INTEGRATION OF SENSOR ELEMENTS IN FIBRE-REINFORCED THERMOPLASTICS USING REMOTE LASER PROCESSING

T. Möbius[1], F. Adam[2], N. Modler[3],
A. Fürst[4], A. Klotzbach[5], J. Hauptmann[6], E. Beyer[7]

[1]Institute of Lightweight Engineering and Polymer Technology, Technische Universität Dresden
Holbeinstr. 3, D-01307 Dresden, Germany
Email: teresa.moebius@tu-dresden.de, web page: http://www.tu-dresden.de/mw/ilk

[2]Institute of Lightweight Engineering and Polymer Technology, Technische Universität Dresden
Holbeinstr. 3, D-01307 Dresden, Germany
Email: frank.adam@tu-dresden.de, web page: http://www.tu-dresden.de/mw/ilk

[3]Institute of Lightweight Engineering and Polymer Technology, Technische Universität Dresden
Holbeinstr. 3, D-01307 Dresden, Germany
Email: niels.modler@tu-dresden.de, web page: http://www.tu-dresden.de/mw/ilk

[4]Institute of Manufacturing Technology, Technische Universitär Dresden
Georg-Bähr-Str. 3c, D-1069 Dresden, Germany
Email: andreas.fuerst@tu-dresden.de, web page: www.tu-dresden.de/mw/if,

[5]Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS Dresden
Winterbergstr. 28, D-01277 Dresden, Germany
Email: annett.klotzbach@iws.fraunhofer.de, web page: www.iws.fraunhofer.de

[6]Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS Dresden
Winterbergstr. 28, D-01277 Dresden, Germany
Email: jan.hauptmann@iws.fraunhofer.de, web page: www.iws.fraunhofer.de

[7]Institute of Manufacturing Technology, Technische Universität Dresden
Georg-Bähr-Str. 3c, D-1069 Dresden, Germany Email: eckhard.beyer@tu-dresden.de, web page: www.tu-dresden.de/mw/if

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ABSTRACT

Within the Collaborative Research Centre 639 the processing chain from filaments up to component parts under the focus of textile-reinforced thermoplastics is considered. Thereby, thermoplastic hybrid yarns (glass/ polypropylene filaments) are processed to multi-layer knitted fabrics and subsequently to complex spacer structures for lightweight constructions.

The applications of hybrid yarns facilitate short flow paths of the matrix systems and thus comparatively low impregnation and consolidation pressures. These process conditions are beneficial for the integration of functional elements as sensors and electronic components in fibre-reinforced thermoplastic parts. Nevertheless, to minimize the strain on these elements during the pressing process, especially in thin-walled components, an adapted lay-up has to be examined. For the variation of the single layer thicknesses the material is excavated in the integration relevant area by a remote laser cutting process. Since high intensities are needed to enable laser cutting of glass-fibre textiles a brilliant laser beam source is recommended. Thereby, the remote-technology is used to deflect the beam onto the material with tiltable scanning mirrors. Furthermore, a precise positioning of the laser cutting path is required. For this reason a camera positioning system is used to detect the working area of the scanner system. Subsequently, the certain work piece features can be extracted by image processing algorithms. The determined data is used for the cutting path generation. Since the cutting process is a thermal process, it is necessary to minimize the heat affected zone to a minimum.

Therefore, a tailored remote laser cutting strategy was developed. This strategy allows an ablation of the hybrid and the knitting yarn to achieve a full cut or a partial exposure of single layers.

Within this work, the enhancement of integration possibilities of sensor elements in thin-walled components will be presented under the focus of locally cut and partial exposed layers of the multi-layer knitted fabrics.

1 INTRODUCTION

The application of optimized lightweight components plays a constitutive role in the context of the shortage of resources. Here, fibre-reinforced thermoplastics offer good mechanical properties with a concurrent good recyclability as well as their processing in highly productive manufacturing processes.

Within the Collaborative Research Centre 639 (SFB 639) an entire process chain from filaments up to functional integrated fibre-reinforced thermoplastic parts is considered. Adapted manufacturing processes are developed within the entire process chain beginning with the manufacturing of hybrid yarns, their further processing to complex textile preforms and ending with the consolidation to lightweight structures. In this context, function integration, particularly the integration of electric and electronic components, forces the expansion of novel applications and enlarges their scope. Simultaneously, the developments of a reproducible integration and consolidation technology determine a fundamental knowledge of the material behaviour during this process. In particular, detailed analyses of the compression behaviour of the textile and the resulting damage behaviour of the integrated sensor nodes have to be examined and adaptions on the textile set-up have to be exhibited. The results of the experimental studies are presented in the following.

2 GENERAL SPECIFICATIONS

2.1 Material

Depending on the production technology, different types and structures of hybrid yarns are realisable. As shown in Figure 1 and mentioned in [1], the arrangement of reinforcement fibres and polymer filaments can differ over the cross section. The structure of the roving influences e.g. the flow path length of the matrix system and the impregnation quality of the later part is influenced as well. [1-3]

Figure 1: Variations of hybrid yarns (after [2]); left: side by side, middle: core skin, right: mixed

Within this research project a mixed yarn is used. It is characterized by a homogenous distribution of glass-fibres and polypropylene filaments and features minimized flow path lengths over the cross section of the roving. In this context, very good impregnation qualities of the reinforcement material can be achieved by applying comparatively low impregnation pressures from 1 – 10 bar and simultaneous short impregnation periods.

The thermoplastic hybrid yarns are processed to complex multi-layer knitted fabrics within the SFB 639, Figure 2. The fabrics are made up of one layer warp and weft threats of TWINTEX®-R PP 60 (glass-fibre/ polypropylene) rovings which are fixed by a mesh threat out of a glass-fibre yarn. Here, the fibre volume content of the multi-layer knitted fabric is 39.3 % and the overall weight per unit area is 1170 g/m^2.

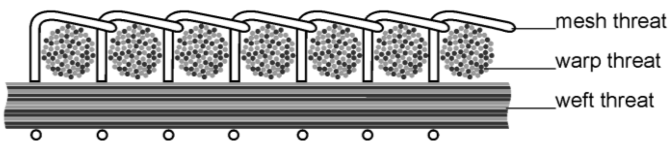

Figure 2: Structure of multi-layer knitted fabrics

Since the reinforcement fibre bundles are elongated within the textile, the application of multi-layer knitted fabrics favours deviant compression behaviour of the preform and relatively higher mechanical properties of the consolidated preform in comparison to conventional fabrics [4].

The differing compression behaviour and rates of this textile require a detailed examination and basic understanding of the material characteristics for the successful integration of electric and electronic elements during a pressing process.

2.2 Sensor elements

The integrated sensor nodes are a project specific development and assembled respectively to different requirements. Figure 3 shows the set-up of these elements. A microcontroller (Texas Instruments, MSP4302013) with small footprints and a number of sensors are included. Besides a magnetic field sensor (Measurement Specialties, KMY20M), a temperature sensor (included in the microcontroller) and a photodiode (Osram, SFH2400) are assimilated. Furthermore, a capacitive touch sensor, formed by a copper electrode, a bicolour LED (Kingbright, KAA-3528SRSGC) to visually signal different operation states and an evaluation integrated circuit (Atmel, AT42Q1011) are integrated. All sensors and functionalities are controlled via the microcontroller unit. In addition, the communication is possible via an I^2C bus system and by using a custom protocol.

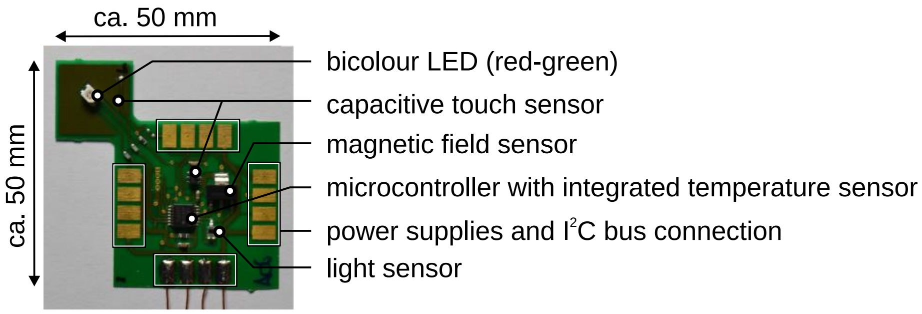

Figure 3: Sensor node

A thin FR4 substrate, with a height of 150 µm, is used as a printed circuit board (PCB). Thereby, the conductive traces are on both sides, whereas the electronic set-up is carried out single-sided. Appropriate to the requirements within the SFB639 and to provide a representative set of electronic components, the elements are of different height.

The communication with an external measurement PC is reached via electric connections. Thus, the functionality of the sensor nodes can be proven during the experiments.

The integration of these sensor elements within a commonly employed pressing process for thermoplastic reinforced parts implicates very demanding temperature and pressure conditions on the electronic elements [5,6]. Thus, test runs are required to avoid damages as e.g. deformed or destroyed electric components and to guarantee the functionality of the electronic elements subsequently to the integration process.

2.3 Remote Laser Processing

To modify single layers of the multi-layer knitted fabric a remote laser processing was used. Here, the application of a high-speed beam deflection system allows a partial explosion as well as a total cut through of the unconsolidated hybrid yarn textile. Additionally, the contour of the relevant sensor element is digitized by Remocut®VIS, developed at the Fraunhofer IWS Dresden, including a high-resolution camera system. The camera is coaxially aligned with the laser beam so that the part position as well as fibre orientation and rovings can be identified accurately. The system calculates the laser cutting path under special consideration of the material properties of the glass-fibre rovings (blue) and the knitting fibre (yellow), as displayed in Figure 4. The relevant processing parameters are defined using the developed CAD/CAM software in dependency on the desired material removal strategy. Subsequently, the knitting and roving fibres are cut by cyclic laser remote processing with the adjusted parameters and subject to the grade of material removal. Rapidly moving mirrors project the laser beam following the desired contour. The high dynamic of the process allows a minimization of interaction between the laser spot and the textile. Thus, thermal decomposition of the polypropylene is reduced and the layers can be cut with a good quality, reproducibility and productivity. [7,8]

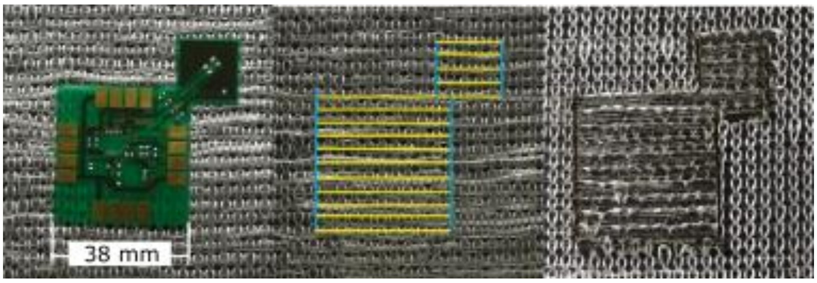

Figure 4: Laser remote processing; left: contour recognition of the sensor element to be embedded, middle: generated power variable laser cutting path, right: formed pocket

In Figure 5 the grades of modification are displayed: a partial explosion and a locally cut of the multi-layer knitted fabric.

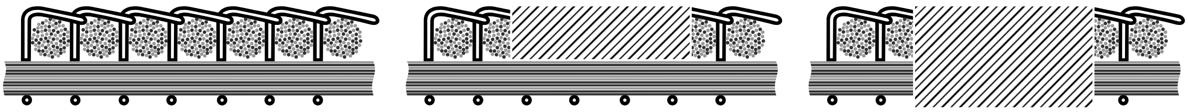

Figure 5: Layer modification; left: exclusive processing, middle: partial exposed; right: locally cut

3 EXPERIMENTS

For the determination of the functionality of the integrated sensor elements in dependency on the amount of layers and layer's characteristics, several experiments were performed. The measurement set-up was adapted to a pressing process, likewise the set-up of layers and the pressure value of 10 bar. The experimental set-up is illustrated in Figure 6. Due to results of preliminary tests the initial material compression has a high influence on the functionality of the sensor elements. To give special consideration on this fact, the experiments were performed at room temperature.

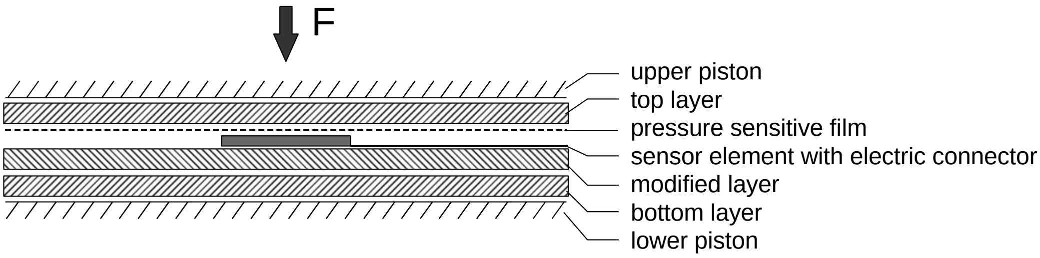

Figure 6: Experimental set-up

The sensor elements were positioned on top of the modified layer to determine the influence of their position in thickness direction of the stack. Furthermore, a FUJIFILM pressure sensitive prescale film for pressure values between 0.5 and 2.5 MPa was used to analyse the effected pressure values on the upper surface of the single sensor elements. The set-up was positioned between the upper and lower plate of a ZWICK Universal Testing Machine with which the defined pressure value of 10 bar (1 MPa) was applied. The evaluation of the pressure values distribution occurred using FDP-8010W evaluation software and image processing with Matlab programming. During the experiments, the functionality of the sensor elements was supervised with an external measurement PC.

4 RESULTS

To determine the pressure distribution and strain on the surfaces of the embedded sensor elements and the compressed textiles a pressure sensitive prescale film was used. Selected results of the experiments are displayed in Figure 7.

It is visible that the adaption of the lay-ups by remote laser-cutting and thus the sensor's position in thickness direction of the stack result in deviance pressure distributions within the single layers. Different pressure values on the single sensor elements are affected.

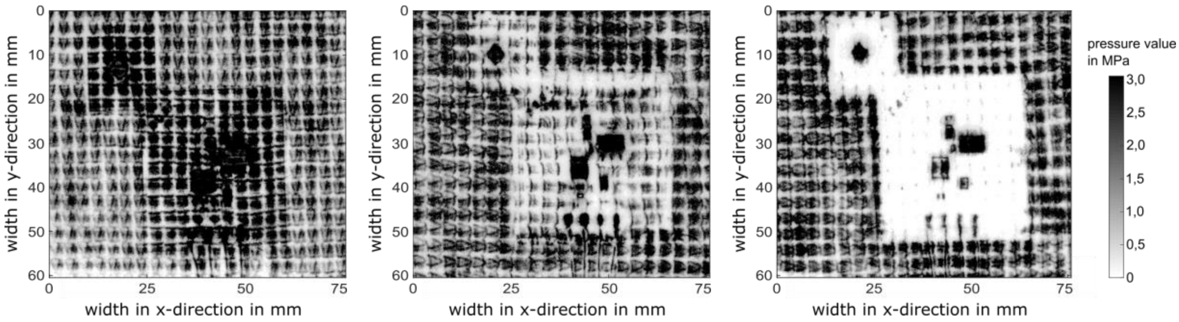

Figure 7: Pressure distribution on surface of sensor element in dependency on remote-laser cutting processed area; left: exclusive processing, middle: partial exposed; right: locally cut

The characteristic design of the single multi-layer knitted fabric results in a local inhomogeneous pressure distribution on the textile surface and in deviant compression behaviour of the textile. Nevertheless, these effects are negligible due to the comparatively larger sensors size.

Besides, Figure 7 (left) shows higher pressure values in the area of the single sensor node components than on the textile preform. A pressure application of 1 MPa results in pressure values higher than 2.5 MPa in the areas of the electronic nodes. Thus, greater loads on the single components are effected which also depends on the single-sided application on the PCB as well as on the different heights of the elements. However, due to the rough scale of the used prescale film a detailed analysis of the loads on the elements is not possible but trends of the pressure distribution can be detected.

By comparing the influences of the modified layers on the strain on the sensor nodes differences are visible, Figure 7. The partial exposed and locally cut lay-up results in less strain on the sensor nodes and single electronic elements than for a stack without laser-remote processing. Additionally, it is more distinctive for the locally cut layer than for the partial exposed one. These results can be explained due to the resulting positioning of the nodes in thickness direction of the stack. A positioning of a sensor in a locally cut layer also results in a deviant stack height in the outer area of the sensor and thus in a different compression behaviour and rate of the textile. On the other hand, the application of a locally cut single layer causes a compression behaviour and rate of the textile that can be classified between these two cases.

Figure 8 displays a more detailed evaluation of the appearing pressure values at the analysed surfaces at single positions of the y-axis. Due to the limited and rough scale of the used pressure sensitive foil and its maximum at 2.5 MPa, the real applying values of the displayed pressure profiles are potentially higher, but a trend can be identified. In both figures the local oscillation can be explained due to the inhomogeneous structure of the stack. Furthermore, differences of the appearing pressure values are visible for the lay-up with a non-modified and a locally cut layer. The locally cut area is identifiable in the right figure in detail, marked by a distinctive lower pressure value in the area of the sensor node. The maximum values of the electronic elements LED, microcontroller and power supplies are identifiable likewise and are equally lower than for the unmodified stack. Thus, the strains on the single electronic components are lower, the possibility of sensor damage decreases and the functionality of the sensor nodes is more likely given. Hence, a partial explosion or locally cut influences positive the functionality of the sensor node. Under the considered boundary conditions an improvement of the sensor's functionality could be proven by material removal of a single layer at sensor position.

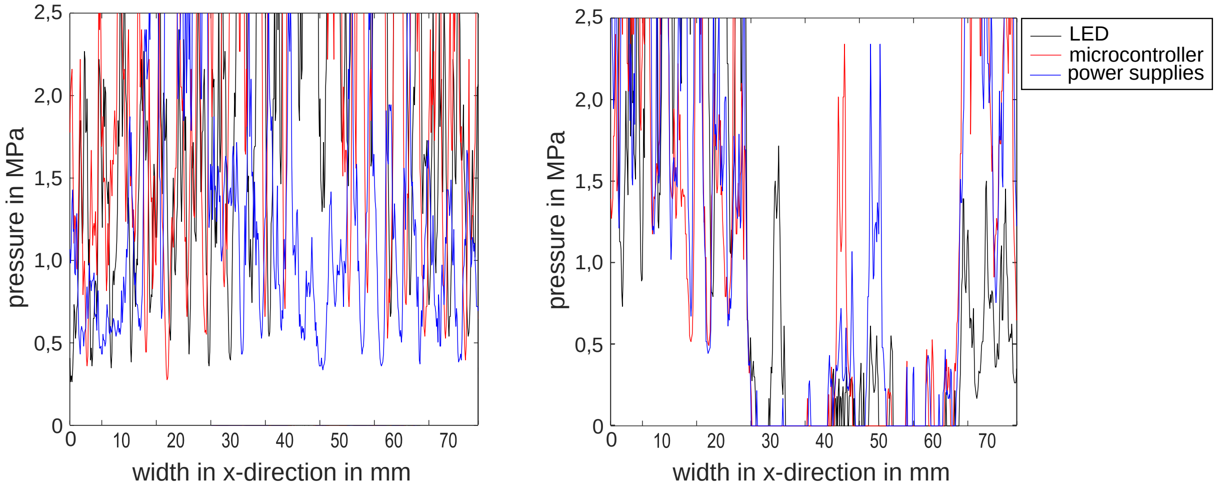

Figure 8: Pressure distribution at selected positions of the sensor node; left: exclusive processing, right: locally cut

5 CONCLUSIONS

The integration of sensor elements in fibre-reinforced thermoplastic textiles using remote laser processing was analysed. The influence of the applied pressure on the sensor node was conducted in dependency on the modification of locally cut, partial exposed and non-modified layers.

The results show an influence of the grade of modification on the appearing pressure value on the single sensor elements. Due to the rough scale of the used prescale film a detailed analyses is not possible, but a trend visible. The positioning of a sensor node in a partial exposed layer decreases the appearing pressure value on the single elements. In addition, it can be decreased moreover by locally cut of the relevant layer. An improvement of the functionality of the sensor element could be shown, by locally cut in comparison to non-modified layers.

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