TENSILE TESTING OF HYBRID METAL-TO-COMPOSITE JOINTS

Sarah Mouring[1], Yang Yang[2], Luke Louca[2], Peter Joyce[3]

[1]Dept. of Naval Arch. & Ocean Engr., U.S. Naval Academy, Annapolis, MD 21402

[2]Dept. of Civil & Env. Engr., Imperial College London, London, UK, SW7 2AZ

[3]Dept. of Mechanical Engr., U.S. Naval Academy, Annapolis, MD 21402

Introduction

The U.S. Navy is investigating the feasibility of hybrid combatant hulls with composites providing tailorability and reduced signature and steel providing excellent stiffness, strength, and ductility. Hybrid joints are most critical and are of major interest to the Office of Naval Research (ONR) Hybrid Composites Survivable Structures Program. This ongoing research project is in support of this ONR program. Specifically the integrity of hybrid steel-to-composite joint details under static and dynamic loading is being examined. 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). This research eventually will give necessary information on how various hybrid joint configurations fail under both static and dynamic loading compared to conventional joints. The paper will focus on a specific hybrid joint concept subjected to static tensile loads. Experimental and analytical results will be discussed.

Experimentation

Tension tests were performed on six steel-to-composite joint specimens and three baseline glass reinforced polymer (GRP) specimens. The hybrid joint specimens were fabricated from 6.5-mm thick x 51-mm wide steel adherends and nominally 13-mm thick x 51-mm solid laminate adherends. The steel adherends were fabricated EH36 steel alloy. The laminate adherends were fabricated from 24 layers of 24 oz. E-glass woven roving and Ashland FV 8084 Derakane VE vinyl ester resin. The lay-up was symmetric and balanced with the fiber orientation of 0°/45°/90°/-45°. The baseline specimens were fabricated using the same laminate (nominally with the same cross sections). Comeld ™ was used in the joining of the steel and GRP where the material surface treatment process, Surfi-Sculpt®, was applied to the steel. During this process, a power beam was used to create small protrusions on the steel surface. In each hybrid joint specimen, a Grade 304 stainless steel 12.8-mm bolt was used to clamp the two small outer steel plates (with Comeld ™ regions) to the thicker steel adherend. Figure 1 shows the hybrid joint specimen configuration including the Comeld ™ region of the hybrid joint.

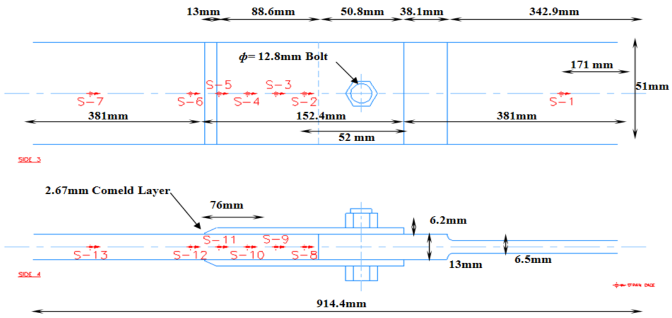

Figure 1. Hybrid joint specimen configuration.

Quasi-static testing was completed at the U.S. Naval Academy using an 890-KN Tinius Olsen Tension Testing Machine. The testing of baseline GRP specimens was completed without any difficulties. All three specimens failed at the grips as expected with an average maximum load of 215 KN.

When testing the first hybrid specimen, B-H-1, an apparent adhesive failure was observed at approximately 76 KN followed by bolt shear failure at 106 KN. Since the bolt was used to clamp the small outer steel plates to the steel adherend and was not actually part of the joint, the bolt was replaced with a higher strength Grade 8 (G8) bolt and the specimen was retested (B-H-1R) failing at 121 KN. This failure was catastrophic with a joint failure at the Comeld ™ interface and bolt shear failure.

Testing of the remaining specimens continued after all of the stainless steel bolts were replaced with G8 bolts. The second specimen, B-H-2, failed catastrophically at 141 KN with a joint failure at the Comeld ™ interface and bolt shear failure. After this successful test, the third specimen, B-H-3, was loaded to 123 KN when again the bolt sheared. Since the joint did not fail, the broken bolt was

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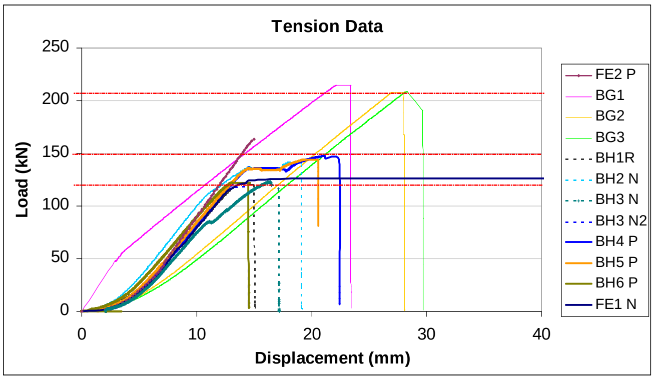
replaced with another G8 bolt and the specimen was retested (B-H-3N). However, this second test (B-H-3N2) resulted in bolt failure at 118 KN. Thus, further modification was needed to achieve the desired joint failure.
After removing the G8 bolt from the third specimen, the hole was enlarged to 19.1-mm and a higher strength dowel pin was used instead of a bolt. This modified specimen was retested (B-H-3P) up to 114 KN with a joint failure at the Comeld ™ interface. Once the modifications were performed on the remaining specimens, all specimens (B-H-4P, B-H-5P, and B-H-6P) were tested up to 147, 144, and 122 KN with joint failures at the Comeld ™ interfaces.

Finite Element Analysis

Two Finite Element (FE) models have been created for numerical testing using ABAQUS 6.7. FE1N is assembled with a G8 bolt and FE2P is assembled with a higher strength dowel pin. The GRP was modeled as a transversely isotropic material, and the steel was modeled as an isotropic material. Cohesive elements were applied to both models for simulating the Comeld ™ surface. Their material properties were based on estimation.

Results and Discussion

The first FE model with a G8 bolt (FE1N) shows that under a 164 KN quasi-static tensile load, the hybrid specimen failed with the G8 bolt failing in shear. This failure mode correlates with the full-scale tensile test results (B-H-3N and B-H-3N2). In the hybrid joint, the G8 bolt has a higher stiffness compared to the Comeld ™ surface and thus will attract most of the load. Hence, most of the load was transferred through the bolt. The hybrid specimen did not show the advantage of combining the Comeld ™ with the bolted set up.
When using a higher strength steel dowel pin to assemble the specimen, the second model (FE2P) shows that the dowel pin does improve the performance of the specimen. Since the pin did not fail in shear, the loads were transferred along the Comeld ™ interface, and spread into the surrounding region.
Figure 2 shows the results from the output of the two FE numerical models (FE1N and FE2P) and the nine specimens. Reasonable agreement can be seen. Three red lines indicate the loading capacity of the three groups of the tested specimens. The top line represents the average load capacity for the baseline GRP specimens which is approximately 215 KN. The middle line represents the average load capacity for the hybrid joint specimens with the higher strength dowel pins. Test results show these specimens fail with debonding at Comeld ™ interface under an average failure load of 140 KN. However, the FE model FE2P shows that these joints could endure at least 165 KN. This error is most likely due to the inaccurate material property input of the Comeld ™. The bottom line shows that the hybrid joint specimens with the G8 bolts have an average load capacity of 130 KN. The FE model FE1N is able to capture this failure load and the deformation profile.



* Note: FE1N: FE model with G8 bolt, FE2P: FE model with dowel pin

Figure 2**.** Load - displacement output from the FE models plotted with experimental results.

Conclusions

Results from both experimental tests and FE models show the load was transferred mainly through the stiff bolt when the specimen was assembled with a stainless steel bolt or a G8 bolt. This bolt shear failure caused a catastrophic failure in the specimen. By replacing the bolt with a higher strength steel pin, the overall specimen performance is improved and the load is distributed more efficiently. From the last three tests, it can be seen that the Comeld ™ surface contributed to the overall performance significantly increasing the joint strength. The FE models gave reasonable estimates of joint performance. However, the material properties of the Comeld ™ surface need to be further investigated to improve the accuracy of the models.

Acknowledgments

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