INVESTIGATION OF A HYBRID METAL-TO-COMPOSITE JOINT CONCEPT

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Introduction

Novel hybrid combatant hull designs are being investigated by the U.S. Navy with steel providing excellent stiffness, strength, and ductility and composites providing tailorability and reduced signature. Hybrid joints are most critical and are of great interest to the Office of Naval Research (ONR) Hybrid Composites Survivable Structures Program. This current research project is in support of this ONR program. Specifically the integrity of hybrid metal-to-composite connection details under static and dynamic loading regimes is being examined. The work is part of an ONR Global NICOP project with Dr. Mouring and Dr. Louca as the U.S. and international co-principal investigators, respectively. The research has included collaboration with two companies involved in a STTR Phase I Option funded by ONR and supported by Naval Surface Warfare Center Carderock Division (NSWCCD). One of the hybrid joint design concepts will be reviewed in this paper. Results from both finite element analysis (FEA) and static load tests will be discussed.

Experimentation

The hybrid joint specimen configuration is shown in Figure 1. Each specimen was fabricated with 6.5-mm thick x 51-mm wide steel adherends (440C) and nominally 13-mm thick x 51-mm wide laminate adherends (24 oz. E-glass woven roving/Ashland FV 8084 Derakane). The configuration was designed to take advantage of both metal fastening and adhesive bonding methods. Adhesives are used to reduce the usual tendency of a fastened joint to shear out. Mechanical fasteners are used to decrease the possibility of a catastrophic and uncontrolled failure caused by debonding at the adhesive interface of an adhesively bonded hybrid joint. In order to increase the effective loaded surface area, top and bottom steel "jacket" plates were adhered to the composite. Three rows of two 18-8 stainless steel pins were applied to offset some shear load to the pins via bearing load as shown in Figure 1.

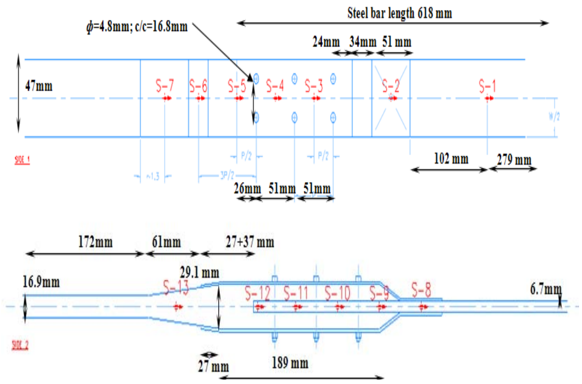

Figure 1. Hybrid joint specimen configuration.

A total of 9 specimens (6 hybrid and 3 baseline) were tested at the U.S. Naval Academy using an 890-kN Tinius Olsen Tension Testing Machine. Baseline specimens were fabricated using the same glass reinforced polymer (GRP) laminate (nominally with the same cross section). A modification of the hybrid specimens was necessary. The stainless steel shoulder bolts were replaced with high strength Grade 8 (G8) shoulder bolts after premature failure of the bolts was observed in the first specimen (SM-H-1). After these bolts were replaced, the load capacity of the hybrid joint was found to be approximately 50% of the load capacity for the baseline GRP. However in most of the modified specimens, a classic, brittle open-hole tension failure was observed (see Figure 2). (Only one specimen, SM-H-3N, saw a failure of the G8 shoulder bolts and adhesive failure between the steel and GRP interfaces.) This unexpected failure alerted us to the use of 440C steel which is very brittle (originally the specimens were supposed to be fabricated with HSLA 65 steel or its equivalent).

Figure 2. Typical damage observed.

Finite Element Analysis

A finite element (FE) model was created for numerical testing using ABAQUS 6.7. The GRP adherend was modeled as a transversely isotropic material, and the steel adherend was modeled as an isotropic material. Cohesive elements were used for simulating the polyurea adhesive where the material properties were based on estimation.

Results and Discussion

The load-displacement outputs obtained from the FE model were recorded and plotted with the results gathered from the tensile tests in Figure 3.

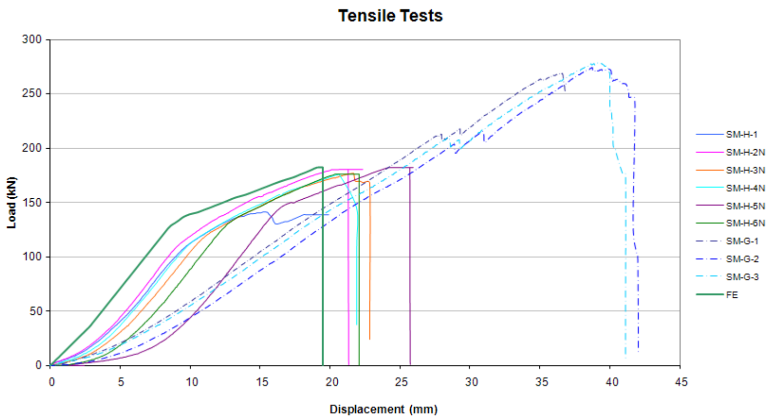

Figure 3**.** Load - displacement output from the FE model plotted with experimental results.

The curves, SM-G-1, SM-G-2 and SM-G-3, show the results obtained from tensile tests of the GRP specimens. The curves, SM-H-1, SM-H-2N, SM-H-3N, SM-H-4N, SM-H-5N and SM-H-6N, are the test results of hybrid joint specimens. The FE results are given by the dark green curve. By comparing the experimental tests results with the numerical model output, reasonable agreement can be seen. The ramp at the start of the curve obtained from the experimental tests indicates there was a sliding in the joints. This is mainly due to the existence of a gap between the holes and the pins. Results from the FE model show that the delamination started at the interface between the steel jacket plates and steel adherend (as load reaches about 140kN) and runs from the loaded end towards the composite adherend (see Figure 4). Thus stiffness of the hybrid joint is reduced providing a more ductile joint failure at 184kN. Results from the physical tensile tests show that the hybrid joint specimens (except for SM-H-3N mentioned above) did not lose their structural integrity until their steel adherends failed at the pin holes with an average tensile failure of 173kN.

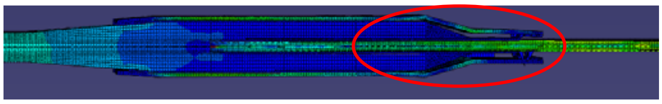

Figure 4**.** FE model results.

Conclusions

FEA results showed that the tapered composite adherend and steel "jacket" plates did improve the overall stress distribution in the hybrid joint. Moreover, the results demonstrated that the metal fasteners in conjunction with the polyurea adhesive were able to prevent the hybrid joint from sudden failure. Initial delamination started from the interface between the steel "jacket" plates and steel adherend, and ran from the loaded end towards the composite part, which reduced the stiffness of the joint. This provided for a ductile joint failure. Experimental results showed that the joints failed suddenly due to a brittle tension failure of the steel adherend at the pin holes. Thus the hybrid joint design can be improved by replacing the brittle 440C steel with a more ductile type of steel. As the FE model indicated, without tensile failure of the steel adherend, the joint can achieve the load capacity of 184kN. Apart from optimizing the material properties, the structural performance of the joint also can be improved by changing the tapering angle and overlap length of the steel "jacket".

Acknowledgments

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