IMPROVEMENT OF PRODUCTIVITY AND QUALITY IN THE WIND ENERGY INDUSTRY THROUGH THE USE OF AN ADVANCED SENSOR SYSTEM

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ABSTRACT

Renewable energy from wind has become an important economic factor over the last decades. As well as in many other industrial sectors, two key success factors are the high productivity at low cost and the high quality. This paper focuses on the improvement of these factors for rotor blades manufacturing. Our approach compromises methods from Industry 4.0 and utilises a new intelligent sensor system which enables a real-time monitoring of on-going resin properties during the manufacturing process of the rotor blade.
The development of the sensor system was performed on different levels, starting on lab-scale and ending in real production processes. Durable non-intrusive sensors as well as flexible sensors have been used for the sensing of resin arrival, viscosity and curing as well as to reveal mixing ratio deviations. The sensor system post-processes the data and provides real-time material state information (viscosity, degree of cure and glass transition temperature) and all the necessary information for process automation and control. The investigations on lab- and full-scale test show the high potential of the sensor system for automating a significant part of the production in the wind energy industry.

1. INTRODUCTION

The wind energy sector boasts one of the highest growth rates for all renewable forms of energy. In order to support this positive further development, companies invest many efforts in optimising every realisation step of a wind energy converter. This means to decrease development times, to improve the capabilities of the supply chain, to enhance the quality of the manufactured components or to slim down processes and increase the efficiency of the production. In parallel the dimensions of wind turbines have changed dramatically. Over the last 40 years the heights of towers increased from around 30 to over 130 m and the rotor diameter grew from 15 to over 130 m. Together with these changes the usable rotor circular area, the energy yield and last but not least the output increased significantly [1]–[3].
Main cost drivers of wind turbines are the tower, the generator, the transmission and the rotor blades. For a modern converter the rotor blades are accountable for approximately 20 to 30 % of

the invest costs for the complete system [4]. This fact shows the enormous importance to optimise the production processes of the rotor blades. While the wind turbine is more or less related to mechanical engineering, the basics of the rotor blade technology can be found in lightweight design and aerospace engineering.

2. STATE OF THE ART

Wind turbine rotor blades can be characterized as thin-walled, multicellular composite beam structures. They are designed for a designated lifetime of 20 to 25 years and to bear highly dynamic multi-directional loads. Issues with these critical elements of a wind turbine are responsible for 8 to 20 % of the total downtime of a wind turbine. Thus, reliability is a crucial aspect, since the structures shall ideally remain free of failure under ultra-high cycle loading conditions throughout their operating time [5], [6]. Therefore, a lot of research and development efforts focus amongst others on predictive numerical models or structural health monitoring [5], [7], [8].
The main components are two outer shell halves with integrated spar caps and an inner shear web. The shear web and the spar caps act as an I-beam structure inside the blade. This results in an improved ratio of weight and mechanical properties [3], [8]. A schematic cross section of a composite blade is illustrated in Figure 1.

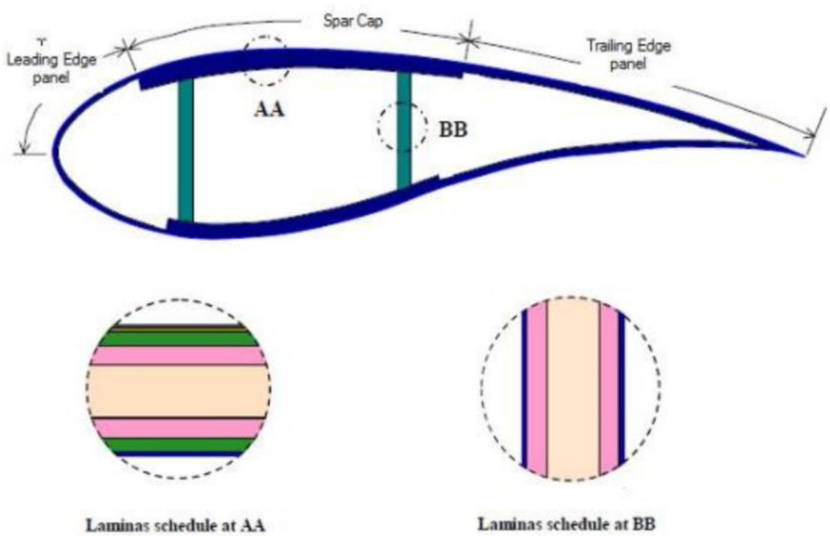

Figure 1: Cross section of a composite blade [3]

Modern rotor blades are typically manufactured using fibre reinforced plastics due to their high specific strength and stiffness properties (Figure 2). Currently, glass fibres are extensively used because of their balanced ratio between reliable mechanical properties and cost efficiency. Besides, the use of carbon fibres increased during the last decade. Reasons can be found in the improved mechanical properties, especially stiffness, which is required for larger blades depending on the specific design [2], [6], [9].

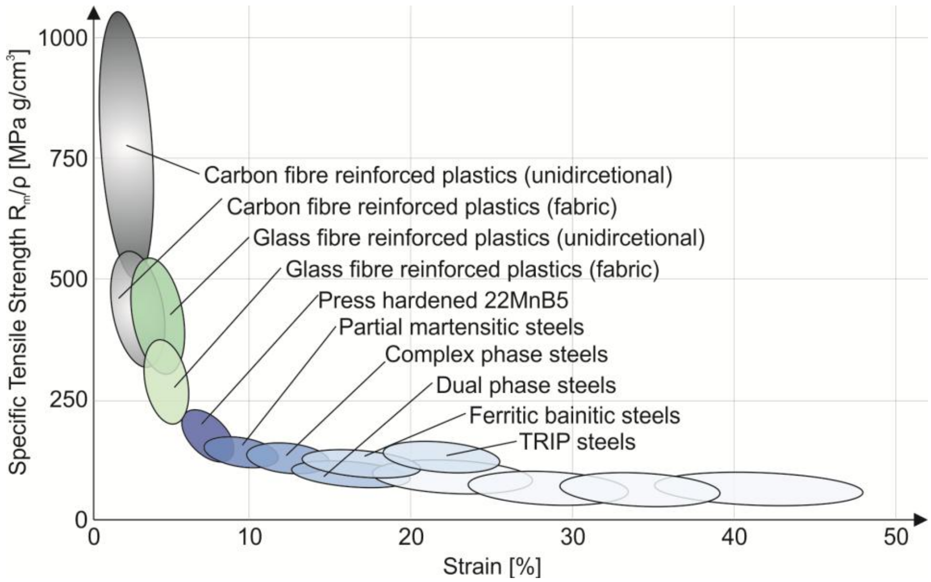

Figure 2: Mechanical properties of construction materials

3. PRODUCTION PROCESSES FOR ROTOR BLADES

Many of the several players in the wind market have own specific structural designs for their rotor blades. The design again affects the manufacturing processes. One widely used technique is a construction, where the structure is parted into two pieces (Figure 3). Here the process is divided into a prefabrication of components, e. g. shear webs or spar caps, the shell fabrication and a bonding procedure. The separation into different work packages leads to specialised processes and offers potentials concerning optimisation approaches, quality control, cycle times, costs or labour organisation.

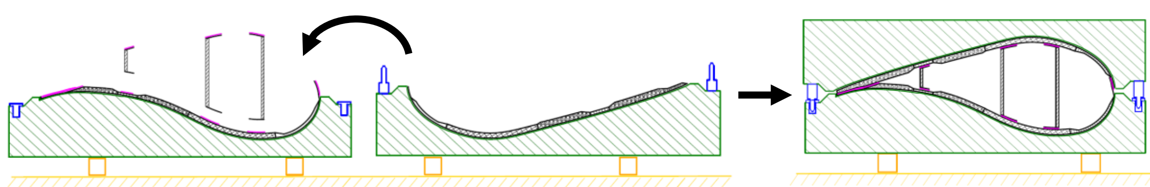

Figure 3: Widespread production method for rotor blades

Advanced moulds are used for the production of rotor blades. A typical main mould set consists of suction and pressure side (Figure 4). A hinge system enables the lifting and rotating of the one half of the mould in order to close the blade (Figure 5).

The production of rotor blades can be divided into three main topics (Figure 6). First, prefabricated components, e. g. spar caps, shear webs or root inserts, are manufactured. These structures are used in the shell and green body production. After application of an adhesive the mould is closed and the prefinished rotor blade can be transferred to the finishing process. For the manufacturing of every fibre-reinforced plastic structure vacuum infusion processes are used. Even today the blade manufacturing is largely still a manual process [8].

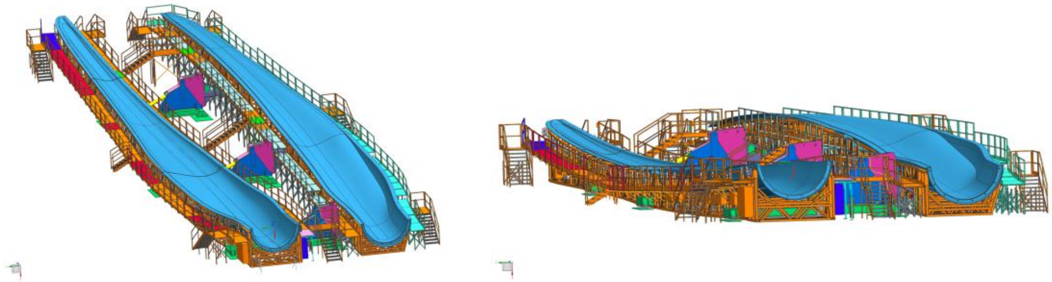

Figure 4: Main mould set of a wind energy rotor blade

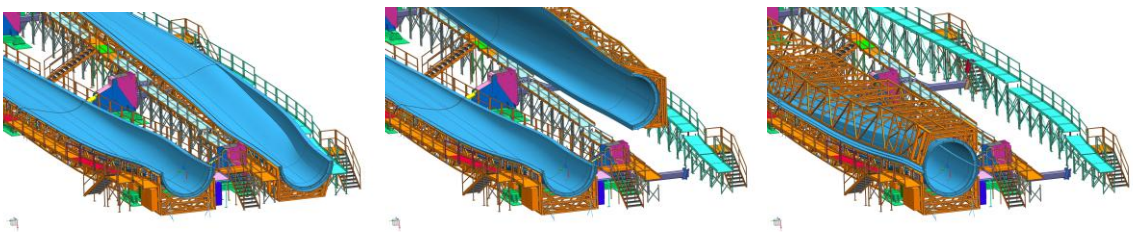

Figure 5: Closing process of the main mould

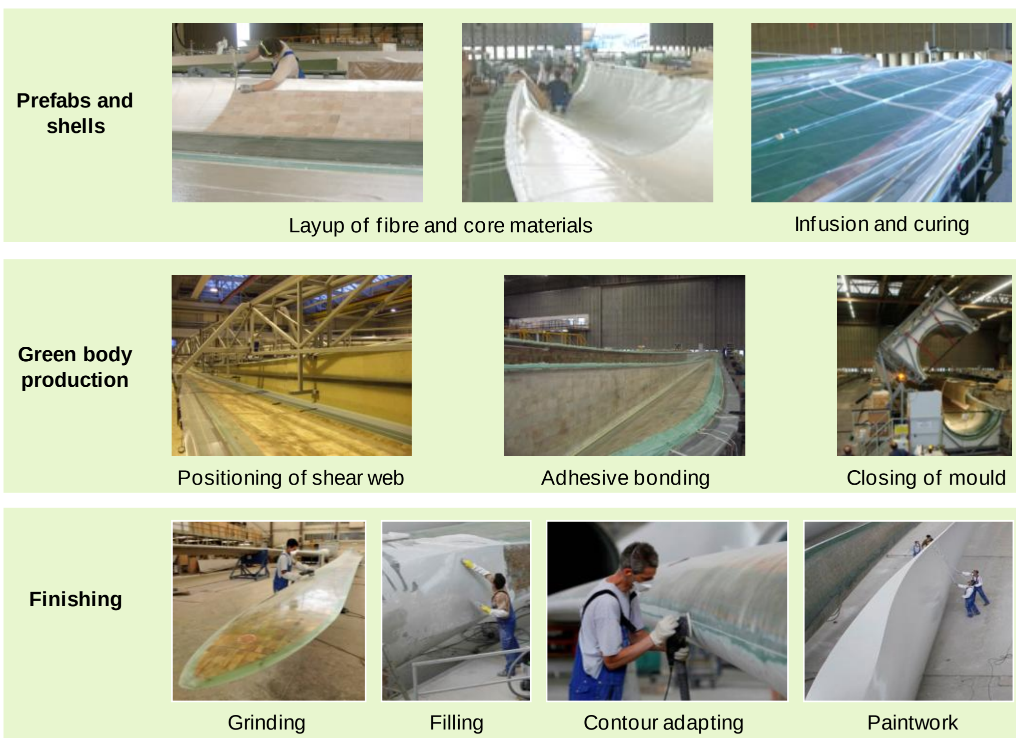

Figure 6: Production steps for rotor blades

An adequate process control is important to fulfil highest quality requirements at low cycle times. Manufacturing flaws can cause problems during the operating time of a wind turbine, which in turn can result in costly repairs and downtimes [10]. This were the starting points for the development of an advanced sensor system to improve quality and productivity aspects.

4. SENSOR SYSTEM

It is widely accepted [11], [12] that the measurement of the electrical resistance of a resin using DC-based measuring systems such as the Optimold system from Synthesites is directly related to the viscosity and, as a result, to the T_g of a thermoset resin. Across these lines, Synthesites has developed a proprietary technology for the online estimation of the development of the T_g and/or the degree of cure not only in the lab but also during production. In this framework and in order to facilitate the use of this system in wind blade manufacturing, Synthesites developed a new durable sensor specifically for vacuum bag applications. As can be seen in Figure 7 left the durable sensor has a wide area where the vacuum bag can be attached and secured quite easily. This durable sensor can be integrated at the top of the laminate through the vacuum bag as can be seen in Figure 7 right in order to monitor the cure at the cure lagging area of the wind blade. In this way, the achievement of a least T_g will be ensured for the whole blade when this threshold is reached at the sensor’s location. Obviously, if a multizone heating system is used, multiple sensors can be installed at representative locations at each zone.

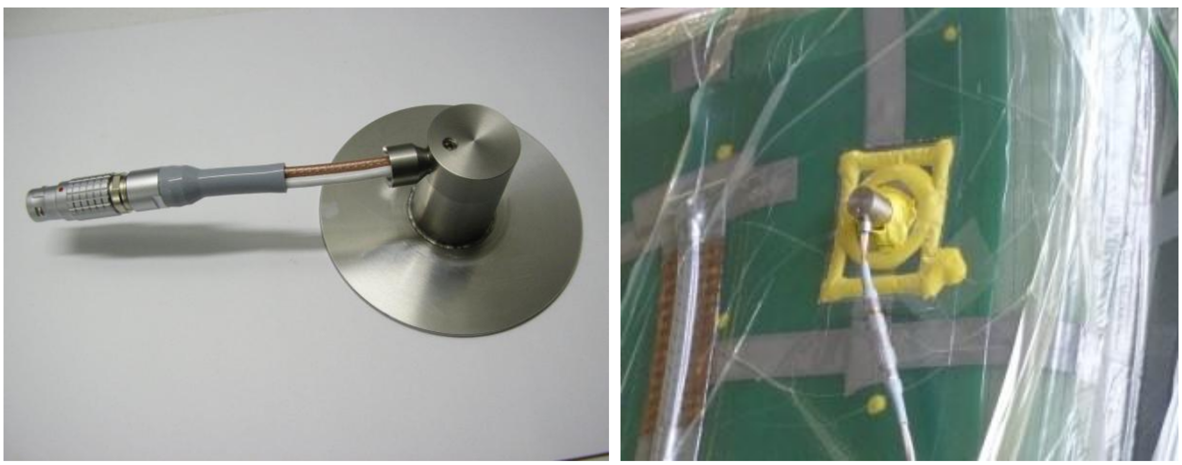

Figure 7: Left: The new durable vacuum bag sensor; Right: Installed at production

Based on the well-established theory that has been proved in practice, the electrical resistivity of a resin is directly related to its viscosity, the rising Glass Transition temperature (T_g) can be estimated online using Synthesites proprietary software, namely the Online Resin State (ORS) module. The ORS module has been developed for a specific resin that Carbon Rotec is using in production and can deal with the strongly non-isothermal conditions that are inherently seen at the wind blades manufacturing environment. The ORS module was initially developed for isothermal cases and was further extended to deal with highly non-isothermal conditions i.e. high exotherms with long cooling stages. The ORS software can run independently for each cure sensor while the online estimated T_g can be used for quality control purposes as well as for actively controlling the curing stage of the whole blade. Finally a signal can be automatically transferred to the temperature control unit to stop heating and potentially to cool down. In this way, a considerable speed-up of the curing cycle can be achieved when a specific and fully reproducible T_g level has been achieved independently of the external conditions

Furthermore a new procedure was developed to allow revealing resin mixing ratio deviations just before the infusion. Depending on the nature of the deviation certain actions can be taken ensuring quality or even abort the infusion saving tonnes of materials.

5. RESULTS

In order to test the new durable sensor and the ORS module at realistic conditions, numerous lab scale trials have been performed by Carbon Rotec in simulated production conditions i.e. representative cure cycles and laminates from a variety of wind-blade components have been tested at the laboratory. In Figure 8 a typical vacuum infusion set-up of a laminate together with cure and temperature sensors can be seen.

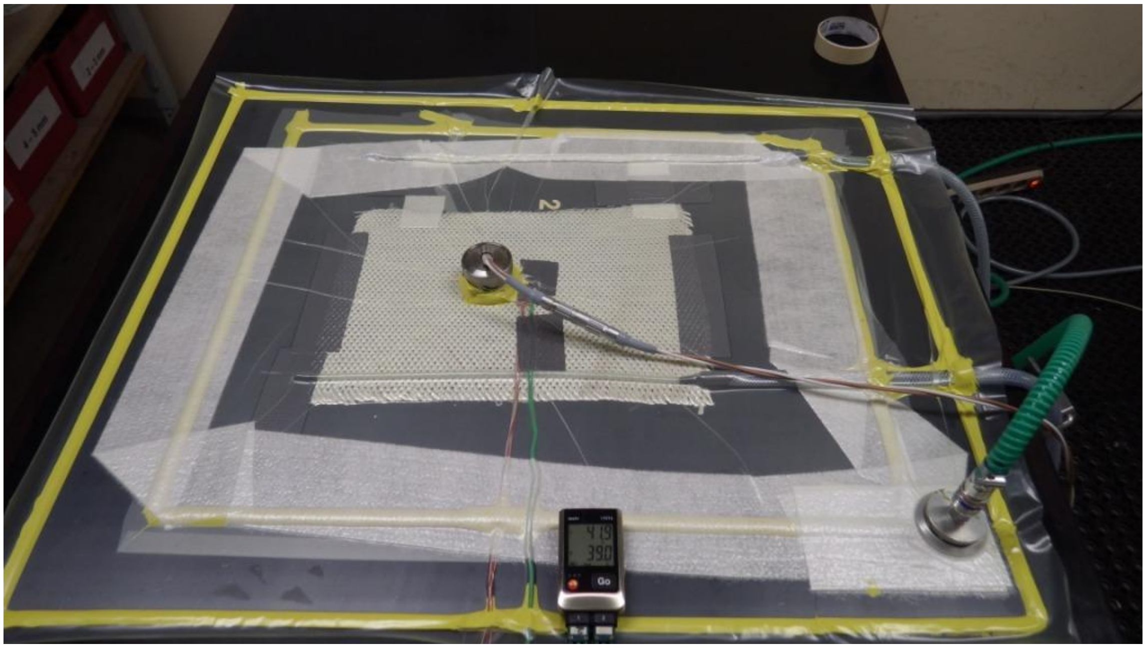

Figure 8: A typical vacuum infusion set-up of a laminate together with cure and temperature sensors on top of the vacuum bag.

In Figure 9 two representative trials are shown: one ‘almost’ isothermal at 80^oC and one highly non-isothermal that take place when curing a rather thick laminate by heating only from the lower part of the laminate. In both cases the online T_g estimation is also depicted as calculated based on the real-time values of electrical resistance and temperature measured by Optimold. Especially in the non-isothermal case the electrical resistance alone cannot provide the necessary information about curing as can be seen in Figure 9 b. On the other hand, the ORS module for the specific resin can provide an accurate and robust estimation of the on-going T_g/degree of cure.

In Table 1 a comparison between the real-time estimated T_g and the T_g calculated by DSC afterwards are provided for various representative isothermal and non-isothermal cases. As can be seen in the last column the difference between these two values is within the DSC accuracy for the isothermal and the non-isothermal cases.

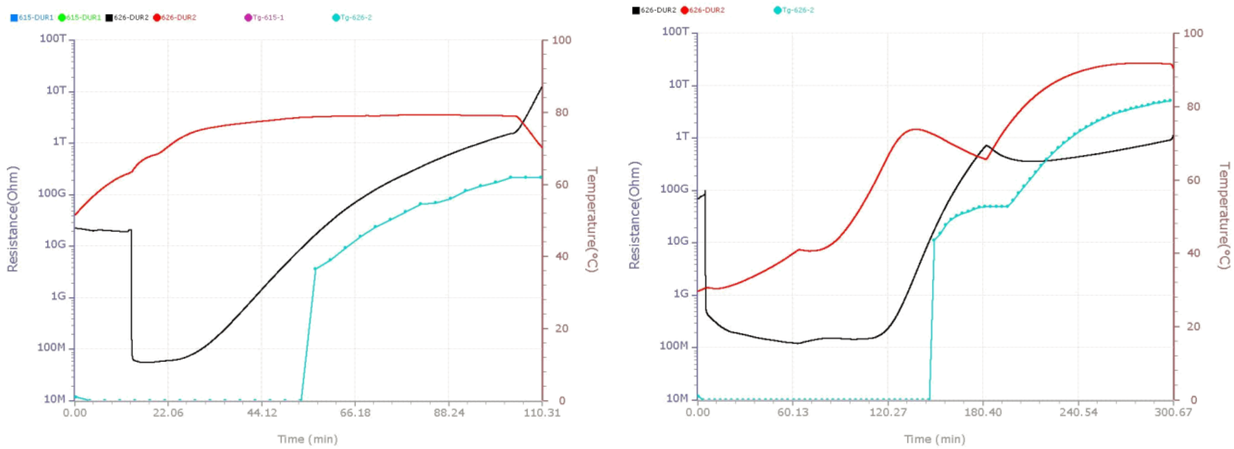

Figure 9: Typical ORS graphs showing the resistance (left vertical axis) together with temperature and T_g (right vertical axis). Left figure: Isothermal case, Right figure: Strongly non-isothermal case

	Trial	Duration [h]	T_g-ORS (^oC)	T_g- DSC (^oC)	Difference (^oC)
Isothermal	80DV1	3	73.17	73.34	-0.17
	80DV3	2.5	70.30	70.91	-0.61
	80DV4	2.5	73.45	72.49	0.96
	80-120'	1.92	66.96	66.02	0.94
	80-90'-1	1.50	62.04	61.80	0.24
	80-90'-2	1.50	65.52	65.21	0.31
	80-D2-2	1.50	61.88	60.59	1.29
	60-260'	4.33	55.02	56.51	-1.49
	70-190'	3.17	64.92	65.39	-0.47
Isothermal cases, mean difference					1.61
Isothermal cases, standard deviation					2.42
Non-isothermal	TEB1-1		61.37	59.54	1.83
	TEB1-2		69.36	70.93	-1.58
	TEB2-1		60.00	58.64	1.36
	TEB2-2		70.02	70.30	-0.28
	LESW1-1		76.97	74.35	2.62
	TESW1		71.34	69.18	2.16
	Shell1-1		80.36	78.92	1.44
	Shell1-2		75.72	77.83	-2.12
	Shell2-1		79.60	77.70	1.89
Non-isothermal cases, mean difference					2.15
Non-isothermal cases, standard deviation					1.26

Table 1: Overview of the various test cases and the difference between Tg measured online with the ORS and T_g measured right after demoulding by DSC.

Regarding the detection of mixing ratio deviations after mixing but before infusion, the new technique has been applied for the detection of hardener deviations in the order of 1uh. This means that for a recommended mixing ratio of 100:28 it was possible to detect hardener's deviations lower than 27 or higher than 29 by measuring the electrical resistance of the mixture at specific temperature. At the same time it was also possible to detect if one of the components is different from its chemical composition. Combining both tools it is possible to detect any small mixing ratio deviations and to ensure that finally the cured resin properties would reach the required specs.

6. CONCLUSIONS

Wind blade manufacturing is one of the most mature composites processes although automation has not been advanced considerably. At the present work a new cure sensor has been developed for the real-time estimation of the T_g and applied in the manufacturing of several composite components which are used for the manufacturing of the wind blade. The new system has proved robust and accurate enough even at the toughest processing conditions.

Next steps are the use of the ORS system in everyday production in order to fully evaluate the system and to plan how to integrate it within production in an optimal way. It is expected that besides the improved quality assurance and traceability at least 20% shorter cure cycles can be achieved.

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