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Characterisation of resin transfer moulded composite laminates under high rate tension, compression and shear loading

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ABSTRACT

The strain rate dependency of carbon fibre reinforced plastic (CFRP) laminate manufactured in a resin transfer moulding (RTM) process was investigated up to strain rates of $10^2\ s^{-1}$. High-speed video imaging in combination with digital image correlation analysis (DIC) and high-speed infrared cameras were applied to evaluate the tests. Specimens were specifically designed for tests at high loading rates. Periodic strain localisations were observed. Thus, multiple fractures occurred at the highest strain rate. Considerable strain rate dependence could be identified. The stress strain curves, and in the case of 90° tension and compression also the strain to fracture exhibited a moderate rise with increasing strain rate. High rate shear tests at ±45° loading direction with large, localised deformations up to failure showed reduced hardening compared to quasi-static tests, probably caused by adiabatic heating. A local temperature rise of about 50 K was determined by high-speed infrared measurements.

1. Introduction

CFRP are going to be increasingly applied in automotive structures because of their excellent lightweight performance. However, the economic fabrication of duplicate parts is an important issue, therefore the high pressure RTM process is gaining more importance. Draped fibre mats are inlayed in moulds; under pressure, the resin is injected and infiltrates these mats. Plates and three dimensional components can be manufactured in serial production with this method.

Within the frame of the German research cooperation "Technology-Cluster Composites, Baden-Württemberg – TC^2", the project "RTM CAE/CAx" was coordinated by the Karlsruhe Institute for Technology KIT. The aim of this project was the establishment of a continuous virtual (CAE/CAx) process chain for the RTM manufacturing process in order to improve the economic production of high performance fibre reinforced plastics [1].

In order to utilise these RTM materials for structural elements in automotive applications, reliable material properties are needed to enable the construction and assessment of components. It is especially important to obtain material properties for high strain rates in order to enable reliable crash simulations for the assessment of a structure's crashworthiness.

Previous results on the strain rate dependency of various unidirectional (UD) and multidirectional (MD) CFRP laminates based on an epoxy matrix are reported in [2–11].

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Nomenclature

CAE/CAx	Computer Aided Engineering/Computer Aided x
CFRP	carbon fibre reinforced plastic
DIC	digital image correlation
FAT	Research Association of Automotive Technology
ICT	Fraunhofer Institute for Chemical Technology
ISO	International Organization for Standardization
IWM	Fraunhofer Institute for Mechanics of Materials
KIT	Karlsruhe Institute for Technology
MD	multi directional
RTM	resin transfer moulding process
SHB	split Hopkinson pressure bar
TC^2	Technology Cluster Composite, Baden-Württemberg
UD	uni directional
b	specimen width
b_r	roving width
ILSS	Inter Laminar Shear Strength
L_0	gauge length
L_{0L}	gauge length for local strain distribution
L_{0x}	gauge length for local shear calculation orthogonal to loading direction
L_{0y}	gauge length for local shear calculation in loading direction
L_C	parallel length of dog-bone shaped specimen
${\sigma_m}^-$	compression strength
${\sigma_m}^+$	tensile strength
$\sigma_{y0,2}$	engineering yield strength
t_L	layer thickness
T_{local}	local temperature
ΔT_{local}	local temperature change
ΔL	elongation
α	fibre orientation angle
$\Delta\alpha$	change of the fibre orientation angle
ε_f	fracture strain
ε_x	strain orthogonal to loading direction
ε_y	strain in loading direction
ε_{yloc}	local strain in loading direction
γ_{12}	shear strain
γ_B	shear strain at fracture
$\tau_{1\%}$	yield shear strength
τ_{12}	shear stress
τ_B	shear strength

Tensile tests in 0° orientation, i.e. longitudinal to the fibre orientation, have been performed in [2]. The results show that moduli and strength values are independent of the strain rate. This result can be explained by the fibre dominance under 0° tensile loading.

Compression tests in 0° orientation show failure governed by in-plane shear of the composites, predominantly due to slight fibre misalignment [3]. Therefore, a significant strain rate dependency of the strength and a moderate dependency of the modulus were found for an UD laminate in [4].

Tensile tests in 90° orientation were presented in [2,5,6]. Dog-bone shaped specimens were used in tests with a split Hopkinson pressure bar (SHB) [5], in order to obtain a homogeneous strain field in the central gauge section. Moderate strain rate dependency was observed: fracture stress and strain to fracture rose with increasing strain rate [5]. In [6], the authors could not detect a change in the almost linear material behaviour transverse to the UD fibre orientation from quasi-static loading up to 1 s^{-1}. But results at strain rates exceeding 10^2 s^{-1} show rising modulus and strength values compared to lower strain rates. In agreement with [6], findings in [2] show increasing tensile strength with increasing strain rates. The behaviour of stitched laminate was investigated in [7]. Under impact loading different damage behaviour was found depending on the pattern of the stitching thread on the surface of the layer.

Compression tests in 90° orientation with servo hydraulic testing machines and SHB are reported in [4,8–10] for UD CFRP laminates and show overall good agreement to each other. The fracture strength and initial slope of the stress strain curves in [8] rise with increasing strain rate. The authors of [4,9] found a linear rise of strength with the logarithm of the strain rate up