

**Process Monitoring.** A new on-line inspection system for non-contact quality control during the manufacture of fiber-reinforced polymer structures can pick up problems early and thus reduce scrap rates. The measurement head at the heart of the system inspects the surface of the part under test with a camera whilst an integrated laser light section sensor acquires its geometry.

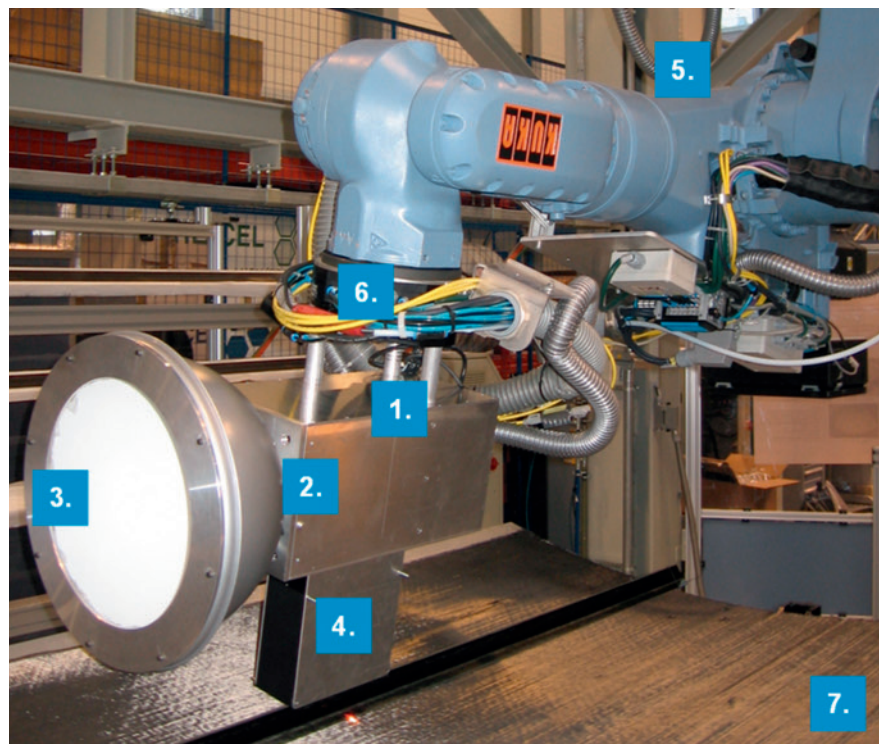
# Looking Right into the Texture

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The areas of application for fiber-reinforced plastics are continuously expanding, since they offer an excellent combination of good mechanical properties and low weight. The starting point for fiber-reinforced plastics are textile preforms that are prepared from individual layers cut from textile stock. The manufacturing process involves numerous manual operations, which leads to high costs. In order to reduce costs and improve reproducibility automation of both the production as well as the quality control processes is desirable.

The InnoNet project Falcon (Fiber Automatic Live Control) has taken up the second challenge, that is the automation of the quality control (see box on the next page). Within this project an on-line inspection system for the automation of quality control during the manufacturing process of fiber-reinforced plastics (FRP) was developed. At the heart of this innovative system is a measurement head comprising an optical camera and a laser light section sensor. This combination allows for non-contact quality control: Whilst the camera inspects the surface the laser light section sensor acquires the geometry of the part under test (Fig. 1).

Defects can thus be recognized early and scrap rates reduced, which alongside economic advantages also makes a contribution to environmental protection. A pilot system that has been integrated into a production cell with a gantry robot at CTC GmbH in Stade, Germany, is currently undergoing practical testing (Fig. 2).



**Fig. 1. Falcon Measurement Head.** 1: robot head, 2: camera sensor and objective, 3: diffuse dome illumination, 4: laser light section sensor, 5: gantry robot, 6: automation interface, 7: test object

## Comprehensive Inspection

Various assessments relevant to product quality can be carried out with the Falcon system during the manufacture of fiber-reinforced plastic structures:

- Material inspection,
- global assessment of the fiber orientation,
- inspection of the edge segmentation of semi-finished textile products,
- inspection of the geometry,
- surface inspection after the laying up of individual layers.

The material inspection ensures that the correct semi-finished product with the required material type (carbon, glass or aramide fibers) and the correct binding structure (e.g. non-crimps, woven) is

used. The global inspection of the fiber orientation guarantees that the correct side of the material is facing upwards and that the fibers are correctly orientated [1].

In order to ensure that the pre-cuts are correctly positioned on the preform after being laid up their edges are initially roughly segmented [1]. During the inspection of the geometry the laser light section sensor looks at the precise path of the contours [2]. In addition the dimensional tolerances of the cut stock can be assessed before being laid up.

The surface analysis recognizes foreign bodies and areas of damage as well as the local fiber orientation after lay up or draping of the cut stock (see below).

The inspection system includes a database that has three functions. Firstly it

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**Fig. 2. A Falcon pilot system is currently undergoing industrial trials at CTC GmbH**

records all quality relevant information concerning the material used and the production techniques in a knowledge base.

Secondly it organizes the test schedules for each component and work step which individually designate which tests have to be performed. This also includes definitions of parameters, specified values and tolerances.

Thirdly the test results for each inspected part are archived in the database

under a unique identifier. In this way the traceability of quality indicators during the entire manufacturing process and beyond is guaranteed.

### Surface Inspection

During the manufacture of the preform the cut stock is laid down in multiple layers and where necessary draped in a three-dimensional form. The forces applied to

the material during this process can influence its quality. Overstretching of the material during draping can lead to the formation of gaps and fiber displacement can occur. Fiber displacements lead to a deviation from the specified fiber orientation. Adhering to the specified fiber orientation is critical for the loading capacity of the component part and therefore must be ensured by the inspection process.

At the Fiber Institute Bremen e.V. (Fibre) using the Intel Open Source Computer Vision Library [3] a software library was developed that provides image analysis techniques for optical quality control of the surface. The library integrated into the Falcon inspection system contains functions for the recognition and assessment of surface defects and foreign bodies as well as the inspection of the fiber orientation.

### Surface Defects and Foreign Bodies

Gaps are a significant defect that occurs mainly with non-crimps. A gap is formed when rovings in the upper fiber layer have been displaced or are missing. Thus the fibers in the layers beneath can be seen through the resulting openings. A newly developed segmenting technique using diffuse illumination recognizes the affected areas from the deviations in the fiber orientation (Fig. 3).

The recognition of foreign bodies, such as film remnants, is based on a special further development of a technique for detecting fiber abrasion, so-called fuzz balls [4] (Fig. 4). It detects when the texture in the affected surface does not show a defined preferred direction but is instead randomly orientated. This is also the case when for example film remnants are stuck to the material (Fig. 5).

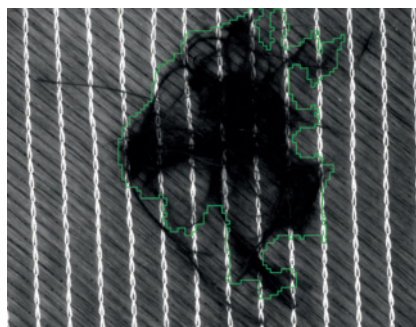
The defects and foreign bodies are automatically measured according to the test protocol and assessed according to the tolerances for the respective defect type. ▶

## The Project Partners

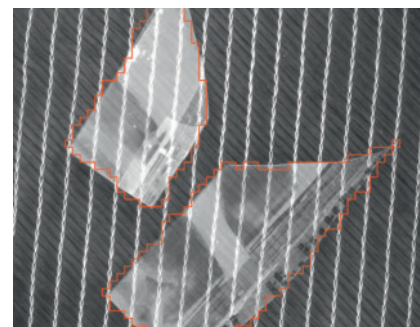
**InnoNet** is an initiative of the German Ministry of Economics and Technology aimed at supporting innovation networks that improve innovative strength and competitiveness of medium-sized companies and help bring research and development results more quickly into the market. The program was designed as a competition for ideas. The Falcon system was developed as part of one of the winning projects in cooperation between the following research institutes: the Laboratory for Machine Tools and Production Engineering (**Werkzeugmaschinenlabor – WZL**), the Institute of Textile Technology (**Institut für Textiltechnik – ITA**) of the RWTH Aachen University and the Fiber Institute Bremen (**Faserinstitut Bremen e.V. – Fibre**). ITA's task was to integrate the system into the manufacturing process. WZL took a leading role in the development of the inspection system. Fibre was responsible for the development of the Falcon database and the image analysis inspection methods for the surface assessments. The project consortium was supported by the sensor manufacturers **Basler AG** and **NoKra GmbH** (camera and laser sensors respectively), **Gimpel Ingenieurgesellschaft mbH**, two manufacturers of fiber-reinforced polymer structures (**Invent GmbH** and **Advanced Composite Engineering GmbH (ACE)**), **Advanced Fiber Placement Technology BV (AFPT)**, a supplier of FRP technology as well as **Composite Technology Center Stade GmbH (CTC)**, an FRP end customer in the aerospace sector.



**Fig. 3. The system recognizes gaps in the structure**



**Fig. 4. The system recognizes fuzz balls on the surface**



**Fig. 5. Recognition of film remnants**

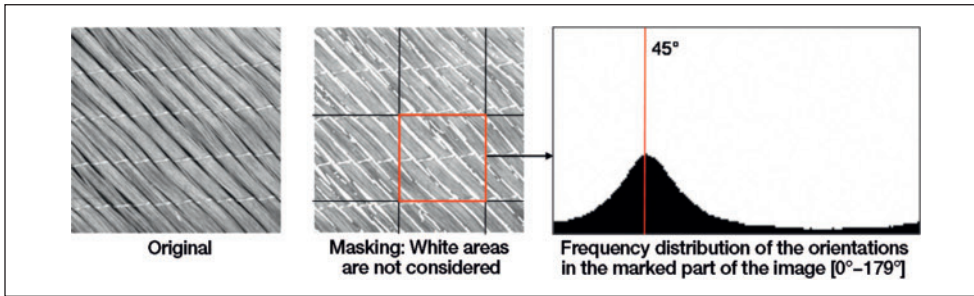


Fig. 6. The basic principle of fiber orientation measurement [3]

### Fiber Orientation

The technique for measuring and evaluating deviations in the local fiber orientation is based on the earlier work carried out in the Pro-CFK Prosa project [4, 5]. This involves rasterizing the surface being inspected into rectangular areas. With the help of an isotropic gradient filter [6] it is possible to measure the texture orientation at every relevant pixel within the area. The frequency distribution of this texture orientation is evaluated and the fiber orientation for the area determined (Fig. 6). The size of the areas is laid down in the test protocol. The measurement result is a matrix that gives an angle for each area. To assess the fiber orientation the measured angles are com-

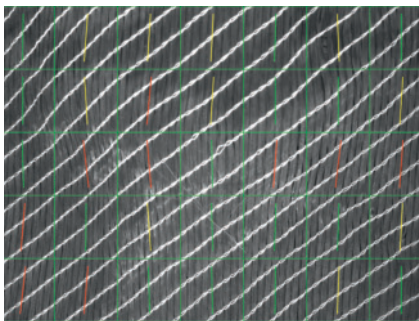


Fig. 7. Measurement and evaluation of the fiber orientation. Specified angle 90°, tolerance 1 ± 2°, tolerance 2 ± 4°, green: good, yellow: questionable, red: unacceptable

pared to the specified orientation. Based on the camera position a definite (x,y,z) position can be calculated for each measured angle. The test protocol contains the specified angle for the test area that is also linked to a global positional value. For level areas a single angle is often sufficient. If the material has been draped then various local specified angles apply. Every measured angle is automatically compared with the nearest specified angle. This means that only as many specified angles as required are stored and that the inspection process works independently from the rasterization selected for the measurement. The assessment of the fiber orientation is carried out using two tolerances in respect of the allowed deviation from the specified angle and results in a classification as good, questionable or unacceptable (Fig. 7). Green angles are rated as good, yellow as questionable and red as unacceptable. A detailed description of the technique can be found in [5, 7]. ■

#### ACKNOWLEDGEMENTS

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