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Experimental benchmark of double-double composite laminates employed in mechanically-fastened joints

Denis Dalli[1], Pedro J Silva Campos[2], Carolina Furtado[3], Anna Volpi[4], Tomas Santos[5]

[1] INEGI, Portugal. ddalli@inegi.up.pt
[2] Faculdade de Engenharia, Universidade do Porto, Portugal. pjscampos@fe.up.pt
[3] Faculdade de Engenharia, Universidade do Porto, Portugal. cfurtado@fe.up.pt
[4] Department of Engineering and Architecture, University of Enna "Kore", Italy. annagiulia.volpi@unikorestudent.it
[5] Faculdade de Engenharia, Universidade do Porto, Portugal. tomasantos02@gmail.com

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Abstract

This work presents the first comprehensive experimental benchmark of the structural performance of Double-Double (DD) composite laminates employed in mechanically fastened joints, compared against in-plane stiffness-equivalent Quad legacy laminates. The study addresses a key gap in the understanding of DD laminate behaviour under combined bearing and pull-through loading conditions, which critically govern the performance and certification of composite bolted joints. DD laminates, formed by two pairs of ply orientations [±φ, ±ψ], extend beyond the conventional (0/90/±45) configuration of Quad laminates, enabling greater design freedom, stiffness-tailored optimisation, and manufacturing simplification. Despite their predicted potential for weight and cost savings of up to 40% [Tsa22], their local fracture and energy absorption characteristics under joint loading remain underex-plored. An extensive experimental campaign was conducted based on standardised single-bolt bearing and pull-through tests. This was extended to combined bearing/pull-through loading scenarios through the novel test method proposed by Pinto [Pin16], inducing controlled combined loads of varying ratios, validated numerically by Furtado et al. [Fur23]. Equivalent DD and legacy laminates were defined using in-plane stiffness homogenisation and lamination pa-rameter equivalence. The combined loading failure envelopes were experimentally characterised

for both quasi-isotropic reference laminates and directional variant configurations. Results demonstrate that DD laminates exhibit comparable global joint stiffness and ultimate strength to legacy counterparts, while showing minor distinctions in their failure morphology. The experimental bearing/pull-through failure envelopes of DD joints reveal a safe operational domain that, at minimum, matches equivalent legacy joint envelopes. These findings provide the first experimental evidence supporting the structural viability of Double-Double lami-nates in bolted joints, validating their potential to reduce weight and conservatism in composite joint design prac-tices. The data further establishes a foundational benchmark for upcoming analytical and numerical modelling analyses within the JOIN3D research programme, contributing to the ongoing effort toward safe and efficient in-dustrial integration of Double-Double architectures in aerospace structures. ACKNOWLEDGEMENTS This work is financially supported by national funds through the FCT/MCTES, under the project 2023.15692.PEX – JOIN3D - JOInt eNergy absorption with Double-Double Design, with DOI: 10.54499/2023.15692.PEX. (https://doi.org/10.54499/2023.15692.PEX).

Keywords:

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