

11-09 Strength and Fatigue Testing of Composite Patches for Ship Plating Fracture Repair

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1.0 OBJECTIVE.

1.1 It is the objective of this research to explore and experimentally validate the use of composite patches for preventing crack growth and extending the lifetime of aluminum and steel ship structures. A composite patch works as a crack arrestor by decreasing the stress in the area of the crack tip. Load is shed from the base plate through an adhesive layer to the composite patch. In addition, the added constraint of the composite patch can prevent these cracks from coalescing into a larger crack. Analytical capabilities exist for predicting the effectiveness of the composite patch configuration, but such analyses demand specific idealizations and assumptions that must be validated experimentally in order for this technology to be used in practice. Our proposed project seeks to develop this technology as a useful and reliable tool for aluminum and steel ship plating fracture repair and to foster its industrial acceptance and implementation.

2.0 BACKGROUND.

2.1 Repeated loading may result in the initiation of cracks in ship structure from fatigue. In particular, repeated loading in areas of stress concentrations leads to fatigue cracks that can grow to critical lengths and result in catastrophic structural failure of components and hull plating. Increased attention to maintenance and corrosion control is therefore particularly important for vessels designed with thinner plating afforded by higher-strength steels. Examples include the hull-structure cracking observed in Trans-Alaska Pipeline Service (TAPS) tankers [1,2,3].

2.2 An important consideration is the determination of critical crack length for a given hull material in order to assess potential for catastrophic failure [4,5]. Once cracking is detected, weld repairs may be conducted and structural modifications may be introduced. These approaches may solve the immediate problem temporarily but too often they move the initiation point for the crack to a new location. A solution is to lower the stress levels caused by load-induced conditions or structural imperfections so that fatigue crack initiation and growth are either prevented entirely or deferred for an acceptable amount of additional service life. The composite patch serves to do just that: reduce the stress intensity level. The reduction in stress intensity reduces substantially the crack growth rate. If it is assumed that microcracks or flaws already exist and the patch is placed in an area of high stress or an area where cracks will likely develop, the composite patch can prevent these cracks from growing or coalescing into larger cracks.

2.3 Composite patches have been proven effective in other industrial applications. In contrast to other repair methods, repairs carried out with composite patches are completed faster, exhibit good fatigue resistance, do not cause stress concentrations, result in low added weight, and are economically attractive [6,7]. In the aerospace community, composite patches are an “effective technique for improving fatigue life and maintaining high structural efficiency” [7,8]. It has been reported that high patch modulus materials attached to an aluminum base plate is a useful technique where surface preparation has enabled the development of adequate adhesive strength [7]. Aircraft components repaired with a composite patch have exhibited an 84% reduction in the stress intensity factor and a 1000% increase in the fatigue life [8]. Composite materials have also been used to rehabilitate steel bridges. Such repairs resulted in a 113% increase in the strength of damaged girders [9].

2.4 As in other industries, general use of composites in the marine industry is on the rise. Limited work in the marine field has been conducted with aluminum vessels [10]. Generally speaking, analytical and numerical studies of adhesively bonded composite patches used as crack arrestors have been

investigated for cracked sheets and plates [11-16] and in particular within the context of ship structure repair [17,18]. The previous work by Edwards and Karr [17] and by Bone et al. [18] forms the basis for the proposed project. This project will extend the previous work to include steel plating and to include testing the composite patches under fatigue conditions [19-24].

2.5 In the previous project by the investigators, 1/6th inch and 1/8th inch thick aluminum plates were used as base plates. The tests were conducted using 7075-T6 aluminum with both glass and graphite patches. Both pre-impregnated and wet lay-up processes were tested for comparison. Additionally, both single and double-sided patches were tested. The aluminum specimens were 12 by 12 inch plates with 2-inch edge cracks. For each test, the crack itself was first machined to a chevron or V-style notch and then fatigued until an initial crack was evident. After this, 4 by 4 inch unidirectional fiber composite patches were placed over the cracked area. The specimens were then tested by applying monotonically increasing load. With just one layer of glass fibers on a 1/8-inch thick plate, the maximum tensile load increases by almost 40%. Putting a layer of carbon fiber patch on both sides of the crack improves the maximum tensile load by almost 55%. These average results were achieved using only a small 1.5 hp vacuum pump for 8 hours, and a room temperature cure of 2 weeks. The primary mode of failure for the test specimens was delamination. Effects of various adhesive systems and additional layers of composite patching were studied. A summary of the load capacity for some 1/16th plates is shown below. The arrow on the upper level test data points indicate that the plates failed by overall yielding rather than composite delamination. The plate was restored to 100% of its pre-cracked capacity, a nearly three-fold increase in static strength. These experiments provide a good basis for further systematic testing for steel plates and fatigue testing.

2.6 Of course elimination of all potential crack initiation sites or conditions in ship structures is not practical, and some dependence on other approaches must be available to preclude catastrophic failure. Major concerns are and will continue to be fitness for service during operation, where the effect of minor cracking is assessed; and life-extension considerations, where the effect of severe structural damage is assessed. When cracking of ship structure occurs during service, decisions must be made about repairs.

Depending on circumstances, immediate repairs may or may not be necessary. Cracks that are load induced must be repaired or an alternative load path provided. Composite patch repairs may be completed rapidly, may exhibit vastly improved fatigue resistance, reduce rather than increase stress concentrations, have lower added weight than metal doublers, and are very cost effective. Thus these composite repairs have the potential as an efficient, economical, and expedient way to extend time between major structural repairs. Our previous studies indicate great promise for this approach in that static strengths of cracked metal plating can be substantially increased. However, such repairs for ship structure must also retain their integrity under repeated loading conditions, hence the need for verification in a fatigue-testing program.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall conduct an assessment of candidate adhesive systems for glass and carbon fiber composite patches to steel plating.

3.1.2 The Contractor shall identify the optimum composite adhesive systems for both aluminum and steel plating.

3.1.3 The Contractor shall design and conduct static strength tests of these systems to supplement existing findings for aluminum plating.

3.1.4 The Contractor shall conduct fatigue tests of the selected designs for composite patching of pre-cracked plates.

3.2 Tasks and Timeline. The project consists of two major complementary components: the numerical analyses and the experiments plus our documentation efforts. The major tasks are as follows, with milestone completion and estimated work hours. The work hours are combinations of the Investigators and student based on a total of 500 hours for student work and 250 hours faculty. Portions of Professor Waas' hours are included as Laboratory director and not charged to proposed project. Portions of Professor Karr's hours are included in thesis supervision and not charged to the project.

3.2.1 The Contractor shall develop Finite Element Analyses for the steel plate systems to supplement the existing analyses of aluminum plates. Completion: 4 mo. from start date. (50 hours).

3.2.2 The Contractor shall analyze, using the Finite Element Software, the aluminum and steel systems to predict crack growth and plate/patch failure. Completion: 6 mo. from start date. (50 hours).

3.2.3 The Contractor shall design candidate crack/plate/patch systems for testing. Completion: 9 mo. from start date. (100 hours).

3.2.4 The Contractor shall develop experimental arrangement for the strength tests. The experiments will be conducted at the University of Michigan's Composite Structures Laboratory (Section 9). Fixtures, such as that shown in Figure 2 below and used in previous projects, will be designed and constructed. Completion: 12 mo. from start date. (100 hours).

3.2.5 The Contractor shall develop experimental arrangement for the fatigue tests. Completion: 12 mo. from start date. (100 hours).

3.2.6 The Contractor shall perform strength and fatigue tests for the developed system designs. Completion: 22 mo. from start date. (250 hours).

3.2.7 The Contractor shall develop and deliver documentation of progress and final results. Completion: 24 mo. from start date. (100 hours).

4.0 GOVERNMENT FURNISHED INFORMATION.

4.1 Standards for the Preparation and Publication of SSC Technical Reports

5.0 DELIVERY REQUIREMENTS.

5.1 The Contractor shall provide quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 The Contractor shall provide a Preliminary Report on the Finite Element Analyses, Initial Static Tests, and Fatigue Life Predictions of the proposed fatigue tests, within 14 months of start date.

5.3 The Contractor shall provide a print ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual.

6.0 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: date of award.

6.2 Project Completion Date: 18 months from the date of award.

7.0 TIME, COST and MAN-HOUR ESTIMATE. These contractor direct costs are based on previous project participation expenses. Costs include one Graduate Student Research Assistant and faculty support for the project, and \$20,000 (as cost sharing with the University) for purchases of fatigue testing equipment and supplies.

7.1 Project Duration: 18 months.

7.2 Project Man-hours: 750.

7.3 Total Estimate: \$100,000.

8.0 REFERENCES.

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9.0 FACILITIES REQUIRED

9.1 Existing office space, computer equipment, state of the art software packages and laboratory facilities will be used throughout the project duration at no charge to the project. The experiments will be conducted at the University of Michigan Composite Structures Laboratory. The Composite Structures Laboratory was established in 1988 by the Department of Aerospace Engineering. Its activities involve research and training of graduate and undergraduate students in the Static and Dynamic Behavior of Structures made of advanced composite materials. During the last decade, the NASA Langley Research Center, the Office of Naval Research, the Air Force Office of Scientific Research, the Army Research Office,

the Department of Energy, the National Science Foundation, and the Ship Structures Committee have funded research projects. In addition, funds have also been received from various industries, most notably the big three automakers and their allied industrial partners, the Automotive Composites Consortium. Most activities of the laboratory are conducted in the FXB Aerospace Building and spans several laboratory rooms designed for different types of experiments. Collectively, these rooms cover an area of approximately 2300 square feet.

9.2 Several servo hydraulic testing frames are available for mechanical characterization of composite structures. These include a large capacity (100k lbf. force-50k inch.lbf. torque) MTS tension-torsion combined loading test frame, a small capacity tension-torsion pneumatically driven test frame(3k lbf capacity), a biaxial planar loading frame (50k lbf capacity), a 10k lbf screw driven Riehle test frame, two miniaturized table top compression-tension loading frames (range from 1 lbf – 50klbf.), a Charpy impact hammer, an instrumented drop tower facility, a 12x6 pneumatically isolated optical table, a Kodak high speed digital camera(1k frames/sec.), and a CORDIN high speed variable framing rate camera(20 frames/microsecond). These loading devices are supplemented by state of the art data acquisition systems and several additional optical devices for interferometric measurements and speckle photographic measurements. The laboratory also has several load cells spanning a broad range of load capacities, displacement measuring mechanical and optical transducers. A well equipped optical and scanning electron micrography laboratory is available for users of the composite structures laboratory. Students training in the laboratory have access to a campus wide network of powerful workstations and personal computers for computational work.