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Material integrated textile sensors in lightweight structures

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ABSTRACT

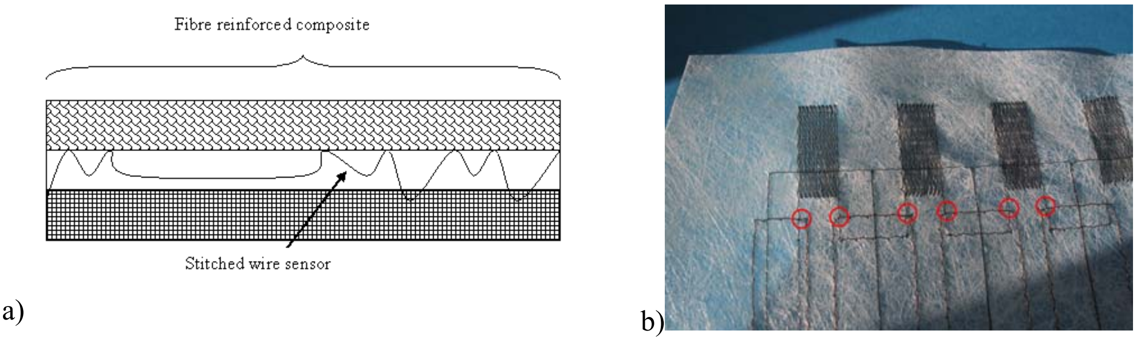
The integration of electronic units, sensors and actuators into complex function-oriented systems is one of the key points in the development of intelligent fibre composite structures. A wide range of materials is available for that purpose and can be used to create active fibre composites ("smart composites") with selective properties, which are suitable especially for application in lightweight components. While the functionality of these solutions could be proved on a laboratory scale, appropriate manufacturing strategies for a competitive series production of components have not been realised so far. Often, these complex systems are manually integrated into the fibre composite with either prefabricated layer materials or as individual elements, or applied to the surface of the fibre composite compound, thus preventing process automation. Therefore, the main goal of the Professorship of Lightweight Structures and Plastics Processing (SLK) is to develop application-oriented technological solutions for series production.

1 RESEARCH POTENTIAL

A crucial requirement for a fibre composite solution to be suitable as mass product lies in its capability to achieve a prefabrication and automation level as high as possible. As a textile technological method, stitching has been used for the integration of new textile sensors and, at the same time, production of complex systems during preform manufacturing. This has been examined with regard to its suitability for large-scale production at the Professorship SLK. Depending on the desired property profile, conductive materials are integrated into the textile semi-finished part precisely according to geometrical specifications. The resulting sensor module works directly within the semi-finished part, which is integrated in a three-dimensional way. The stitching technology allows for flexible structuring and planar mounting. At the same time, variation of the stitch sequence and the use of different materials are possible.

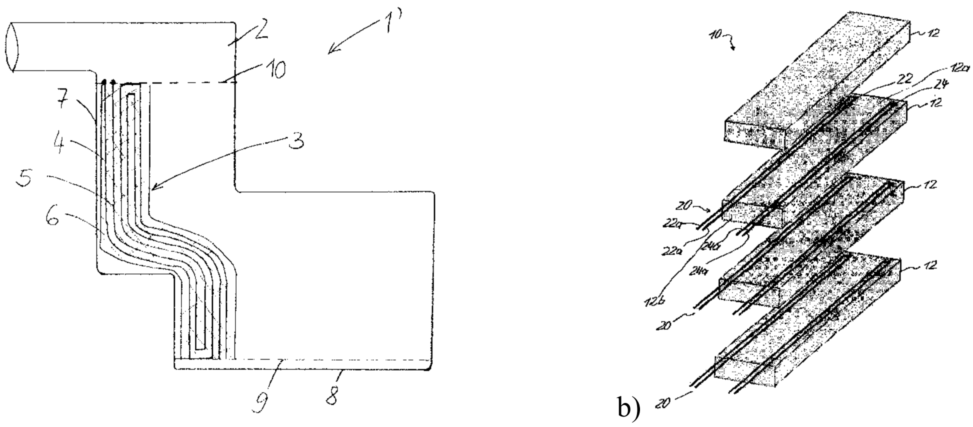
2 STITCHED TEXTILE WIRE SENSOR

For the construction and technological realisation of active lightweight structures, different methods and production processes for practical problems have been developed at the Professorship of Lightweight Structures and Plastics Processing (SLK) in cooperation with Kompetenzzentrum Strukturleichtbau e.V. For example, a novel textile sensor technology integrated by stitching has been developed (figure 1). With the stitched sensor technology several methods of measurement are possible. The focus is mainly on measurement of resistors and of capacities. To measure the resistor we can get a signal dependence of the elongation. With the measurement of capacity several applications are possible. For example to measure the liquid level, to create a touch sensor or to detect a malfunction of an adhesion in laminated wood (figure 2).



a) b)

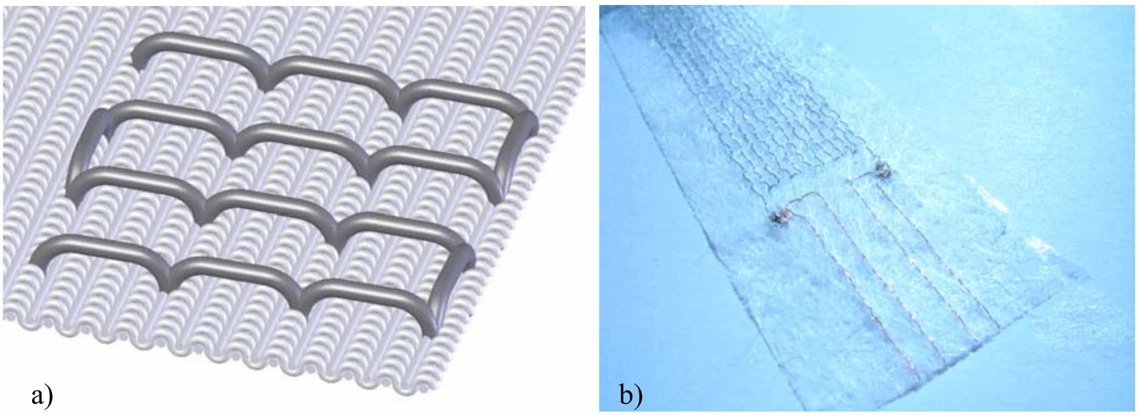
Figure 1: Stitched textile wire sensor technology.
a) Scheme of fibre reinforced composite with integrated stitched wire sensor.
b) Stitched wire sensors.



a) b)

Figure 2: Applications of the stitched wire sensor with measurement of capacity.
a) Scheme of measurement the liquid level.
b) Scheme of measurement to detect a malfunction of an adhesion in laminated wood.

At the Professorship of Lightweight Structures and Plastics Processing, concepts have been developed and tested for simple functional samples which allow for near large-scale production of active basis components. The goal is to combine individual technologies suitable for near large-scale production in order to create a continuous process chain for quantity-oriented products.



a) b)

Figure 3: Design of a two-dimensional wire sensor produced with stitching technology.
a) Diagram of stitched wire sensor.
b) Sample of mechanically produced wire sensor.

This approach also marks the development of a flat sensor system suitable for large-scale production for which a two-dimensional wire sensor (cf. figures 3a and 3b) is fixated and integrated into a laminate (cf. figure 1a) by means of stitching to get a signal dependence of the elongation. First pilot tests show a high reproducibility of the test readings and the possibility of differentiation between stress directions in the measuring section.

Another interesting test is to compare the signal of the stitched wire sensor with a strain gauge. We integrated a stitched wire sensor and a strain gauge in a simple bending beam (figure 4). The signals of both sensors are comparable (figure 5).

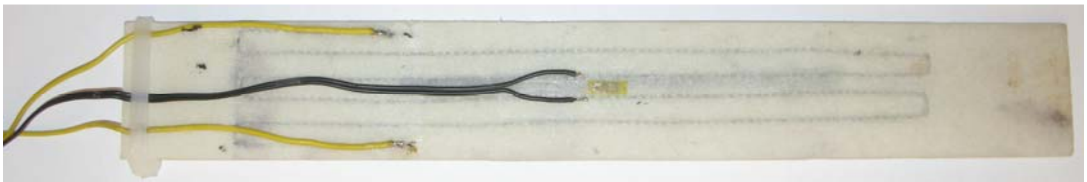


Figure 4: Bending beam to compare the stitched wire sensor with a strain gauge.

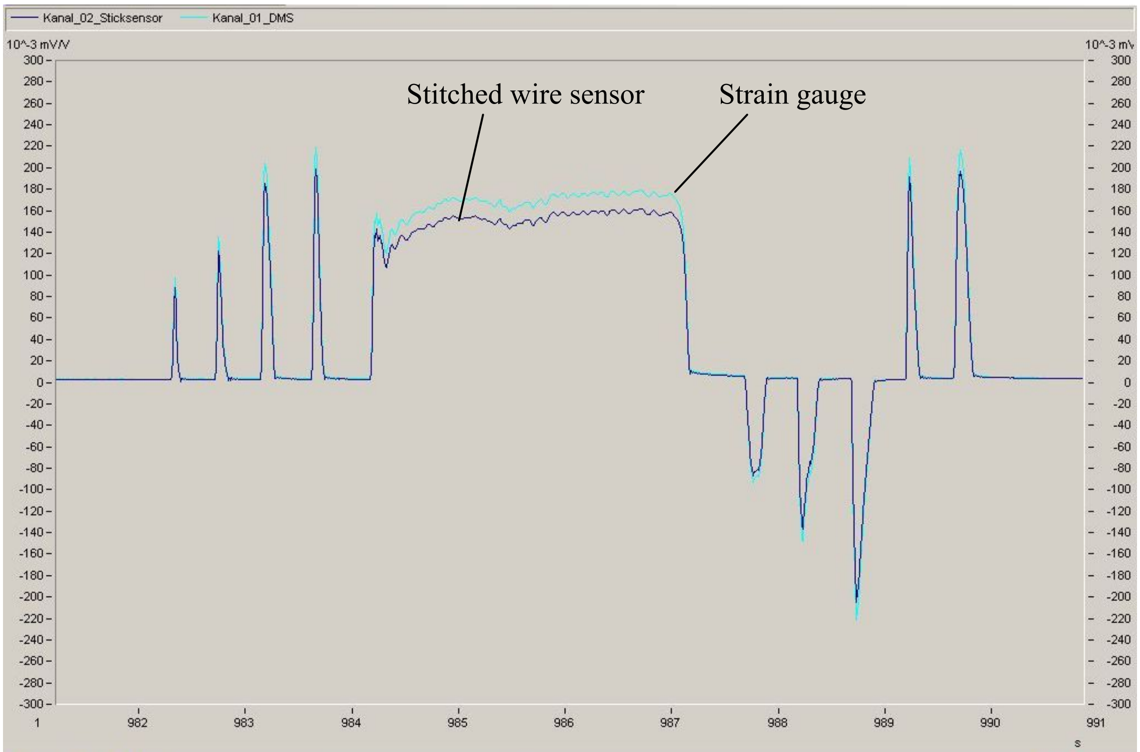


Figure 5: Comparison of the signal of the stiched wire sensor and a strain gauge.

The textile semi-finished parts used for the wire sensor contribute to the reinforcement of the structure components and allow tapping the full lightweight potential because of stress-adapted thread architecture. The production of sensor-integrated textile materials using stitch-bonding technology can be realised in more than one way. Both an upper thread as well as an under thread can be used to stitch the sensors into the textile. However, since the number of reversal points is smaller for under threads, the material stress is lower as well, which makes this method particularly suitable for very thin wires (0.03 mm). According to its desired functional properties, the sensor material can also be influenced in through-thickness direction of the textile by adjusting the thread tension. Alternatively, the tailored fibre placement (TFP) process can be applied as well.

3 SENSOR-INTEGRATED FIBRE REINFORCED LIGHTWEIGHT TENSION ROD SYSTEM

In civil engineering fibre -reinforced plastics are increasingly used for supporting and bracing functions, for example in bridge buildings and structural engineering. Fibre-reinforced plastics with a primarily unidirectional fibre orientation exhibit an extraordinary high lightweight potential, especially as highly tensioned components and constructions. For an optimised load transmission, the pronounced material-conditioned anisotropy must be taken into consideration. To utilize the high lightweight construction potential, the forces have to be transmitted evenly into the reinforcing fibres taking into consideration the low strength across the fibre. The focus of the researches at the Professorship of Lightweight Structures and Plastics Processing is directed towards unidirectional glass fibre reinforced plastic profiles (GFRP rods) that are applied as tension rods in structural constructions inside the building (figure 6) and in bridges. Here, the tension profiles are used as static elements in supporting structures.

Tension profiles are usually made of steel. The disadvantages of steel, however, are for example high weight, corrosion and the increasing steel price. In addition, the monitoring of steel tension rods, which is very important in case of overloading (e.g. snow and hurricane), is complex and time-consuming in its execution. The aim of our development was to eliminate these problems through use of new intelligent lightweight composite materials, including new stitched wire sensors.

Based on the structural advantages of fibre reinforced plastics, the objectives of our research were to develop a new fibre reinforced lightweight tension rod system with

- high tensile stress by load in direction of the fibre structure,
- optimised load transmission in the connecting region,
- flexibility in execution, rapid machining and assembly,
- low weight combined with great strength,
- low flammability, high temperature resistance, corrosion and weather resistance,
- low costs for the material, transportation and assembly,
- newly integrated sensors to monitor the tension rod system.

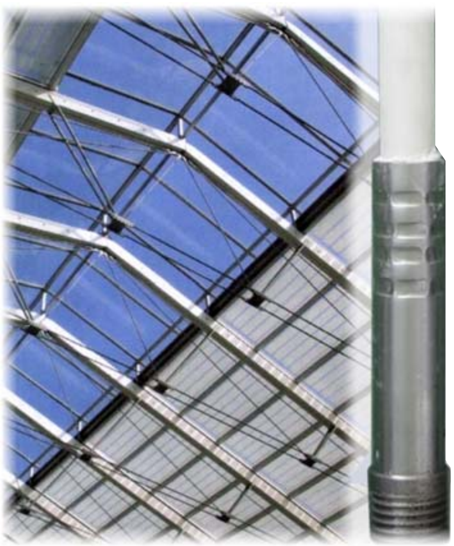


Figure 6: Sensor-integrated tension rod.

3.1 Structure of the fibre reinforced lightweight tension rod system

Construction: - Tension profiles (rods, tubes, bars, I-profiles, T-profiles) made by glass fibre reinforced plastics
- Fibre orientation: unidirectional; high fibre volume fractions
- Integrated stitched wire sensors for tension rod system monitoring

Components: - Glass fibre reinforced plastics (GFRP)
- Thermosetting polymer resin matrix (with low flammability)
- Rovings made of fibreglass
- Continuous filaments

Manufacturing: Pultrusion (figure 7)

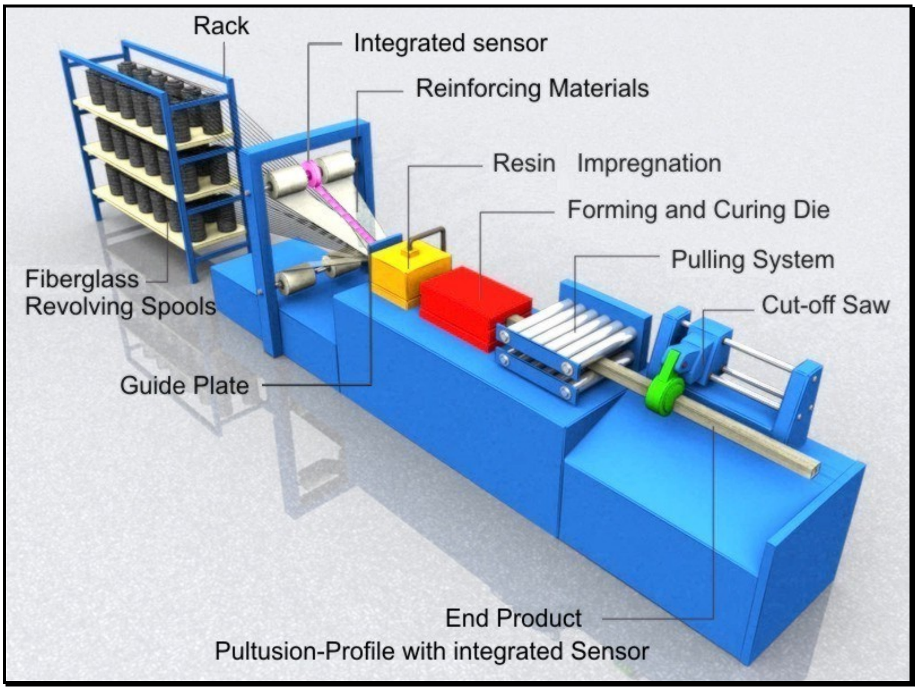


Figure 7: Sensor-integrated manufacturing process by means of pultrusion.

3.2 Sensor system

Furthermore, the intelligent lightweight tension rod system includes new stitch ed wire sensors. During the process of pultrusion the ne w sensor system will be integrated in the matrix of resin and fibres. After assembly and installation, th e sensors wil l be contact ed and calib rated according to the load profile.

With the use of these integrated sensors monitoring of the construction is possible. The sensor s detect extensions inside the tension rods. If th e critical extension is exceeded, the sensor system gives a signal. This specifi c feature i s very important in the case o f overloading (snow), which can reduce the capacity to carry load, because the danger of collapse can be prognosticated. The new tension rod integrate d sensors are able to detect extensions and reduced load bearing capacity and, thus, to prevent danger to human life.

The transfer of this integrated sensor technol ogy is also possible for bui ldings m ade b y pultruded profils or wood glue beams.

4 CONCLUSIONS

The integration of textile sensors and actuators into complex function-oriented systems is of particular importance in the development of intelligent fibre composite structures. Therefore, the Professorship of Lightweight Structures and Plastics Processing has developed application-oriented technological solutions for series production. The textile technological method of stitching has been used for the integration of new textile sensors during preform manufacturing. Depending on the desired property profile, conductive materials are integrated into the textile semi-finished part precisely according to geometrical specifications. The resulting sensor module works directly within the semi-finished part, which is integrated in a three-dimensional way. The stitching technology allows for flexible structuring and planar mounting. At the same time, variation of the stitch sequence and the use of different materials are possible.

For the construction and technological realisation of active lightweight structures with textile sensors, so-called direct material control (DMC) systems, different methods and production processes for practical problems have been developed. For example, a novel fibre reinforced tension rod system for online monitoring of constructions and a new accelerator pedal system with active fibre composite components have been designed, produced and successfully tested. The textile semi-finished parts used for the wire sensor contribute to the reinforcement of the structure components and allow tapping the light weight potential because of stress-adapted thread architecture.

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