and travel expense and allows them to maintain control of their experiments in real time.

Clemson's School of Materials Science and Engineering has a history of advanced materials research for a variety of industries, including automotive and aerospace. Its research centers include the Clemson Conservation Center, at the Clemson University Restoration Institute in Charleston, S.C., where research is under way on corrosion of metals. The Center for Advanced Engineering Fibers and Films is also part of Clemson's materials research with implications for the automotive industry.

From the ground up, so to speak – from tires to fabrics, from optics to lightweighting, Clemson researchers at CU-ICAR and in other research centers are working collaboratively to support the automotive industry.

For more information: John M. Ballato is Associate Vice President for Advanced Materials, Office of Research and Economic Development, Advanced Materials Research Laboratory, Clemson University, 91 Technology Drive, Anderson, SC 29621; tel: 864/656-1035; ballato@clemson.edu.; www.clemson.edu.