EFFECT OF ADHESIVE SYSTEMS IN THE TEXTILE PREFORMING PROCESS ON THE STATIC AND DYNAMIC INTER LAMINAR SHEAR STRENGTH OF TEXTILE REINFORCED COMPOSITES

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Abstract

Textile-reinforced polymers offer a very high potential for the application in high-technology lightweight structures. The mechanical properties of textile-reinforced composites strongly depend on the reinforcement architecture and the textile preform quality. For an efficient and reproducible manufacture of high quality products adhesive systems are often used in the textile preforming process for fixing different textile semi-finished products. Appropriate adhesive systems have to be carefully selected not only from the process-sided point of view but especially from mechanical point of view. Therefore, the influence of different adhesive systems such as hot-melt adhesive fabrics or spray glue on the mechanical properties of textile reinforced composites has been investigated. Static and dynamic inter laminar shear tests have been carried out under different environmental conditions such as room temperature and hot/wet-test condition.

1 Introduction

Textile reinforced composites with their high specific mechanical properties and the possibility to create a tailored property profile offer a great potential for the application in highly stressed lightweight structures [1-8]. To fully exploit this potential, a load-adapted reinforcement architecture as well as reproducible preforming processes and assembly techniques, which enable the economic manufacture of near net shape preforms, are absolutely necessary [2, 3].

Novel textile technologies, such as tailored fibre placement (TFP) enable an efficient, repeatable manufacture of near net shape preforms of complex shape with continuous, load-adapted fiber reinforcement [9]. Within the textile preforming process, adhesive systems for fixing different textile semi-finished products, such as woven or knitted fabrics or TFP-products, are often used. These facilities however influence the mechanical properties of the finished composite material and can lead to a degradation of the composite strengths and stiffness.

The effects of different adhesive systems such as hot-melt adhesive fabrics and spraying glue, which have been used in the textile preforming process supported the tailored fibre placement technique, on the static and dynamic inter laminar shear strength (ILSS) of textile reinforced composites have been investigated using three-point bending test on short beam-like samples made of carbon fibre reinforced epoxy resins. The test conditions were varied from tests at room temperature as well as under hot/wet conditions.

2 Textile performing and infiltration

The tailored fibre placement technology enables the manufacture of reinforcing structures with stress field aligned fibre orientations. This performing process is based on the well known embroidery technology, which is currently used for decorating fabrics. The main advantage, compared to the common textile technologies, is the ability to arrange reinforcing fibres in every direction of the reinforcing area from an angle of 0° to 360°. Accumulation of fibres can be achieved by stitching several times across the same area. The principle of the production process is shown in Fig. 1.

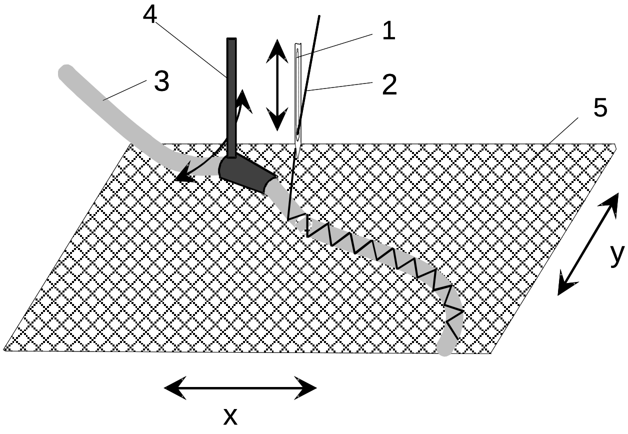

Fig. 1. Principle Tailored fibre Placement (TFP)

With a needle (1) and needle tread (2) a roving (3), controlled by roving placing device (4) is fixed through stitches on a base material (5). Between the stitches the base material can be moved by numeric control in the x-y-direction. The roving is placed on the base material by zig-zag stitches on either side of the roving. The roving can be made of carbon, glass fibres or other types of fibres and moreover the use of bindered rovings is possible. As base materials different layers can be chosen such as fabrics, non crimp fabrics (NCF), non-woven or pure binder material.

For the manufacture of the test material, NCF-material layers and TFP-layers have been stapled and fixed with the binder systems which were placed of one binder layer between every single layer. Hot-melt adhesive fabrics binder systems were used as 20 g/m^2, therefore the fraction of binder is higher than necessary but helps to identify properties differences of the test specimens. For same reasons higher fraction of spray glue were placed on the single layer.

In Fig. 2 the application of a binder system on carbon fibre fabrics is demonstrated. The binder film can be applied locally and is suited for local attachment of dry fabrics to prevent slippage effects of the fabrics and following fibre misalignments. Also more accurate free edges of the fabric are achieved by applying the local edge consolidation based on a thermoplastic binder system.

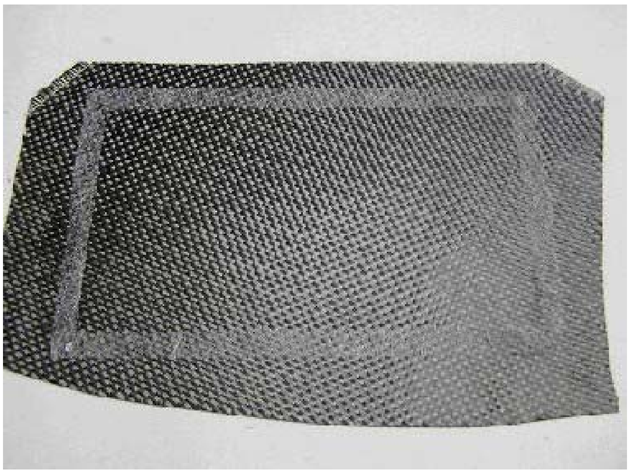

Fig. 2. Carbon fibre fabric showing the rectangular frame of a binder system for fixation

The carbon fibre TFP-preform is placed within a metallic mould (Fig. 3). The mould system is designed for an automated resin transfer moulding (RTM) process, where all relevant process parameter as vacuum, pressure, temperature profile as well as resin flow content can be controlled and recorded. Due to high injection and curing pressures at elevated temperatures the deformation of the RTM moulding system needs carefully to be understood for mitigating risks of thickness variations. For each plate type a specific moulding gate is used which defines the exact alignment and final thickness of the fibres during the lay-up process of the preform in the moulding system. For a high fibre volume content a specific pressure-temperature profile must be applied to eliminate typical RTM manufacturing defects as e. g. fibre washing and bubbles due to high local injection pressures and dry spots by local inclusions (Fig. 4). The applied profile includes a low pressure injection (0.5 bar) at the beginning of the infiltration and finishes with a high pressure (6 bar) process step at the end of the infiltration and for the curing of the two selected standard epoxy resin systems at 120 °C (EP1) and 180 °C (EP2) for 2 hours. The fibre volume contents of each sample plate (600 mm x 600 mm) are calculated using the weight comparison of dry preforms and RTM-injected plates. Non-destructive quality assurance by ultrasonic inspection as well as destructive examinations of specimen cut-ups (microscopic surface analyses, chemical testing) are used to control the sample quality with regard to void levels, fibre alignments and fibre volume fractions.

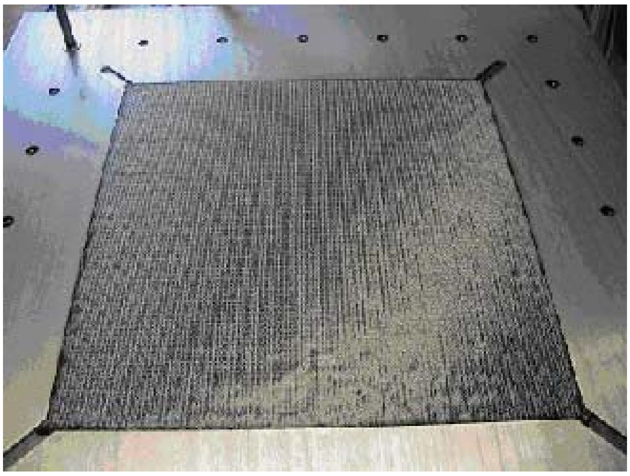

Fig. 3. TFP-preform within metallic moulding gate prepared for RTM-process

Fig. 4. Surface of a RTM injected carbon fabric showing local dry spots due to infiltration irregularities

3 Static and dynamic inter laminar shear tests and test conditions

For the determination of the effects of the different adhesive systems to the mechanical properties of the textile reinforced composites, quasi-static and dynamic inter laminar shear tests were carried out using three-point bending tests in accordance with DIN EN 2563 (Fig. 5). Rectangular specimens were cut from the carbon reinforced epoxy resin plates by water jet cutting. Due to application reasons of the chosen composite lay-up, specimen dimensions twice as much as the prescribed size were selected in contrast to the standards. So the specimens were 40 mm in length, 20 mm in width and had a thickness of 4 mm.

The static inter laminar shear tests were conducted at a displacement rate of 1mm/min on a universal testing machine ZWICK Z250. The strains of the specimens were measured by strain gauges which were applied on the bottom of the specimens (Fig. 5).

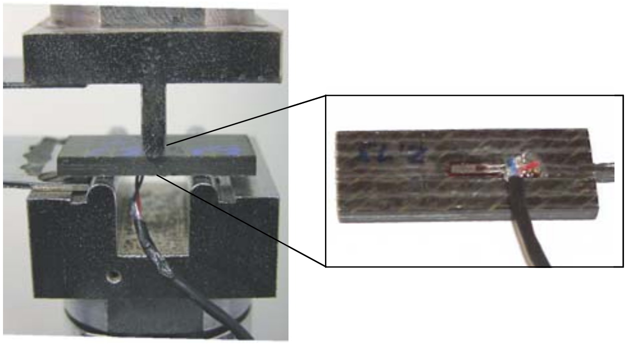

Fig. 5. Three-point bending test equipment and specimens with strain gauge

The dynamic tests were performed on a servo-hydraulic testing machine of the INSTRON PSB series (Fig. 6). The testing machine is equipped with a digital PID-controller and a measuring amplifier. The specimens were dynamically loaded with sinusoidal forces at a frequency of 5 Hz. The maximal loads were given by selecting a value between 40 % and 80 % of the maximum measured quasi-static interlaminar shear stress. Furthermore, the specimens were held under constant prestress (R = 10) to avoid stress peaks. Continuous temperature control guaranteed a temperature of the specimen lower than 30 °C.

Fig. 6. Servo-hydraulic testing complex INSTRON PSB with climatic chamber

Within the experimental investigations two different climatic test conditions were applied. On the one hand the quasi-static and dynamic tests were performed at room temperature; on the other hand so called hot/wet-conditions with a temperature of 70 °C and a relative humidity of 85 % were applied using a modular test unit. The hot/wet-conditions were generated in a climatic chamber, as shown in Fig. 6. This atmosphere was transferred in the climatic chamber around the testing unit using special pipelines. Inside the smaller climatic chamber a hygroscope controls the climatic conditions during the tests. Additionally the specimens were stored before testing in the same humid atmosphere in accordance with DIN EN 2823 until a constant weight was reached.

4 Experimental results

4.1 Results of quasi-static tests

The inter laminar shear stress were calculated in accordance with the standard with the measured forces and displacements. Selected results of the quasi-static tests in terms of stress-strain curves at room temperature are shown in Fig. 7 whereas Fig. 8 depicts representative stress-strain curves determined under hot/wet-test conditions.

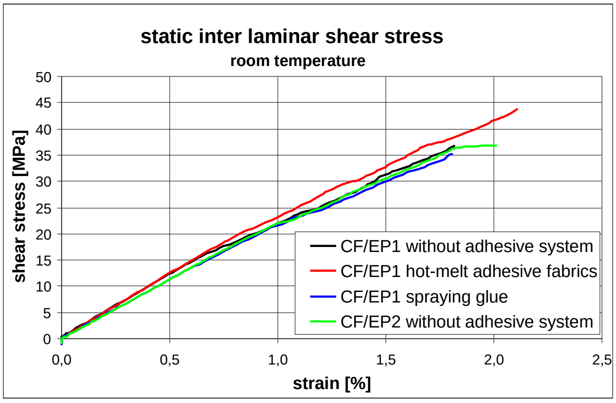

Fig. 7. Stress-strain curves of different CF/EP-composites with and without adhesive systems at room temperature

A comparison of the quasi-static test results at room temperature shows on the one hand a slightly increased interlaminar shear stiffness and strength for the specimen with hot-melt adhesive fabrics as adhesive system. On the other hand the spraying glue has no identifiable effect on the displacement behaviour.

In contrast to that, the use of hot-melt adhesive fabrics leads to a considerable decrease in the inter laminar shear strength and stiffness under hot/wet-test conditions, whereas the humid and warm atmosphere has no significant influence on the mechanical properties of the reference specimens without adhesives and with spray glue respectively.

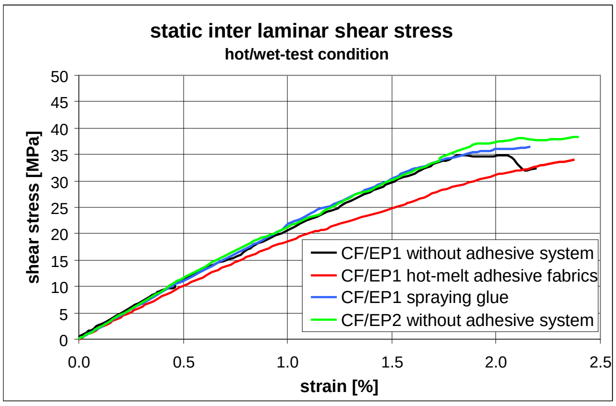

Fig. 8. Stress-strain curves of different CF/EP-composites with and without adhesive systems at hot/wet-test conditions

4.2 Results of dynamic tests

The quasi-static test results served in a further step as start data for the dynamical investigations, which were performed at 40 % and 80 % of the maximum measured quasi-static interlaminar shear strength. Selected results of the dynamic tests are shown in Fig. 9 and Fig. 10 in form of S-N curves in semi logarithmic diagrams for the mean values of five tests each. At room temperature the composites with hot-melt adhesive fabrics show an increased degradation of the inter laminar shear strength compared to the reference CF/EP-composites without adhesive systems. A lower degradation in the dynamic ILSS-behaviour can be observed for the composites in which performing process spraying glue and in which no adhesive systems have been applied respectively Fig. 9.

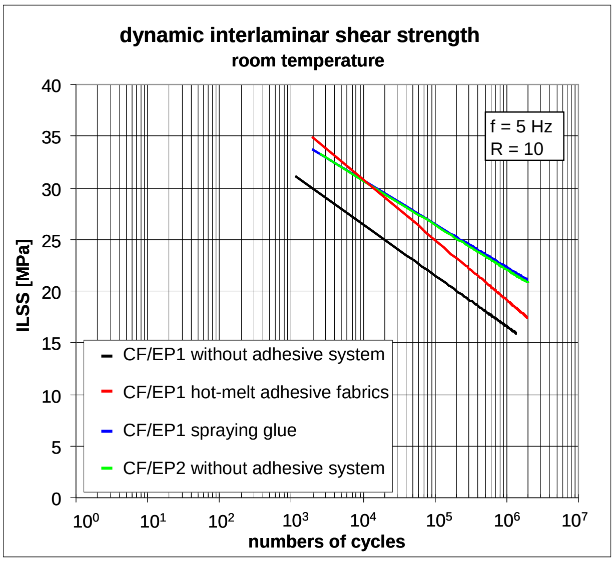

Fig. 9. S-N curves of the dynamic ILSS at room temperature for CF/EP-composites with and without adhesive systems

On the other hand the use of binders in dynamically loaded CF/EP-composites, which are subjected to an additional hygro-thermal loading, can lead to an obvious material degradation as shown in Fig. 10. The specimen, for which hot-melt adhesive fabrics has been used in the performing process show the lowest dynamic ILSS values however with a similar degradation compared to the reference specimen with regard to the load cycles. The highest ILSS has been determined for the specimen with spray glue. For high load cycles the absolute ILSS values for all specimen converges.

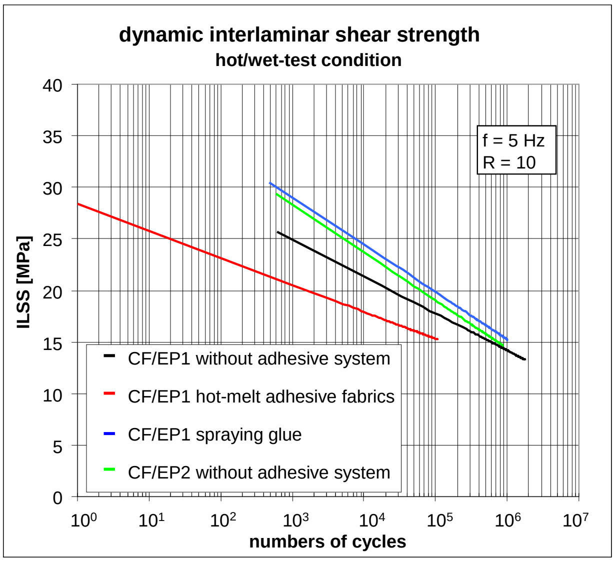

Fig. 10. S-N curves of the dynamic ILSS at hot/wet-test conditions for CF/EP-composites with and without adhesive systems

5 Conclusions

The influence of different adhesive systems, which are commonly used in the textile performing process, on the mechanical behaviour of carbon fibre textile reinforced composites has been studied in various quasi-static and dynamic loading tests under different environmental conditions. The degradation of the inter laminar shear stiffness and strength dependent on two different binder systems, hot-melt adhesive fabrics and spray glue, has been investigated. For selected composite materials it has been shown that the use of Hot-melt adhesive fabrics leads to an increased stiffness and strength behaviour at room temperature and quasi-static test conditions, whereas a significant degradation in the properties can be observed under hot/wet-test conditions. The influence of spray glue on the quasi-static mechanical behaviour has been detected to be negligible at room temperature as well as at hot/wet-test conditions. In case of dynamic loading conditions the use of the thermoplastic binder system generally leads to a higher material degradation compared to specimen in which performing process spraying glue has been used.

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