Werner Hufenbach[1], **Manuela Andrich**[2], **Maik Gude**[3], **Albert Langkamp**[4]
Institut für Leichtbau und Kunststofftechnik (ILK), Technische Universität Dresden 01062 Dresden, Germany

CONTRIBUTION TO THE SIMULATION OF TEXTILE REINFORCED PLASTICS UNDER CRASH AND IMPACT LOADS

Novel textile reinforced composites have outstanding specific mechanical properties and superb energy absorption capabilities, which makes them excellent candidates for impact and crash resistant elements. Despite their distinguished properties, textile reinforced composites have not experienced a broad application yet, mainly due to the lack of realistic failure models, that account for the complex mechanisms involved in the dynamic failure of such materials. In developing appropriate simulation and failure models for textile composites under dynamic loading, basic experimental investigations are required to understand the complex structural and failure mechanisms. The performed experiments provide the necessary knowledge to develop adapted material models, which take into account the textile reinforcement structure and serve for the simulation of the impact and crash behaviour with the help of numerical programs.

Key words: **textile reinforced, crash and impact test, strain rate dependent properties, failure model**

SYMULACJA ZACHOWANIA TWORZYW SZTUCZNYCH WZMOCNIONYCH TEKSTYLNIE PRZY OBCIĄŻENIACH DYNAMICZNYCH

Nowe kompozyty ze wzmocnieniem tekstylnym posiadają znakomite właściwości mechaniczne oraz doskonałe zdolności absorpcji energii, dlatego są one predestynowane do zastosowań w elementach i konstrukcjach obciążonych udarowo. Kompozyty tekstylne nie są do tej pory w pełni wykorzystane w praktyce z powodu braku realistycznych modeli zniszczenia, wyjaśniających złożone mechanizmy pękania przy szybko narastających obciążeniach. Do opracowania modeli umożliwiających symulację niszczenia kompozytów tekstylnych niezbędne jest przeprowadzenie szczegółowych badań eksperymentalnych w celu zrozumienia przebiegu pękania. Eksperymenty wykonane w ILK dostarczyły danych służących dopasowaniu modelu materiału, uwzględniającego tekstylną strukturę wzmocnienia przy bardzo dużych prędkościach obciążenia.

Słowa kluczowe: **wzmocnienia tekstylne, testy udarowe, model pęknięć**

INTRODUCTION

For the development of realistic simulation models for textile reinforced lightweight structures under dynamic loading, such as crash or impact loads, basic experimental investigations of textile reinforced composites are necessary in order to gain an indepth knowledge about their dynamic material behaviour and failure mechanisms [1]. This article focuses on the experimental investigation of strain rate dependent material properties of textile reinforced composites and their time dependent deformations and failure behaviour. Experimen- tal results of highly dynamic tests on woven and biaxial knitted reinforced epoxy specimen are presented. The results serve as a basis for the development of material and failure models for the numerical simulation of the structural behaviour and the assessment of spatial states of stress of textile reinforced composites due to highly dynamic loading [2-4].

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. The strain rate dependent material properties are essential input data for high dynamic structural analyses.

For the determination of the strain rate dependent material properties dependent on different fibre/matrix combinations, reinforcement architectures and fibre orientations, a servo-hydraulic high-speed test unit was used (Fig. 1). The high-speed test unit enables mechanical stiffness and strength 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 additional temperature chamber but also by the adapted grip unit, which enable an abrupt application of the force.

[1] Prof. Dr.-Ing. habil., [2] Dipl.-Ing., [3, 4] Dr.-Ing.

Fig. 1. Servo-hydraulic high-speed test unit at ILK

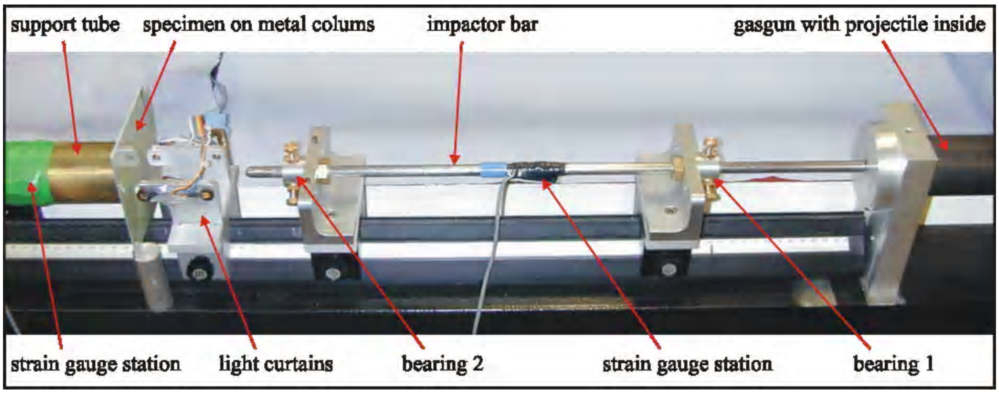


Fig. 2. Components of the Hopkinson device [6]

In addition to high-speed tensile tests, impact tests were also carried out. To apply the desired impact loading on specimen plates a loading system also known as the split Hopkinson-bar device was used, which enables impact test with velocities up to 10 m/s [5]. The particular device used, allowed for the impact of a titanium bar with hemispherical tip to be applied to a specimen plate which was supported by a long brass tube. The system is illustrated in Figure 2.

The projectile, accelerated by high air pressure, collides with the impacter bar of the same shape, size and mass thus enabling the kinetic energy to be transferred entirely to the impacter bar, which theoretically continues to move unstressed. Having cut through the light curtains of the timer, the impacter bar hits the specimen plate which is leaning against the support tube. The impact causes the plate to bend and push against the support tube which then starts to move in the direction of impact.

Only two strain gauge stations, each consisting of 4 strain gauges, are used for data acquisition. One station is in the middle of the impacter bar and the other is placed on the support tube 100 mm away from the interface with the specimen. To control the triggering and to check the initial velocity of the impacter two light curtains are installed between the impacter bar tip and the specimen plate. Before impact occurs the impacter bar tip cuts through the two light curtains and the time delay between closing the respective electric circuits is measured. During impact the generated axial strain within the impacter bar and support tube is recorded by the strain gauges and converted into a voltage using an uncompensated Wheatstone bridge. The data was acquired at the frequency of 1 MHz (one data point per μs). The recorded voltage signals were converted into force signals by multiplication with a calibration factor f [N/V]. For the determination of these factors the impacter bar as well as the support tube were statically loaded with a defined force which resulted in a certain difference of the strain gauge voltage [6].

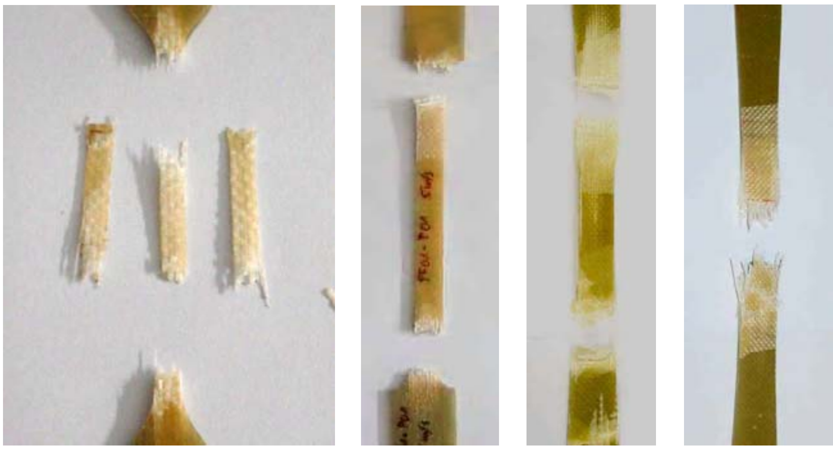


Fig. 3. Fracture types of high-speed test specimen with conventional and optimised geometries

HIGH-SPEED TENSILE TESTS

Primarily to the high-speed tests, the specimen geometry had to be adapted to high-speed tensile test conditions in order to get a defined fracture area. Tests on specimens with parallel edges showed multiple fractures, delaminations in the whole specimen and fracture in the grip area. Therefore, adapted specimen geometries were developed and tested [7]. A choice of tested specimens is shown in Figure 3. It can be seen that specimens with a variable width, as is known from metallic specimens, show fractures in the notched area. Only after several optimisation loops in combination with numerical simulations an optimal specimen geometry could be found, which leads to a defined failure.

After the manufacturing of the specimens, first high-speed tensile tests were carried out on glass fibre reinforced specimen with a fabric reinforcement structure [7]. The strain rates were varied from 0.0004 1/s (quasi-static test) up to 40 1/s (highly dynamic test). The associated stress strain diagrams of the single tensile tests are shown in Figure 4. It can be seen, that the strain at failure and the tensile strength increases with an increa-sing strain rate.

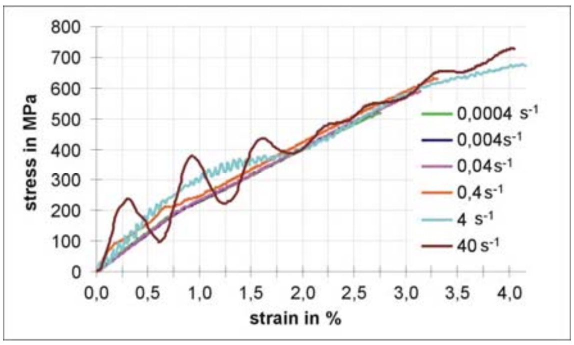


Fig. 4. Strain rate dependent stress-strain diagrams of glass fibre reinforced specimen

Moreover, after a linearisation of the measured stress strain curves in a range from 0 to 0.9% strain, a qualitative and quantitative increase of Young's modulus with an increasing strain rate can be observed (Fig. 5).

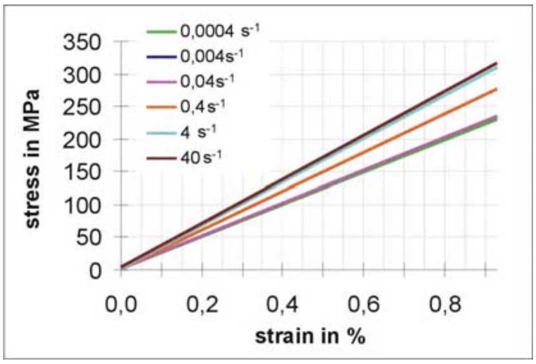
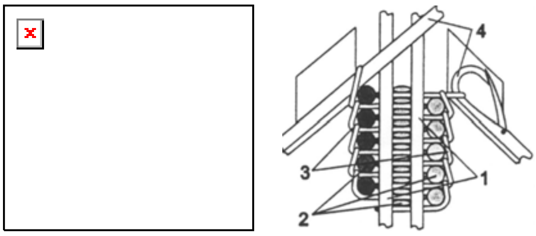


Fig. 5. Strain rate dependent stress-strain diagrams of glass fibre reinfor-ced specimen (linearised)

IMPACT TESTS

In numerous impact tests, failure phenomena of multi-layered knitted fabrics (MKF) made by the Institut für Textil- und Bekleidungstechnik (ITB), TU Dresden were investigated under several impact speeds. The MKF specimen with the textile architecture as illustrated in Figure 6 are based on glass fibres and were infiltrated with an epoxy resin by the resin transfer moulding (RTM) process. Two different lay-ups were analysed: MKF 1 (consists of two layers of MKF type 1, which are arranged symmetrically) and MKF 3 (consists of one layer MKF type 3). The specimen size is 100 mm×100 mm. The impact load is realised by a cylindrical steel impacter with a diameter of 9.8 mm.

The aim of the analysis consists of an evaluation of the failure behaviour of textile composites under impact loads and the description of their energy absorption capabilities. Dependent on the impact speed, different failure modes (fiber failure, inter-fiber failure and delamination) emerge with variable intensity. For the evaluation of the damage of the tested specimen optic and ultrasonic excited thermography and nonlinear vibrometry analysis were used beside the well established ultrasonic inspection (Fig. 7).



MKF type 1 MKF type 3

Fig. 6. Basic architecture of multi-layered knitted fabrics (MKF) of ITB: 1 - warp thread, 2 - weft thread, 3 - knit thread, 4 - knitting needle [8]

Dependent on the impacter velocity, different intensities of the fracture modes fibre failure, inter-fibre failure and delamination could be observed. A summary of the non-destructive investigations of the impact specimen is given in Fig. 8. The crack length in x- and y-direction is shown dependent on the impact velocity. The extent of the crack field in y-direction of MKF 1 is, for all impact velocities, bigger than of MKF 3, which is reasoned by an additional reinforcement in y-direc-tion of MKF 3. In the x-direction however, the crack field of MKF 1 is smaller compared to MKF 3, although there is no additional reinforcement.

CONCLUSIONS

The load-adapted design of textile reinforced polymers, especially for highly dynamic loads, requires a reliable knowledge of the strain rate dependent deformation and failure behaviour. 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. For the experimental determination of the strain rate dependent material properties and the energy absorption capability dependent on different fibre/matrix combinations, reinforcement architectures and fibre orientations, a servo-hydraulic high-speed test unit and an impact test stand were modified and used. First strain rate dependent material properties and textile specific characteristics due to impact loads were analysed. The increase of stiffness and strength with increasing strain rates was quantified for textile reinforced composites and the fracture extents of composites with

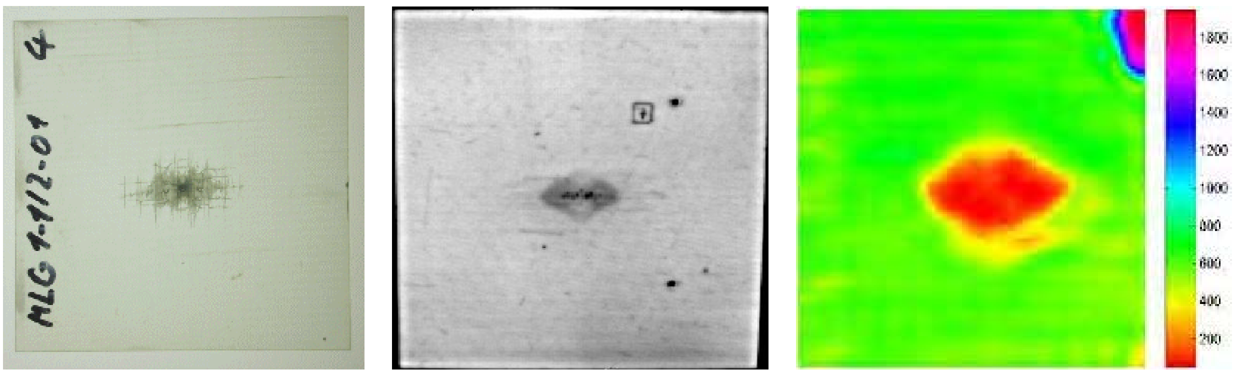


Fig. 7. Multi-layered knitted fabric test specimen after impact and associated optic excited thermography photo and ultrasonic inspection exposure

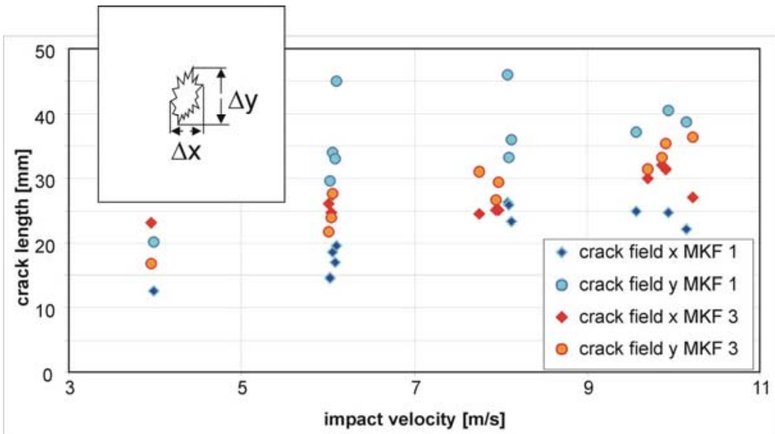


Fig. 8. Fracture extents of different MKF dependent on the impact velocity

multi-layered knitted fabric reinforcement due to impact loads was characterised. This experimental data serve as the basis for the development of simulation models and novel failure criteria for the realistic assessment of three-dimensional states of stress due to highly dynamical loads.

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Recenzent
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