Accepted Manuscript

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PII: S0263-8223(17)32417-0
DOI: https://doi.org/10.1016/j.compstruct.2017.11.025
Reference: COST 9091

To appear in: *Composite Structures*

Received Date: 31 July 2017
Accepted Date: 8 November 2017

Available online at www.sciencedirect.com
ScienceDirect
Composite Structures 00 (2017) 1–8
Short Journal Name

Experimental and numerical investigation of the strain rate-dependent compression behaviour of a carbon-epoxy structure

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Abstract

The usage of fibre-reinforced composites in automotive body structures is still a rarity. The main goal in body structure development is to design lightweight structures as cost-efficient as possible. This research contributes to the approach of maximal material usage by considering the strength increase of a carbon-epoxy laminate with increasing strain rate. The objective was to substantiate the well-known material characteristic's strain rate dependency from a coupon level to realistic body structure component - experimentally and numerically. Hence, a special compression fixture was developed to obtain all necessary characteristic values of the investigated T700S DT120 prepreg system. The rectangular coupon specimens were loaded with quasi-static to intermediate strain rates (2×10^{-4} to $70\,s^{-1}$). A second compression fixture was developed to axial load omega cross-sectional specimens with strain rates from 2×10^{-4} to $5\,s^{-1}$. The experimental tests showed a significant increase of +23% and +21% in compression strength for rectangular coupon specimens and omega cross-sectional components, respectively. Furthermore, the numerical simulation showed the same increase in strength of +21% for omega cross-sectional components. This work has proven the necessity of considering the strain rate dependency of a composite material to accurately predict the maximum load capacity of a structure during a dynamic load event like a crash.

Keywords: Carbon fibre, Epoxy, Prepreg, Strain rate, Compression strength, Finite Element Analysis

1. Introduction

With increasing usage of fibre-reinforced composites for structural components across the automotive and aerospace industry, it became crucial to understand how these materials behave when subjected to high loading rates, which are encountered in the case of crash events. In the past, structures were investigated based on their specific energy absorption (SEA) [1, 2, 3, 4]. Components within the car body responsible for structural integrity are not supposed to fail during a crash event. Hence, the maximal laminate strength and fracture strain is the design limiting parameter. Especially, the improved strength with increasing strain rate is a key factor to achieving maximal material usage. Consequently, for a proper numerical implementation and a good correlation between Finite Element Analysis (FEA) and experiments a holistic investigation of the characteristic of fibre-reinforced plastics (FRP) at different strain rates is mandatory.

The first results of dynamic tensile testing of unidirectional carbon-epoxy composites were published by Harding and Welsh [5], who used a tensile Split Hopkinson Pressure Bar (SHPB) and found no correlation between the tensile properties in fibre direction and the rate of loading. Similar results were found by Taniguchi et al. [6] for unidirectional T700S/2500 carbon-epoxy specimens at strain rates up to $100\,s^{-1}$. These results are in agreement with the tensile tests that Zhou et al. [7, 8] performed on carbon fibre bundles and found no change in the tensile properties of carbon fibres with varying strain rate.
Since the tensile properties of fibre-reinforced polymers loaded in fibre direction are fibre-dominated, it is comprehensible that the composite response at different strain rates is similar to the behaviour of carbon fibre bundles, i.e. not strain rate sensitive.

On the other hand, the mechanical response of a unidirectional composite when loaded in the direction transverse to the fibres is matrix-dominated. Gilat et al. [9] and Taniguchi et al. [6] performed dynamic tension tests on unidirectional carbon-epoxy laminates in transverse direction. Both studies

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