UD-CCM's Applications & Technology Transfer Laboratory Design and Fabricate Prototype of Composite Components for NASA Z-2 Spacesuit

On Mars, not just any suit will do

NASA seeks impact resistance in next-generation space suit.

Author: Jeff Sloan
Source: CompositesWorld, Dec. 2016 - reprinted with permission

The race to send humans to Mars has begun. In late September of this year, Elon Musk announced that he and SpaceX (Hawthorne, CA, US) are working on plans to make human travel to Mars not just feasible, but (relatively) affordable. Musk thinks he can get the cost of travel to the Red Planet down to a meager US$200,000 per person, and he believes there could be millions of people living on Mars by 2060.

Competitor Boeing's (Chicago, IL, US) CEO Dennis Muilenburg presented in early October his vision for an entire commercial space travel industry, replete with a variety of destinations in Earth orbit and new supersonic jets whisking travelers between continents in just a few hours. Capping it off, he asserted, "I'm convinced the first person to step foot on Mars will arrive there riding a Boeing rocket."

Indeed, NASA is eager for its partners to help the space agency put people on Mars as soon as the 2030s. This effort will start in 2018 with a series of missions designed to test propulsion, spacecraft and, eventually, human performance at increasing distances from Earth, culminating in what NASA calls Earth Independence.

Whether humans first touch down on Mars in a SpaceX or Boeing vehicle, a top priority will be full and continuous protection to ensure their survival in a decidedly unfriendly Martian landscape. Setting aside for the moment concerns about deadly cosmic rays and gravity that is just 38% that of Earth's, there are five Martian environmental factors that are immediately and particularly problematic.

The first is the atmosphere, which is 96% carbon dioxide. Compare this with Earth's, at 78% nitrogen, 21% oxygen, and other gases.

Second, the atmospheric pressure on the Martian surface averages 600 pascals, which is 0.6% of Earth's mean sea level pressure of 101.3 kilopascals. This puts

Fig. 1: NASA's Z-2 spacesuit prototype. One of the first spacesuit iterations designed specifically for use on the harsh Martian surface, NASA's Z-2 features a hard upper torso (HUT), back hatch and briefs made with composites, primarily for impact and ballistics resistance. Although NASA provided general design principles for the parts, design engineering and prototype fabrication was performed by the University of Delaware – Center for Composite Materials — Applications & Technology Transfer Lab (UD-CCM-ATTL), which also fabricated a working prototype. Source: NASA

Top STORY

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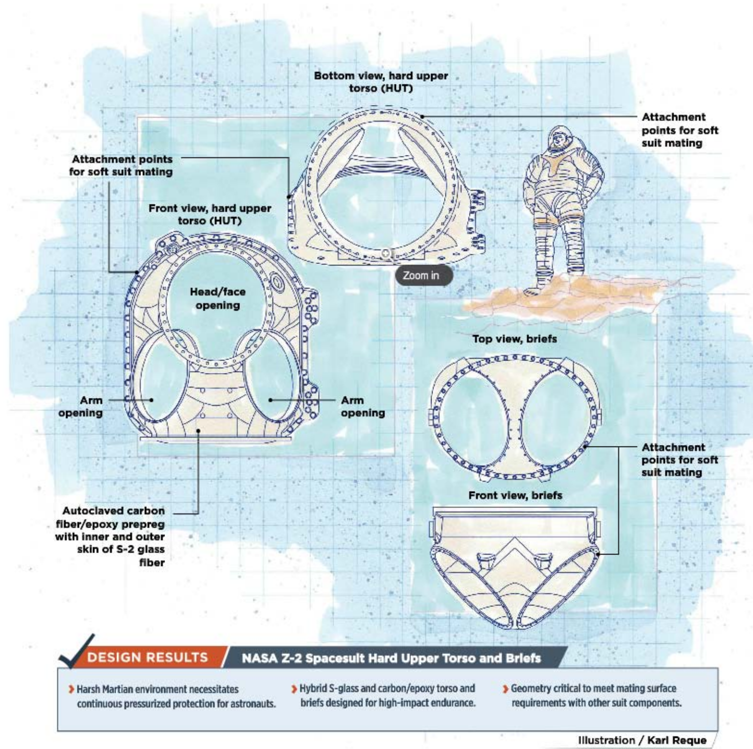
the Martian atmosphere below the Armstrong limit, meaning unprotected humans on Mars would suffer immediate and painful evaporation of their saliva, tears, skin mucous and whatever fluid exists in their lungs.

Third, on Mars, temperatures can range from a comfortable 70°F/21°C to an unlivable -225°F/-143°C. Fourth, there are dust storms of a size, ferocity and duration sufficient to cover whole regions of the planet's surface.

Finally, there is the threat of falling micrometeorites. Because the Mars atmosphere is so thin, these impact the planet, for the most part, remain intact and, thus, present a very substantial ballistic hazard.

Anticipating these challenges, NASA has begun development of a new spacesuit. Called Z-2, it is designed for what NASA calls planetary extravehicular activity (EVA), that is, for astronauts who will climb in and out of vehicles and habitats as they travel and study the planet. Z-2 is a project of NASA's Advanced Exploration Systems Division.



What a suit needs

The Z-series of suits feature a rear entry port that docks with the habitat or spaceship, allowing the astronaut to leave the suit and dirt outside. For Z-2, NASA decided on lightweight hard-shell components covering the torso to provide the astronaut better protection. Three composite parts make up the Z-2 torso: the HUT (hard upper torso), the brief, and an entry hatch that mounts to the back of the HUT. Each component must mate with bearings and seals, as well as the helmet and the arm and leg sections. Further, many of the life support and communication systems are mounted to the HUT and the hatch inside and outside the suit. The rigid composite torso could not sacrifice mobility and could impose only minimal weight increase.

To prove the viability of the Z-2 suit, NASA turned to ILC Dover (Frederica, DE, US), which has a long history of manufacturing spacesuits, going back to Apollo program days.

ILC DOVER *creating what's next*

NASA

Working as the prime contractor on the suit program, ILC Dover engaged the University of Delaware – Center for Composite Materials — Applications & Technology Transfer Lab (UD-CCM-ATTL) to help push spacesuit performance to the next level by optimizing design and manufacturing while reducing defects found in earlier composite parts.

Top STORY

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This was a challenge, partly because NASA wanted a flight-quality test article that would be safe for human mobility trials and astronaut training in a vacuum chamber. "Project funding and timeline allowed for only one chance at fabricating the suit components, which was to be done under supervision of government quality auditors and required rigorous process documentation and control," says Dan Molligan, assistant director for application development at UD/CCM/ATTL. Molligan notes that, "ATTL is an off-site ITAR restricted facility which has an infrastructure very unlike other universities; it has rigorous SOP, SMP, and quality standards which conforms to commercial industry protocol."

Early in Z-2, ILC screened candidate materials (fiber and matrix) and processing methods. In addition to lightweight and high strength, materials had to be "space-qualified" and non-toxic. The team decided to base the reinforcement on high-modulus carbon fiber, adding outer layers of S-glass to improve impact resistance. Using woven fabrics (versus unidirectional) would further improve impact resistance. A toughened epoxy with good hot/wet performance and good processiblity was selected as the matrix. Out-of-autoclave (OOA) processing of prepregs was selected to achieve near-autoclave performance at lower cost.

Working from the functional requirements and feedback provided by ILC and NASA, ATTL engineers used solid modeling software to design the Z-2 component geometry. The HUT especially had highly contoured surface geometry. After ATTL completed the initial laminate design for the HUT, hatch door and brief based on structural analysis of static pressure and external load cases using FE software, CCM campus researchers ran impact simulations of various mission profile mishaps that could occur during planetary exploration, such as tripping and falling onto a rock.

While the impact study was going on, the team at ATTL designed molds for the HUT, brief and hatch. By then, the outer surfaces of the parts were fixed, and any design changes (i.e., thickness buildups, changes in laminate design) would affect only the inside surfaces, which would be controlled by a conformable vacuum bag. ATTL also conducted trials to develop a process for OOA prepreg by fabricating numerous test panels and subelements. During these trials, it became apparent that OOA processing would not produce Z-2 parts with acceptably low void content because debulking steps entrapped too much air in the prepreg. "Consequently, autoclave processing was chosen for final preform consolidation and curing, which required another round of process development, with the prepreg modified for autoclaving," says Bill Patterson, technical manager, at UD-CCM-ATTL. Ultimately, mechanical testing at ATTL showed no property loss from multiple debulks compared to panels consolidated and autoclaved in one step.

Geometry, geometry, geometry

The greatest challenge, say Molligan and Patterson, in designing and fabricating the Z-2 components was dealing with their geometric complexities. First, the interfaces between the torso components and between the torso and the helmet, arm sections and leg sections led to highly complex outer surfaces. Even for parts with uniform thickness, each preform layer consisted of many patterns due to the shear limits of the fabric feedstock material, each requiring precise location and shearing into the final shape.

TOP STORY
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Second, the parts were not of uniform thickness, but had local buildups at various hardware attachment locations. The main challenge was to make thick flanges in the HUT and the hatch to form the door-locking features that NASA used on previous HUTs. The locking mechanism consists of a toothed, linked belt that runs in a track in the inside surface of the HUT flange, and a string of gear teeth around the outer perimeter of the hatch. The belt is moved to engage and disengage the hatch teeth. On the hatch, the flange was roughly 1-inch wide by 2 inches high (25.7 mm by 50.1 mm) in cross-section.

For the hatch, NASA's initial preference was to have composite teeth, as in the Mark III, for additional weight savings, but after numerous design iterations and process trials it was decided to provide a hybrid design where the outer perimeter with metallic teeth were retained to mitigate risk in the flight-quality test article. This would ensure that the load transfer from the hatch to HUT would be handled by a robust, fail-safe design.

Many options for forming the flanges were evaluated, but Molligan and Patterson chose to fabricate inserts from precured and machined prepreg after testing showed that there was no loss in interlaminar shear strength at the interface of prepreg and pre-cured insert. For the hatch, however, the only reliable way to ensure safety was to hybridize the component, using a metal outer ring and internal composite panel.

Finished prototypes were delivered to ILC Dover in July 2015. NASA conducted nondestructive testing of the parts, using flash infrared technology. ILC Dover subsequently assembled the composite parts with other suit components and delivered the finished Z-2 suit to NASA for evaluation.

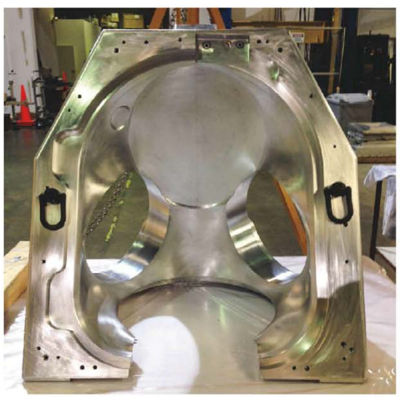


FIG. 2 Toolmaking makes the difference

The aluminum female mold for the Z-2 HUT had to be separable to permit extraction of cured parts and avoid hang-ups. (The tool's parting line is barely visible in the tool's vertical center.) UD/CCM/ATTL did all of the tool design, simulation and process analysis for the Z-2. Source | UD/CCM/ATTL

FIG. 3 Managing the process

Z-2's prime contractor, ILC Dover (Frederica, DE, US), wanted to fabricate the suit's composite parts using an out-of-autoclave (OOA) process, but this proved unworkable. Instead, UD/CCM/ATTL employed PMTF-4A, a carbon fiber/epoxy prepreg from Patz Materials & Technologies (Benicia, CA, US), which made layup of the complex ply buildups and drop offs more practical. Source | UD/CCM/ATTL

FIG. 4 Performance key: Mating surface accuracy

Mating surfaces on the HUT and other Z-2 composite parts are critical because the suit must, first and foremost, maintain pressure at all times. UD/CCM/ATTL was challenged by the variable thicknesses of the composites, which required use of multiple ply drop-offs. These, when combined with the autoclave process, forced the use of several intermediate debulks to expel entrapped air. Source | UD/CCM/ATTL

NEWS

CAMX Discussion Emphasizes Importance of Industry Collaboration

Author: Mary Lou Jay
Source: Composites Manufacturing, Sept. 2016

Companies that want to spur innovation need to find collaboration partners, according to Jon Riley, vice president of digital manufacturing at the National Center for Manufacturing Sciences, a non-profit, applied R&D institution. "All we do is collaboration," says Riley. "We have a vision for a vibrant, competitive U.S. manufacturing base that is driven by innovation and powered by collaboration and really confident in a future of success."

Riley was the initial speaker and moderator at the panel discussion on "Accelerating Innovation through Collaboration" on Tuesday morning at CAMX. He mentioned three challenges to innovation:

- **Technology** – the customer's existing infrastructure, products and processes can be difficult to overcome.
- **Economics** – the current provider may have economic advantages over competitors because they have an existing relationship.
- **Politics** – people don't like change or have different measures of success even in the same company.

Trust is the essential foundation for effective collaboration, he added.

The University of Delaware Center for Composite Materials (UD-CCM) has partnered with many different agencies and private companies with the goal of moving technology from the research and development phase to the market, according to **Dirk Heider**, assistant director. One recent project for NASA involved an impact-resistant space suit for lunar and Mars exploration.

Jim Staargaard, president and CEO of Plasan Carbon Composites, discussed how collaboration with seven different partners helped his company create a composite frame to replace the magnesium frame for the removable roof of a Corvette. One essential is to involve customers in the project early on so they have buy-in, he said.

Dr. Steven Shepard, president of Thermal Wave Imaging Inc., spoke about how his company worked in a collaborative process to improve thermography technology, making it more effective in inspection processes. He noted that the ideal collaborations involve primary tech suppliers, small applications and the end users working together.

During the discussion period, the audience and panel members touched on several issues that could derail or slow the collaborative process, including bureaucracy. "Bureaucracy will kill innovation," says Staargaard. "The more restrictions you put on people to innovate, the less you will get out of them."

"For us, a synonym for bureaucracy sometimes is inertia," added Shepard. For instance, his company has had large aerospace companies ask them to accomplish something within a very short time frame. While Thermal Wave Imaging could meet the schedule, the customers' internal procurement departments could not get the necessary processes completed to accommodate the product timeline.

A big challenge the panelists and audience discussed was intellectual property. In a collaborative relationship, each partner wants to protect its own interest. Therefore, it's important to resolve any issues up front and find a common ground.

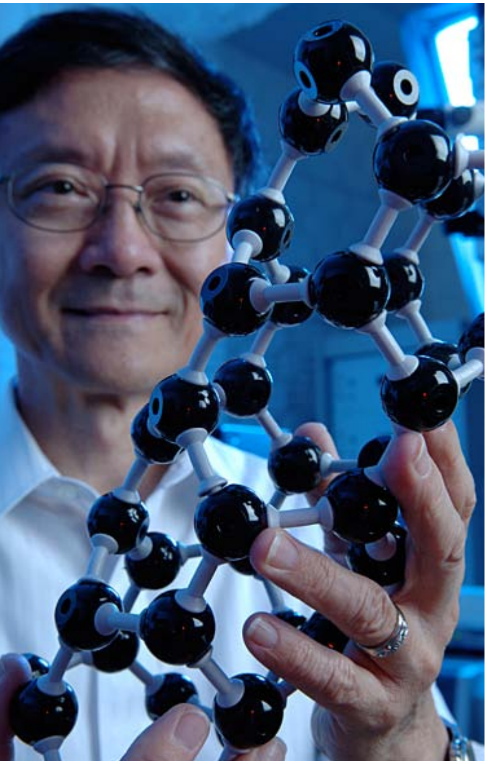
NEWS

For university partnerships, the issue of intellectual property can become particularly muddy. The federal government encourages the transfer of university tech research it funds to the private sector. However, for-profit companies want to protect any research that they fund from their competitors. Heider said that academic research institutions, which cannot charge private companies more than the actual cost of the research, would like to receive additional compensation for their efforts, such as a license to use the product developed or defined financial compensation over a number of years. Collaborative partnerships can only be successful when each partner has real equity in the project. It can be difficult, however, to figure out the appropriate metrics when the partners are very different in size and/or have different levels of contribution.

NEWS

Achivement Award

Chou recognized by ASM International for seminal work in composites, energy storage



Tsu-Wei Chou, Unidel Pierre S. du Pont Chair of Engineering at the University of Delaware, and one of the founders of CCM, has been selected to receive the 2017 Albert Sauveur Achievement Award from ASM International, a professional organization for materials scientists and engineers.

Chou was recognized for seminal theoretical and experimental work on the processing-microstructure-property relationship essential to the engineering of advanced fiber composites, nanocomposites, and energy storage devices.

The award, which was established in 1934, recognizes “pioneering materials science and engineering achievements that have stimulated organized work along similar lines to such an extent that a marked basic advance has been made in materials knowledge.”

The award presentation will be made at the MS&T ’17 - Materials Science and Technology Conference and Exhibition in Pittsburgh, Pennsylvania.

A composites pioneer who launched his career 47 years ago, Chou has worked with a wide variety of materials and geometries, including hybrid composites, textile structural composites, flexible composites, and most recently nanocomposites. He and his research team have demonstrated unique applications of carbon nanotube-based continuous fibers in multifunctional composites and energy storage devices.

In 2011, Times Higher Education ranked him 34th on its list of the top 100 materials scientists of the past decade.

Chou joined the UD faculty in 1969 and was a founding member of the Center for Composite Materials (CCM). In addition to his technical achievements, he is credited with pioneering and sustaining many of the international collaborations that have made CCM recognized throughout the world.

The author of some 350 journal articles and several books, Chou is editor-in-chief of Composites Science and Technology.

A fellow of six professional societies, he has received the Charles Russ Richards Memorial Award, the Worcester Reed Warner Medal, and the Nadai Medal from ASME; the Distinguished Research Award from the American Society for Composites; and the Medal of Excellence in Composite Materials and the Francis Alison Award from the University of Delaware.

Read the full article on UDaily

NEWS

2017 MACH Conference

Call for Abstracts Due December 15, 2016

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Modeling and Characterization of Fiber-Matrix Interphase
Sanjib C. Chowdhury (UD), Timothy W. Sirk (ARL) and John W. Gillespie Jr. (UD)

This session is seeking papers on fiber-matrix interphase of composites. Topics include (but not limited to)

- Modeling (particular interest is in molecular modeling and design of composite interphase)
- Processing and synthesis of interphase
- Characterization of structure and thermo-mechanical properties of interphase
- High strain rate response of interphase
- Visualization of interphase failure

Transverse Impact of Ballistic Fibers, Yarns and Laminates
Subramani Sockalingam (USC), John W. Gillespie, Jr., (UD) Tusit Weerasooriya (ARL)

High performance polymer fibers such as Kevlar and Dyneema are used in ballistic impact applications in the form of flexible textile fabrics and composite laminates. Ballistic impact onto these materials is a complicated multi-scale problem due to the hierarchical multiscale architecture, anisotropic material behavior, multiaxial loading, statistical fiber failure, projectile geometry and others. A fundamental understanding of the dynamic fiber response and fiber-level mechanisms during impact are needed in order to design next generation fibers with enhanced properties and improved energy absorption mechanisms. Capturing real time information at the fiber (micron) length scale during impact is challenging due to small length scales and time scales. This symposium invites talks focused on fiber properties, microstructure, failure mechanisms, modeling and experiments of these materials at different length scales relevant to impact loading.

Submit an Abstract

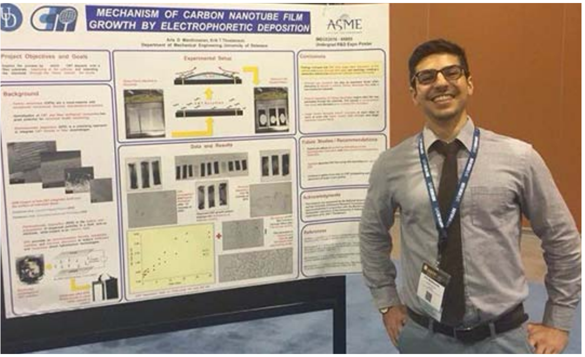
Student Achivements

UD-CCM Ph.D. students win 2nd prize in the ASC Student simulation challenge

Raja Ganesh, Ph.D. M.E., **Sagar Doshi**, Ph.D. M.E., and **Sandeep Tamrakar**, PhD. C.E. comprised the UD-CCM team who won the 2nd place prize for their design of a lightweight composite wing for an Unmanned Air Vehicle. The objective of this challenge was to prove using simulations that it will be able to withstand all the load requirements and that the design is manufacturable using a low pressure RTM process.

NEWS

ASME International Undergraduate Research and Design Expo, Phoenix, Arizona



Aris Mardirossian, a junior mechanical engineering major, recently won second place for his poster, "Mechanism of Carbon Nanotube Film Growth by Electrophoretic Deposition," at the ASME International Undergraduate Research and Design Expo in Phoenix, Arizona. The poster session, scheduled in conjunction with the opening reception of the International Mechanical Engineering Congress and Exposition, provides undergraduates with a professional and technical forum for presenting their research, design projects, and other engineering solutions and endeavors. Mardirossian is advised by Prof. Erik Thostensen and is also affiliated with UD's Center for Composite Materials.

SAMPE-UD students meet with SpaceX Team

A team of engineers and a university recruiter from SpaceX visited CCM on November 15, 2016 to meet and interact with the students involved in SAMPE. The students gave the team a lab tour of CCM which included live demonstrations of the various processes that are employed by SAMPE-UD to manufacture high-quality composite parts.

The SpaceX team was comprised of lead engineers with extensive experience in composites, including CCM/MEEG '08 alum Jason McLaughlin. SAMPE-UD President Raja Ganesh said that they were quite impressed with the manufacturing methodologies employed by the SAMPE-UD students and gave valuable suggestions on further improving their processes. The team also collected resumes from students who were potentially interested in joining SpaceX in the future.

SPACEX

SpaceX designs, manufactures and launches advanced rockets and spacecraft. The company was founded in 2002 to revolutionize space technology, with the ultimate goal of enabling people to live on other planets.

SpaceX is a private company founded in 2002 by CEO and Lead Designer Elon Musk. The company has more than 4,000 employees at its headquarters in Hawthorne, California; launch facilities at Cape Canaveral Air Force Station, Florida, and Vandenberg Air Force Base, California; a rocket-development facility in McGregor, Texas; and offices in Houston, Texas; Chantilly, Virginia; and Washington, DC. SpaceX has suppliers in all 50 states.

NEW PUBLICATIONS

Quan, Zhenzhen, Zachary Larimore, Xiaohong Qin, Jianyong Yu, Mark Mirotznik, Joon-Hyung Byun, Youngseok Oh, and Tsu-Wei Chou. "Microstructural characterization of additively manufactured multi-directional preforms and composites via X-ray micro-computed tomography." Composites Science and Technology 131 (2016): 48-60. http://dx.doi.org/10.1016/j.compscitech.2016.05.015

Meng, Fancheng, Miao Wang, Weibang Lu, Qingwen Li, Tsu-Wei Chou, and Lianxi Zheng. "An electromechanical behavior of reduced graphene oxide fiber." Carbon 105 (2016): 244-247. http://dx.doi.org/10.1016/j.carbon.2016.04.037

Yu, J., Lu, W., Smith, J. P., Booksh, K. S., Meng, L., Huang, Y., Li, Q., Byun, J.-H., Oh, Y., Yan, Y. and Chou, T.-W. (2016), A High Performance Stretchable Asymmetric Fiber-Shaped Supercapacitor with a Core-Sheath Helical Structure. Adv. Energy Mater., 1600976. http://dx.doi.org/10.1002/aenm.201600976

Gao, Xiguang, Chunyu Li, Yingdong Song, and Tsu-Wei Chou. "A continuum mechanics model of multi-buckling in graphene–substrate systems with randomly distributed debonding." International Journal of Solids and Structures 97 (2016): 510-519. http://dx.doi.org/10.1016/j.ijsolstr.2016.06.037

Chou, Tsu-Wei. "Multifunctional continuous fibers based on aligned carbon nanotubes." Journal of Physics D: Applied Physics 49, no. 46 (2016): 461002. http://dx.doi.org/10.1088/0022-3727/49/46/461002

Ganesh, R., S. Sockalingam, B. (Gama) Haque, and J. W. Gillespie, Jr., "Dynamic Effects of Single Fiber Break in Unidirectional Glass Fiber-Reinforced Composites," Journal of Composite Materials, September 15, 2016. http://dx.doi.org/10.1177/0021998316669218

Misumi, J., R. H. Ganesh, S. Sockalingam, and J. W. Gillespie, "Experimental Characterization of Tensile Properties of Epoxy Resin by Using Micro Fiber Specimens," Journal of Reinforced Plastics and Composites, September 21, 2016. http://dx.doi.org/10.1177/0731684416669248

NEW PUBLICATIONS

Tamrakar, S., B. Haque, J. W. Gillespie, Jr., "High Rate Test Method for Fiber-Matrix Interface Characterization," Polymer Testing, 52, pp 174-183, 2016, http://dx.doi.org/10.1015/j.polymertesting

Sockalingam, S., J. W. Gillespie, Jr., and M. Keefe, "Modeling the Fiber Length-Scale Response of Kevlar KM2 Yarn During Transverse Impact," Textile Research Journal, September 2016, http://dx.doi.org/10.1177/0040517516669074

Preston B. McDaniel, Subramani Sockalingam, Joseph M. Deitzel, John W. Gillespie Jr. Michael Keefe, Travis A. Bogetti, Daniel T. Casem, Tusit Weerasooriya "The Effect of Fiber Meso/Nanostructure on the Transverse Compression Response of Ballistic Fibers." Composites Part A: Applied Science and Manufacturing (2016) http://dx.doi.org/10.1016/j.compositesa.2016.12.003

NEW CONFERENCES

Sockalingam, Subramani, John W. Gillespie Jr, Michael Keefe, Dan Casem, and Tusit Weerasooriya. "Transverse Compression Response of Ultra-High Molecular Weight Polyethylene Single Fibers." In Dynamic Behavior of Materials, Volume 1, pp. 7-13. Springer International Publishing, 2017. http://dx.doi.org/10.1007/978-3-319-41132-3_2

Meyer, Christopher S., Christopher T. Key, Bazle Z. Gama Haque, and John W. Gillespie Jr. "Initial Experimental Validation of an Eulerian Method for Modeling Composites." In Dynamic Behavior of Materials, Volume 1, pp. 103-110. Springer International Publishing, 2017. http://dx.doi.org/10.1007/978-3-319-41132-3_14

CONSORTIUM NEWS

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