Project Results Summary

Improved Affordability for Composite Structures

Technology Investment Agreement 2007-373

March 30, 2009

Executive overview

Lightweight, corrosion resistant composites structures provide Navy ships with many performance advantages and help to lower total ownership costs. Future use is threatened by high acquisition costs due, in part, to the current labor intensive production process (VARTM).

This project investigated the potential to significantly lower labor costs by assembling composite structures from standardized pultruded panels with integrated edge joints. Standard balsa core sandwich panels were pultruded in an automated process. A robust assembly process was developed to assemble a 20 foot by 40 foot test panel. A VARTM test panel was also fabricated. All production and assembly labor was documented. The pultruded and VARTM panels were cut into test coupons and evaluated for comparative strength.

Goals were to reduce labor cost by 40% and for the joints to be as strong as the panel. Key project findings and accomplishments were:

- Pultrusion reduced labor by 60% to 88% compared to VARTM
- The annual saving potential is $3.7MM to $5.5MM based on the business case
- The pultrusion process produced over 200 feet of 10' wide sandwich panels with integrated edge joints
- Physical testing showed 100% joint efficiency in one of the 3 static strength tests

This project demonstrates the potential for dramatic labor savings in the fabrication of composite structures using standardized pultruded flat panels. Based on these results, it appears that additional savings could be achieved using pultruded connectors to eliminate the labor intensive VARTM joining process. Pultrusion technology can easily produce connectors for the corner, Tee, and cruciform joints needed to assemble panels into 3-dimensional ship structures. This concept is being demonstrated in a follow-on NSRP project.

Contact Information

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Collaborators

Project participants were:

- Northrop Grumman Shipbuilding (NGSB) – Project Lead, responsible for documentation of costs, panel assembly, preparation of test coupons, and project reporting.
- KaZaK Composites Incorporated (KaZaK) – Subcontractor, responsible for pultruding the 10' wide panels.
- Naval Surface Warfare Center Carderock (NSWC) – Subcontractor, responsible for coupon testing.

Description of methodology

Pultrusion is known to be a low cost method for producing composite parts, but no information was available on the total labor required to produce sandwich panels and assemble them to make large parts such as decks or bulkheads. The project needed to develop a realistic cost comparison for the competitive processes: 1) pultrusion and assembly, and 2) one piece molding.

To accomplish this, a 20' x 40' pultruded, assembled panel was fabricated. All labor input to the pultrusion, handling, preparation, and assembly was documented. Project budget limitations prevented the fabrication of an identical molded panel, but the project did obtain an estimate for a 20' x 40' panel and actually fabricated a smaller 10' x 25' to obtain specimens for physical testing. Extrapolation of fabrication labor from the smaller panel, along with the estimate and historical cost data, was used to derive a labor input value for the current molding process. Both the pultruded and the molded panels used the same density and type of balsa, the same resin system, and the same weight and direction of fabric.

Another project requirement was to test the strength of the assembled pultruded panel in comparison to a large molded panel. The goal was for the jointed pultruded panel to be as strong as the molded panel. To measure this, test specimens were cut from the assembled pultruded panel and from the molded panel. The pultruded specimens included a set with joints and a set without joints. All three sets of specimens were shipped to the NSWC at Carderock for testing. Physical tests measured the strength of the test specimens in bending, shear, and tensile modes.

A third project objective was to develop a robust assembly process that could be easily implemented in a typical shipyard environment. The assembly methods were developed and tested using small panels with a joint length of 2 feet. Assembly procedures were then scaled up to production scale panels with joints 20 feet in length. Several scale-up problems were identified and corrected during the course of the project. Final procedures and lessons learned were documented in separate reports.

Resources Needed

Fabrication of composite structures using standard pultruded panels is, in some ways, more like traditional shipbuilding activities than the molding process. It was found that the craft workers in the composite yard identified with the assembly concept and seemed interested in seeing it succeed.

The primary resource needed to implement this technology is a source of pultruded panels. They could be obtained either from existing pultrusion suppliers or by installing and operating a pultrusion machine.

Fixtures and jigs are required to align the panels and a method of pressing the panels together is also required. NGSB used 12 volt winches to draw the panels together, however, other similar projects have used hydraulic jacks and other methods. More advanced automated systems are possible, but are not required.

Production scale operations will benefit from adhesive mixing and application equipment. While not absolutely necessary, it will speed assembly and may eliminate a source of error.

Production of large panels will require fewer people, or preferably can be accomplished faster with the same crew levels, than traditional molding processes. Shipyard composite technicians, riggers, blasters, and others involved required minimal instruction prior to participation. The same crew leader was assigned to the project from beginning to end. That person became familiar with the project and trained others as needed.

Evaluation and Analysis Methods

The cost analysis for the pultruded assembled test panel was a straightforward process of recording the crews that were assigned to production, and measuring the output. Some estimation and extrapolation was required to account for pultrusion machine productivity, waste produced, and start-up / shut-down timing.

The cost analysis for the molded panel was obtained by comparing the project estimate, extrapolating unit labor used for the smaller molded test panel, and historical data for similar panels.

Quality of the adhesive bond was evaluated by visual inspection of thin cut sections. This method revealed void problems during development that were resolved in later assemblies. A non-destructive test would be desirable for routine production, but development was beyond the scope of this project.

Joint strength was evaluated by physical testing of large coupons, up to 2 feet by 10 feet in overall dimension. Jointed pultruded test coupons were found to support the same loading as un-jointed molded coupons in shear bending mode. Two other tests, tensile and 4 point bending, were not considered to be valid due to unexpected failure modes. An investigation attributed this to quality problems in the pultruded face sheets and cores.

The 10 foot wide panels used in this project are still developmental in nature, and while the product has been shown to be equivalent in strength to molded panels, the particular panel used for the test coupons was not up to those standards. Until the production process is matured, quality testing should be employed routinely.

Time Estimate

This project took about two years to complete. The panels used had been developed under a prior Navy funded program. Significant work remains to certify the panels for Navy ship applications.

Apart from certification issues, a shipyard could expect the lead time for newly designed panels from existing suppliers to be about 6 months, if new dies are required. The lead time for repeat orders would depend primarily on inventory or production schedules. Assembly fixtures and equipment are typical of shipyard items and could be fabricated in a month or two. This project was able to assemble 80 feet of joint in an afternoon with a crew of 4 or 5 technicians. Automated adhesive equipment would improve productivity.

If pultruded panels for shipbuilding can be truly standardized, delivery of panels from inventory would dramatically reduce lead times.

Limitations or Constraints

This project shows that there is significant economic incentive to use pultruded panels for ship structures. This is especially true when lightweight structures are required.

This project was not able to demonstrate conclusively that the pultruded panels are as strong as an un-joined molded panels in all test modes. For applications where this is not absolutely required, pultruded parts may very well be the most economical solution and certification could be pursued right away.

For Navy applications, extensive qualification testing will be required. Some of this will be undertaken in a follow-on project which should be completed in 2011.

Major Impacts on Shipyard

As described above, this project will require extensive qualification testing prior to implementation on Navy ships. Therefore, the current impact on the shipyard is minimal.

Since assembly of panels is somewhat analogous to steel shipyard practices, this new technology represents a blend of traditional methods with new materials. We anticipate that the technology can be assimilated at the production level with moderate efforts.

Cost Benefit Analysis/ROI

The business case is based on a large shipyard building two deckhouse type structures a year. The project cost analysis shows potential annual labor savings from $3.7MM to $5.5MM per year for assembly vs. molding. The 10 year net present value is $23MM to $35MM based on the project investment of $2MM.

Lessons Learned

The reason that a VARTM panel requires so much labor input is because it is produced in a batch process where all materials are placed by hand. Panels tend to have unique features, because they are easy to add. The overall effect, however, is very high labor costs. Consider how expensive it would be to have sheet steel delivered with unique features on each piece.

Pultruded panels are automated which imposes a degree of standardization. Their assembly to form a deck or a bulkhead can be accomplished with considerably less touch labor than a comparable VARTM panel.

Key lessons learned during project execution:

1. Coupon testing should be modeled prior to the actual test to verify that the test set-up is configured to produce the desired failure mode
2. Budgeting should allow for the fabrication of extra test materials
3. Panel quality should be verified prior to assembly
4. Adhesive system performance should be verified using the proposed panel and surface preparation method
5. Adhesive viscosity has a large effect on the assembly pressure required
6. Small scale trial assemblies are useful to develop a basic method and identify potential problems
7. Scale up will introduce unexpected problems
8. Ideas from the production crew improved the assembly procedures and reduced assembly time.

Implementation and Technology Transfer

This project was implemented in the Gulfport shipyard. Fixtures were constructed to join the ten foot wide twenty foot long panels into a single 20 by 40 foot panel. The panels were joined by craft personnel from the shipyard workforce. The technology could be readily implemented in any shipyard with the requisite rigging equipment to handle the panels.

To implement in any size or type ship yard would take only a few months, given a source of pultruded panels. Should a shipyard want to pultrude panels, there would be a considerable delay in implementation due to procurement of equipment, training, and start-up issues. As agreed in the technology transfer plan, the information concerning this project has been presented to industry representatives at two NSRP Panel meetings and at the ShipTech Conference in 2008 and 2009.