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ORIGINAL RESEARCH

Numerical simulation of pin-loaded joints of fiber metal laminate

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Abstract

Fiber metal laminate (FML) is an advanced composite material, which consists of metal layers and polymer matrix composites. Due to the combination of the advantages of traditional metal and composite materials, FML has been widely used in the aircraft industry. Due to advantages in inspection and reliability, the mechanically fastened (riveted or bolted) joints are essential for a complex structure. The present study investigated the effects of geometry parameters and ply stacking sequences on the mechanical properties of pin-loaded FML joints. A three-dimensional progressive failure model had been created to investigate the failure response of FML joints. A comparison between simulation and experimental results showed a good agreement on the strength and internal damage pattern (fiber damage, matrix damage, and cohesive layer delamination between 0° fiber and outer aluminum) for the pin-loaded FML joints. It was found that ultimate failure strength increased with the increase of width-to-diameter ratio (*W*/*D*) or edge distance-to-diameter ratio (*E*/*D*). The failure modes of pin-loaded FML joints were dissimilar by varying the ratios of *W*/*D* and *E*/*D*. The dominant failure mode of studied joints was bearing failure mode. Numerical simulation results showed that ply stacking sequence has obvious effects on the mechanical properties of FML joints.

Keywords Fiber metal laminate · Pin-loaded joints · Finite-element analysis · Mechanical properties

Introduction

Fiber metal laminate (FML) is a set of laminated materials consisting of metal layers (aluminum alloys, titanium alloys, etc.) and composites (aramid, glass, carbon, PE, M5, etc.) [1, 2]. FML has already proven superior in terms of fatigue, impact, bearing, corrosion properties, and fire resistance [3–5].

Due to the combination of the advantages of traditional metal and composite materials, FML can be widely used in the aircraft industry. For instance, glass fiber-reinforced aluminum laminate (Glare) has been successfully applied to the fuselage skin and leading edge of the wings of Airbus A380 [1]. A fuselage skin structure is generally constructed of several sheets, which are connected with mechanically fastened (riveted or bolted) joints. The fastened joints is usually a potential danger area in a structure by reason of higher stress near the rivet and bolt hole. For safety of structural design, it is critical to understanding the mechanical joint behavior of FML.

A few experimental investigations on FML joints were studied, which mainly focused on the effects of lateral restraint [6–8], geometry parameters [9–11], ply stacking sequence [12, 13], and fiber types [14] on the bearing strength. The data generated by Caprino et al. [6] were devoted to the FML behavior under pin and bolt-loaded. The authors showed that the failure bearing strength of bolt joints was sensibly larger than the pin joints. The damage bearing strength and failure bearing strength increased slightly with increasing torque.

Wu and Slagter [7] experimentally studied the influence of geometric parameters on the bearing behavior of FML joints. The authors found that bearing strength and failure modes were influenced by specimen geometry. To use the excellent bearing strength of FML, the designers should use a minimum *E*/*D* ratio of 3 and *W*/*D* ratio of 4. Yeh et al. [14] investigated the bolt-loaded bearing behavior of the commingled boron/glass fiber-reinforced aluminum laminate (COBRA), non-commingled hybrid boron/glass/aluminum fiber metal laminate (HFML), and GLARE. The results

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