Strongwell Corporation

Composite Materials Sought as Replacement for Steel and Concrete

In 1994, the U.S. Federal Highway Administration estimated that 230,000 of the nation's 575,000 bridges were structurally deficient or functionally obsolete, and they would require an expenditure of $130 billion in public funds in the coming years. Because steel and concrete decay cost the nation billions of dollars for repair and replacement, new technology that lengthened the functional lives and sped the repair of roadways and bridges was clearly needed. Composite materials held this promise. Strongwell Corporation, the world's largest pultruder of fiber-reinforced structural parts, applied for and was awarded $2 million in cost-shared funding from the Advanced Technology Program (ATP) to research and develop a process to manufacture large, fiber-reinforced polymer (FRP) composite structures that could reduce the cost of maintaining the country's existing civil infrastructure.

Strongwell successfully developed a manufacturing process to pultrude a 36 x 18-inch "double-web" I-beam in a vinyl ester matrix known as the EXTREN DWB™. This structural shape is more complex in design and 4½ times stronger than existing composite structural shapes. The large composite structures made of these carbon and glass reinforced polymer composites have attracted interest from state transportation agencies, the offshore oil industry, the construction industry, and the defense industry. Strongwell's beams have been used successfully in two Virginia bridges, but commercialization depends on acceptance by bridge engineers, who are still awaiting test data before they commit to using this new technology. Through a joint venture with Ebert Composite Corporation, the advanced pultruding process Strongwell developed with the help of ATP is being used to manufacture composite poles and towers for electric utility companies and other industries.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * *

Research and data for Status Report 94-02-0010 were collected during January - March 2002.

Expense and Technical Barriers Delay Composite Structure Development

The accelerated highway and bridge-building programs of the 1960s and 1970s enabled the United States to build a transportation infrastructure that meets most of the nation's needs. Although the need for new roads is limited, the maintenance of existing roads has become an enormous economic burden. The majority of the nation's roads and bridges were not designed to accommodate the current high volume of business and recreational traffic, let alone future travel needs. U.S. roadways and bridges are breaking down at an alarming rate, and their maintenance is of critical importance.

Manufacturers, designers, and engineers recognized the ability of composites (a hybrid of two or more materials) to produce high-quality, durable products. Several technical barriers, however, were preventing their use.

First, composite materials were expensive and difficult to engineer into structures of appropriate shape and size with adequate stiffness and overall performance for civil structures. Second, the industry lacked experience using fiber-reinforced polymer (FRP) composites as a structural material, and research and development (R&D) had not been performed to determine the size and strength of the equipment needed to produce the large FRP components. Finally, conservative civil engineers have delayed the acceptance of FRP structures by regulatory agencies. Many engineers lack confidence in composite materials for civil infrastructure because not enough testing has been done on their long-term durability.

Strongwell Proposes an Advanced FRP Composite

Strongwell's goal was to design and produce a new, high-strength, advanced FRP phenolic composite that could be used in bridge and building construction. Phenolics are thermosetting resins that cure through a condensation reaction that produces water that must be removed during processing.

Phenolic composites have many desirable performance qualities, including high temperature resistance, excellent thermal insulation, sound-damping properties, and corrosion resistance; therefore, they last far longer than conventional materials, such as steel and concrete.

Strongwell's goal was to design and produce a new, high-strength, advanced composite that could be used in bridge and building construction.

Strongwell recognized that it would take several years for civil engineers to accept FRP as a replacement for steel and concrete. Rigorous testing, validation, and demonstration of this material would be required to ensure product quality and safety. As a result, Strongwell was unable to attract either internal or external private capital for this project because the return on investment was expected to be greater than 10 years. Because of these barriers, Strongwell submitted a proposal for ATP funding.

Strongwell Identifies Benefits of Large Composite Shapes

Strongwell forecasted that $2 million from ATP could translate into savings of billions of dollars for the bridge construction industry. Successful completion of this research to develop large composite shapes using FRP would represent a major breakthrough in composite technology. As an improved alternative to conventional steel and concrete, it would provide the basis for dramatic improvements in the U.S. road transportation system and other civil engineering and construction applications. U.S. taxpayers would benefit from lower life-cycle costs of existing structures and reduced time and cost to build new structures.

A reduction in the effort required to maintain the nation's highways could lead to less traffic disruption, which would speed the transport of U.S. products by the trucking industry. Moreover, Strongwell envisioned that its new technology would be used in a range of applications, including short-span bridges, offshore oil platforms, and other industrial applications where corrosion is a problem. Additional savings also would be realized in other industries such as aircraft and space.

Revolutionary Shape Solves Key Technical Challenge

Strongwell's objective was to design and produce a 36- x 18-inch FRP phenolic and vinyl ester composite beam that could be used in bridge and building construction. Strongwell intended to build on its expertise in pultrusion (a manufacturing process for composites) to create a structure large enough, as well as strong enough, for civil projects. Pultrusion is used in producing continuous lengths of reinforced plastic parts with constant cross-sections. The process involves pulling these raw materials through a bath of thermosetting resin and then into a heated forming and curing die to produce composite structural shapes. As the reinforcements are saturated with the resin mixture in the resin bath and pulled through the die, the heat from the die initiates the hardening of the resin, and a rigid, cured profile is formed that corresponds to the shape of the die.

One key technical challenge was to design a structure that combined structural strength with corrosion and chemical resistance, as well as one that performed better than existing beams used for infrastructure. Strongwell solicited the expertise of Dr. Abdul-Hamid Zureick, head of the structural engineering and mechanics group of the School of Civil and Environmental Engineering at Georgia Institute of Technology, to assist in the design of the FRP shape.

The double-web I design improved performance, increased the shear load distribution capability of the beam, and improved the stiffness, making the beam resistant to bending; and therefore very useful in building bridges.

"double-web I" or "modified box" beam in which two vertical webs are connected by a flange across the top and bottom. The double-web I design improved performance, increased the shear load distribution capability of the beam, and improved the stiffness, making the beam resistant to bending. The box-like shape also is simple, making it easier for Strongwell to manufacture using the complex phenolic resin process and a vinyl ester resin system.

Another key technical challenge was to create a pultrusion machine capable of manufacturing this large 36- x 18-inch shape while achieving a complete cure of the resin and fiber laminate. Although the company had extensive experience creating pultruded shapes, no shape that large had ever been pultruded using phenolics.

Manufacturing Process Proves Successful In

September 1996, Strongwell manufactured two 8 x 6-inch subscale prototypes of the double-web I-beam using a fiberglass and carbon composite. The first prototype was created with vinyl ester resin, which is less viscous and therefore easier to use in the pultrusion process, while offering excellent corrosion resistance and weight reduction compared with steel. The second prototype was created with phenolic resin, which requires a more sophisticated manufacturing process but provides the added benefit of superior heat resistance. With the help of the Georgia Institute of Technology, Strongwell optimized the beam shape for torque resistance, eliminating the need for support braces. The stiffness of the subscale prototype composite beam is roughly 6.3 msi (millions of pounds per square inch), which is more than twice the stiffness of a standard fiberglass I-beam. The beam also performed well in tests for fatigue, creep (or stretching under tension), and strength under static loading. Strongwell's ability to create the 8 x 6-inch beam encouraged the company to continue its efforts to manufacture the 36 x 18-inch shape. However, Strongwell encountered several technical challenges as it moved forward. The thicker, multicored, closed shape of Strongwell's 36 x 18-inch shape represented a substantial increase in complexity from the small, square tube manufactured using a phenolic matrix.

The pull forces required for this project were unheard of for pultrusion, as was the design of the saw needed to cut the beams. A machine capable of exerting 120,000 pounds of force-more than Strongwell originally anticipated would be needed-was required to pull thousands of tightly packed fibers through a bath of polymeric resin and into molding and curing dies of the required size and shape. Strongwell designed and fabricated a dual-reciprocating hydraulic puller system that uses two clamping and pulling mechanisms. This was one of the first machines to synchronize four large cylinders at one time. At that time, the machine had the largest pull capacity of any pultrusion machine in the world and three times the pulling capacity of Strongwell's next-largest machine.

By the end of 1997, Strongwell had successfully developed the manufacturing process to create the longer double-web I-beam using both a phenolic matrix and a vinyl ester matrix. The company later marketed the beams made with the vinyl ester resin as the EXTREN DWB™.

Strongwell proved that the dissimilar materials of carbon and glass fibers could be combined using either a phenolic or a vinyl ester matrix to create a large structural shape that did not delaminate. The outcome was a 36 x 18-inch structural shape more complex in design with a much better strength-to-weight ratio than conventional steel and concrete shapes.

The company's other tooling accomplishments related to this project include:

- Designing and fabricating a unique start-up winch powered by a clamping and pulling mechanism
- Working with a saw manufacturer, DoALL, Inc., to design and build the largest pivoting head band saw ever created in order to cut the EXTREN DWB™
- Working with BASYS Technologies (currently BIOREM Technologies) to successfully use biofiltration as an emission control during the phenolic process

Widespread Applications of Strongwell's Technology

In 1997, Strongwell used the technology from this project to create one of the first composite short-span vehicular bridges in the United States, the Tom's Creek Bridge in Blacksburg, Virginia. Jack Lesko, an associate professor of engineering science and mechanics at Virginia Polytechnic Institute and State University, is working with Strongwell, the Virginia Transportation Research Council (a National Science Foundation-supported research center at Virginia Tech that focuses on high-performance polymeric adhesives and composites), and the Center for Innovative Technology (CIT) in Herndon, Virginia to test the beams. Testing will assess changes in the composite materials, which, although they do not rust or corrode, may undergo changes in weight, volume, or other characteristics. Test results also will be useful in establishing implementation standards for composite bridges.

When they were used to replace the Thomas Creek Bridge's corroded steel beams, the composite beams provided immediate benefits. For example, the bridge's capacity was upgraded from 10 tons to 20 tons, and the rehabilitation of the bridge took less labor, time and resources. According to Julius Volgi, a Virginia Department of Transportation engineer, "Two people on scaffolding can handle the new beam with their hands, versus having to use a light crane or a backhoe to lift it in place." Furthermore, the entire bridge rehabilitation was completed in five days, which resulted in less inconvenience to the more than 1,000 cars that cross the bridge daily.

As a result of the ATP award, Strongwell has applied some of its new processing technology to its other products, such as a material that combines glass fiber with carbon fiber and the improved use of engineered glass fabrics. Mr. Glen Barefoot, head of corporate marketing, stated, "As a result of developing a large structural beam for vehicular bridge girders, Strongwell has instituted an R&D plan to develop an FRP bridge deck to be used for bridge rehabilitation of new bridges with the double web beam."

Other structural applications of Strongwell's ATP-funded technology have included bridge demonstrations for the U.S. Navy and the Departments of Transportation in Connecticut and Kansas. Strongwell received the Best of Show Award at the Composite Fabricators Association Conference in San Antonio in October 1998. In 1999, Strongwell presented the beam at the International Bridge Conference and Trade Show. Press releases have been published in *Civil Engineering, Engineering News Record, and Composite Technology*.

Strongwell Faces Challenges to Commercialization

Lack of acceptance by bridge engineers of the FRP beam as a structural material to replace steel continues to be a barrier to commercialization and will remain so until years of test data and demonstrations are completed. Bridge engineers are extremely conservative and have limited knowledge of composites and their use as a structural material. The low initial cost of steel and concrete is an important consideration for most new bridge designs. Composites, however, have a higher initial price, but they require much less ongoing maintenance, which reduces overall life-cycle costs.

Strongwell is committed to increasing the acceptance of this technology and is working with the Virginia Technical Institute and CIT to develop a design handbook that will provide a comparative analysis of the composite shape to steel and concrete. CIT provided Strongwell with two $20,000 Innovation Awards to support production of the design book, as well as further testing of the beam.

Other Applications Proposed for Strongwell's Technology

Strongwell's technology is being considered to replace steel in many other applications, including offshore oil platforms where the components' lighter weight, durability, and resistance to salt water and salt air provide significant benefits. On September 30,1997, Strongwell gave a presentation at the Composites for Offshore Operations Conference in Houston, Texas that demonstrated the uses of the ATP-funded composite shape. Since that time, oil companies have expressed interest in substituting composite components for steel to reduce weight on tension leg platforms on large, mobile drilling rigs.

In 1998, Strongwell managers met employees of Ebert Composite Corporation, another ATP awardee. Ebert had designed and demonstrated an affordable manufacturing system that reduced production time for making large structural parts from composite materials. The companies decided to form a joint venture company, Strongwell-Ebert LLC, in Bristol, Virginia. This company, now a wholly owned subsidiary of Strongwell, markets and sells composite poles and towers to electric utilities and other industries.

Strongwell also is talking to the U.S. Navy about using the company's large FRP structures as a replacement for steel. The Navy is interested in the large FRP composites' high strength-to-weight ratio, durability, and inherent resistance to weather and the corrosive effects of salt air, sea, and aggressive chemicals. In 2001, Strongwell completed a bridge that spans 39 feet over Dickey Creek in Sugar Grove, Virginia, a project that represents the first use of Strongwell's full-scale 36 x 18-inch beams. The beams weigh approximately 70 pounds per linear foot—about half the weight of similar steel beams.

Conclusion

Although Strongwell still faces several commercialization barriers, the company is confident that the EXTREN DWB™ and the other large composite shapes developed during the ATP-funded project will gain a larger share in construction markets. "Without ATP funding, we could not have developed the process for creating high-performance composite shapes," stated Mr. Barefoot. The ATP-funded project reduced the time to market for high-performance shapes by approximately 10 years, and Strongwell is confident that once the shapes receive acceptance as a building material, the benefits of decreased installation and maintenance costs will be recognized.

PROJECT HIGHLIGHTS
Strongwell Corporation

Project Title: Composite Materials Sought as Replacement for Steel and Concrete (Innovative Manufacturing Techniques to Produce Large Phenolic Composite Shapes)

Project: To develop large, cost-effective, high-performance composite shapes that last longer and are maintained more easily than the concrete and steel that is now aging and deteriorating in the country's transportation infrastructure.

Duration: 2/1/1995-1/31/1998
ATP Number: 94-02-0010

Funding (in thousands):

ATP Final Cost	$ 2,000	64%
Participant Final Cost	1,142	36%
Total	$ 3,142	

Accomplishments: During this three-year project, Strongwell achieved the following significant accomplishments:

- Developed a manufacturing process to create a 36 x 18-inch double-web I-beam made from vinyl ester and phenolic composites.
- Designed and fabricated a dual-reciprocating hydraulic puller system using two clamping and pulling mechanisms placed in tandem, hand-over-hand, and synchronized by a programmable linear controller. This was one of the first machines to synchronize four large cylinders at one time. At the time, it was believed to have the largest pull capacity of any pultrusion machine in the world.
- Designed and fabricated a unique start-up winch powered by a clamping and pulling mechanism.
- Worked with a saw manufacturer, DoALL, Inc., to create the largest pivoting head band saw ever built.
- Worked with BASYS Technologies to successfully use biofiltration as an emission control.

Commercialization Status: Strongwell continues to present and demonstrate the EXTREN DWB™ beam for a variety of civil infrastructure applications. Strongwell has installed composite beams in two bridges in Virginia and has received substantial interest from oil companies for mobile drilling rig applications. The company formed a joint venture company with Ebert Composite Corporation to manufacture and sell composite poles and towers. Strongwell continues to develop engineering design guidelines so engineers can develop and test the applicability of FRP shapes for other large civil infrastructure projects.

Outlook: Strongwell has received positive response to its high-performance composite shapes; however, industry codes and design standards must be modified to accommodate composite structures before full-scale commercialization of the technology is feasible. Maintaining and rebuilding the U.S. roadway system using composites presents a tremendous market opportunity well into the 21st century.

Composite Performance Score: * * *

Focused Program: Manufacturing Composite Structures, 1994

Company:
Strongwell Corporation
400 Commonwealth Avenue
P.O. Box 580
Bristol, VA 24203

Contact: Glenn Barefoot
Phone: (276) 645-8000

Research and data for Status Report 94-02-0010 were collected during January - March 2002.