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TAILORED 3D-TEXTILE REINFORCED COMPOSITES WITH LOAD-ADAPTED PROPERTY PROFILES FOR CRASH AND IMPACT APPLICATIONS

Novel 3D-textile reinforced composites with a stretched fibre orientation have very good specific mechanical properties and outstanding energy absorption capabilities. Additionally, advanced textile techniques and the combination of different fibre materials enable even the efficient manufacture of hybrid 3D-textile performs with tailored property profiles. Dependent on the application, 3D-textile performs can be adjusted to specific requirements regarding stiffness, strength and crash-worthiness. Thus, hybrid 3D-textile preforms with tailored property profiles are excellent candidates for the application in impact and crash components of modern lightweight structures. For the load-adapted design of highly dynamically loaded lightweight structures and especially for the tailoring of adequate textile reinforcement structures, a validated knowledge about the strain rate dependent mechanical material behaviour of 3D-textile reinforced composites and appropriate material and failure models are necessary. This article focuses on the qualitative and quantitative investigation of the strain rate dependent material properties of composites with hybrid multi-layered flat bed weft knitted fibre reinforcements consisting of different fibre combinations such as glass-glass, glass-aramid and glass-polyethylene.

Keywords: **textile reinforced composite, failure, light speed tests**

INTRODUCTION

Due to their high specific mechanical properties and the adjustable energy absorption capacity novel 3D-textile reinforced polymers are predestined for the use in impact and crash relevant structures. For the reliable design of highly dynamic loaded components, advanced knowledge of the strain rate dependent deformation and failure behaviour and realistic simulation models are necessary, but absent for the new group of textile reinforced materials [1].

This article focuses on the experimental investigation of the strain rate dependent material properties and the failure behaviour of textile reinforced composites. Experimental results of highly dynamic tests on 3D-reinforced epoxy specimen with multi-layered knitted fabric reinforcement made of different fibre materials such as glass, aramid and polyethylene are presented. Dependent on the loading velocity and on the fibre combinations in the textile architecture of the composites, the directional stiffness, strain at fracture, tensile strength as well as the occurring failure modes and measures of damage have been studied. The results provide an indication for an advanced design of textile performs with respect to the specific loading conditions and serve as a basis for the development of material and failure models for the numerical simulation of the structural behaviour of 3D-textile reinforced composites under highly dynamic loading [2-4].

TAILORED COMPOSITE MATERIALS

The highly dynamic material tests were performed on epoxy composites with multi-layered flat bed weft knitted fabric (MKF) reinforcement developed by the Institute for Textile and Clothing Technology of the Technische Universität Dresden. In Figure 1 the basic architecture of the MKF is shown. Different to the crimp of woven fabrics, the flat bed weft knitted fabrics are characterized by a stretched fibre orientation, which leads to very good in-plane properties with regard to stiffness and strength. Additionally, the knit thread offers a reinforcement in z-direction, which significantly improves the delamination behaviour of the composite [5, 9].

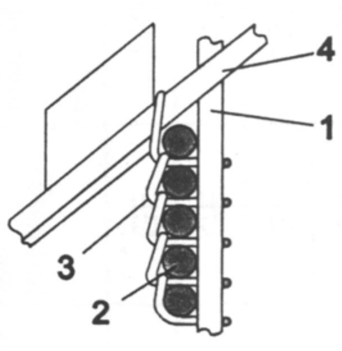

Fig. 1. Basic architecture of multi-layered flat bed weft knitted fabrics (MKF) [5]: 1 - warp thread, 2 - weft thread, 3 - knit thread, 4 - knitting needle

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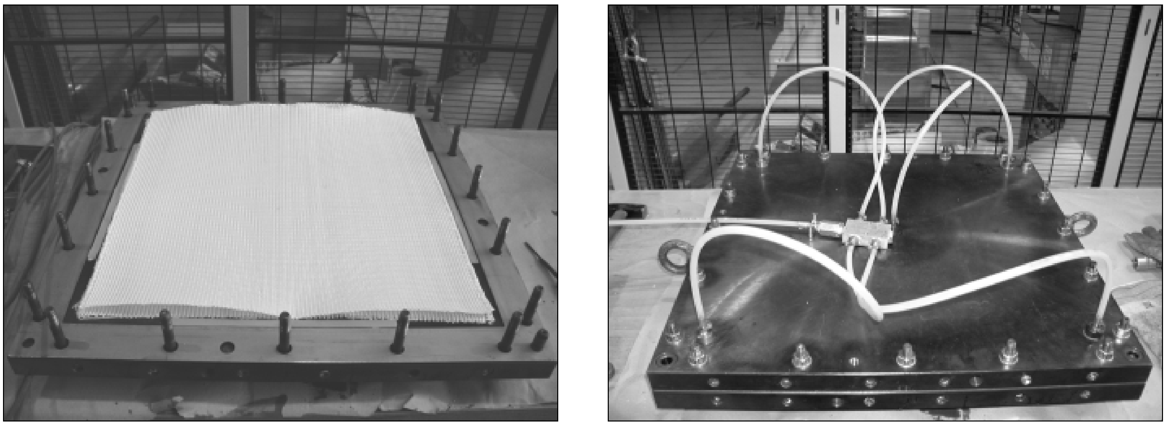

Fig. 2. Textile preform in the infiltration tool and closed mould with resin supplies

The fabric is made up of glass fibre strands with a yarn count of 2400 tex in warp and 1200 tex in weft direction. For a nearly equal reinforcement in 0° and 90° the yarn density for warp thread is 20 yarns per decimetre and for weft thread 38.9 yarns per decimetre. The knitting density of MFK is 39.4 stitches per decimetre in warp and 19.7 stitches per decimetre in weft direction. Within the performed investigations, the knit thread was varied in its material for analysing the influence of different knitting materials on the composite crash behaviour. Threads from glass fibres (GF) with a yarn count of 136 tex, aramid filaments (AR) with 168 tex and dyneema (high modulus polyethylene, PE) fibres with 172 tex were used.

The specimen were made by vacuum assisted resin transfer moulding (VARTM), whereby the textile performs were infiltrated in a flat steel mould by epoxy resin (Fig. 2). The mould was evacuated before and during infiltration process in order to avoid pores and to guarantee high quality specimen. After curing and tempering test samples were cut from the composite panels by water jet cutting.

TEST TECHNIQUES FOR HIGHLY DYNAMIC MATERIAL TESTS

Within the experimental work, basic investigations of the material's phenomena of textile reinforced composites under high strain velocities and the determination of the resulting time dependent deformation and fracture characteristics were performed.

For the determination of the strain rate dependent and directional material properties dependent on different knit thread materials, a servo hydraulic high-speed test unit was used (Fig. 3). The high-speed test unit enables tension and compression tests with velocities up to 20 m/s and maximum forces of 160 kN. This test unit differs from conventional high-speed test stands not only in the increased maximum forces and an addi-

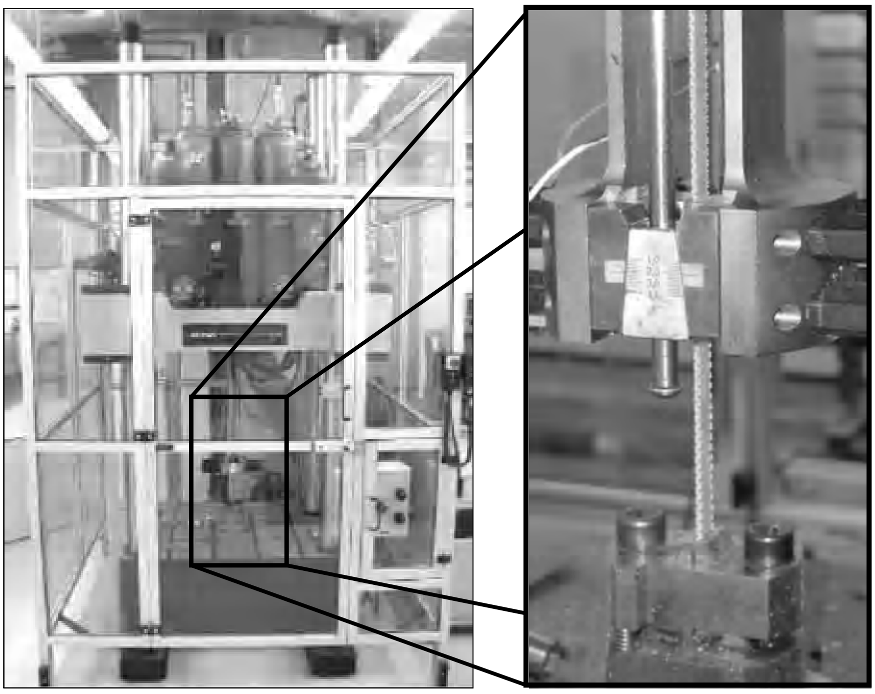

Fig. 3. INSTRON servo hydraulic high speed test unit and adapted grip unit at ILK

tional temperature chamber but also by the adapted grip unit, which enables an abrupt application of the force without damaging the specimen in the acceleration period of the upper clamping device. In addition to high-speed tensile tests, impact tests were carried out using a split Hopkinson-bar test unit [9].

EXPERIMENTAL RESULTS OF HIGH SPEED TESTS

High speed tensile tests were performed, to analyse the influence of different knit threads on the energy absorption capacity and to determine the materials parameters necessary for future numerical simulation of the crash behaviour of lightweight structures. The specimen were stressed with increasing loading velocities and strain rates. The same specimen geometry and length between the clamping jaws were used to ensure the comparability of the results in every test.

The influence of the strain rate to the failure behaviour was investigated by tensile tests with loading velocities of 0.1 mm/s up to 10 m/s. Considering the materials behaviour under quasi-static loads up to impulse-like highly dynamic loads the influence of the strain rate concerning the raising of the strength was observed. The strain rate dependent tensile strengths of the investigated multi-layered flat bed weft knitted fabric reinforced composites are displayed in Figure 4 within a logarithmic chart. The investigation shows the influence of different knit threads on the tensile strength, where glass and aramid fibre threads cause higher strengths compared to MKF with polyethylene threads. Especially for a loading in weft direction (90°) a significant lower tensile strength of GF/PE-MKF-composites compared to GF/GF- and GF/AR-MKF-composites can be observed.

Figure 5 shows the increase of the strain at failure with growing strain rates. The increase of the tensile strengths and the strains at failure under raising loading speeds points to the strain rate dependence of the energy absorption capacity of MKF-composites. Different to the tensile strength, the influence of knit thread material on the fracture strain is less significant for the strain rate dependent strain at fracture.

Analogous to the tensile strengths and fracture strains, the directional stiffness also increases with rising strain rates (Fig. 6). This effect is higher for GF/AR- and GF/PE-MKF-composites than for GF/GF-MKF-composites and is explicable by the growing influence of the matrix and reinforcement viscoelasticity on the resulting stresses.

Parallel to the high speed tension tests, impact tests were performed in cooperation with the Department of Engineering Science of the University of Oxford. The aim of the analysis consists of an evaluation of the failure behaviour of hybrid MKF-composites under impact loads and the description of their energy absorption capabilities. Furthermore, the impact tests serve for the verification of material and damage models as well

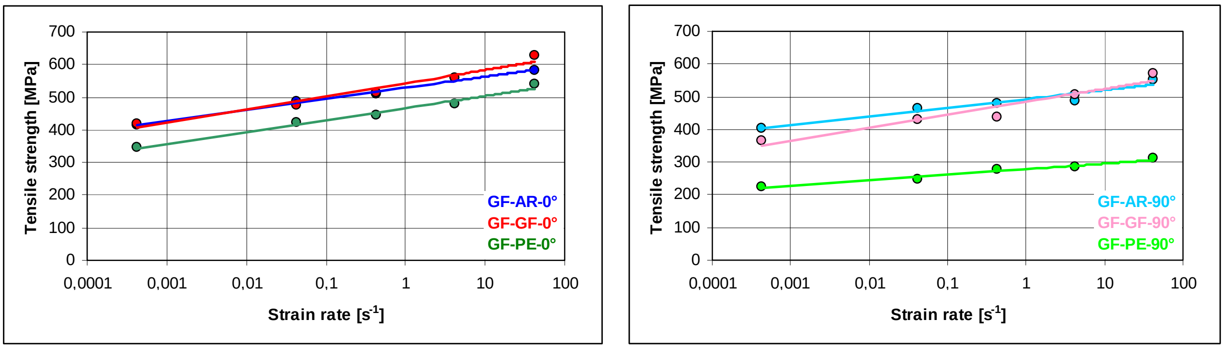

Fig. 4. Strain rate dependent tensile strengths of hybrid MKF-composites in warp (0°) and weft (90°) direction

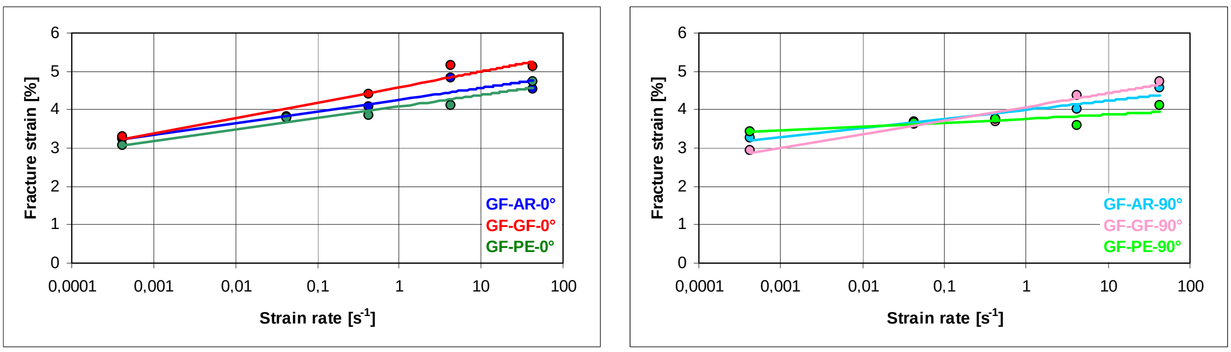

Fig. 5. Directional strain rate dependent strains at failure of hybrid MKF-composites

as for the validation of numerical impact simulations [9]. Dependent on the impact speed and the material of the knit thread, different failure modes (fibre failure, inter-fibre failure and delamination) emerge with variable intensity. The evaluation of the damage was performed by microscopic analysis and fluoroscopy. (Fig. 7, 8). As an example, in Figure 7 the delamination between the weft and warp thread can be seen, whereas the delamination between warp threads is shown in Figure 8 on the left hand side. Moreover, Figure 8 (right) shows the influence of the knitting on crack propagation in the matrix material. Crack propagation become stopped or decelerated.

For the analysis of the failure dependent on knit thread and impact velocity, the damage field and the delamination field were measured (Fig. 9). Thereby, the damage field is defined by the whole area, where damages can be detected and the delamination field surrounds only the delamination zone.

In Figure 10 the extent of damage and delamination fields are compared for the different MKF-composites threads and impact velocities. The tests show, that GF/PE-MKF-composites have the highest capability to reduce the degree of damage. The smallest delamination field was detected on composites with an aramid knit thread.

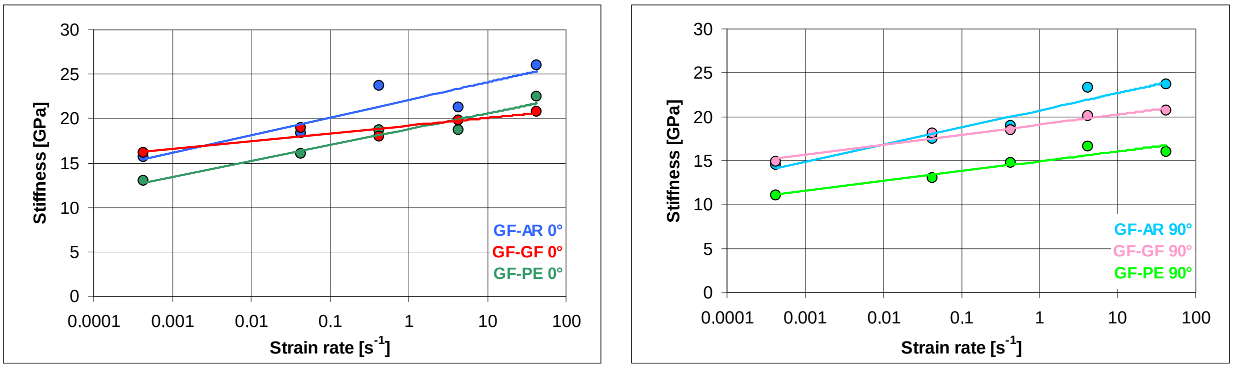

Fig. 6. Directional and strain rate dependent stiffness of hybrid MKF-composites

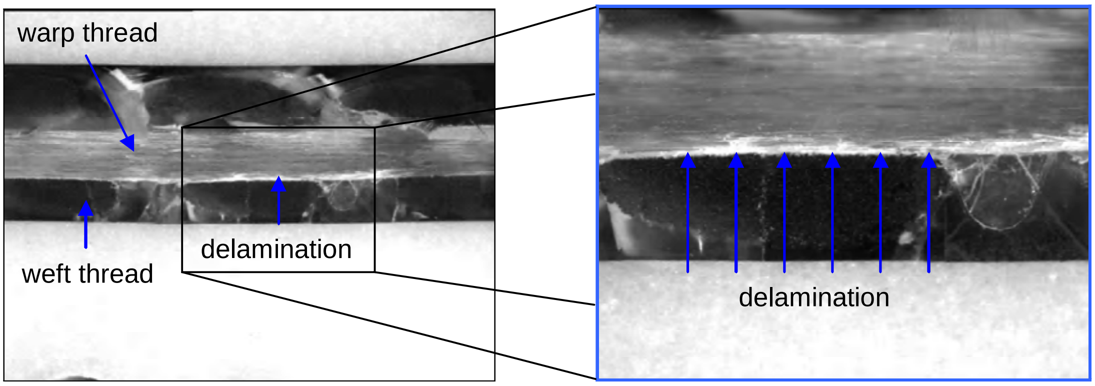

Fig. 7. Delamination between weft and warp thread

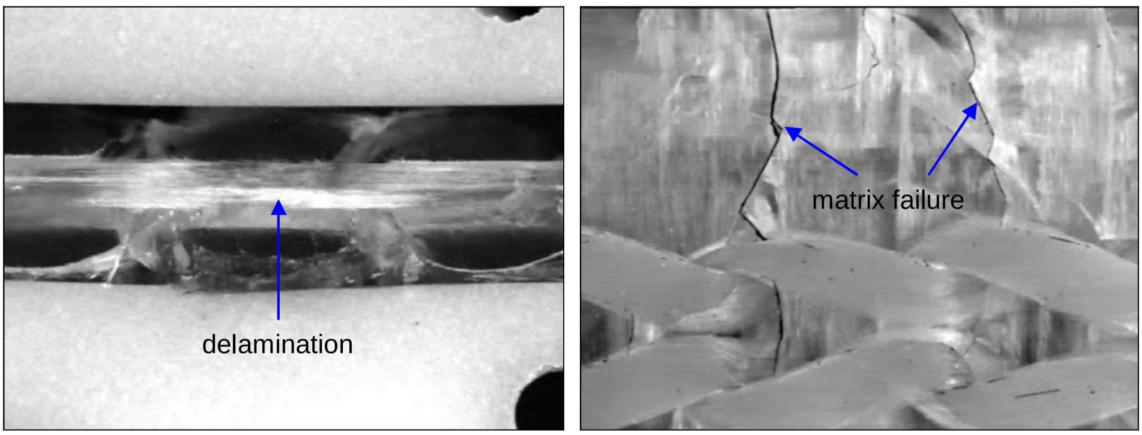

Fig. 8. Delamination between warp threads (r.) and matrix cracks (l.)

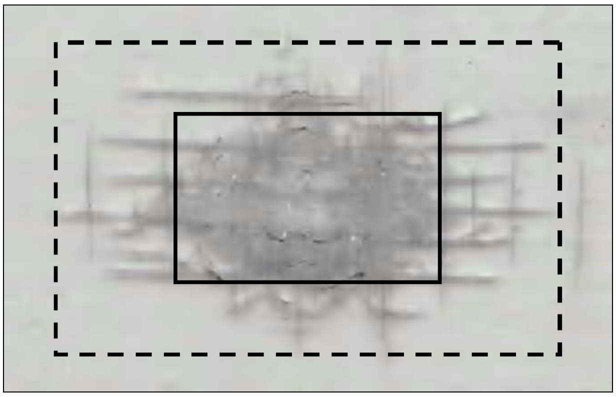

Fig. 9. Damage field (– –) and delamination field (—)

Furthermore, the damage extents of composites with multi-layered knitted fabric reinforcement due to impact loads was characterised. Different knitting materials cause miscellaneous slopes of materials parameters with rising strain rates. Here, the GF/PE-MKF-composites show partly better damage behaviour than GF/AR- or GF/GF-MKF-composites respectively.

The experimental data serve as an indication for the design of tailored textile preforms and build the basis for the development of novel failure criteria and simulation models for the realistic assessment of three-dimensional states of stress due to highly dynamical loads and for the structural simulation of novel lightweight crash stuctures.

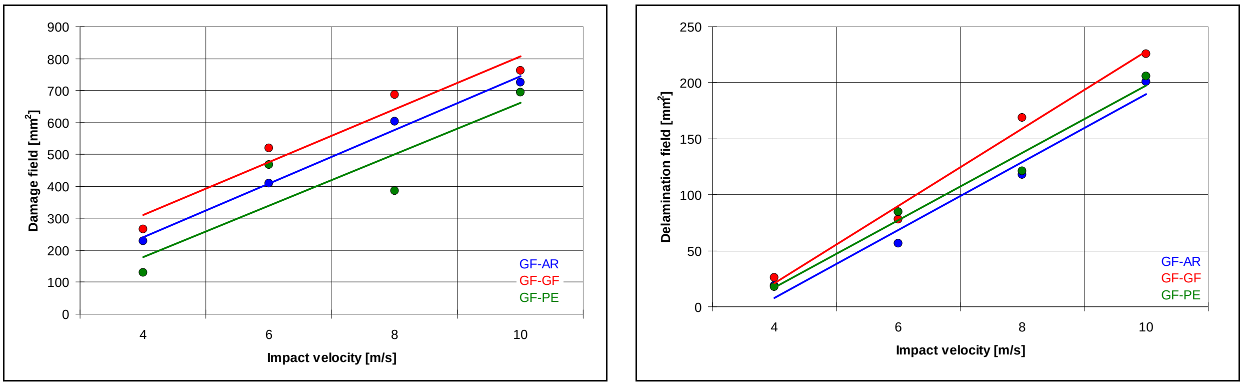

Fig. 10. Damage and delamination fields depending on impact velocity and knit thread

The energy absorption capacity of glass fibre composite with glass fibre knit thread is lower than of composite with polymeric knit threads because of the higher toughness of aramid or dyneema fibres.

CONCLUSIONS

For the development of realistic simulation models for textile reinforced lightweight structures under highly dynamic loading, such as crash or impact loads, basic experimental investigations of MKF reinforced composites are necessary in order to gain an in depth knowledge about their dynamic material behaviour and failure mechanisms. This paper focuses on the analysis of material phenomena of textile reinforced composites under highly dynamic loading as well as the determination of time dependent deformation and fracture characteristic affected by different knitting materials. The influence of knit threads made of glass, aramid and dyneema fibres on strain rate dependent material properties and textile specific characteristics due to impact loads were analysed. Generally the increase of strength, strain and stiffness with increasing strain rates was quantified for all MKF reinforced composites. For composites with GF/PE-MKF reinforcement partly significant lower in-plane properties have been observed.

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