



# Structural Carbon Nanotube-Based Composites

## Developing Composite Technology to Rehabilitate Aging Bridges

Exploratory Advanced Research . . . Next Generation Transportation Solutions



Sensing layer only      'Structural-sensing' layer

**A**s steel bridges age, accumulating stress from traffic can cause structural fatigue, weakening of solid components such as girders, and degrading of connections that hold bridge elements together. In 2016, 16 percent of the 178,923 steel bridges in the United States were considered in poor condition, according to the Federal Highway Administration (FHWA) National Bridge Inventory. (FHWA 2018) That same year, 18,706 of the Nation's steel bridges, regardless of condition, were described as "fracture critical"—i.e., they contain tension members whose failure could cause a portion of or the entire bridge to collapse. For these bridges, FHWA requires a hands-on inspection, at intervals not to exceed 24 months, to detect damage such as fatigue cracking. (GPO 2016) When inspectors find damage, bridge engineers use rehabilitation methods such as bolting steel plates to reinforce cracks or restore corroded sections. Engineers also may use strain gauges, accelerometers, and displacement sensors to monitor crack growth as well as the integrity of repairs.

Supported by FHWA's Exploratory Advanced Research (EAR) Program, researchers at the University of Delaware have developed strong glass fiber reinforced plastic (GFRP) composites for the rehabilitation of damaged areas. The GFRP patches developed through this project, "Development of Structural Carbon Nanotube-Based Sensing Composites," also incorporate electrically conductive carbon nanotube (CNT) networks for monitoring postrepair crack growth and, thus, provide an integrated strengthening and monitoring system.

### New Materials That Can Mend and Monitor

University of Delaware researchers developed a composite material that uses a matrix of GFRP and a layer of CNT-based sensors to develop a sandwich of materials that can be applied like a patch, strengthening a bridge while providing real-time monitoring capabilities. Ultimately, the researchers hope the technology will provide bridge owners with quantifiable data that gauge the effectiveness of repairs performed on the rehabilitated sections of a steel bridge.

During the first phase of the project, the research team developed and refined methods for manufacturing and applying adhesive-backed CNT-GFRP composites to steel and insulating the conductive properties of the CNT network against the substrate. Next, the researchers gauged the composite's response to realistic environmental conditions on large-scale beam specimens, developing a calibration scheme for real bridges and designing hardware and software components for a field-ready wireless monitoring system that would use this composite technology. They used laboratory validation testing to evaluate how CNT-GFRP composites performed in situations mimicking field installations on steel bridges, such as exposure to wide temperature variations and high-cycle fatigue. Testing included large-scale experiments on prototype steel bridge members with fatigue-prone defects and simulated section loss, and evaluation of off-the-shelf components to minimize costs for an effective monitoring system.

### Flexible, Lightweight Adhesive Sensors

The composite material is lightweight, can adhere to different shapes, has two-dimensional distributed sensing capabilities, and is highly sensitive to strains and microdamage. The CNT-GFRP composite can provide continuous feedback on how the reinforcement is performing structurally.

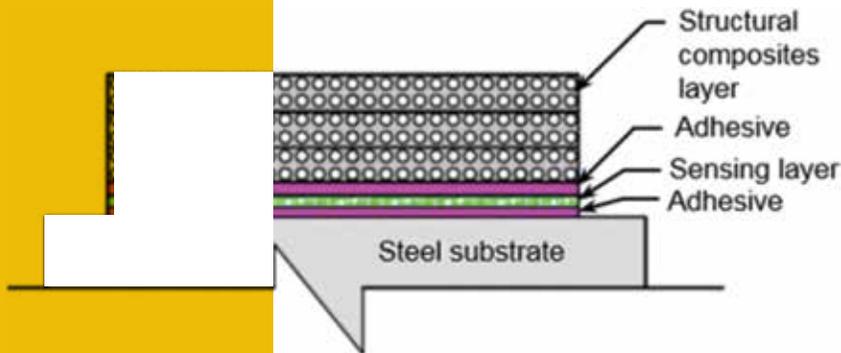


U.S. Department  
of Transportation

Federal Highway  
Administration

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"This project will provide technology that serves the dual purpose of strengthening a bridge, while also providing real-time monitoring capabilities. These features represent important advances in the effort to maintain and enhance the durability of critical highway structures," says Frank Jalinoos of FHWA's Office of Infrastructure Research and Development.

The next step in the project will involve collaboration with one or more State departments of transportation to install CNT-GFRP composites to retrofit and create a limited monitoring system for existing structures in need of repair; this approach should be less expensive and data intensive than upkeep of current monitoring systems.

If the technology can be applied successfully in real-life situations, the researchers say it has the potential to extend the lifespan of steel bridges. The data gathered from using the technology with structural health monitoring systems may enable engineers to assess the performance of bridge repairs and provide guidance on how best to retrofit existing bridges and design new ones. Since this technology allows for continuous monitoring, it also works around the difficulty of observing the crack growth that occurs under bolted steel plates. A long-term vision for the technology is using CNT-based sensing layers on other types of materials and

### EXPLORATORY ADVANCED RESEARCH



#### What Is the Exploratory Advanced Research Program?

The EAR Program addresses the need for longer term, higher risk research with the potential for transformative improvements to transportation systems. The EAR Program seeks to leverage advances in science and engineering that could lead to breakthroughs for critical, current, and emerging issues in highway transportation by experts from different disciplines who have the talent and interest in researching solutions and might not do so without EAR Program funding.

To learn more about the EAR Program, visit <http://highways.dot.gov/research/exploratory-advanced-research>. The website features information on research solicitations, updates on ongoing research, links to published materials, summaries of past EAR Program events, and details on upcoming events.

components used in highway infrastructure, including infrastructure that may be hidden below grade or under water.

#### Learn More

For more information on this project, contact Frank Jalinoos, FHWA Office of Infrastructure Research and Development, at 202-493-3082 (email: [frank.jalinoos@dot.gov](mailto:frank.jalinoos@dot.gov)).

#### References

Federal Highway Administration. (2018). "National Bridge Inventory." (website) McLean, VA, obtained from: <https://www.fhwa.dot.gov/bridge/nbi.cfm>, last accessed September 11, 2018.

GPO. (2016). *Subpart C—National Bridge Inspection Standards*, 23 CFR Ch. I, Sec. 650.311, "Inspection frequency" (4-1-16 Edition), Government Printing Office, Washington, DC, obtained from: <https://www.gpo.gov/fdsys/pkg/CFR-2016-title23-vol1/pdf/CFR-2016-title23-vol1-part650-subpartC.pdf>, last accessed September 11, 2018.

© 2017 American Society of Civil Engineers. Researchers at the University of Delaware are developing a composite material that can provide bridge-strengthening and monitoring capabilities. The material will be applied onto a bridge like a patch.

Photo credit, page 1:  
© 2016 Center for Composite Materials, University of Delaware. The CNT-GFRP composite material, which consists of various layers, is being tested in a laboratory setting to evaluate how the material performs in field-like situations.