Investigation of bolt torque and environmental conditioning on the mechanical performance of bolted composite laminates

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In the aerospace industry, limitations of producing large complex structures, functionality, and maintenance constitute the main reasons for using bolted joints, accepting the introduction of discontinuities caused by the insertion of notches (holes). The optimal design of bolted composite joints is crucial for structural integrity and weight minimisation of structures such as aircraft and spacecraft [1, 2]. Among the basic failure modes of composite shear joints, net-section failure comprises an instant and catastrophic joint member failure stemming from excessive tensile stresses, tangential to the hole edge [3, 4]. It usually arises due to a high ratio of hole diameter to spacing width and/or by-pass loading to bearing strength [5]. The strength of the bolted joint member in this case is determined through filled hole tests capturing the complex biaxial stress state developing in the laminate due to the presence of the fastener [6].

One major parameter that has been experimentally examined for its effect on this test is the torque-up level and therefore the clamping force introduced in the laminate [7, 8].

For aerospace components harsh operating conditions, i.e. high temperature and humidity also influence the strength of bolted joints [9]. However, little literature exists that investigates the combined effects of bolt torque in 100% bypass cases [10] under hot-wet conditions. Therefore, the aim of this work is to examine experimentally and numerically the effect of fastener torque and harsh environmental operating conditions on the mechanical strength of composite bolted laminates. To this end, open and filled hole specimens with different torque-up levels and humidity content were subjected to tensile loading at elevated and room temperatures in an environmental chamber (see Figure 1). Digital image correlation (DIC) was employed for strain monitoring, and a high-fidelity linear finite element analysis was conducted.

The combined experimental and numerical analysis demonstrated that at room temperature the moisture content did not affect the strength or the stiffness of the filled hole specimens. However, elevated temperatures and varying the clamping force heavily influenced the laminate's strength, with both the highest and the lowest strength values of the test matrix exhibited under elevated temperature for low-torqued and highly torqued specimens with a relative difference of up to 10%. Finally, the finite element predictions were used to shine light on the failure mechanism at play, especially under the washer area, where the in situ experimental technique could not provide any data.

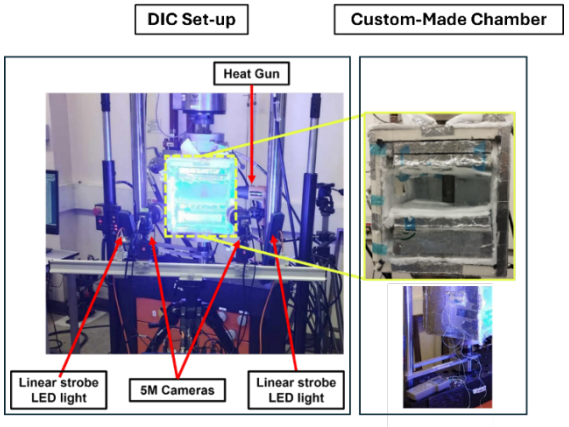

Figure 1: The experimental set-up for elevated temperature conditions is illustrated describing the DIC set-up as well as the fitting of the custom-made chamber within the hydraulic grips.

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