An innovative strategy to design and monitor safe, reliable and ligthweight composite structures under in-service loading

Marino Quaresimin*, Paolo Andrea Carraro, Lucio Maragoni, Michele Zappalorto

University of Padova, Department of Management and Engineering, Stradella San Nicola 3, 36100 Vicenza Italy

Abstract

Fatigue failure and in-service loss of stiffness of composite parts are due to a multi- mechanisms damage evolution which mainly includes cracks, delamination and fibre failures [1-3]. The talk presents an innovative, comprehensive framework for the fatigue design of composite parts, based on the actual physics of damage evolution. The initiation and growth of each mechanism, its interaction with the others and the effects on the strength and stiffness of the parts are described by suitable models and experimentally validated [4-6]. The combination of all these models into a single design framework already represents a significant step forward with respect to the design tools available on the market, resulting in an enormous increase in the safeness and reliability of the structural applications made with these materials. The in-service reliability and safety of the composite parts can be further improved by using a new structural health monitoring methodology [7]. This methodology, based on the exploitation of the self-sensing capabilities of conductive laminates, allows the continuous assessment of the damage state and the correlation of its evolution with the

residual elastic and strength properties of the composite parts. Damage induced by unexpected events can be also monitored. The basis behind the approach will be briefly outlined leaving space to the discussion of the application procedure, with examples of implementation on parts of industrial interest.

Keywords: [Composite, Damage Mechanics, Fatigue, Stiffness loss, Health monitoring]

References

[1] Quaresimin M., Susmel L., Talreja R., Fatigue behaviour and life assessment of composite laminates under multiaxial loadings, International Journal of Fatigue, 32 (1) 2–16 (2010)

[2] Quaresimin M., Carraro P.A., Pilgaard Mikkelsen L., Lucato N., Vivian L. , Brøndsted P., Sørensen B. F., Varna J., Talreja R. Damage evolution under internal and external multiaxial cyclic stress state: a comparative analysis, Composites Part B, 61, 282-290 (2014).

[3] Quaresimin M. , Carraro P.A., Maragoni L., Early stage damage in off-axis plies under fatigue loading, Composites Science and Technology 128, 147-154 (2016).

[4] Carraro P. A., Maragoni L., Quaresimin M., Prediction of crack density evolution in multidirectional laminates under fatigue loading, Composites Science and Technology, 145, 24-39 (2017).

[5] Maragoni, L., Carraro, P.A., Simonetto, M., Quaresimin, M., A novel method to include crack-induced delamination in a fatigue damage predictive procedure for composite laminates. Composites Science and Technology 238, 110011 (2023)

[6] Carraro, P.A., Maragoni, L., Quaresimin, M., Stiffness degradation of symmetric laminates with off-axis cracks and delamination: an analytical model, International Journal of Solids and Structures 213, 50–62, (2021).

[7] Quaresimin M., Schulte K., Todoroki A., Zappalorto M., Fiedler B., Structural health monitoring of fatigue degradation in fibre reinforced polymers in Fatigue in Composites- Science, Damage Mechanics, and Design Applications , M. Quaresimin editor, Elsevier (2025)