The Challenges of Testing Bulk Adhesives

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Abstract

With the development of composites applied to civil engineering structures such as bridges and wind turbines the need for testing bulk in addition to fibre reinforced structural adhesives has risen since joints in such structures are much thicker than what is found in the well documented field of Aerospatiale. However, reliably testing bulk adhesives to accurately find its mechanical properties presents new challenges.

This project addresses many of the unforeseen specimen behaviour providing explanations based on laboratory testing and finite element calculations with the ultimate aim of raising researchers awareness and understanding of parameters influencing results.

Experimental campaign

Pure tensile testing was done on moulded Sikadur-330 specimens based on Type I shape of ASTM D638 standard. MTS Landmark and Acumen tensile testing machines were used to respectively perform quasi-static and fatigue testing. Measurements were done by displacement and force sensors of the tensile testing machines, digital image correlation and high-speed camera.

Side view of tensile testing setup

Theoretical moment

A theoretical analysis of moment due to the misalignment of the specimen in the grips and grips misalignment was done to evaluate the plausibility of it inducing unwanted failure

Finite element model

A finite element model of the specimen was built on Autodesk Fusion 360 using an auto-generated mesh of 3D 1mm wide parabolic tetrahedra elements. The calculation simulates a perfect specimen with both grip pressure and axial force applied.

The 3 main challenges

The presentation of the findings and conclusions is sorted in accordance to failure location (drawing hereunder) to highlight the prevailing concerns and parameters in each case.

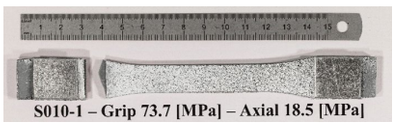
1. Avoiding tab failure

Tab failure is a recurrent issue in bulk adhesive tensile testing. The experimental results and theoretical bending analysis show that tab failures are linked to stress concentrations and can be due to a combination of:

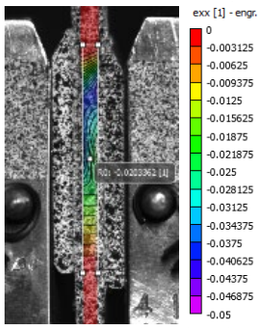
- Higher grip pressure than necessary
- Tilt of tab due to uneven adhesive surface
- Use of tab without taper
- Misalignment of top and bottom grips
- High frequency in fatigue testing

Those results lead to the following solutions to mitigate tab failure:

- Use minimum grip pressure required to avoid slipping
- Choose manufacturing process creating smooth surface (ex: Specimen machining in hot pressed adhesive plate)
- Use tapered tab with maximum area possible
- Limit fatigue testing frequency to 25 Hz
- Check grips alignment



Example of specimen undergoing tab failure

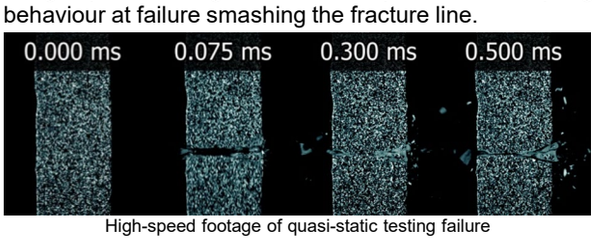


Non-uniform horizontal strain in adhesive due to tab tilt

2. Interpreting narrow cross-section failure

An explanation is provided for each of the following unexpected behaviour observed in experiments with failure happening in the intended area, the narrow cross-section.

- Non-linear crack
  - Failures with triangular opening on one side showed correlation with the offset between the specimen axis and grip axis suggesting the presence of unwanted moment and therefore early failure.
- Cyclic behaviour at failure
  - High-speed footage at 40'000 fps revealed spring like behaviour at failure smashing the fracture line.



High-speed footage of quasi-static testing failure

- Non-linear Young's modulus
  - Even after 7 days of cure at ambient temperature an 30 minutes at 90ºC the adhesive still showed substantial relaxation making Young's modulus calculation time dependant.
- Effect of frequency in fatigue testing
  - Fatigue cycle resistance showed no significant variation going from 10 to 25 and 40 Hz

3. Discarding or not edge case

Failure sometimes happen at the limit of the narrow cross-section. To understand whether or not to use those results the following effects are highlighted:

- Specimen shape
  - The dog-bone shape creates higher axial stress on the sides of the specimen than in the middle in the area 3. This results in crack with big triangular opening.
- Specimen rotated while installed in grips
  - Specimens not placed vertically in the grip induce a triangular moment in the specimen which, due to geometry, has a greater effect in 3 than in 1 and 2.