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QUALIFY LIGHTWEIGHT

Technological innovation

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LONG TERM PERFORMANCE OF ADHESIVELY BONDED COMPOSITE-TO-METAL JOINTS

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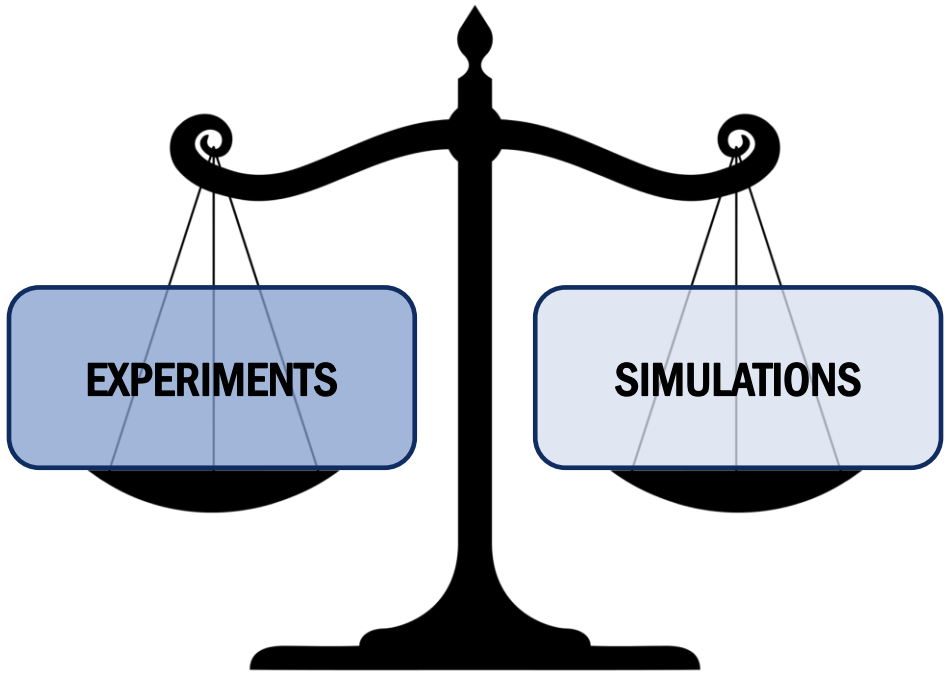
A MULTI-LEVEL EXPERIMENTAL/NUMERICAL APPROACH HAS BEEN DESIGNED AND IMPLEMENTED



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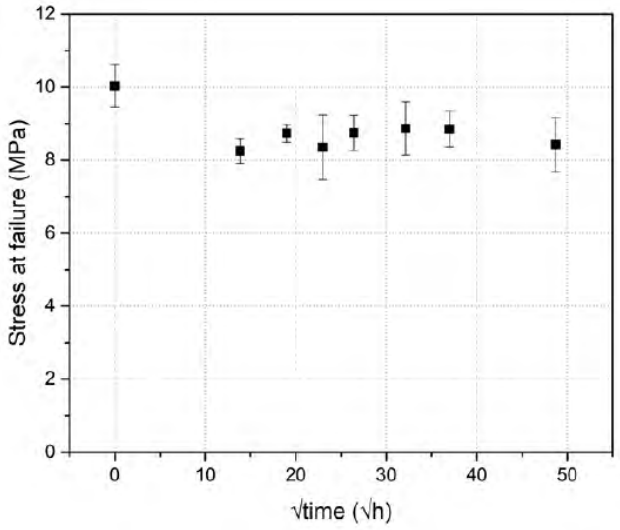
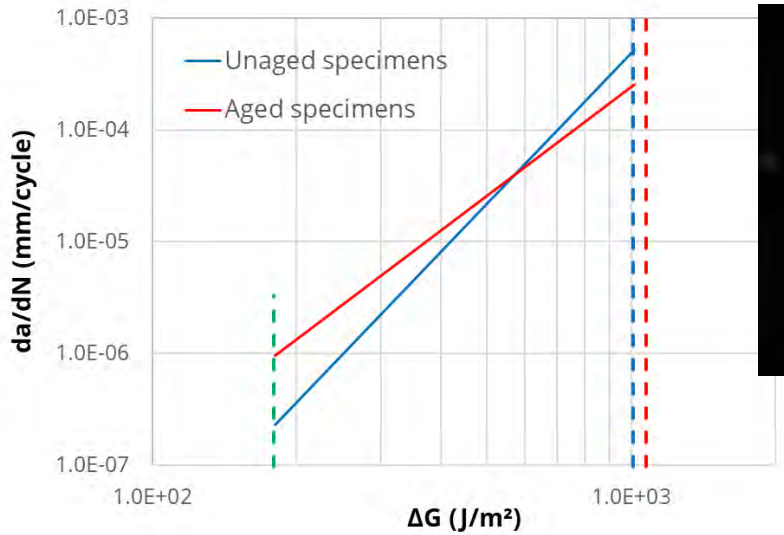
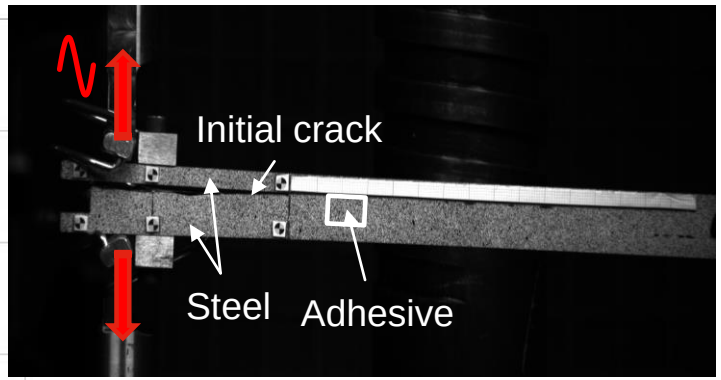
THOROUGH SCREENING AND CHARACTERIZATION OF ADHESIVE, ADHERENDS AND INTERFACES

- Mechanical properties: tensile, shear, mode I & II toughness of adhesive/steel interface
- Physical properties: moisture uptake, glass transition temperature
- Effect of exposure to a marine environment on mechanical properties of MMA adhesive and interface toughness
  - Salt spray ageing (ASTM B117-11): 6 weeks @ 35°C, 50% RH and 5% salinity







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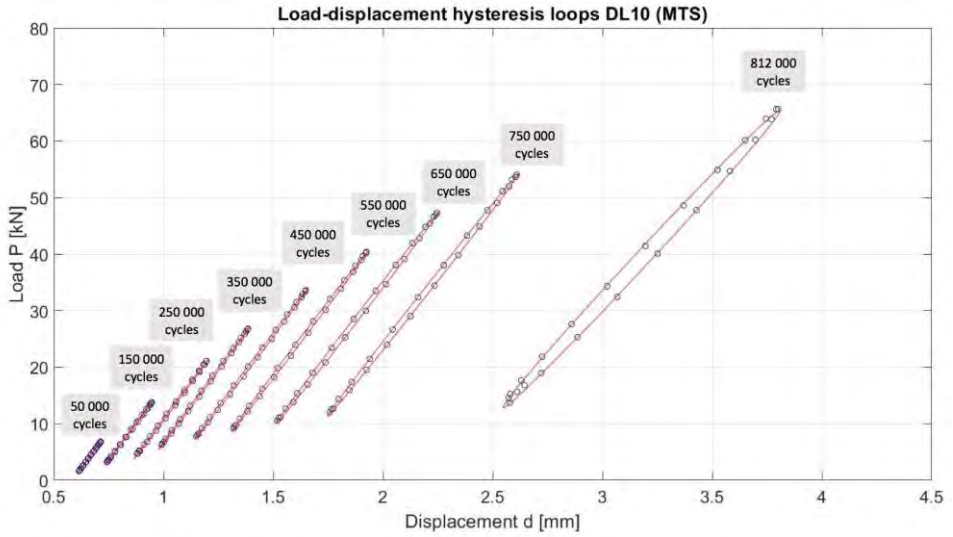
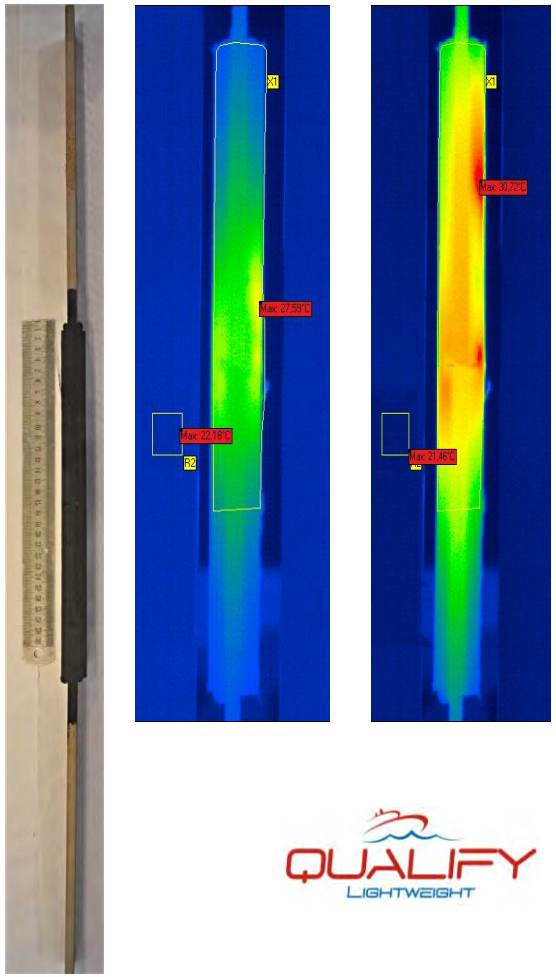
IDEALIZED JOINTS WERE USED TO EVALUATE FAILURE MODES, STRENGTH AND FATIGUE RESISTANCE

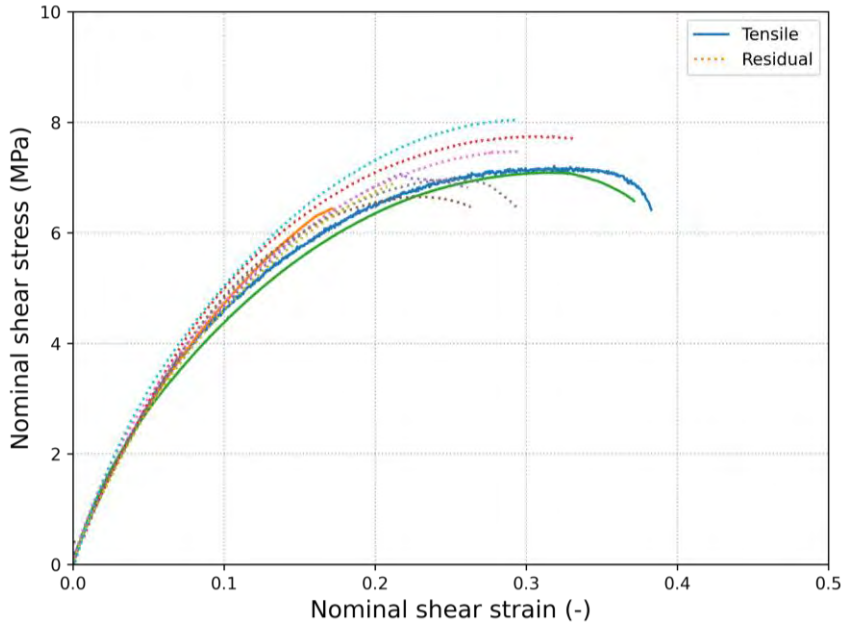
- Frequency of 4Hz; R-ratio = 0.1
- Fatigue response characterized by hysteresis cycles
- Damage monitoring: visual inspection and infrared thermography

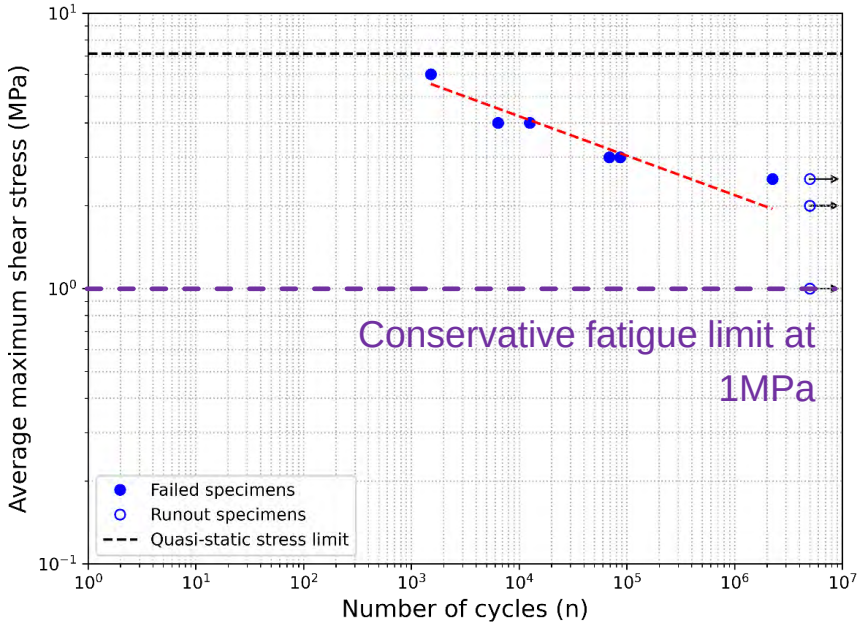




FATIGUE LIMIT AND STRESS-LIFE RELATIONSHIP HAS BEEN DETERMINED FOR AGED DOUBLE STRAP SPECIMENS

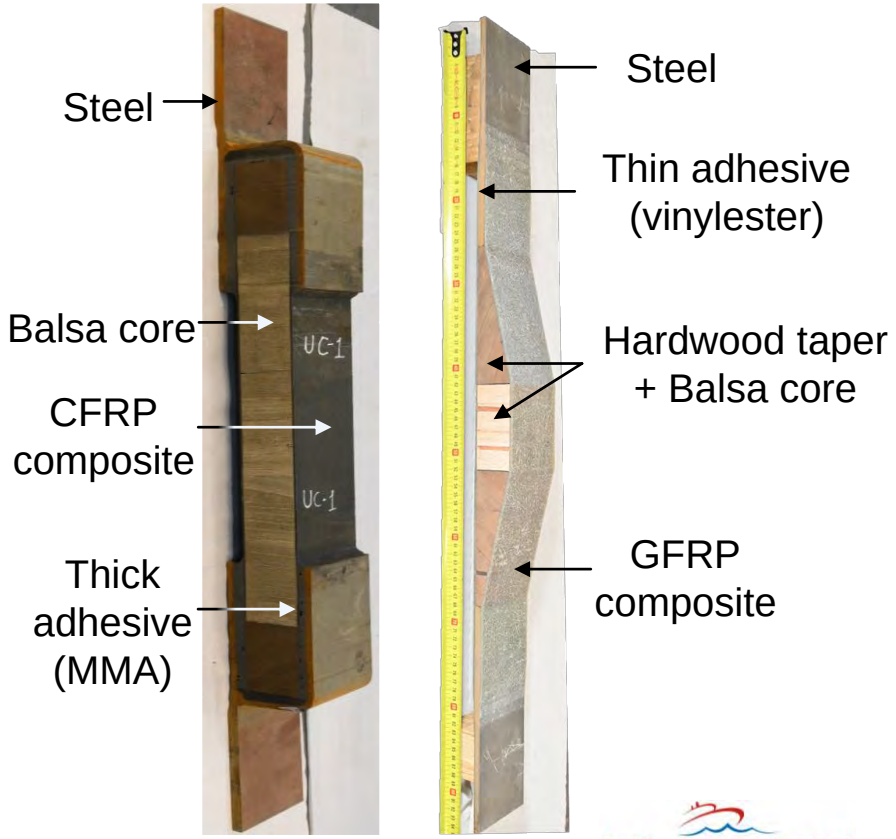
- Final rupture occurs due to composite delamination
- Run-out specimens
  - @1MPa no visible damage; @2MPa - 2.5MPa some hackles in the adhesive
  - Residual strength comparable to quasi-static strength





A SERIES OF TESTS HAVE BEEN PERFORMED ON JOINTS HAVING THE REAL GEOMETRY

- Specimens manufactured in shipyard conditions
- Loading conditions
  - Tensile, arcan, compression, bending
  - Quasi-static and fatigue
- Ageing by immersion

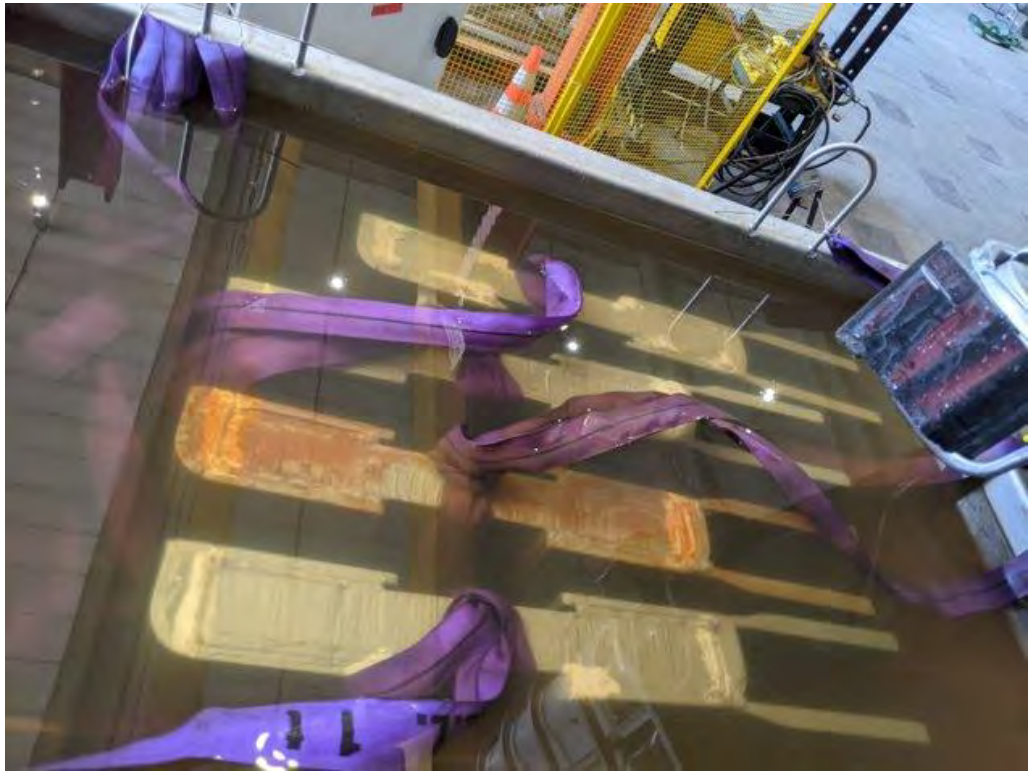


PROTOCOL FOR AGEING BY IMMERSION HAS BEEN DESIGNED TO REPLICATE DEGRADATION IN OPERATIONAL CONDITIONS

- Degradation mechanisms
  - Moisture diffusion through the adhesive
  - Creeping corrosion at the steel/adhesive interface
- Simulate at least 5 years of exposure to 35°C and 50% RH
  - A similar distance of significantly wet adhesive is reached by removal of 15mm of adhesive followed by 10 weeks of immersion in salt water (3.5% NaCl) at 50°C
  - A scribe line is applied through the paint on the steel near the adhesive to allow initiation of corrosion

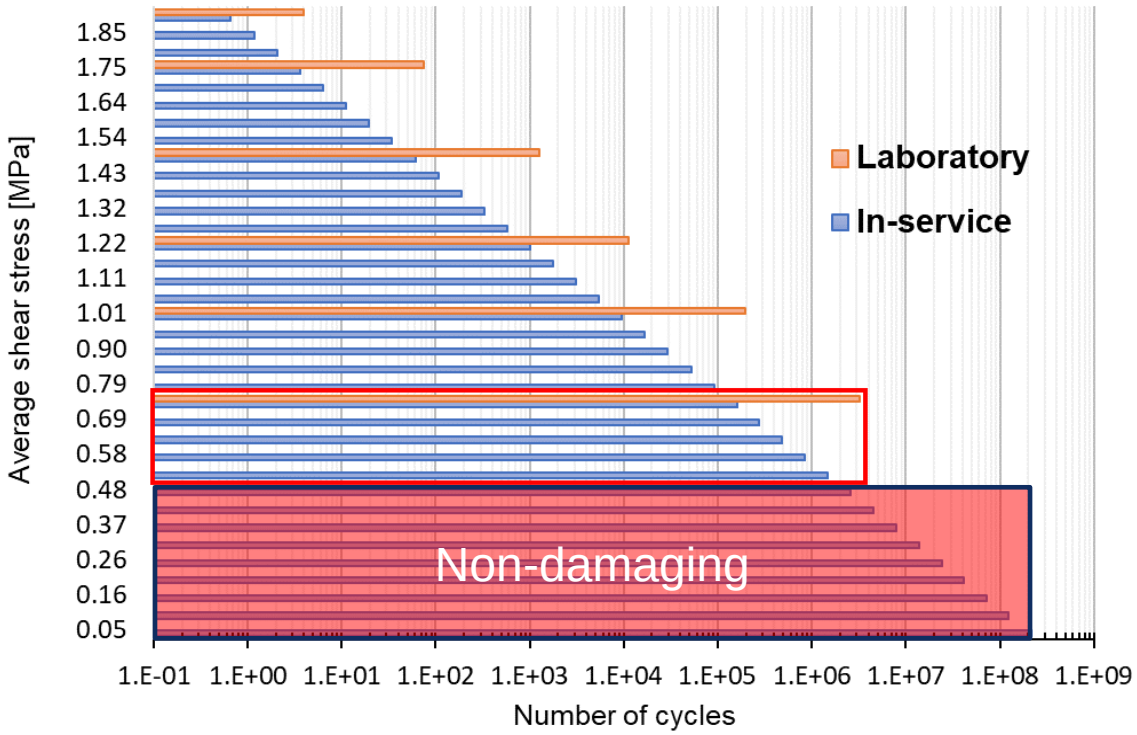
SALT WATER IMMERSION BATH HAS BEEN DESIGNED AND BUILT

- Height 1.4m, length 1.2m, width 1.0m



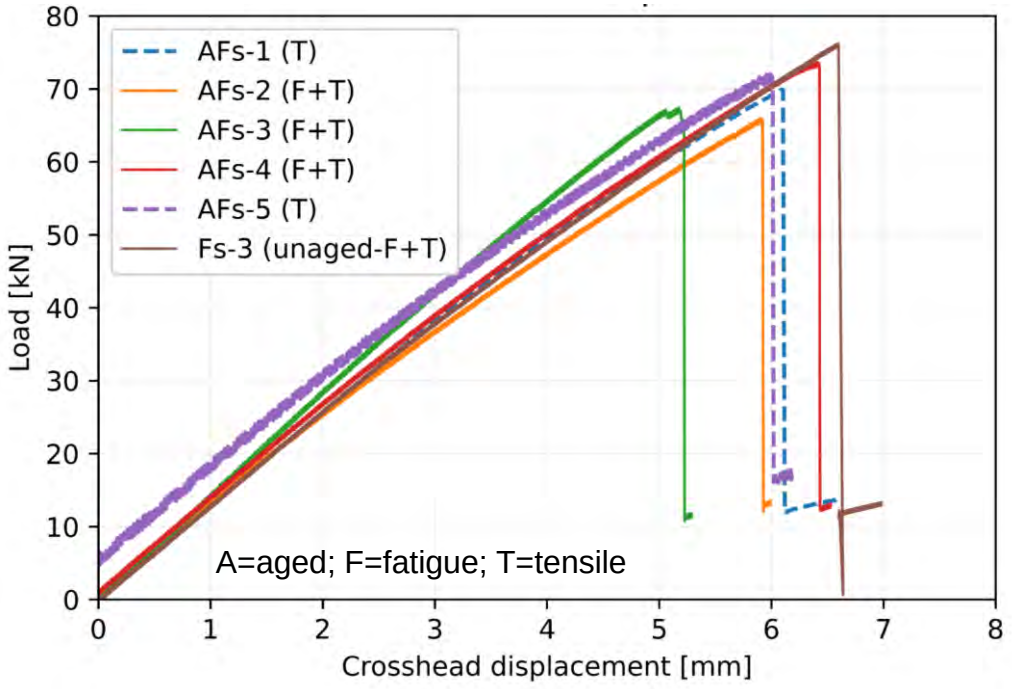
JOINTS HAVE BEEN SUBJECTED TO ACCELERATED FATIGUE TESTING

- Histogram for 25 years of operation
  - Stress levels in adhesive joint of an actual ship
  - Safety factor of 10 on number of cycles
- Laboratory histogram
  - Removal of cycles below 0.5 MPa (safety factor of 2 on fatigue limit)
  - Stress level bins of 0.25MPa (0.75 … 2.00 MPa) and all cycles applied at highest bin stress level to add conservatism
  - At a test frequency of 4Hz this corresponds to around 10 days



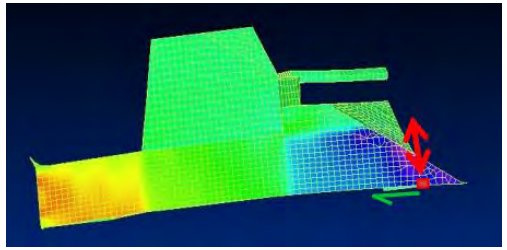
SPECIMENS DID NOT FAIL DURING THE FATIGUE TESTS AND NO SIGNS OF DAMAGE WERE FOUND

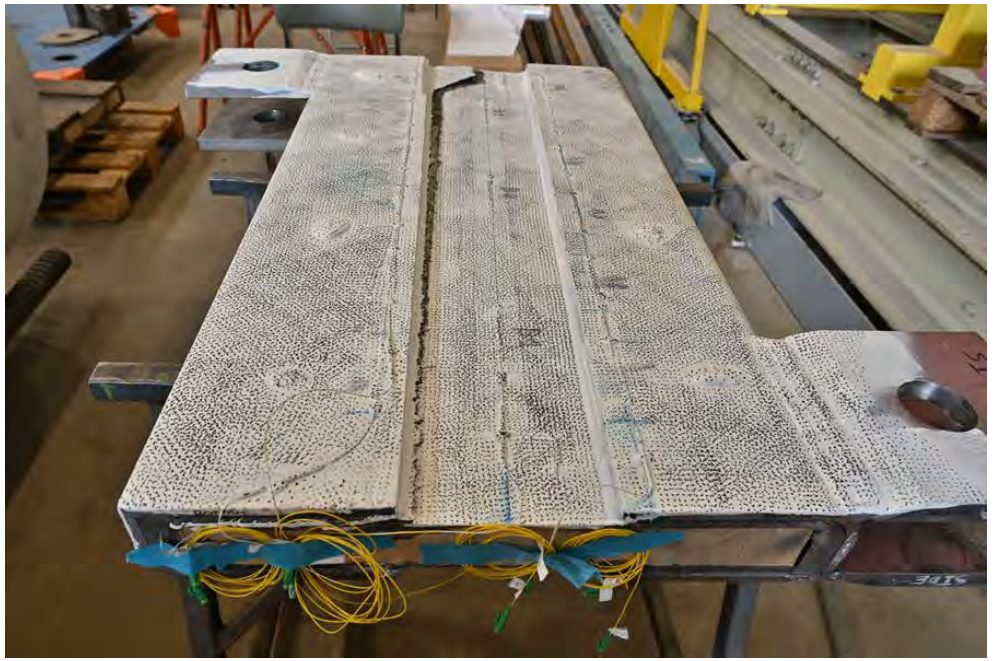
- Residual strength is similar to quasi-static strength of aged and unaged specimens
- Final rupture is triggered due to delamination of the CFRP

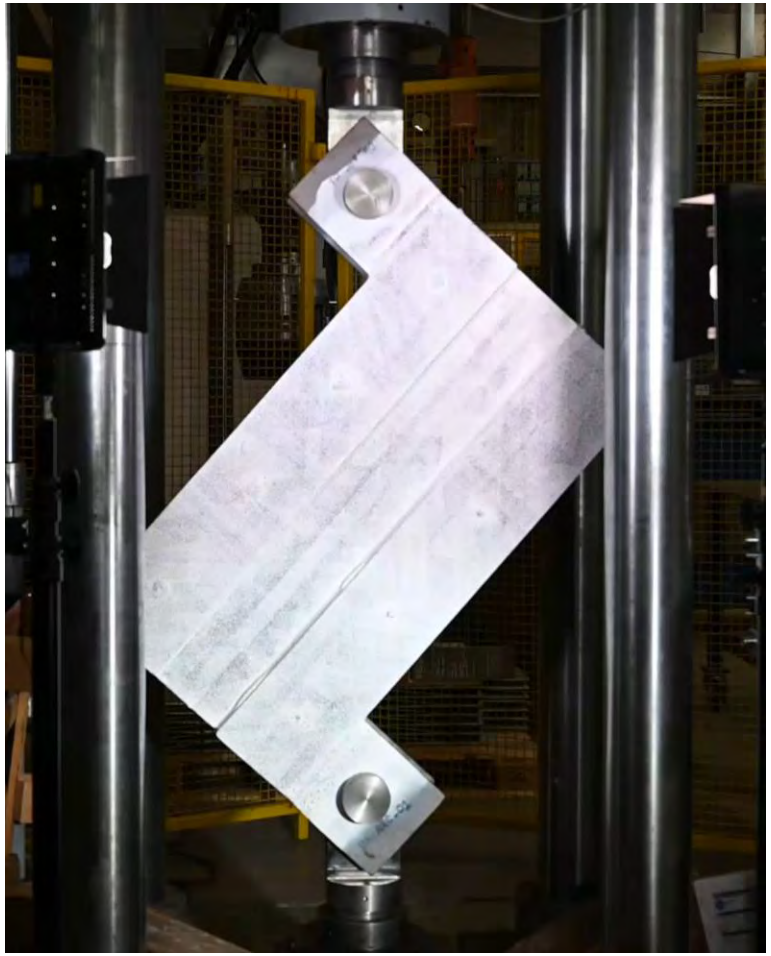


ARCAN TEST SPECIMENS HAVE BEEN DESIGNED TO REPLICATE COMBINED VERTICAL AND HORIZONTAL SHEAR STRESSES AT THE FORE BULKHEAD

- Quasi-static tensile tests on aged and un-aged specimens show similar strength values
- Final rupture is initiated by delamination of the CFRP panel
- Fatigue tests ongoing







TO CONCLUDE

- The long-term performance of bi-material adhesive joints has been evaluated by fatigue tests at different levels
- Fatigue limit and stress/life relationship has been established for salt spray aged idealized joints
- A salt water immersion protocol has been developed to age components representative for real scale joints
- A conservative load histogram for accelerated laboratory fatigue testing has been designed
- Aged components withstood the fatigue load without signs of damage, and their residual strength is similar to the quasi-static tensile strength
- Joint failure is triggered by CFRP delamination

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This research was carried out within the project "QUALIFY – Enabling Qualification of Hybrid Joints for Lightweight and Safe Maritime Transport", co-funded by the INTERREG 2SeasMers Zeeën programme
http://www.interreg2seas.eu/qualify