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Novel lightweight solutions by load-adapted textile reinforcements

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In endeavouring to fulfil extreme lightweight requirements the material characteristics need precisely to be matched to the prevailing stresses and strains. New textile-reinforced composite materials together with the optimum construction methods offer a high degree of innovative potential for high-tech applications that has so far been insufficiently exploited. This article deals with some aspects involved in the development of load-adapted textile-reinforced composite components in lightweight construction applications, the main focus being placed on the modelling and simulation of semi-finished products and fibre preforms as well as components under different loading conditions.

1. INTRODUCTION

The textile construction methods used in engineering not only provide the designer with a load-adapted reinforced arrangement, but also with an extensive range of options in tackling crash safety, structural damping and additional function integration. Moreover, the new textile processes permit a rapid manufacture of reproducible reinforced semi-finished products, for example, in the shape of preforms, for ultralight, reliable and efficient component structures exhibiting a high degree of contour complexity.

The textile composite construction method possesses the great advantage that both the components as well as the structure of the material itself are formed simultaneously in one process [1]. This is why the method still often employed today of considering the individual sub-areas of materials, design and manufacture separately needs to be improved. It is only by integrating all sub-areas that engineers, which until now have only been partially successful in the use of textile semi-finished products as reinforcing material, will achieve the expected breakthrough on a broad front.

In order to fully exploit the high degree of property potential of textile composite construction methods reliable computational concepts and configuration strategies are required that take into account both the particular structural behaviour as well as the special manufacturing restrictions inherent in the material [2]. Furthermore, the requisite close intermeshing in the development chain – material characterisation, draft, preform design, manufacture – means that realistic component simulation takes a particularly prominent position.

2. MATERIAL CHARACTERISATION

As part of the material characterisation process tensile strength tests are conducted on flat specimens and tensile/compressive torsional tests on textile-reinforced tube specimens for different textile reinforcement structures to determine the stiffness and strength values. These tests determine the exerting forces and moments by means of force sensors and the resulting elongation is determined by means of extensometers and strain gauges [3, 4, 5, 6]. An example is shown in Figure 1 which depicts the parameter functions for Young's modulus, shear modulus and Poisson's ratio of textile-reinforced CF/EP composite material.

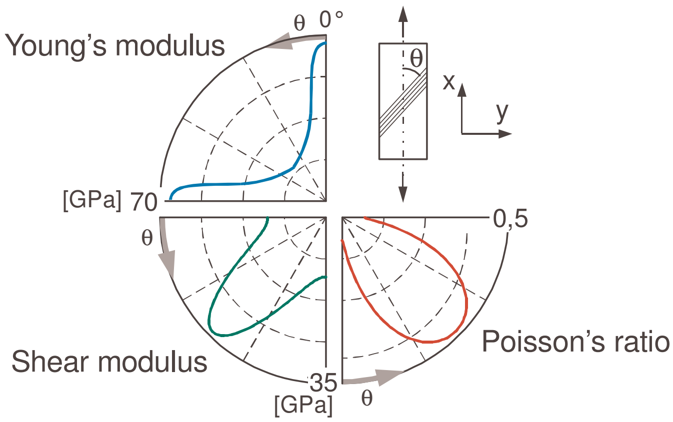

Fig. 1. Parameter functions for textile-reinforced CF/EP

To solve the present material mechanics problem concerning local and global failure, extensive uni- and biaxial fracture tests were conducted on CF textile-reinforced tube specimens at the institute using a tensile/compression torsional machine. The established basic strengths serve as input data for adapted, physically-based fracture criteria, for example, on the basis of Hashin/Puck. Figure 2 shows selected textile-reinforced tube specimens together with their fracture curve.

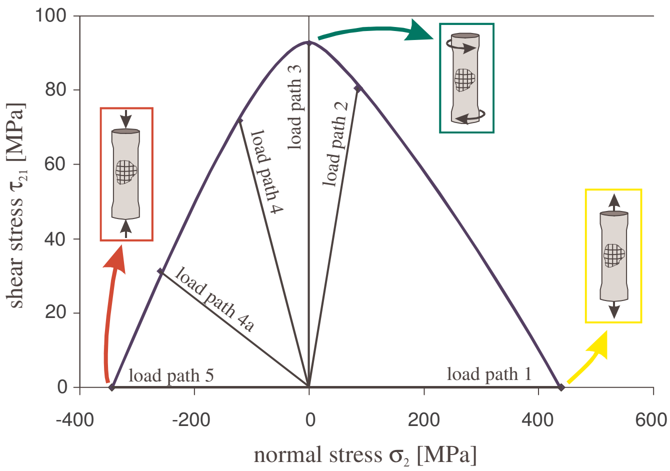

Fig. 2. Textile-reinforced CF/EP tube specimens and their fracture curve

3. PREFORM DESIGN AND DRAPABILITY

When designing a load-adapted preform the engineer must not only consider the stiffness and strength requirements but also that the textile preform displays adequate drapability. This is of critical importance especially when designing components of complex geometry, such as, for example, double curved structural components. This is because it is only good drapability that ensures that the formation of folds and uneven loading of the preform can be avoided. This requires draping simulations to be conducted with suitable textile preforms as early as the design stage. Figure 3 shows a comparison of the quality of draping behaviour of different preforms for a double curved top blade of a rotor.

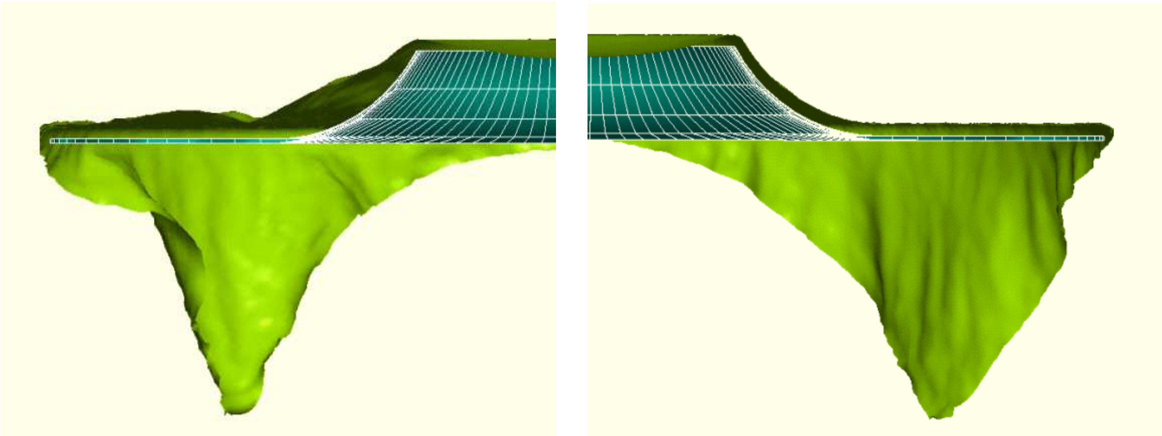

Fig. 3. Comparison of the draping behaviour of different textile preforms

4. COMPONENT SIMULATION

The structural behaviour of textile-reinforced composites is of a very complex and diverse nature. Each of the often spatial arrangement of threads in woven, braided, knitted, twined and multiaxial layings differ from one another (Fig. 4). Each type of pattern can also be broken down into sub-types exhibiting different crossover points, loops, kinks and knots in variable arrangement to one another [6].

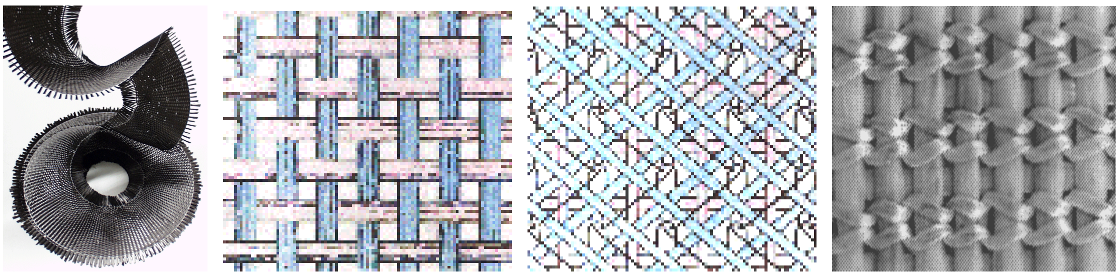

Fig. 4. Patterns of 2-dimensional textile semi-finished products

The high variability of textile preforms, however, makes it difficult for the engineer to calculate the description and modelling of base cells when configuring the structure as is the case, for instance, for metal composites in the form of elementary cells or in fibre composite technology in the form of UD base elements [7].

When defining "textile" elementary cells, therefore, the characteristics of the respective pattern must be suitably depicted in the modelling (Fig. 5).

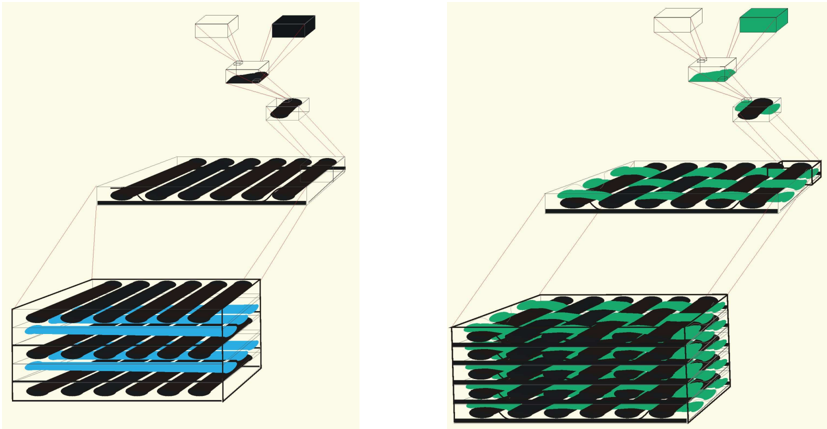

Fig. 5. Modelling base cells for unidirectional and textile-reinforced composites

As a consequence of the different thread crossover points and loops complicated multi-axial, stress states are usually useful both at the elementary cell level (micro-level) as well as at the structural level (macro-level). At the same time most textile fibre matrices possess only a few pronounced symmetry planes, which can lead to unusual coupling effects taking place at the macro-level. This structural complexity leads to complicated material laws and failure hypotheses that must be taken into account when designing load-adapted textile-reinforced components [8].

The simulation of the structural behaviour of highly stressed lightweight components with textile reinforcement such as is the case with textile-reinforced fan rotors (Fig. 6), fan blades and gear housings has been undertaken at the institute with the aid of the Finite Element Method under consideration of the property characteristics of the base cell previously defined [6, 9]. This captures the complex structural behaviour realistically and serves as a basis for the manufacture of initial prototypes.

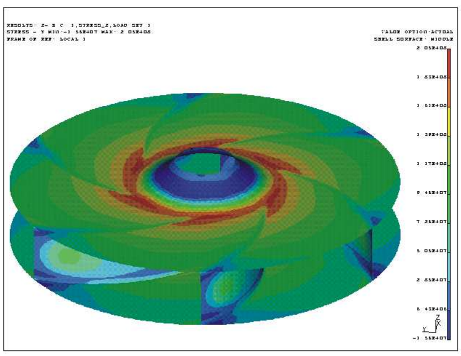

Fig. 6. FE simulation of the structural behaviour of a textile-reinforced fan rotor under centrifugal loading

5. MANUFACTURE

The vacuum autoclave process is particularly ideal for the manufacture of textile-reinforced components of complex geometry as here uniform pressurisation as well as very precise temperature and pressure flow can be assured. In order to observe the pre-calculated textile reinforcement arrangement and orientation during the consolidation phase and, at the same time to achieve a high degree of geometry flexibility of the tool, it is essential to provide special kinematical and adaptive shaping tools and to integrate them in the autoclave process. Figure 7 shows an example of a preform in the tool as well as a consolidated textile-reinforced rotor.

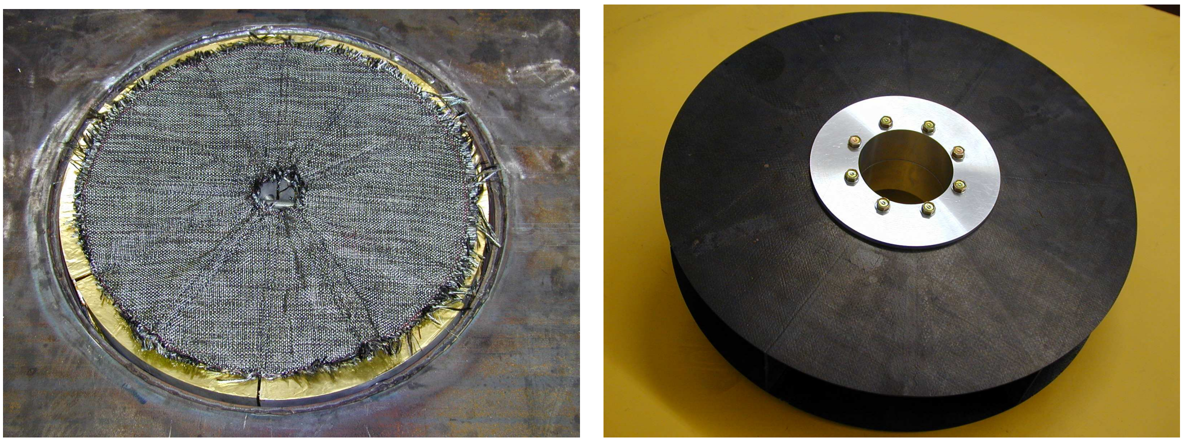

Fig. 7. Textile rotor preform with tool and consolidated rotor

6. SUMMARY

By successful utilising the novel multi-dimensional textile reinforcement systems, for example, in high speed rotors, a significant technological leap both regarding an improved mechanical behaviour as well as regarding increased efficiency can be expected. To fully exploit the lightweight construction potential of textile-reinforced composites, novel computational concepts and optimisation strategies suited to the material have been developed and implemented in practice.

When designing the load-adapted textile reinforcement, it is particularly important to also consider the manufacturing restrictions and the drapability of the textile surface formation for example as regards double curved surfaces such as fan impeller blades.

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REFERENCES

1. Hufenbach, W.; Kroll, L.; Archodoulakis, G.; Langkamp, A.: Design and processing of textile-reinforced Polyetheretherketone (PEEK) for complexly loaded lightweight structures. Proceedings of the 21st International SAMPE Europe Conference, Paris, 18-20 April 2000, 255-264
2. Hufenbach, W.; Archodoulakis, G.; Langkamp, A.: Analytisches Simulationsmodell zur Berechnung des Spannungs-Verformungs-Verhaltens dreidimensional textilverstärkter Faserverbund-Leichtbaustrukturen. DGLR-Jahrbuch 2000, Bonn 2000
3. Hufenbach, W.; Kroll, L.; Langkamp, A.; Gude, M.: Realistische Versagenskriterien für Faserverbundstoffe mit spröder Matrix. Verbundwerkstoffe und Werkstoffverbunde. Publ. K. Schulte and K.U. Kainer, WILEY-VCH-Verlag Weinheim, 1999, 319-324
4. Hufenbach, W.; Kroll, L.; Langkamp, A.; Höpken, J.: Bruchmodebezogene Versagenskriterien für langfaserverstärkte Werkstoffe. Verbundwerkstoffe und Werkstoffverbunde, Publ. B. Wielage und G. Leonhardt,: Wiley-VCH-Verlag Weinheim, 2001, 303-308
5. Hufenbach, W.; Kroll, L.; Lustig, V.; Gude, M.: Experimentelle Verifizierung neuer Festigkeitshypothesen für faserverstärkte Verbundwerkstoffe. Tagungsband der 20. Internationalen Konferenz "Verstärkte Kunststoffe '99", Karlsbad, 25.-27. Mai 1999, S. 77-84
6. Hufenbach, W.; Offermann, P.; Rödel, H.; Pfeifer, G. et al.: Zwischenbericht der DFG-Forschergruppe „Textile Verstärkungen für Hochleistungsrotoren in komplexen Anwendungen – Beanspruchungsgerechte und versagenstolerante Hybridstrukturen. Dresden, November 1999
7. Gude, M.: Zum nichtlinearen Deformationsverhalten multistabiler Mehrschichtverbunde mit unsymmetrischen Strukturaufbau. Dissertation, TU Dresden 2000
8. Langkamp, A.: Realistische Versagensmodelle von faser- und textilverstärkten Verbundwerkstoffen mit polymerer, keramischer und metallischer Matrix. Dissertation submitted at TU Dresden, 2002
9. Hufenbach, W.; Gude, M.; Kroll, L.; Zhou, B.; Grothaus, R.: Design and testing of fibre reinforced conical rotors. XII International Conference on Mechanics of Composite Materials (MCM-2002), Riga, 9.-13. Juni 2002