- Energy and Commerce Committee Hearing -

Advanced Material Development and Manufacturing, with Focus on Infrastructure Application

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Current Position Statement

Efficient infrastructure systems such as highways, bridges, buildings, pipelines, flood control systems, and utilities are all necessary for economy growth and a high standard of living. However, our infrastructure is in a dire state, as the American Society of Civil Engineers (ASCE) report card gives the US infrastructure a grade of D+. ASCE attributes the bulk of this low grade to the funding gap of $4.59 trillion between revenue and infrastructure needs, which in turn costs each household $3,400 per year (ASCE, 2016). Advanced Fiber Reinforced Polymer (FRP) composite materials offer a more efficient use of taxpayer dollars compared to conventional materials. FRP composites result in a paradigm shift in material usage because of their favorable material properties and enhanced service life, including non-corrosiveness and high strength to weight ratio, thus leading to reduced life cycle costs. The adaptability of FRP composites has led to a wide variety of uses, with many advances in the automotive and aerospace industries. For instance, the use of FRP composites on the Boeing 787 Dreamliner allowed it to be 20% more fuel efficient than its predecessor. FRP composites have been used in infrastructure for over 30 years, including:

- Corrosion resistant reinforcing bars (rebar) for highways with a 90 year service life
- Bridge decks and superstructures
- Hazardous material containers and pipelines
- Structures with longer spans (> 10,000 feet span) resulting in reduced self weight
- Utility poles and towers
- Strengthening and wrapping of in-service structures including navigational structures
- Many others, including composite deck houses for the next generation battle ships.

The United States of America is the largest producer and user of FRP composites and the world leader in composite technology development and implementation. Such leadership is attributed to the major thrust provided by the federal and state government agencies. The shipment of advanced FRP composites in the US is about 5 billion lbs annually with about 32% of share in transportation and 21% in construction.

Over the past 30 years, various federal and state agencies have worked in cooperation with American composites industries to promote and advance the FRP composites for civil infrastructural applications. The automotive and aerospace fields benefit from the ability to build and evaluate many prototypes, thus making the risk factors of the final product minimal. Civil infrastructure instead relies on codes and standard practices built on the lessons learned from many different contractors over years of implementation. As such, the incorporation of new materials is outside the scope of the current codes, which increases the risk and complexity of the project. The US government has played a unique role in accelerating the adoption of advanced composite materials by being a willing participant in the use of these materials for government projects. Indeed, I have been fortunate as the director of the Constructed Facilities Center at West Virginia University to receive funding from the National Science Foundation, US Army Corps of Engineers, US

DOT, and others to implement advanced FRP composite materials into infrastructure. However, there is still work to move these efforts firmly into the private sector, including collecting data on in-service field responses, incorporating this information into design specifications and training engineers to properly use these new materials.

Research and Implementation

The US government established numerous research programs in FRP composites for civil infrastructure applications to lay the groundwork for the robust data set necessary to allow for widespread field implementation. Work began with laboratory studies of the materials, including accelerated test programs to predict long-term performance of infrastructure systems. In parallel, a number of field demonstration projects have been sponsored to better understand composites under real world field conditions. As with any new endeavor, there have been a handful of less than successful projects, but the vast majority of these one-and-done field demonstration projects have been highly successful and are still in-service, several well beyond their original expected design life. From a scientific standpoint, this government funded work has provided priceless data on the field performance of FRP composites. Additionally, there have been many innovations with material development, efficient structural design, and manufacturing techniques. For example, the most successful story to tell is the evolution of FRP bridge decks, leading to six-fold increase in strength and a three-fold decrease in unit cost of FRP deck components over the past 20 years. A major thrust of recent research has been away from non-renewable petroleum-based products and towards green composites made with renewable plant fibers and US agricultural products such as soy. Another research endeavor is the development of FRP composite pipes for natural gas transmission, thus enabling US energy to reach the market via US-produced pipelines that are corrosion resistant and less susceptible to leaks.

Technology Transfer

In addition to the major push in terms of fundamental research efforts since 1980s, NSF played a critical role in technology transfer strategies. For example, the Center for Integration of Composites into Infrastructure (CICI), a NSF Industry/University Cooperative Research Center (I/UCRC) program, provides an excellent platform for university and industry interaction. The 30 member CICI industrial advisory board directs collaborative research to benefit the entire FRP infrastructure industry.

Design Codes

The research advances through government sponsored programs resulted in developing numerous private and government codes and design guidelines, including FRP rebar, FRP strengthening of concrete members, and FRP design specifications for pultruded shapes. These codes and specifications would not exist today if not for previous government sponsored work. Advent of these codes will help FRP composites to compete on a level playing field with other construction materials like concrete, steel, wood and aluminum, materials with well-established codes. Performance criteria for design, specification and installation will mean a higher degree of confidence for professional engineers and contractors to design and construct with advanced composite materials, in addition to instilling confidence in owners to field implement advanced FRP composite materials.

Mass Production of Advanced Composite Materials

Manufacturing of composites is economical at mass scale via factory production using such methods as pultrusion, filament winding, resin transfer molding and sheet molding. Each of these methods has unique advantages, thus the manufacturing method is chosen to best fit the final application. For instance, filament winding is ideal for producing round structures such as flues for smokestacks, while pultrusion is best suited for very high strength structural shapes. Factory manufacturing is most cost-efficient with limited changes to the assembly line, thus costs can be greatly reduced when large quantities can be produced with a given setup. The one-and-done nature of past demonstration projects does not allow for these cost efficiencies to be realized. However, a commitment to specify a large quantity of advanced FRP composites would allow manufacturers to produce in bulk with less risk of excess inventory.

Additive Manufacturing for Rehabilitation of Constructed Facilities

Additive Manufacturing (AM), also known as 3D printing, is a new manufacturing technique in which successive layers of materials are applied via a robotic armature to create a structure. A number of research groups have been able to use these powerful tools to create high quality complex parts with advanced composite materials. AM has the potential to provide unique ability to research, design, develop, and produce a wide range of "engineered" parts in a matter of hours, including custom prosthetics, industrial grade aircraft and automotive parts, full size electric vehicles and a 6-story concrete apartment building,. Additive manufacturing is revolutionizing traditional fabrication and construction methods by producing high quality products with excellent durability characteristics.

In the US, many bridges are currently rated as structurally deficient and in need of repair. Based on recent patent pending work, WVU-CFC has demonstrated that structural integrity can be improved by focusing repairs at strategic locations in complex mechanical/structural systems; we intend to produce such parts in-situ to enhance structural integrity of large systems by several hundred percent. The WVU-CFC team further intends to use drones to 3D photograph structurally deficient bridges, buildings, and lock gate systems and then take advantage of 3D printing techniques to retrofit these structures with 3D printed parts, thus enhancing their service life in the most economical manner.

Societal Impact

Academia in cooperation with government and industry has made major strides in developing advanced composites for infrastructure applications, including structures for highway and waterway, utility poles, wind turbine blades, and pipelines. These implementation efforts have been driven by recent market acceptance of composites, especially in highway construction. In the state of West Virginia alone, more than 25 highway bridges were built or rehabilitated with advanced composite materials and many thanks to support rendered by NSF, USDOT, and WVDOT-DOH. In addition, the WVDOT-DOH is developing plans that may lead to the rehabilitation of 400-500 concrete bridges using advanced composite wraps in the next 5 years because of their cost effectiveness and minimal user inconveniences.

Government sponsored R&D in composites has opened up large markets for composites in infrastructure. In just the highway system, advanced composites can be used for bridge decks, rebar, dowel bars, stringers, abutments, signposts, signboard, guardrail systems, sound barriers, and drainage systems. Each of these products represents a multibillion potential market and provide a longer service life than conventional materials, thus reducing future government expenses. Similarly, pipelines for gas, water and sewer are a billion dollar annual market, while the utility pole potential market is of an order of 4 billion dollars per year.

Barriers for Broader Use of Advance Composites

To utilize the advantages of advanced composites, engineering communities need to reduce the ART TO PART gestation period. On February 8-9, 2017, NIST sponsored a workshop with a goal of determining the barriers to widespread adoption of polymer composites for sustainable infrastructure applications. There were 60 participants representing industry, government and academia that were informed by key stakeholders including owners, designers, and contractors on challenges they face in the infrastructure market. Breakout groups representing new construction, repair construction, and stand-alone FRP products used in the infrastructure market collaborated on the 5 most critical barriers to success in that respective sector. The most common barriers identified included training and education, codes and standards, composites durability and service life prediction, and testing. The US government can play a key role in breaking down these barriers by supporting efforts to evaluate in-service FRP composites, which would provide the data needed to evaluate durability and develop specifications.

With recent launching of new design codes, new markets will open up and existing markets will further broaden for the advanced composites industry. The support of the US government has been integral in the initial implementation of advanced composites. With continued support, manufacturers will continue to expand, creating jobs for Americans and improving our infrastructure. Advanced composite materials will become an integral part of civil infrastructure providing the American public benefits in terms of cost effectiveness and reduced user inconveniences due to ease of installation, low maintenance, longer service life, and greener products.

Field Implementation: Initial versus Life Cycle Costs

Figure 1. Market Street Bridge (Wheeling, WV, built in 2000) with FRP decks (WVU)

Fig 2. Pavement with FRP Rebar, WV Route 9, Martinsburg, WV (WVU, 2007)

Fig 3. Pavement with FRP Dowels Elkins Corridor H-Project, Elkins, WV (WVU, 2003)

Figure 4. FRP utility poles (BRP, 2010)

Figure 5. 16 inch diameter FRP pipe being tested at WVU-CFC laboratory (2011)

Figure 6. Durable FRP Gas Tanks (Liang, 2014)

Figure 7. Large diameter FRP chimney flue liner, a) a module liner section and b) connection elbow (Rider, 2009)

Figure 8. Multi-purpose FRP building with modular panels, Weston, WV (WVU, 1995)

Figure 9. FRP composite house being erected at BRP Inc. manufacturing facility (WVU, 2008)

Figure 10. Rehabilitation using FRP wraps of Madison Avenue Bridge, Huntington, WV (WVU, 2014)

Figure 11. Retrofitting of railroad bridges using FRP wraps, Moorefield, WV (WVU, 2010)

Figure 12. Rehabilitation of corroded steel H-pile bridge using composites, East Lynn Lake Bridge, East Lynn, WV. The repair cost 35% of the cost of a conventional repair. (WVU, 2014)

Figure 13. Composite Wicket gates and its field implementation in lieu of deteriorated wood wicket gate. The composite gate is ½ the cost with a much longer expected design life. (WVU, 2015)

Figure 14: Additive manufacturing of advanced composite materials part, with automatic fiber placement (Cormier, 2016)

Figure 15: 6-story 3D printed apartment building (Sevenson, 2015)