Fatigue life modeling of GFRP composites considering viscoelastic behavior

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Introduction

The tension-tension fatigue behavior of angle-ply GFRP laminate is studied in this work. The main objective is to develop an efficient methodology to obtain time- and cycle-dependent properties considering their interaction. Different aspects of time-dependent deformation on fatigue behavior are discussed. The S-N curves are adjusted according to the true stress state resulting from large creep deformation under fatigue loading. Moreover, the effect of fiber orientation on fatigue stiffness evolution is investigated. A simple analysis is performed to exclude the stiffening effect due to fiber orientation from the monitored fatigue stiffness evolution, which provides the fatigue stiffness evolution due to pure fatigue damage. An experimental methodology is proposed for time-dependent properties to evaluate the effect of fatigue damage on viscoelastic properties. DMA experiments were used to obtain the time-dependent properties of the fatigue-damaged specimen. Finally, this work presents the feasibility of extending the time-temperature superposition principle to time-temperature-fatigue damage superposition, aiming to predict the viscoelastic properties depending on the fatigue damage level.

Methodology

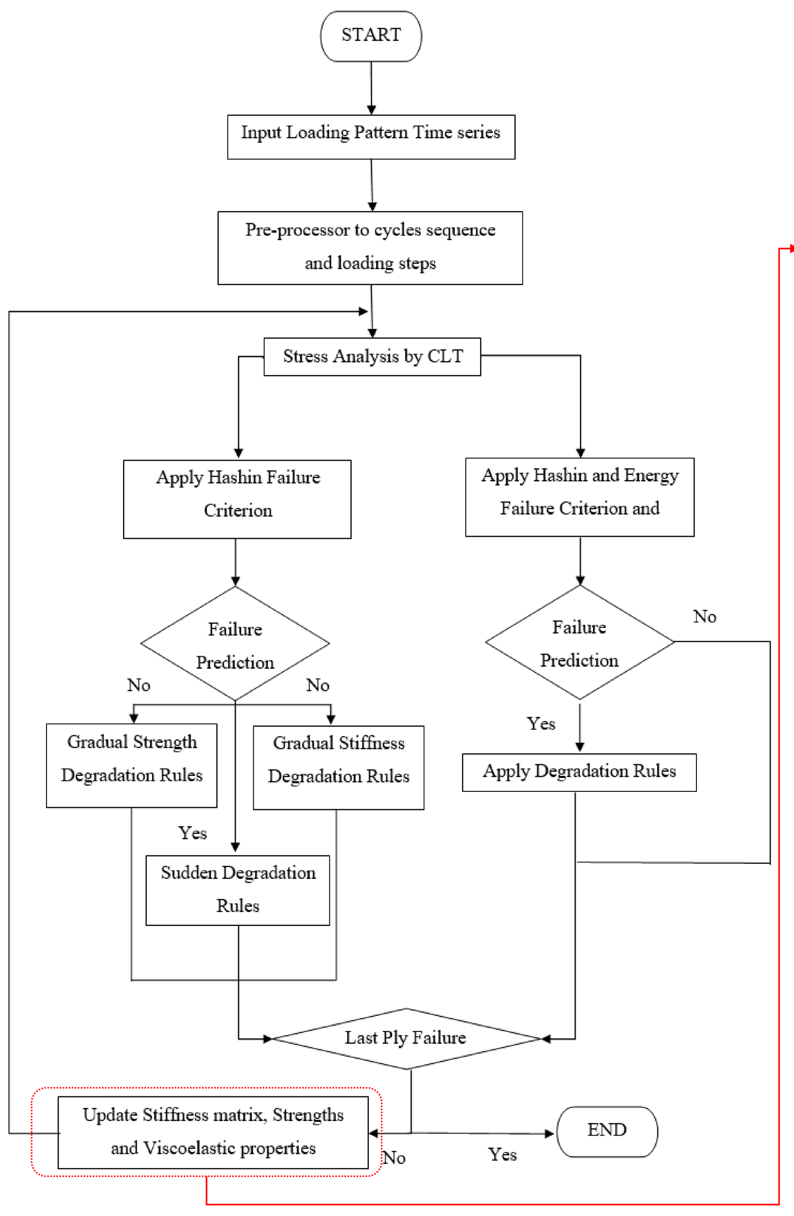

Figure 1. Flowchart for creep-fatigue interaction modeling

Creep-fatigue interaction:

- Modeling time-dependent (viscoelastic) properties in terms of fatigue damage level under loading
- Modeling viscoelastic deformation effect on cycle-dependent properties (fatigue stiffness, strength)

Cycle-dependent properties:

- ❖ Fatigue testing for residual strength and stiffness models considering viscoelastic deformation and resulting fiber orientation

Time-dependent properties:

- ❖ DMA testing and TTSP for fatigue-damaged material

Results

Cycle-dependent properties

- ❖ The S-N curves for fatigue testing of $[\pm 45]_{2s}$ GFRP laminates for R=0.1, 0.5 and 0.8 has been modified for stress increase resulting from viscoelastic deformation.
- ❖ Residual fatigue stiffness has been decomposed for fatigue damage degradation and stiffening effect due to fiber reorientation

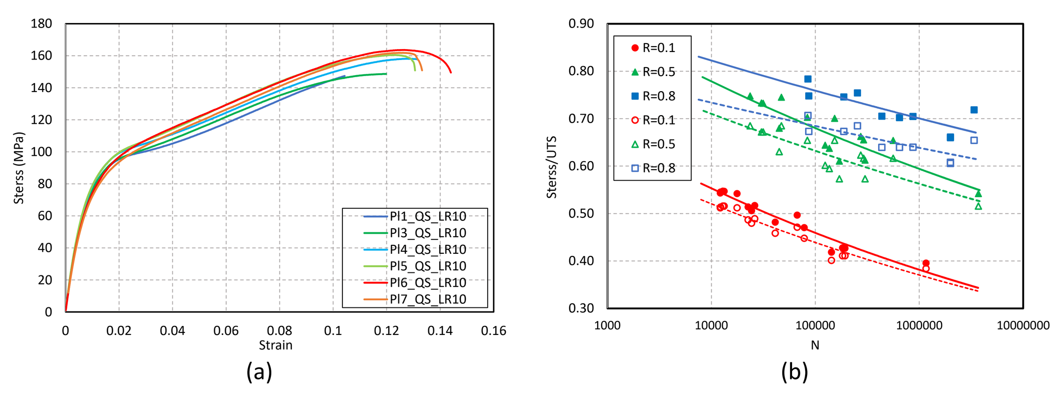

Figure 2. (a) Stress-strain for same the GFRP laminates fabricated (b) S-N curves for R-ratio of 0.1, 0.5, and 0.8, before (dashed lines and unfilled shapes) and after (solid lines and filled shapes) stress adjustment

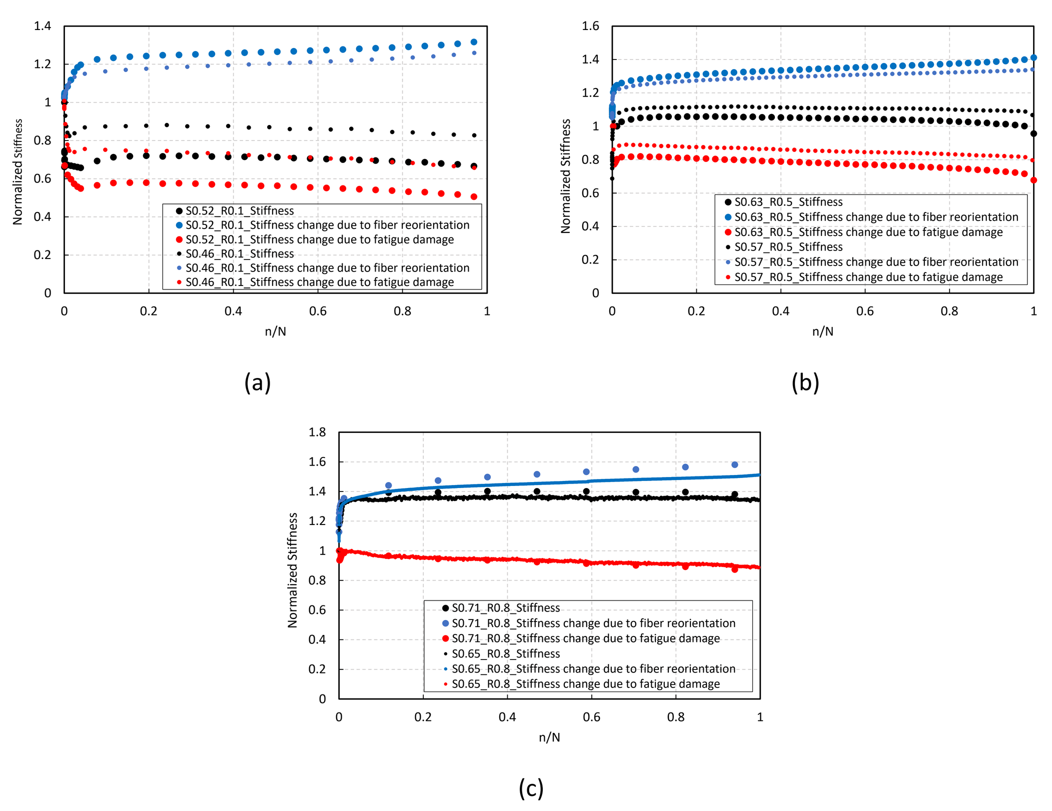

Figure 3. Decomposition of fatigue stiffness evolution due to fiber reorientation and fatigue damage high and low stress levels at R-ratio of (a) R=0.1, (b) R=0.5, and (c) R=0.8

Time-dependent properties

- ❖ DMA Creep-recovery tests with 1 and 2 hours for creep and recovery parts
- ❖ TTSP for the temperatures range from 25 to 75 °C
- ❖ Derivation of creep master curve for damaged and undamaged material
- ❖ Correlation of fatigue damage levels and accelerated creep behavior

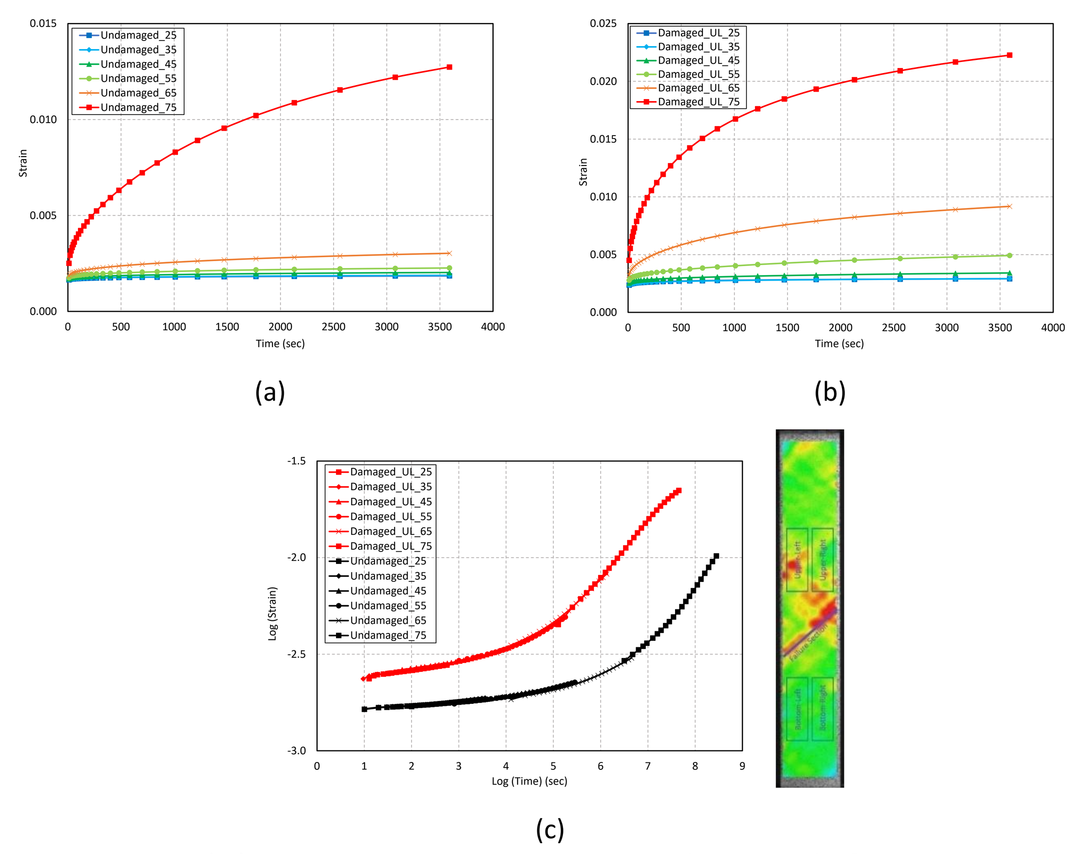

Figure 4. (a) Creep strain curves obtained from creep-recovery tests for temperatures in the range of 25–75 °C on (a) undamaged GFRP laminate, (b) Damaged specimens cut from fatigue test of S0.46_R0.1 (The top-left position in the DIC image), (c) Comparison of creep master curves

Damage initiation and propagation

- ❖ DMA Creep-recovery tests with 1 and 2 hours for creep and recovery parts
- ❖ TTSP for the temperatures range from 25 to 75 °C
- ❖ Derivation of creep master curve for damaged and undamaged material

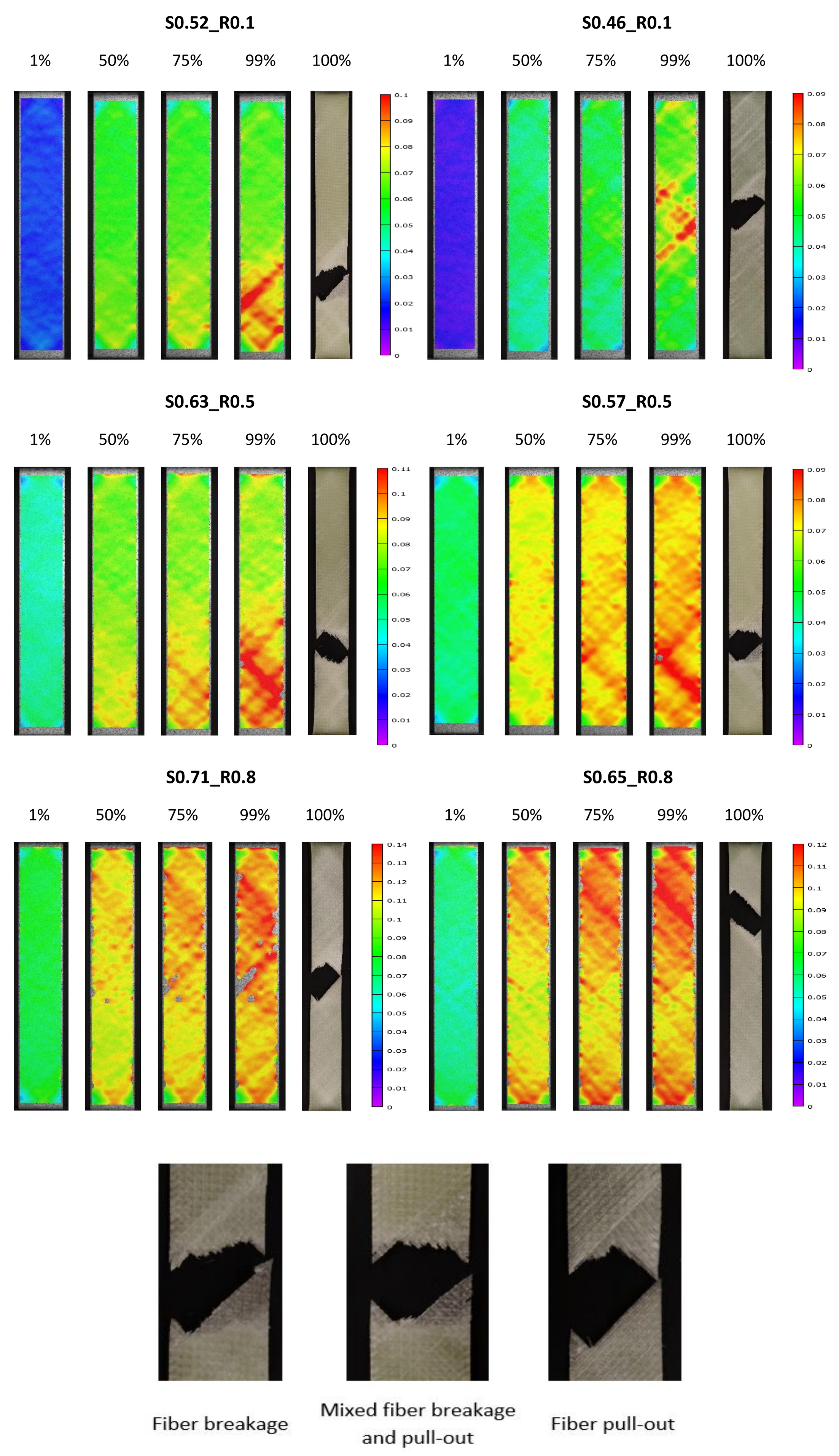

Figure 5. The DIC measurements for longitudinal strain during fatigue tests for R-ratios of 0.1 (top), 0.5 (middle) and 0.8 (bottom) as well as their failure modes

Conclusion

For cycle-dependent properties, the S-N curves were underestimated due to the increasing stress state under fatigue loading, i.e., resulting from large creep deformation, especially for higher R-ratio and stress levels. A simple analysis was performed to decompose the stiffening effect due to fiber orientation from the fatigue damage stiffness evolution, which provides more accurate residual stiffness models representing the pure fatigue degradation. An experimental methodology using DMA testing was suggested to evaluate the effect of fatigue damage on viscoelastic properties. The results have shown the feasibility of using the time-temperature superposition principle for damaged material, which can provide viscoelastic properties depending on the fatigue damage level. Finally, the evolution of DIC measurements and failure surfaces has shown that depending on the R-ratio, the damage distribution and failure modes could differ under creep and fatigue-dominated loading.

Acknowledgements

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References

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