August 10, 2005

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RE: "Design & Technology of Composite Plate Joints"

Dear Dr. Ibeh:

I am glad to inform you that the summer portion of the ONR program has been completed.

This will allow you to see what my report consists of from the types of materials used in the making of boat hulls, to the types joints that are being tested using composite materials and carbon fiber pre-preg. This report will also give a detailed procedure on the processes that were used in joining the composite plates and the process that was used to apply the carbon fiber pre-preg. The Instron Universal Testing machine was used to test the tensile strength of the joints.

Sincerely,

Jarvis Wintjen

"Design & Technology of Composite Plate Joints"

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Date: August 10, 2005

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Summary

This research report gives a detailed description on the different types of joint used in the joining of composite material. Although there are several different joints that could be explored, the focus in this report was on the "Butt joint" and the "Dovetail joint". Fiberglass composite was used as the base of the joint, in other words it was the material that was used to create the joint. Uni-directional carbon fiber pre-preg was used as the binder of the joints. A total of ten plys (or layers) were applied to each side of the joint. The joints were then put under heat and pressure to be cured. After being cured, test bars were cut out with the table saw and tested using the Instron Universal Testing Machine and the Zwick/Roell Tensile Testing Machine (ran by Zac Tyler). The results proved to be consistent throughout the experiment.

Introduction

With the demand for techniques of joining composite plate joints increasing, based on real naval and aerospace part configurations, the navy must meet specific requirements. One requirement that must be met is the quality of the surface. The ship must maintain a smooth surface and shape. In order to create a ship that is productive in the navy, the boat must maintain a hydrodynamic shape, so that it can easily flow through the water without any extra resistance. Also, any joints that may exist in the structure of the ship must be hermetically sealed off, to prevent any leakage that may occur. In past years, boat hulls have primarily been made out of metals. With the great freedom of shape and excellent weather/water resistance, composites would be a great material to use on navy ships on a large scale in the future.

Literature Review

Kasten, Michael, "Metal Boats",
http://www.pilothouseonline.com/current/features/Metal%20Boats/metal_boats.htm

Boat Hull Materials

Over the years, metals have been the primary choice in the creation of boat hulls. Whether one uses steel, aluminum, copper nickel, or stainless, there will always be a need for a lightweight material that exhibits the properties that metals exhibit. There are several aspects that must be considered in selecting the type of material. One aspect that must be considered is the sea kindliness. In other words, some boats may need to be made from steel in order to survive the harsh waters. Aluminum wouldn't work as the material of choice if the boat were to sail in rough waters. Due to the extreme lightness of aluminum, some hulls may result in a more harsh motion.

http://www.unitedcomposites.net/usapages/whycomposites2.htm

Why Composites?

A composite is a combination of two or more materials (reinforcing elements, fillers, and composite matrix binder) differing in form or composition on a macro-scale. In essence, plywood, reinforced concrete, and natural fiber reinforced clay are all forms of composite materials. The basic difference between composite materials and metals is that composites have an An-Isotropic behavior, which means that the habits of the composite material or formed laminate are directional depended. Metal materials on the other hand have an isotropic behavior, which means that their habits in all directions are the same. Some other differences include:

- Fibrous composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements
- Higher specific strength (material strength/density material). Aramide and Carbon Fiber reinforced epoxies have approximately 4 to 6 times higher specific tensile strength than steel or aluminum
- Great fatigue endurance especially for aramide and carbon reinforced epoxies, compared with metals

http://www.mdacomposites.org/mda/psgbridge_cb_mfg_processes_print.html

Surface Preparation and Bonding

A key component to a successful lamination is the bonding process of the layers. There are three basic components, which make up the bonding process. First is the surface preparation of the laminate, which improves the substrate's ability to accept and adhere to an adhesive. Surface preparation varies depending on material type. Composites use sanding and grinding, surface texturing, or solvent cleaning. The second component is the adhesive itself, including epoxies, urethanes, phenolics, polyesters, solvents, acrylics and others. Each adhesive has its attributes depending on substrate type, in use requirements and process constraints. As a general rule, a maximum bond is achieved for a given substrate type when the material itself fails during an ultimate strength test. The maximum lap shear strength of an adhesive is achieved when the adhesive exhibits a cohesive failure in the bond line. The third component of lamination is the process by which the materials are bonded together. This involves a host of parameters primarily time, heat pressure, mixture, moisture and catalysts (initiators). It is important that the three basic components of bonding are properly employed to achieve a successful lamination.

Design & Technology of Composite Plate Joints

History of the Boat Hull

Over the years, the material of choice for making boat hulls has primarily been metal; whether one chooses in favor of steel, aluminum, copper nickel, stainless, etc. In order to choose the right material for a boat hull a few aspects must be considered. First of all, sea kindliness must be considered. In other words, some boats may need to be made from steel in order to survive harsh waters out in the oceans. Aluminum wouldn't be a good choice of material for a boat if it were to sail in rough waters all of the time. Composite would be a good material for rough waters because of the strength that they exhibit. One of the main problems that one is faced with when working with composites is the joining of the composites. It isn't as easy as metals that can be welded together and still maintain almost full strength after being welded.

Composites vs. other materials

A composite is a combination of two or more materials (reinforcing elements, fillers, and composite matrix binder) differing in form or composition on a macro-scale. The basic difference between composite materials and metals is that composites have an An-Isotropic behavior, which means that the properties of the composite material or formed laminate are directional depended. Metal material on the other hand has an isotropic behavior, which means that their properties in all directions are the same.

Composites have several advantages over other materials. These advantages include the following:

- Very high specific strength (high strength & low weight)
- Great freedom of shape
- Excellent fatigue endurance concerning number of load cycles (many times higher than with metals) and residual fatigue strength
- Excellent chemical resistance against acids, chemicals etc
- Excellent weather/water resistance
- Composites have excellent RAM features (Radar absorbing materials). It's also possible to make special laminates which are radar and sonar transparent
- Excellent impact properties

Preparing the surface for Bonding

A key component to a successful lamination is the bonding process of the layers. There are three basic components, which make up the bonding process. First is the surface preparation of the laminate, which improves the substrate's ability to accept and adhere to an adhesive. Surface preparation varies depending on material type. Composites use sanding and grinding, surface texturing, or solvent cleaning. The second component is the adhesive itself, including epoxies, urethanes, phenolics, polyesters, solvents, acrylics and others. Each adhesive has its attributes depending on substrate type, in use requirements and process constraints. As a general rule, a maximum bond is achieved for a given substrate type when the material itself fails during an ultimate strength test. The maximum lap shear strength of an adhesive is achieved when the adhesive exhibits a cohesive failure in the bond line. The third component of lamination is the process by which the materials are bonded together. This involves a host of parameters primarily time, heat pressure, mixture, moisture and catalysts (initiators). It is important that the three basic components of bonding are properly employed to achieve a successful lamination.

Methodology

Equipment used:

- Band Saw
- Table Saw (located in W129)
- Belt Sander
- Oven
- Instron Machine (located in W124)
- Customized composite plate transfer press mold (machined by Tom Musgrove)

Materials used:

- Acetone
- Scissors
- Utility knife
- Rubber gloves
- Putty knife
- Cytec Engineered Uni-directional Carbon Fiber Pre-preg
- Fiberglass composite (base)

Procedure

Milling

Butt Joint & Dovetail Joint

1. Obtain .250” thick sheets of fiberglass composite, found in W123.
1. Obtain design drawings. (Compliments of Dale Widiger)
2. Take material to the wood department.
3. Using the CNC milling machine, enter all the data from the drawings.
4. Put the material in the machine and run it.
5. With the drawings entered into the machine the material should come out just like the drawings.

* Dimensions of samples are located in the Appendix.

Preparation & Construction

1. Take some paper towels, apply acetone, and wipe the surface of the area to be bonded. Allow to dry.
2. Using the carbon fiber pre-preg, cut forty strips, ten for each side of each sample in the longitudinal direction, to the dimensions specified in the appendix.
3. Once the milled samples are cleaned with acetone, remove the paper backing from the carbon fiber and apply one at a time, using a putty knife to press down on the material to remove any bubbles.
4. Once one side of the sample is finished, flip the sample over and repeat the steps for the other side.
5. Do the same for the dovetail sample.

Pressing & Curing

1. Turn on breaker to side of machine.
2. Set temperatures of both top and bottom platen to 350°F.
3. Allow machine time to warm up.
4. Set clamp pressure to 7 tons.
5. Apply mold release to two aluminum plates to keep the sample from sticking to the plates.
6. Place sample between the aluminum plates.
7. Set the sample in between the two platens.
8. Let the platens warm the material for one hour with no pressure.
9. Press both "Clamp Close" buttons (green) until red light comes on.
10. Apply a constant 7 tons of pressure to the sample for one hour.
11. Press both "Clamp Close" buttons (green) until red light comes on.
12. Using gloves, remove the aluminum plates from the press.
13. Place the sample in the oven for approximately 30 minutes for additional cure.
14. Allow the sample to cool off for approximately one hour and then remove the sample from the aluminum plates.
15. Repeat for other samples.
16. When finished, simply turn the breaker off and clean up surroundings.

Material Testing for Properties

1. Using the carbon fiber pre-preg, cut out ten layers that measure 12" x 12".
2. Apply mold release to the two 12" x 12" pieces of aluminum.
3. Place one of the aluminum pieces into the mold.
4. Remove the paper backing from the carbon fiber.
5. Stack one layer at a time and make sure all of the bubbles are out of the pre-preg and then add the next layer.
6. Repeat until all of the layers have been placed on top of each other.

7. Once all the layers have been placed, apply the second aluminum plate onto the carbon fiber.
8. Next, heat the Hull Transfer Press to 350°F (both platens).
9. Allow machine to heat up.
10. Place mold in the middle of the machine.
11. Allow mold to heat up for one hour without pressure.
12. Set the clamp pressure to 7 tons.
13. Apply pressure for one hour.
14. Release the pressure.
15. Shut the machine off.
16. Remove mold with gloves and allow time to cool.
17. Cut the material into test strips with the table saw.
18. Test the material using the Instron Universal Testing Machine, to determine the properties of the material.

Results

Fiberglass Plate

Sample	Peak Force (N)	Max Displacement (mm)	Modulus (Mpa)	Strength (GPa)
1	39509.1	8.61	$65181.5*10^9$	910.35
2	29930.9	7.29	$21478.0*10^9$	817.78

Unidirectional Carbon Fiber Pre-preg

Sample	Peak Force (N)	Max Displacement (mm)	Modulus (Mpa)	Strength (GPa)
1	40375.9	7.44	$53073.6*10^9$	903.97
2	41726.3	7.26	$49816.9*10^9$	880.92

Fiberglass Plate layered with Carbon Fiber Pre-preg (Butt Joint)

Sample	Peak Force (N)	Max Displacement (mm)	Modulus (Mpa)	Strength (GPa)
Extensometer	16142.3	329.7 um	$32637.2*10^9$	$64.63*10^6$
1	30666.1	5.77	$61789.9*10^9$	$122.79*10^6$
2	31219.8	5.26	$62676.6*10^9$	$143.68*10^6$

Fiberglass Plate layered with carbon Fiber Pre-preg Using Rivets (Butt Joint)

Sample	Peak Force (N)	Max Displacement (mm)	Modulus (Mpa)	Strength (GPa)
1	8453.1	2.06	$36673.7*10^9$	$39.51*10^6$

* When cutting samples with rivets, there was delamination, which caused the sample to become a failure. Results cannot be validated, because of failure.

Discussion of Results

The test method used to test the bond strength of the various bonds was tensile testing using the Instron 4467 and the Zwick/Roell Tensile testing machine. The material used as the base was Fiberglass Composite. The material that acted as the binder between the two pieces of composite was Unidirectional Carbon Fiber Pre-preg. Two different joint designs were used in the experiment, the “Butt Joint” and the “Dovetail Joint”.

As soon as we got started in the lab, we tested the fiberglass composite to find out how strong the material is itself before any modifications. Also, the carbon fiber pre-preg was tested alone to determine its strength. Once this had been completed, the construction of the joints began. Problems were reached after the dovetail joint was made. We were unable to discover a way of cutting the samples out without destroying the carbon fiber. In order for any of the samples to be cut out, a waterjet cutting machine or a laser cutting machine will have to be used to insure a clean cut. Once the pieces are cut out then they will be tested. After observing the results, it shows that the fiberglass composite itself is stronger than when the pieces were assembled and reassembled with carbon fiber pre-preg. As one can see, the results concerning the joint that contained rivets cannot be considered valid, because of delamination. The point in which the delamination occurred was where the rivets were placed. This caused the carbon fiber to weaken around the rivets. From the evidence collected so far, there hasn’t been a technique found that could combine composites without losing a lot of strength along the way. Some of the joints yet to be tested are the dovetail lock joint and also the dovetail lock joint with rivets. Hopefully these specimens can be tested in the near future to further investigate the ideal joining technique.

Conclusion

Based on research and experiments conducted, the base sample by itself proved to exhibit the best overall properties, although the dovetail samples have yet to be tested. Continuing work will be done in order to obtain results for the dovetail joint and the dovetail joint + rivets. Currently, a testing device, which prevents the sides from blowing out on the dovetail joints, is being worked on. Also in the future, the flexural test will be performed on the specimens. A new flexural testing device is also in the works, because the previous testing mechanism turned out to be too small.

Recommendations

There are a few recommendations that should be taken in order to continue research on this research project. First of all, a bigger testing machine is needed to test these joints. The testing machines currently being used don't have enough force to pull some of the samples apart. The cross-section of the specimens needs to be decreased in order for them to be able to break. Secondly, in order for the specimens to be cut accurately and without degrading the carbon fiber, either a water jet needs to be used or even laser cutting.

References

Parmley, Robert O., Standard Handbook of Fastening and Joining. 3rd Edition McGraw-Hill, 1997.

Schwartz, Seymour S. and Sidney H. Goodman. Plastics Material & Processes. New York: Van Nostrand Reinhold Company, 1982.

http://www.unitedcomposites.net/usapages/whycomposites2.htm

http://www.pilothouseonline.com/current/features/Metal%20Boats/metal_boats.htm

http://www.cytec.com/business/EngineeredMaterials/Cycom%205250-4.shtm

http://www.new-technologies.org/ECT/Civil/snap.htm

http://www.ctd-materials.com/index.htm

www.manufacturingcenter.com/dfx/archives

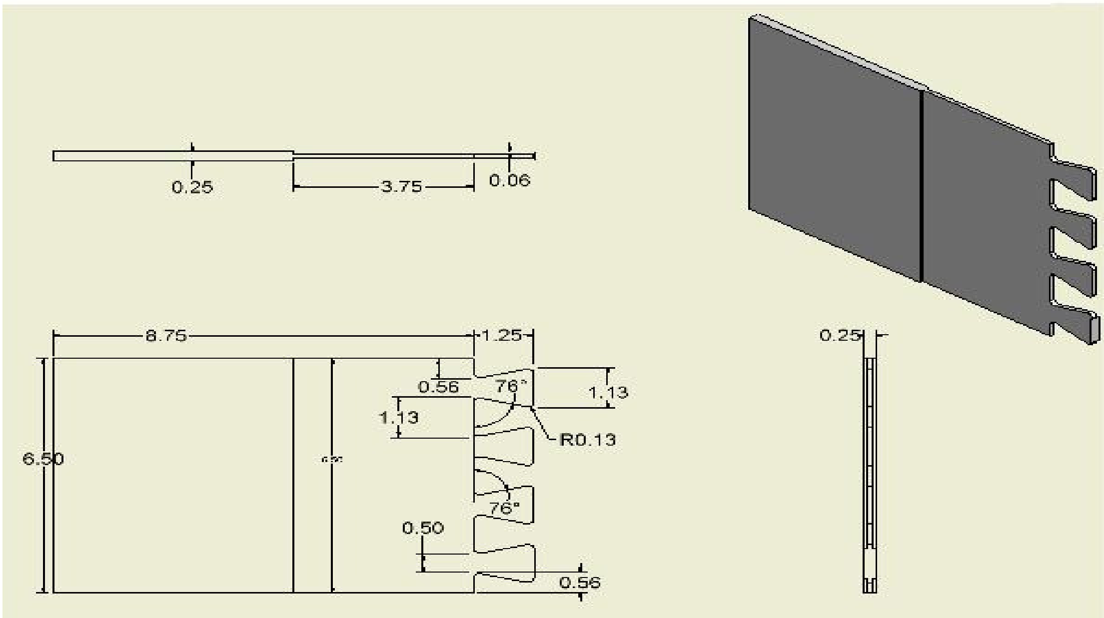
Appendixes

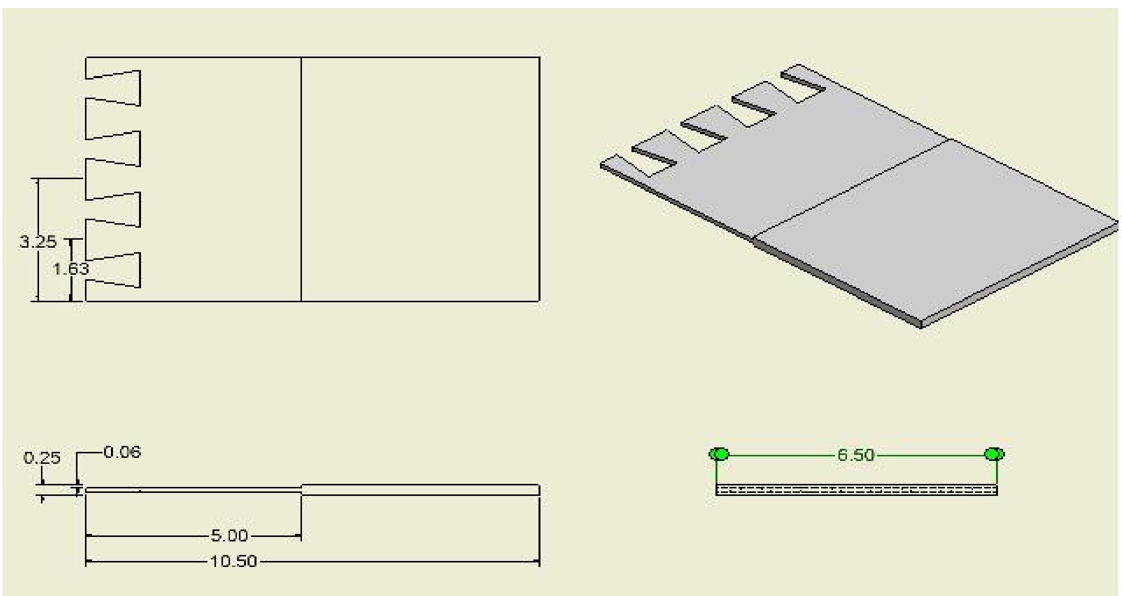
Equipment Operation Procedure

Instron 4467

1. Turn on power strip
2. Turn on Computer
3. Click on Blue Hill icon
4. Turn on IEE488 button
5. Follow the computer on-screen instructions
6. Load material
7. Hit start button on computer
8. When test is finished, print out results.

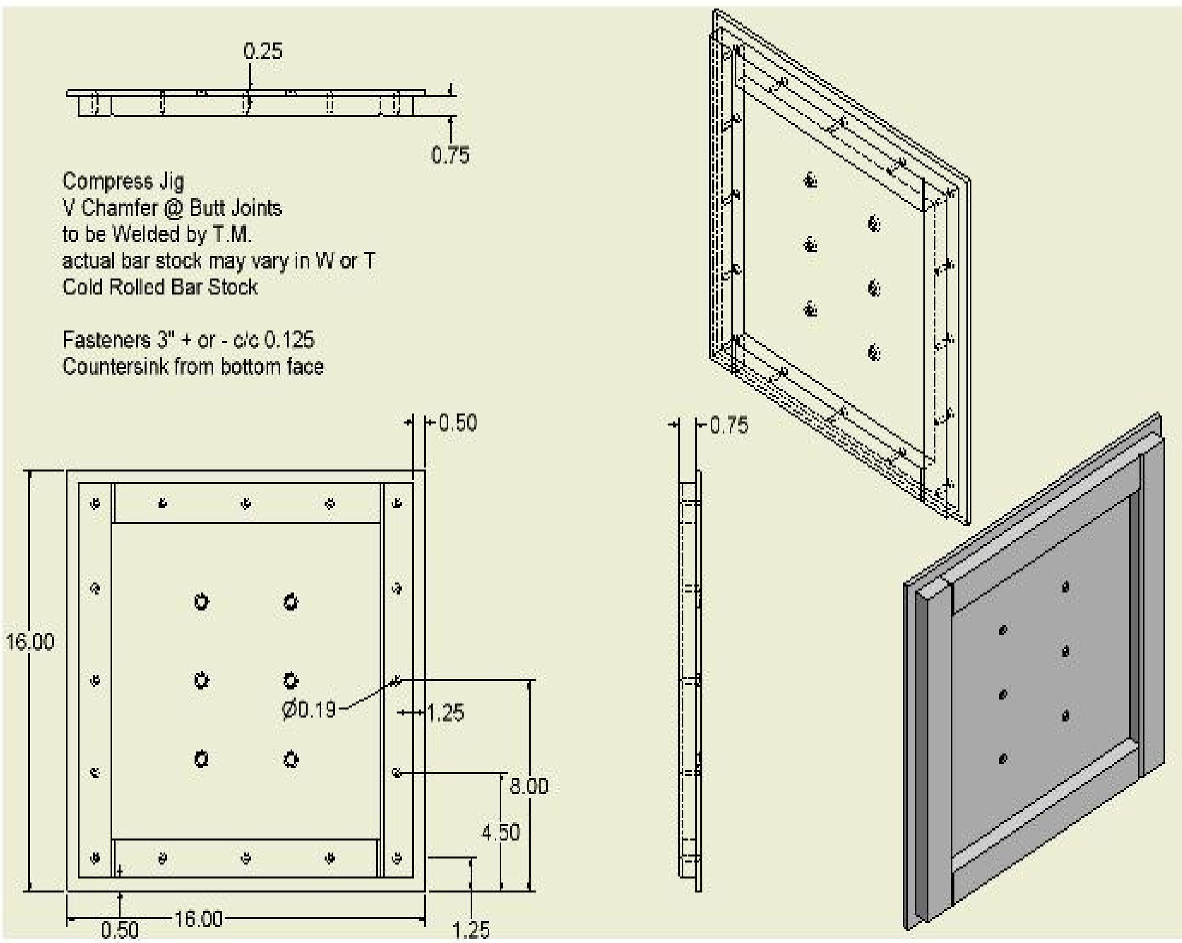
Sample Dimensions





(The "Butt Joint" has the same dimensions as the "Dovetail" as pictured above, except that the two pieces are not locked; they just butt up against each other. Pictures of "Butt Joint" were not available at the time of submission of paper.)

Composite Plate Transfer Press Mold



Acknowledgments

Dr. Christopher C. Ibeh -- CNCMM Director, Advisor, Supplies
Andrey Beyle – CNCMM staff, Advisor
Professor Bob Susnik – Advisor
Tom Musgrove – Lab Technician
Fitzgerald Madu – Colleague
Dale Widiger – Colleague
Zac Tyler – Colleague