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Series production technology for high-performance fibre composite components with structure integrated sensors

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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 composites. A wide range of materials is available for that purpose, for example piezoelectric textile sensors, fibre-optic fibres as well as shape memory alloys and prefabricated information elements. These elements can be used to create active fibre composites ("smart composites") with selective properties, which are suitable especially for application in stressed 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 in automotive and mechanical technologies have not been realised so far. One crucial obstacle which impedes a breakthrough for such active lightweight components is the lack of technologies suitable for large-scale production. Generally, 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 goal of the Institute of Mechanical Engineering and Plastics Technology (Chemnitz University of Technology) is to develop application-oriented technological solutions for series production.

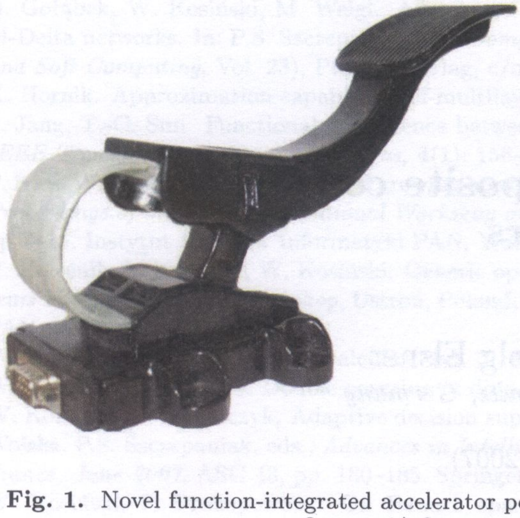
1. Research potential

A crucial requirement for a fibre composite solution to be suitable as mass product lies in its capability to achieve as high a prefabrication and automation level as possible. An efficient production of structure integrated fibre composite components is realised if function-determining components are directly integrated in or applied on the textile structure before they are put into the matrix. In recent years, preform technology has made considerable progress with textile technological developments and provides the characteristics for serial production. As a textile technological method, stitching has been used for the integration and, at the same time, production of complex systems during preform manufacturing, and it has been examined with regard to its suitability for large-scale production at the Department of Lightweight Structures and Plastics Processing (Chemnitz University of Technology) in cooperation with the Kompetenzzentrum Strukturleichtbau e.V. 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. Accelerator pedal system with active fibre composite components

For the construction and technological realisation of active lightweight structures, different methods and production processes for practical problems have been developed at the Department of Lightweight Structures and Plastics Processing [5]. For example, a novel accelerator pedal system

a) b)



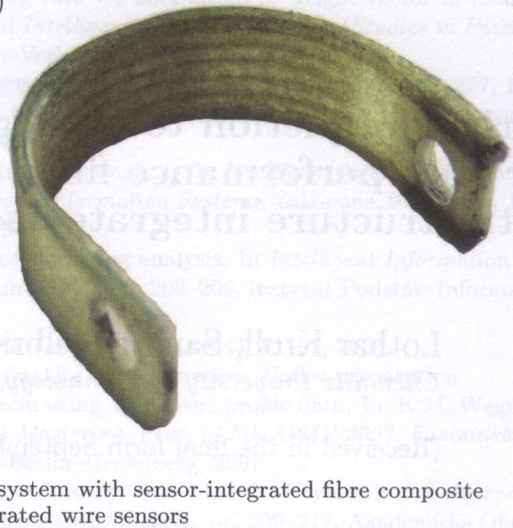
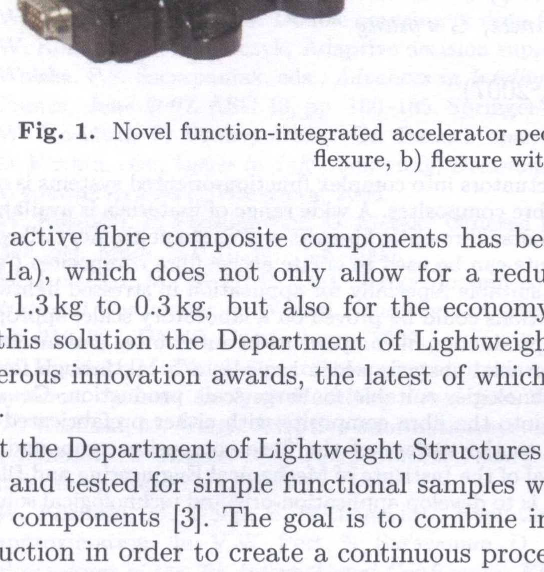


Fig. 1. Novel function-integrated accelerator pedal; a) system with sensor-integrated fibre composite flexure, b) flexure with integrated wire sensors

with active fibre composite components has been designed, produced and successfully tested (cf. Fig. 1a), which does not only allow for a reduction of part variety from 13 to 3 and of weight from 1.3 kg to 0.3 kg, but also for the economy of mounting processes and production costs [2]. For this solution the Department of Lightweight Structures and Plastics Processing has received numerous innovation awards, the latest of which at the EIMA International in Bologna in October 2006.

At the Department 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 [3]. 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)



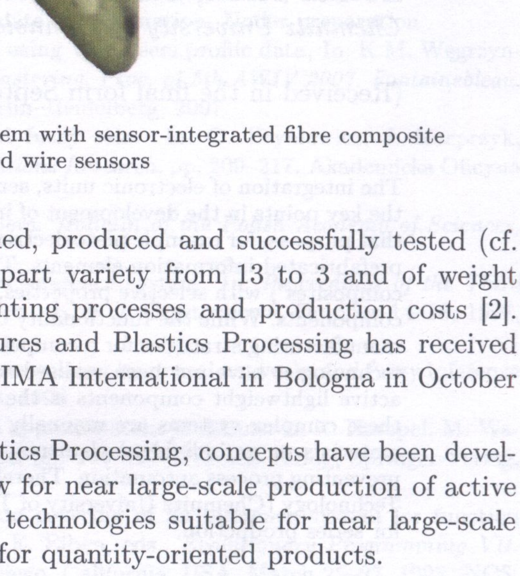


Fig. 2. Design of a two-dimensional wire sensor produced with stitching technology; a) diagram of stitched wire sensor, b) sample of mechanically produced wire sensor

This approach also marks the development of a flat sensor system for which a two-dimensional wire sensor (cf. Figs. 2a,b) is fixated and integrated into a laminate (cf. Fig. 1b) by means of stitching, which is suitable for large-scale production. First pilot tests show a high reproducibility of the test readings and the possibility of differentiation between stress directions in the measuring section [4].

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.

3. Intelligent fibre reinforced lightweight tension rod system

Another interesting application of the new stitched wire sensor is the development of an intelligent fibre reinforced lightweight tension rod system as static element in supporting structures. The largest area of application of tension rods are industrial halls, constructed by combinations of wood glue binders and tension rods. State of the art is to apply such tension rod systems made of steel.

The disadvantages of steel are the high weight, corrosion, fire protection and the increasing steel price. Furthermore monitoring, which is important in case of overloading (snow), of steel tension rods is complex and time-consuming in the execution. The aim of our development was to eliminate these problems by the use of new intelligent lightweight composite materials, including new stitched wire sensors.

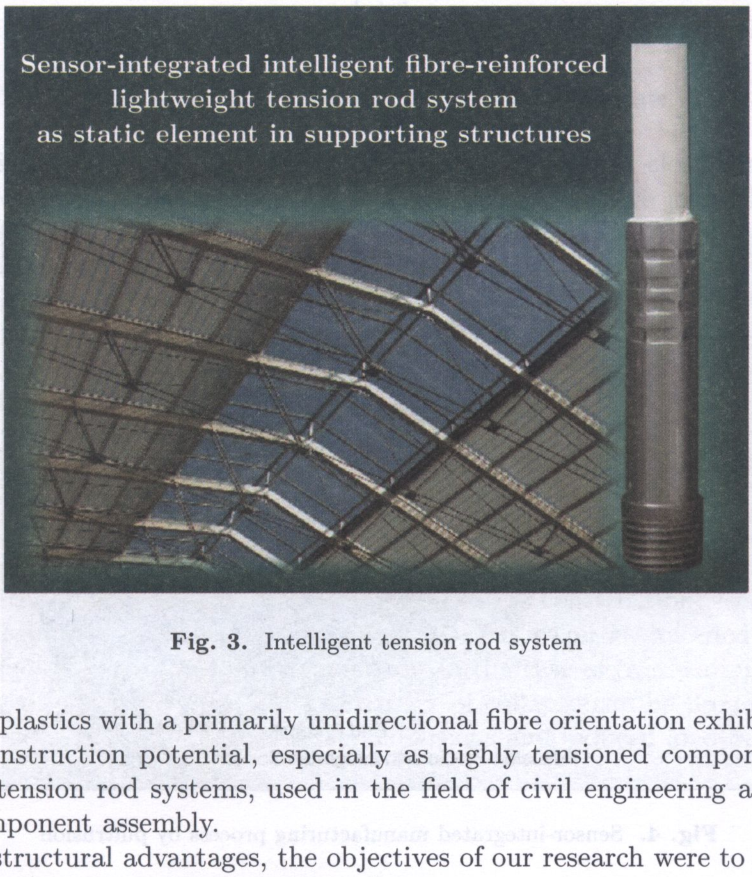


Fig. 3. Intelligent tension rod system

Fibre reinforced plastics with a primarily unidirectional fibre orientation exhibit an extraordinary high lightweight construction potential, especially as highly tensioned components and constructions. Lightweight tension rod systems, used in the field of civil engineering and bridge building, are part of this component assembly.

Based on these structural advantages, 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,
- optimized load transmission in the connecting region,
- flexibility in execution, rapid machining and assembly,
- low weight combined with great strength,
- low flammability, low flame spread, heat release and high temperature resistance (fire-resistant resin),
- corrosion and weather resistance,
- low costs for the material, transportation and assembly,
- new integrated sensors to monitor the tension rod system.

3.1. Structure of the fibre reinforced lightweight tension rod system

- Construction:
  - Tension rod system made by glass reinforced plastics (GRP)
  - Fibre orientation: unidirectional; high fibre volume fractions
  - Integrated stitched wire sensors for tension rod system monitoring
- Components:
  - Fibreglass reinforced plastics
  - Thermosetting polymer resin matrix (with a low flammability)
  - Rovings made of fibreglass; continuous filaments
- Manufacturing:
  - Pultrusion

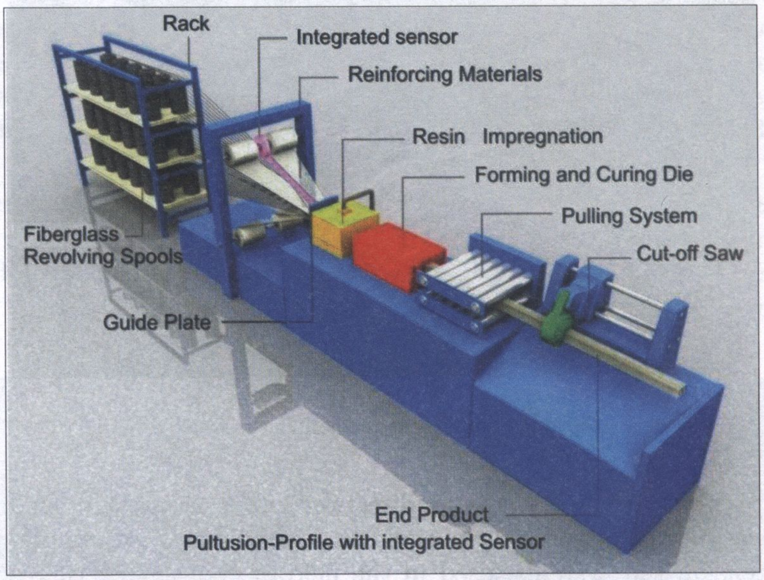


Fig. 4. Sensor-integrated manufacturing process by pultrusion

3.2. Load transmission systems

The development of a load transmission element was necessary to transfer the load into the construction. Therefore a metal element specially dimensioned for the material and the loading was designed.

For load transmission we selected a combined connection composed of a pressing connection and a bond connection. To realise the pressing connection we designed and dimensioned a special press outline that can be positioned on the surface of the metal bush. By using the developed jointing clamp and the appropriate die plate, the outline application is possible (Fig. 5). The pressing operation can be executed by a hydraulic compression press. This press can apply an accurately defined forming pressure.

To generate a new combined connection with better properties, the pressing connection was added by a special adhesive joint. As a result of our development, a new combined connection is

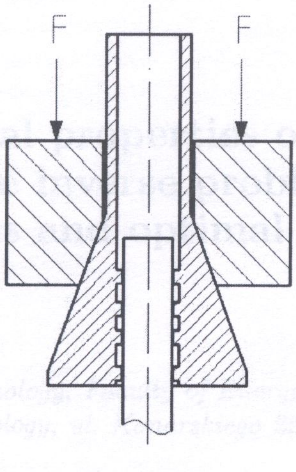


Fig. 5. Jointing clamp and the appropriate die plate

provided. With this new adhesive and pressing connection the form closure and force closure of the pressing connection will be added by the strength of the adhesive joint. This is a purposeful interaction of different connection categories [5].

With this connection a tensile load of about 70 kN (350 MPa) is possible. In comparison to steel the tensile load of the new fibre reinforced lightweight tension rod system is about 20 percent higher.

3.3. Sensor system

Furthermore, the intelligent lightweight tension rod system includes new stitched wire sensors. During the process of Pultrusion the new sensor system will be integrated in the matrix of resin and fibres (Fig. 1). After assembly and installation, the sensors will be contacted and calibrated according to the load profile.

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

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