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BEARING FAILURE PREDICTION FOR COMPOSITE PIN-LOADED HOLES AND BOLTED JOINTS USING ONSET THEORY

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Summary. *This paper presents a progressive failure analysis based on Onset Theory which has been implemented in the MSC Marc Finite Element program and applied to predict the bearing failure of pin-loaded holes and bolted joints. It has been shown that Onset Theory can predict the onset and progression of failure within these highly complex loading environments.*

1 INTRODUCTION

The complex deformation state within a loaded composite bolted joint leads to many different macroscopic failure modes, depending on the loading direction and joint geometry. This makes empirical strength prediction methods unreliable and consequently large investment has been made in extensive experimental characterisation of bolted joint failures. Failure within a bolted joint is characterised by both in-plane and through thickness failure modes and is usually progressive. Consequently, ultimate load can be well above the load at which the onset of failure first occurs.

Any theory used to predict failure in a bolted joint must be capable of predicting all composite failure modes and must also include other physical variables such as temperature if it is to be universally applicable. Onset Theory is a physics-based failure prediction approach for composite materials. It has been shown that all failures in composite materials can be reduced to a small set of constituent failure mechanisms characterised by critical strain invariants [1, 2]. Onset Theory accounts for all mechanical loads and also accounts for thermal residual strains as a result of thermal expansion mismatch between the fibre and resin and between different plies in the laminate. Onset Theory is an ideal tool to predict failure within a composite bolted joint as it can intrinsically predict all composite failure modes and can account for complex load cases without modification. Onset Theory has been extended for this paper to include a progressive damage technique. The damage progression algorithm can track the growth of damage within the joint and predict the eventual failure mode [3].

2 NUMERICAL IMPLEMENTATION

An implementation of the failure theory has been generated for the implicit finite element software MSC Marc. The failure theory is included via a Fortran subroutine. Onset Theory is used to check for failure at every integration point at each load increment. If failure is detected, the element stiffness is degraded using a custom strain based element degradation algorithm based on the magnitude of the strain invariants in the fibre and resin.

3 PIN-LOADED HOLES AND BOLTED JOINTS

The algorithm has been applied to a number of pin loaded holes and bolted joints. One simulation, shown in Figure 1, represents a single lap bolted joint. The full 3-D contact finite element simulation includes a ply-by-ply composite laminate mesh. The analysis includes three load steps; a free thermal contraction of the laminate, a bolt preload step and then the applied in-plane displacements. The predicted distortional strain index is shown in Figure 2. The analysis predicted the failure locations and failure modes for all geometries tested. Progressive failure was well captured initially and the ultimate failure load was well predicted. The progressive failure algorithm diverged from the experimental result as the simulation progressed due to the intrinsic limitations of the damage mechanics approach.

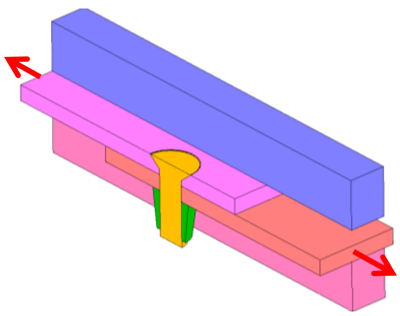

Figure 1: Geometry of single lap countersunk bolted joint model including the ATSM D 5961 test fixture and the direction of the applied displacements.

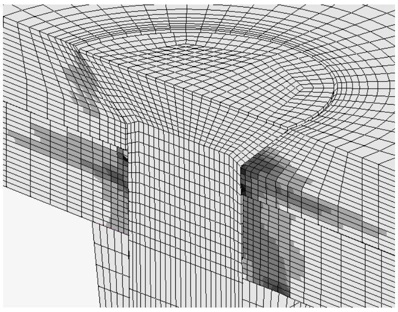

Figure 2: Distortional strain invariant index around a loaded single lap bolted joint including the effect of bolt clamp-up. (Darker tone represents a higher index)

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