EFFECT OF STRAIN RATE ON THE FAILURE MECHANISMS AND ENERGY ABSORPTION IN POLYMER COMPOSITE ELEMENTS UNDER AXIAL LOADING

M. David, German Aerospace Center (DLR), Institute of Structures and Design, Pfaffenwaldring 38-40, Stuttgart, Germany

A. F. Johnson, German Aerospace Center (DLR), Institute of Structures and Design, Pfaffenwaldring 38-40, Stuttgart, Germany

H. Voggenreiter, German Aerospace Center (DLR), Institute of Structures and Design, Pfaffenwaldring 38-40, Stuttgart, Germany

ABSTRACT

The paper is concerned with the development of Finite Element (FE) codes and design tools suitable for detailed fine scale modelling of crush behaviour observed in composite crashworthy structures. A numerical modelling methodology was developed in this paper to replicate the crush behaviours and accurately simulate identified energy absorbing mechanisms determined from experimental work. This experimental work focuses on understanding the varied crush response of chamfered carbon fabric-epoxy tube segment elements under varying axial loading regimes (quasi-static to dynamic). The testing methodology [1] included the use of a high speed camera to capture the crushing behaviour of the specimen during the crush tests. In addition to capturing the crushing behaviour of the specimen during the crush tests, High-resolution Computed Tomography (HRCT) scanning of the specimen was performed to enable a detailed analysis of crushed elements. From analysing these experimental test results, the differences in the crushing process and therefore the energy absorption performances between the two loading regimes were attributed to the fibre layup coupled with the strain rate dependent nature of the epoxy matrix.

The commercial explicit Lagrangian FE code PAM-CRASHTM that was developed for automotive crash simulations was utilized for the Finite Element Analysis (FEA) documented in this paper. The methodology undertaken consists of firstly, the numerical modelling of damage development in the FRP composite laminate. From the experimental crush tests described above, the critical influence of both ply damage and delamination in controlling failure mode and energy absorption was identified and hence included in the numerical models. As an efficient way of modelling delamination failure in a composite laminate, the meso-scale composite damage model was extended to stacked shells which allow interface delamination failures [2]. In this stacked shell approach, the FRP composite laminate is represented by multi-layered shell elements connected by cohesive interfaces, which are damaged and fail when the prescribed interface fracture energy is reached. The second feature of the numerical methodology focuses on the implementation of innovative numerical triggers into the numerical models. These numerical triggers were designed to replicate in the numerical model, the initiation, propagation and complex failure mechanisms of the crush responses observed in the experimental crush tests.

To capture the strain rate effects on the crush response, material models were formulated for each loading regime from experimental coupon tests under quasi-static and dynamic loads to
retrieve input parameters for the material models. The paper concentrates on segments with both 0/90 and ±45 fibre layups with respect to the segment axial loading direction. The changed axial stiffnesses in the segments led to different failure modes, which were also influenced by the materials rate dependence. The numerical investigations presented show the robustness of the numerically models for the crush behavior and energy absorption of structural elements consisting of different fibre layups, composite materials, geometry and crush failure modes.

This two part numerical methodology achieved considerable qualitative and quantitative improvements in the correlation between experimental and numerical results when compared with current modelling techniques.