# Effects of Strain Gauge Coatings on Water Intrusion in Submerged Composite Coupon Testing

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Strain gauge durability mostly depended on strain levels. Water intrusion likely occurred at loading points. Future plans include measuring strain levels and identifying potential wear locations in composite testing and marine energy structure designs.

## INTRODUCTION

- Marine energy structures are often made of advanced composite materials, and they operate in underwater environments.
- Structures are repeatedly loaded by currents and waves, which cause two environmental conditions:
  1. Water intrusion
  2. Mechanical fatigue.
- Past research:
  - Sequential: hygrothermal aging → mechanical testing.
- This research:
  - Combined: submersion + mechanical testing.
- Submerged instrumentation is needed to validate marine energy component loads.
- Strain gauges were fixed to composite coupons, and coupons were submerged fatigue four-point bend tested in the load frame setup in Figure 1.
- Strain gauge coatings were applied over strain gauges and wire connections to protect strain gauges from contamination, delamination, and water intrusion.
- This study was conducted to understand the effectiveness of coatings in mitigating water intrusion into composite materials and strain gauges.

## OUTPUTS

- Outputs:
  - Cycles to composite failure (Table 1)
  - Cycles to strain gauge failure (SGF) (Table 2)
  - Failure modes (Figure 6).
- Methods developed and measurements taken at the coupon scale will be used to inform methods and designs for subsequent:
  - Submerged subcomponent testing
  - Full-scale testing
  - Standards development.
- The benefits of designing marine energy structures to informed standards and designs are decreased lifetime costs and increased reliability and energy production.

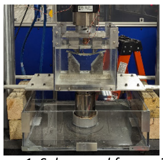

*Figure 1. Submerged four-point bend load frame assembly.*

## RESULTS

*Table 1. Cycles to coupon failure for polyurethane and polysulfide coating types for submerged composites. Five coupons were tested for each combination of composite and coating types.*

| Composite Type | Polyurethane | Polysulfide |
|---|---|---|
| Vinyl Ester | 4,545 ± 4,987 | 4,511 ± 2,536 |
| Thermoplastic | 47,823 ± 27,618 | 58,670 ± 24,140 |
| Epoxy | 12,602 ± 7,212 | 12,584 ± 2,666 |

*Table 2. Cycles to SGF for submerged composites with top and bottom gauges summed together. The number of gauges that were included in each average are in parentheses.*

| Composite Type | Polyurethane | Polysulfide |
|---|---|---|
| Vinyl ester | 1,012 ± 716 (8) | 525 ± 568 (8) |
| Thermoplastic | 1,092 ± 722 (9) | 1,237 ± 831 (9) |
| Epoxy | 294 ± 177 (9) | 368 ± 665 (8) |

Cycles to SGF averages for all submerged composites:
- Gauges coated with polysulfide: 703 ± 777
- Gauges coated with polyurethane: 817 ± 677.

→ The polysulfide coating did not extend the overall life of the strain gauges.

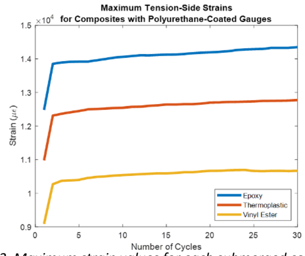


*Figure 3. Maximum strain values for each submerged composite type for the first 30 cycles.*

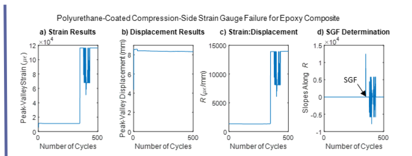


*Figure 4. Plots of (a) peak-valley strain, (b) peak-valley displacement, (c) the ratio of peak-valley strain and peak-valley displacement (R), and (d) the slopes along R. The number of cycles to SGF was determined by the initial spike in plot (d).*

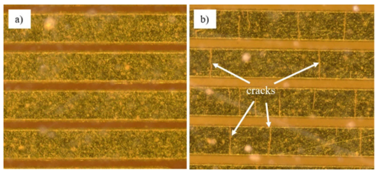


*Figure 5. Optical microscopy images (300 × magnification) of polyurethane-coated strain gauge Constantan foil resistive grid (a) before and (b) after submerged fatigue testing. The white arrows in (b) point to some of the cracked Constantan locations.*

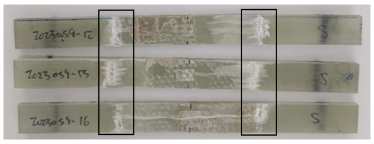

*Figure 6. Epoxy specimens with rectangles indicating top sheet crush locations from loading noses.*

## MATERIALS

- Glass fiber reinforced polymer composite coupons with three different resin systems:
  1. Epoxy
  2. Thermoplastic
  3. Vinyl ester.
- Manufactured at NREL's Composites Manufacturing Education and Technology Facility (CoMET) using Vacuum Assisted Resin Transfer Molding (VARTM).
- Strain gauges were coated with two different coatings (Figure 2):
  a) Polysulfide
  b) Polyurethane.

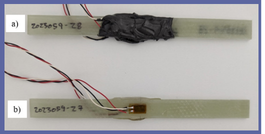


*Figure 2. Composite coupons with (a) polysulfide and (b) polyurethane strain gauge coatings.*

## METHODS

- Specimens were tested in submerged fatigue conditions using the load frame setup in Figure 1.
  - Test frequency: 0.65 Hz
  - All coupons were tested at 75% of the flexural strength of the thermoplastic composites.
- Cycles to SGF were compared for the two coatings and three composite types. SGF was determined in three steps (Figure 4):
  1. The ratio *R* of peak-valley strain and peak-valley displacement was calculated (Figure 4c).
  2. The slopes of *R* between each cycle were calculated and plotted (Figure 4d).
  3. Strain gauges were considered failed when the plot of the slopes of *R* spiked (arrow in Figure 4d).

## CONCLUSIONS

- Thirty composite coupons with 60 strain gauges were tested in submerged fatigue conditions.
- Coatings did not have an apparent effect on the number of cycles to failure of the composite materials, likely because water intrusion occurred at loading points (Figure 6).
- Strain gauges did not last the duration of testing and likely failed when the metal in the strain gauges cracked (Figure 5).
- Strain gauge durability was more dependent on strain values than the coating types used.
- Results will be used for future submerged fatigue subcomponent and full-scale instrumentation methods.
- Submerged fatigue tests with adequate instrumentation methods will lead to effective validations of marine energy structural components.

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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 the U.S. Department of Energy Water Power Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. 

UMERC+METS Marine Energy Research Conference
Duluth, MN
August 7-9, 2024
NREL/PO-5700-89376