TEAMER Technical Support for Aquantis (Materials)

Cooperative Research and Development Final Report

CRADA Number: CRD-21-17762

NREL Technical Contact: Scott Hughes

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5000-89745
April 2024

TEAMER Technical Support for Aquantis (Materials)

Cooperative Research and Development Final Report

CRADA Number: CRD-21-17762

NREL Technical Contact: Scott Hughes

Suggested Citation
Hughes, Scott. 2024. *TEAMER Technical Support for Aquantis (Materials): Cooperative Research and Development Final Report, CRADA Number CRD-21-17762.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-89745. https://www.nrel.gov/docs/fy24osti/89745.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5000-89745
April 2024

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Water Power Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Cooperative Research and Development Final Report

Report Date: April 22, 2024

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Aquantis, Inc.

CRADA number: CRD-21-17762

CRADA Title: TEAMER Technical Support for Aquantis (Materials)

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

Scott Hughes | scott.hughes@nrel.gov and Paul Murdy | paul.murdy@nrel.gov

Name and Email Address of POC at Company:

Peter Stricker | pstricker@ecomerittech.com

Sponsoring DOE Program Offices:

Office of Energy Efficiency and Renewable Energy (EERE), Water Power Technologies Office (WPTO), in conjunction with the U.S. Testing Expertise and Access to Marine Energy Research Program (TEAMER)

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$85,000.00
Year 1, Modification #1	$.00
Year 2, Modification #2	$.00
TOTALS	$85,000.00

Executive Summary of CRADA Work:

The Aquantis Tidal Power Tug is a unique synthesis of best-available technologies and materials configured as a novel spar vessel to create an optimal platform for tidal stream energy conversion. The Power Tug utilizes an upstream-facing horizontal, 2-bladed rotor. To drive down capital costs and extend life, Aquantis proposes to employ new materials for the blades that are both less expensive than current state-of-the-art materials and are potentially better suited for survival in a submerged, seawater environment. Coupons from a novel geopolymer material will be tested in a load frame to characterize material properties.

The Requestor is requesting technical assistance for evaluating mechanical properties of a novel geopolymer material for application in tidal stream energy conversion systems. This work will establish characteristic properties of a geopolymer material under dry and saturated conditions through material coupon testing. Material coupons will be tested to characterize properties including:

a) Tensile strength

b) Compression strength

c) Flexural strength

d) Modulus of elasticity

e) Fatigue strength at varying load levels

The types of material tests performed will be guided by characteristics required to validate material properties for use in full-scale structures. Characterization of material properties that consider the demands of a full-scale structure is a necessary step in research and development that can enable the use of geopolymer materials in tidal stream energy conversion systems.

Summary of Research Results:

Task 1: Establish test program for property characterization of geopolymer test coupons.

The geopolymer material test matrix was developed alongside the structural design, and design for manufacturing, of a complete tidal turbine blade. The test matrix was adapted throughout the project to provide information and data most relevant to the design of the complete blade. Initial testing focused on understanding material properties necessary for general structural design, including flexural and tensile properties. Characterizing shear and compression properties of geopolymers became increasingly important as the project continued. The manufacturability of reinforced geopolymers influenced the number of geopolymer and reinforcement selections as well as the test type. Combined, 218 coupon tests were performed. Testing included:

- Flexure – 19 specimens
- Tensile – 64 specimens
- Shear – 32 specimens
- Compression – 103 specimens

Task 2: Test Coupon Preparation

Geopolymer panels and test specimens were provided by Aquantis. For tensile and shear testing, coupon specimens were cut from panels of geopolymers. Panel dimensions varied, but were typically 300 mm by 300 mm. Panel thickness also varied between 5 and 12 mm. Coupons were cut from the panels by water jet cutting. Tensile and shear coupon shapes were taken from ASTM standards, ASTM D3039 for tensile specimens, and ASTM D7078 for shear specimens. The quantity of tensile and shear specimens varied from panel to panel. Figure 1 provides photographs of an as-delivered panel, and the panel after tensile and shear coupons were cut from the panel. The long, slender profile is that of the tensile coupons while the rectangular profile is that of the shear coupons.

Figure 1 – As-delivered geopolymer panel (left), and geopolymer panel after coupons were cut via water jet (right)

Geopolymer bars were provided by Aquantis to characterize the flexural strength of geopolymers with different types of reinforcements. Geopolymer bars were approximately 50 mm by 50 mm by 300 mm. Geopolymer cubes and cylinders were provided by Aquantis for characterizing the compressive strength. Cubes were typically 50 mm along each edge, and cylinders were approximately 50 mm long with an outer diameter of approximately 50 mm. A select number of cylinders included a containment ring on the outer diameter to characterize the compressive strength of the geopolymer constrained in the lateral direction by the containment ring. Geopolymer bar, cube, and cylinders were tested as delivered. Figures 2, 3, and 4 provide images of these specimens.

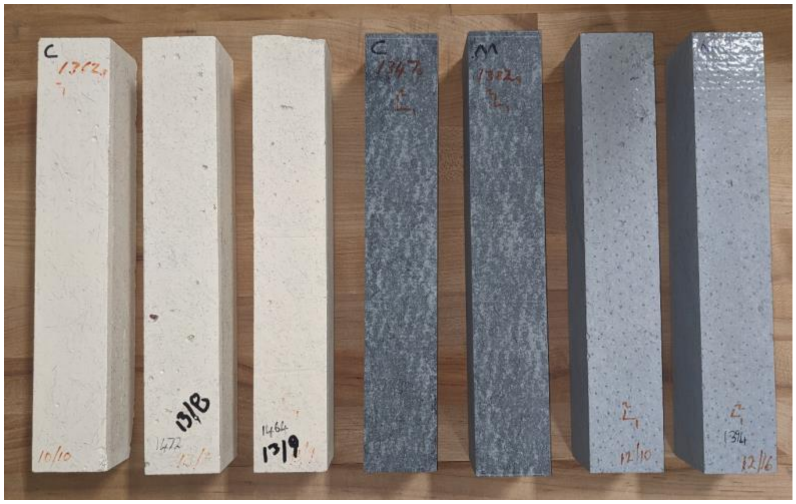

Figure 2 – Geopolymer bar specimens

Figure 3 – Geopolymer cube specimen

Figure 4 – Geopolymer cylinder test specimens

Task 3: Test Coupon Accelerated Conditioning

Limited work was performed on conditioning or accelerating aging of the geopolymer specimens. Several geopolymer specimens were conditioned by submerging the specimens in an elevated temperature distilled water bath for several weeks. Only qualitative visual observations of the conditioned specimens were performed. Work in this project focused on evaluating the mechanical performance of several types of geopolymer formulations as they were originally constructed (not conditioned) in their original. This approach emphasized the determination of geopolymer formulations best suited for the design environment. Depending on the final design configuration of a complete structure, validation of conditioned specimens could further improve material property values.

Task 4: Geopolymer test coupon testing

Coupon characterization was performed in servohydraulic load frames at NREL's Flatirons Campus. Tensile and shear characterization was performed in a 100 kN load frame, flexural testing utilized the 100 kN and 250 kN load frames, and compression characterization was performed in the 500 kN load frame. Data collected during coupon characterization included applied load and actuator displacement. For tensile specimens, an extensometer was used to measure the elongation of the test article in the gauge section.

Geopolymer beams were loaded in flexure using a long beam test fixture. The long beam test fixture applies the load supplied by the load frame to the beam as a four-point load. For the specimens tested, the distance between the outer support pins was 229 mm, and the distance between the loading pins was 72 mm. Loads were applied with the load frame actuator in displacement control, with crosshead speeds ranging from 0.7 to 1 mm per minute. Figure 5 provides images of geopolymer beam specimens in the long beam test fixture.

Figure 5 – Geopolymer beam specimens in a long beam test fixture

Hydraulic grips were used to clamp tensile specimens in the load frame. Loads were applied using displacement control, with the crosshead speed of 0.5 mm per minute. Figure 6 shows images of a tensile specimen installed in the hydraulic grips of the load frame, and an image of several of the tested tensile specimens.

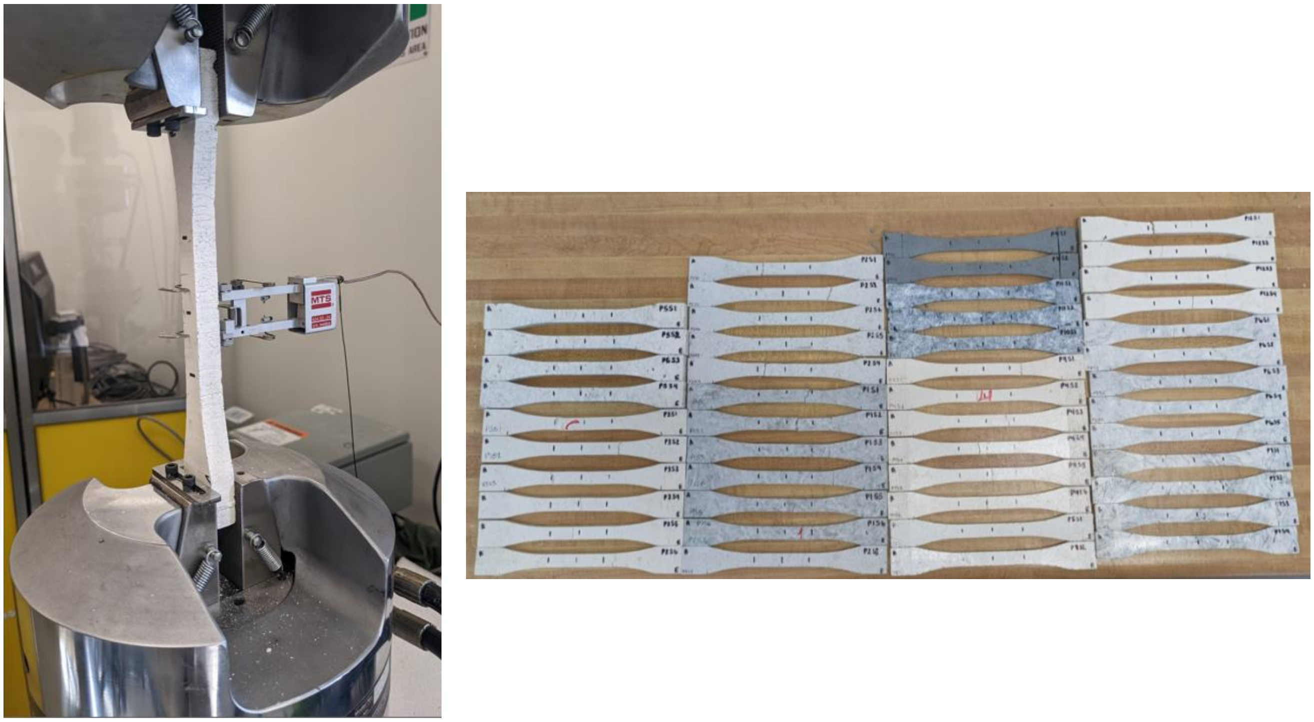

Figure 6 – Geopolymer tensile specimen in the 100 kN load frame (left), post-failure tensile specimens (right)

Shear testing of coupons was performed by cutting coupons conforming to the shape of ASTM D7078 coupons and testing in a V-Notched rail shear test fixture. Testing was performed using displacement control, with a crosshead speed of 0.3 mm per minute. Figure 7 provides an image of a post-failure shear specimen.

Figure 7 – Geopolymer shear coupon, post-failure

Compression testing of geopolymer cubes and cylinders was performed in the 500 kN load frame. Test specimens were fixtured between compression platens, with the upper compression platen containing a spherical bearing. Compressive loads were applied by the actuator in displacement control, with a typical crosshead speed of 0.7 mm per minute for cubes, and 0.8 mm per minute for cylinders.

Figure 8 – Geopolymer compression cube before loading (left) and post-failure (right)

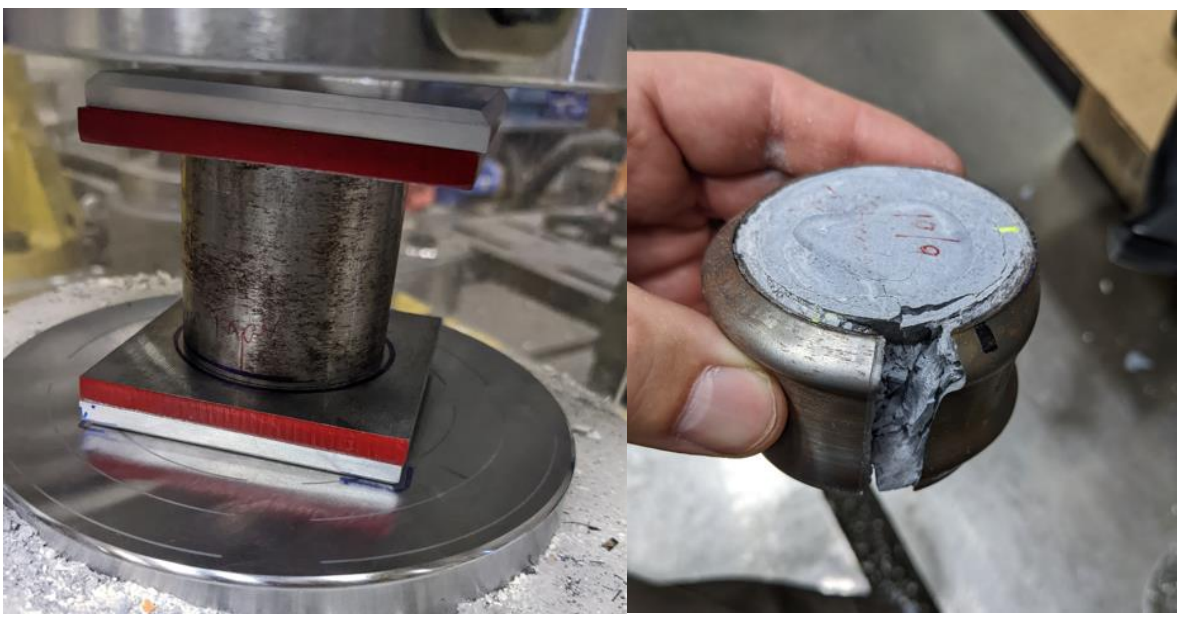

Figure 9 – Geopolymer compression cylinder with a steel containment ring before loading (left), and post-failure (right)

Task 5: Project reporting and dataset

Data from each of the tests was evaluated and summarized. Summary reports for each of the test types were provided to Aquantis. Reports included dimensional measurements of the coupons, reporting of maximum loads, plots of load and displacements, and calculated values of stiffness. An example of the data presented in these proprietary reports provided to Aquantis is shown below as Figure 10, where load versus displacement for cylinder specimens is presented.

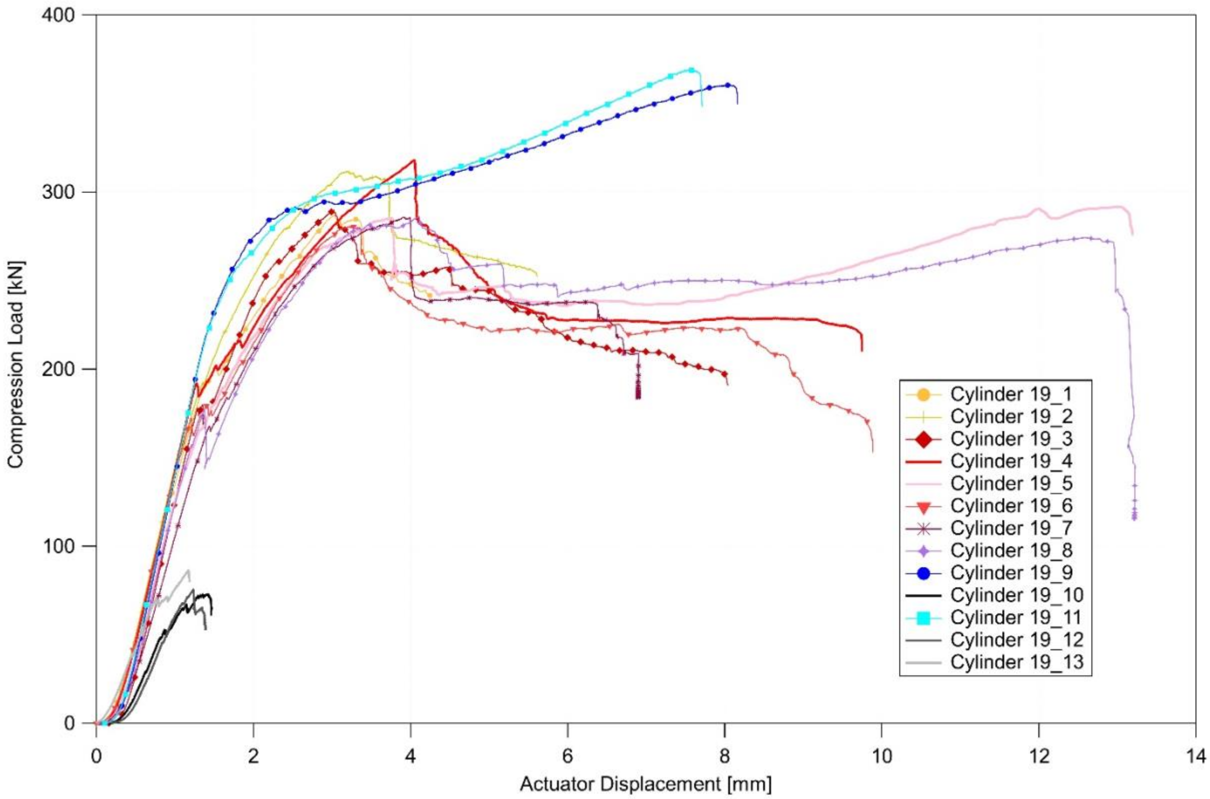

Figure 10 – Geopolymer compression cylinder load versus actuator displacement

<u>Subject Inventions Listing</u>:

US Patent Application No. 17751635 "MARINE CURRENT TURBINE PLATFORM WITH FAIRED SPAR"

US Patent Application No. 17688772 "FIXED AND PITCHING BLADES, SPAR SHAFT, BEARINGS AND MATERIALS FOR MARINE CURRENT TURBINE"

<u>ROI #</u>:

None