Stacking sequence effect on the fatigue behavior of single lap shear bonded joints

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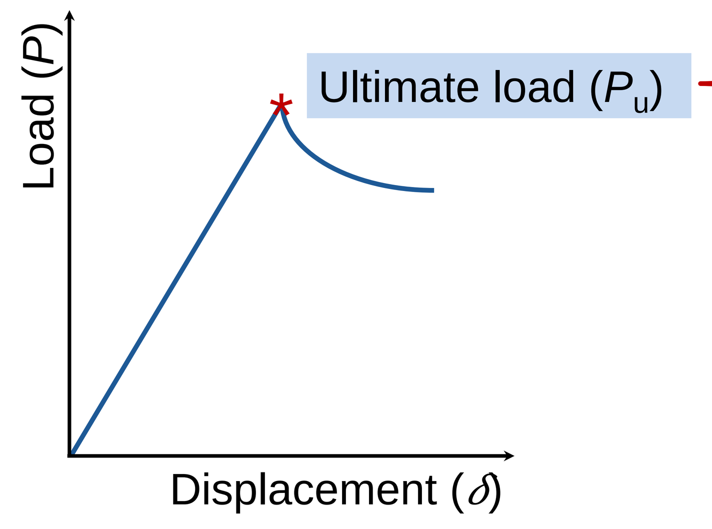
OBJECTIVES

Evaluation of the stacking sequence effect on the fracture and fatigue behavior of composite adhesively bonded joints using single lap shear specimens

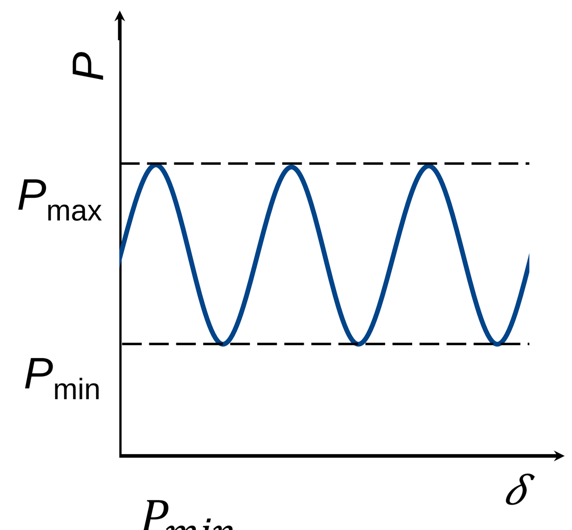
Fatigue damage accumulation was described using a phenomenological approach based on stiffness degradation as a damage parameter

Fracture characterization

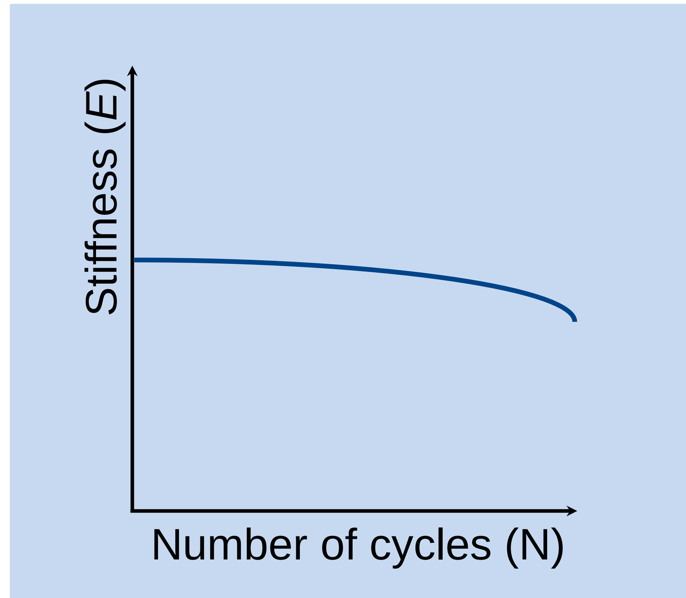


P_{max} = 40% P_u

Fatigue characterization



$$R = \frac{P_{min}}{P_{max}} = 0.1$$



- ✓ Stiffness degradation model
- ✓ Damage evolution
- ✓ Fractography and microsectioning analyses

STATE OF THE ART

Pros and cons of bonded joints

- \+ Low stress concentrations on the bonded area compared to riveting
- \+ Capacity of joining dissimilar materials
- \+ Design flexibility
- \+ Allows repairs solutions in case of localized damage
- – Sensitive to harsh environments
- – Complex mechanism of failure

Stacking sequence effect

- ✓ Under fatigue loading multidirectional laminates exhibit a strength decrease of about 20-40% in comparison with unidirectional laminates
- ✓ The fiber's orientation at the adherend/adhesive interface plays an important role on fracture
- ✓ The crack path usually grows through the plies adjacent to the adhesive layer

Fatigue damage model

Based on the stiffness evolution of a structural component under fatigue loading

Such models:

- ✓ present a high sensitivity to damage progression
- ✓ can be measured during testing

$$D(N) = \frac{E_0 - E(N)}{E_0 - E_f}$$

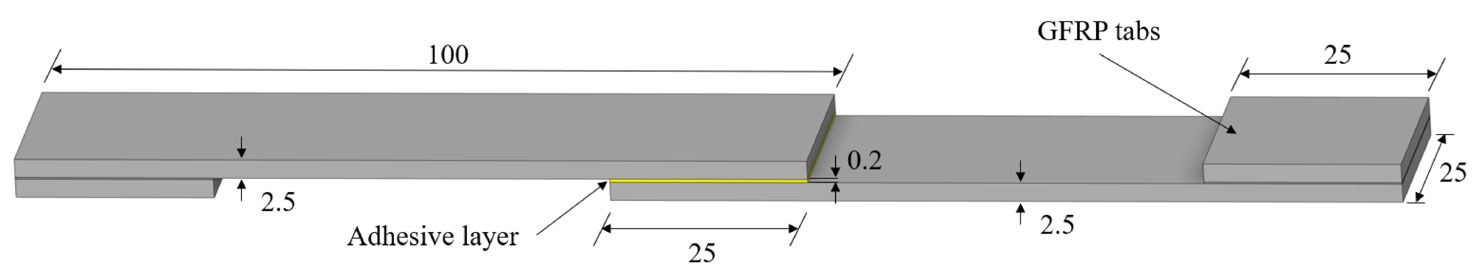
D: accumulated fatigue damage
E_0: initial stiffness
$E(N)$: current stiffness
E_f: stiffness measured before total failure

EXPERIMENTAL PROCEDURE

Materials

- Substrates: multiaxial, non-crimp E-glass fiber fabrics with an epoxy resin system
- Adhesive: two-component epoxy-based adhesive system *SikaPower*® 880
- Stacking sequences: **B** $[0°/90°/90°/0°]_s$ / **Q** $[0°/45°/90°/-45°]_{2s}$

Single lap shear specimens



Fracture tests

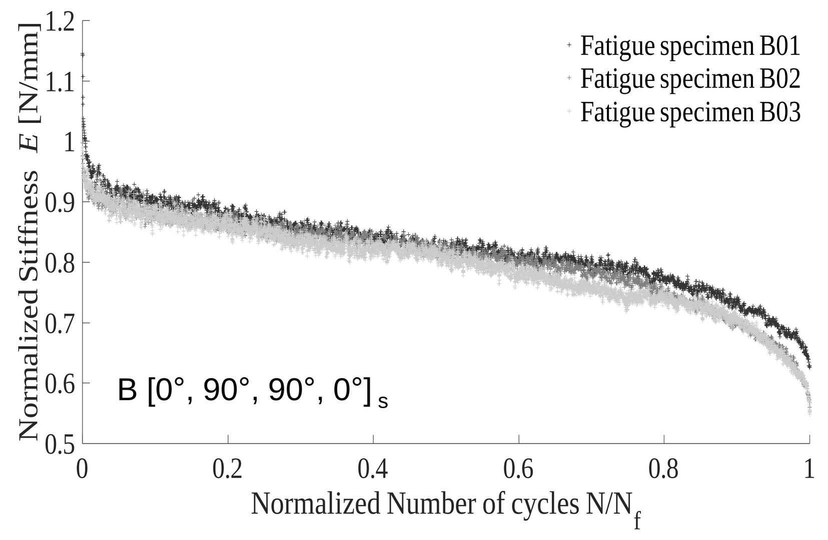
Zwick testing machine / Rate=0.2mm/min

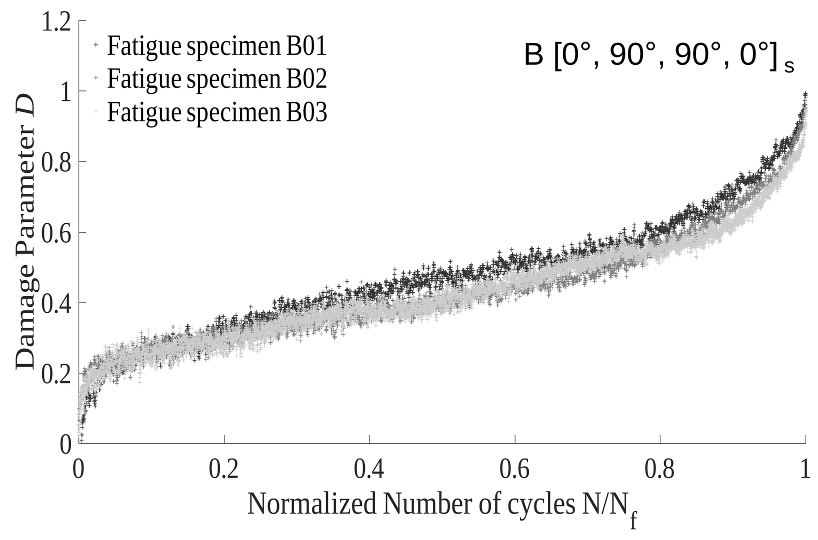
Fatigue tests

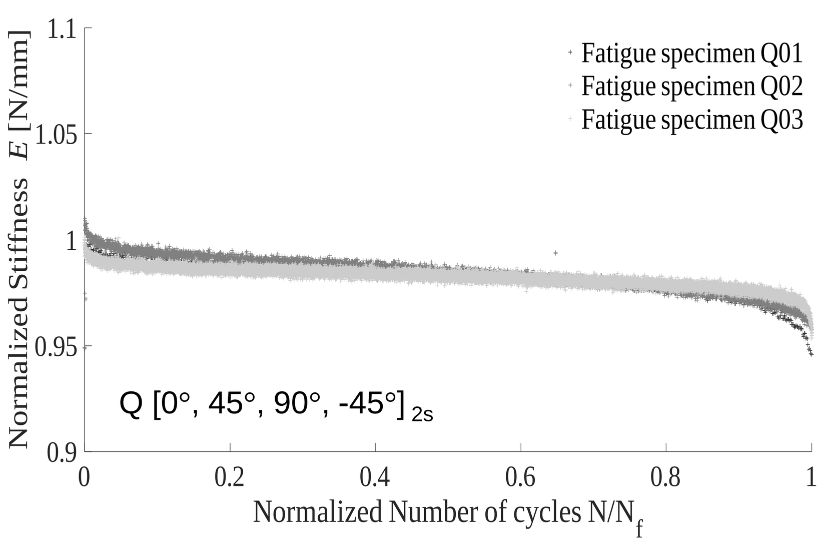
MTS servo–hydraulic testing machine

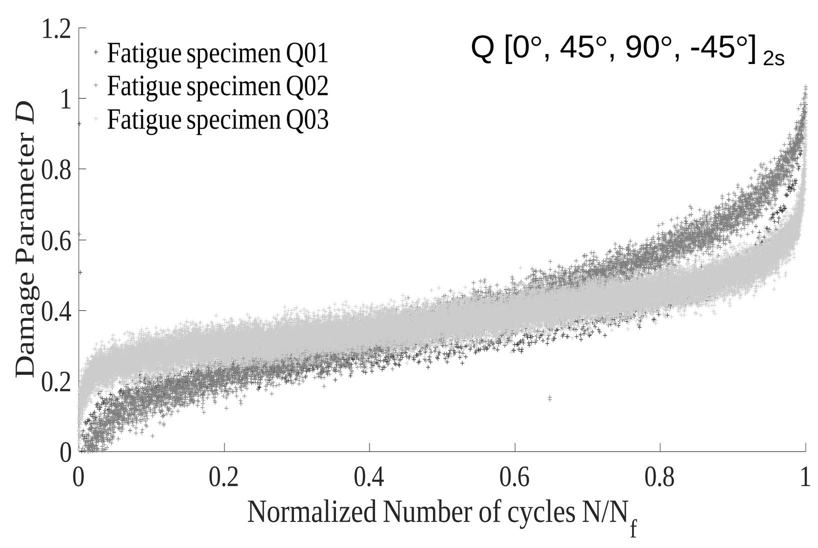
Loading control / 7 Hz frequency / *R* = 0.1

RESULTS









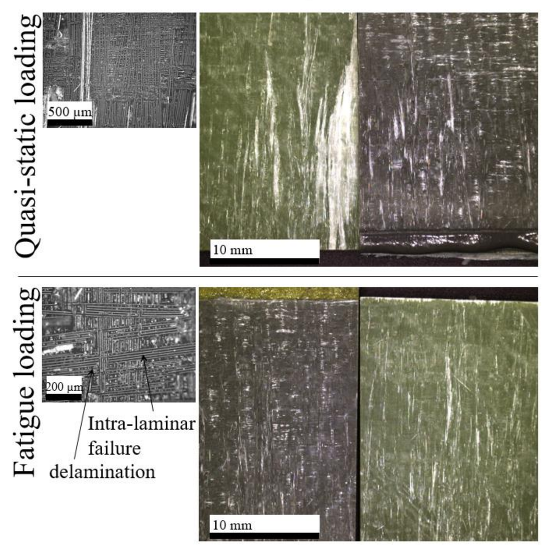
Fatigue damage evolution

$$D(N) = 1 - \left(1 - \left(\frac{N}{N_f}\right)^{\alpha}\right)^{\beta}$$

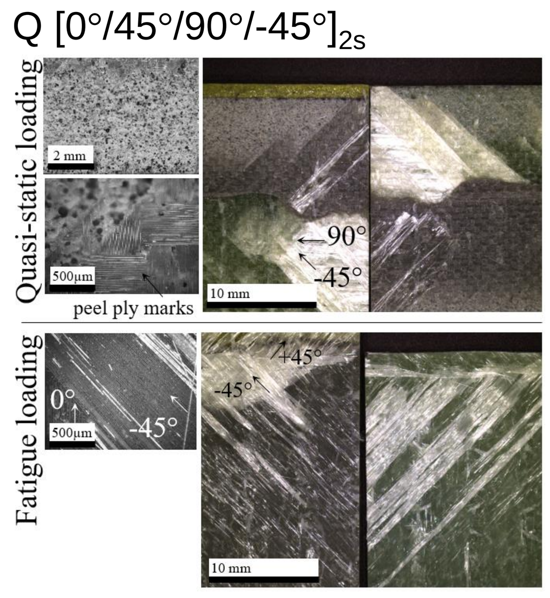
N: fatigue number of cycles
N_f: number of cycles to failure.
α and β are the shape parameters

	B $[0°/90°/90°/0°]_s$	Q $[0°/45°/90°/-45°]_{2s}$
α	0.185	0.473
β	0.259	0.362
R^2	0.963	0.974

B $[0°/90°/90°/0°]_s$



Q $[0°/45°/90°/-45°]_{2s}$



CONCLUSIONS

- ✓ The Q series exhibited a higher P_u (23%) due it's complex fracture path
- ✓ The stiffness degradation model proved to be accurate for describing the fatigue damage accumulation
- ✓ The B series presented a high stiffness degradation of 40%, while in the Q series, the stiffness only decreased by 5%.
- ✓ The B series fatigue life was significantly lower (77.5%) than the Q series
- ✓ 0° layers at the interface are usually the locus of intra-laminar delamination and can accelerate failure

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