**BladeMaker – Advancing and Demonstrating Automated Manufacturing of Rotor Blades**

Heiko Rosemann*, Roman Braun, Puneet Malhotra, Peipei Wang, Florian Sayer

Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)

Am Seedeich 45, 27572 Bremerhaven, Germany

*Phone: +49 471 14290 341, Fax: +49 471 14290 111, eMail: heiko.rosemann@iwes.fraunhofer.de

http://www.blademaker.de

**Summary**

Rotor blades for wind turbines have a significant (25%-30%) share of wind turbine costs and are determining loads and thereby costs for the other parts as well. Current labor-intensive manufacturing leads to high tolerances, requiring high safety factors and less-than-optimal parameters, and reaches its borders with current and upcoming blade dimensions. Automated manufacturing promises significant improvements leading to higher reliability, higher blade value and ultimately lower cost-of-energy for the entire turbine.

The BladeMaker research project, funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, brings together the wind industry, material suppliers, process experts and automation technology suppliers to advance current automation concepts, develop new concepts, transfer ideas from other industries and demonstrate the results in a demo center at Fraunhofer IWES capable of building 25m sections of 40m blades. Based on an extensive cost model and process analysis, BladeMaker will finally suggest parts of the blade manufacturing process to be automated for different batch sizes and quantify the expected savings in material and labor costs as well as the feedback to blade design. The target decrease in total blade cost is above 10%.

Processes in the BladeMaker scope include advanced mold concepts with carbon fiber heating systems, automated continuous and discrete (pick and place) fiber placement, automated roving placement, innovative core foam production in the main mold, automated glue application and automated finishing processes. Based on these processes, the material parameters and possibly the blade design will be adjusted to maximize the automation benefits.

## Current rotor blade production

Currently, blade manufacturing is a highly manual process, requiring highly trained personnel to manufacture blades at a constant quality. Production steps include mold preparation, dry fabric layup, vacuum infusion, adhesive application, positioning the parts, demolding, finishing and coating, most of which are conducted by manual labor as shown exemplary in Figure 1 and Figure 2.

**Figure 1 - Dry fabric layup (Picture by SINOI GmbH)**

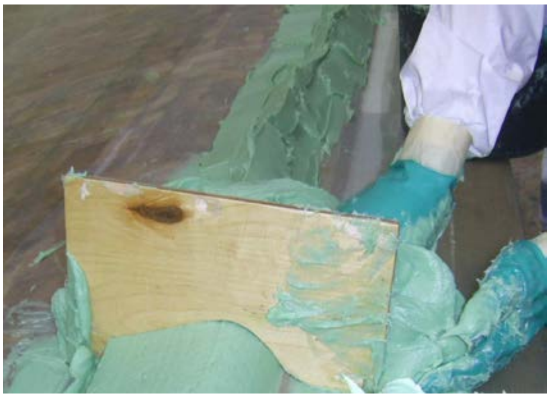


**Figure 2 - Adhesive application (Picture by SINOI GmbH)**

The quality of the blades manufactured in these processes is very sensitive to the know-how, experience and also the form of the day of the workers responsible. These fluctuations require high safety factors in the design and still lead to significant portions of discarded blades or blades that need to be repaired right out of production.

On the other hand, blade dimensions are increasing continuously, the length having already passed the 80m mark. Blades of this size, with root diameters around and above 4m, are proving increasingly difficult to manufacture manually while meeting the quality level required for offshore and modern onshore wind turbines.

## State of automation in rotor blade production

Automation is a promising approach to reduce costs and increase the reproducibility of rotor blade production quality. However, the margins in rotor blade production and also the research budgets are low and the combination of high fatigue loads over a long lifetime, low maintenance and big part dimensions is unique to wind turbine rotor blades, so the automation technologies used in other industries cannot be directly applied to rotor blades.

Automation solutions for some isolated processes exist (root-end machining, e.g. [1], coating, surface finishing) and many concepts (e.g. [2]) have been and are being developed, though not transferred to industrial production yet.

## The BladeMaker approach

BladeMaker, a research project funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, brings together the wind industry, material suppliers, process experts and automation technology suppliers to advance current automation concepts, develop new concepts, transfer ideas from other industries and demonstrate them in a demo center.

The BladeMaker project is based on an integrated view of the entire blade design and manufacturing process, identifying the costs of each step and weighing potential aerodynamic gains against increased structural and/or manufacturing complexity, leading to the answer to the all-governing question of the lowest cost-of-energy. Both blade design and material design are being adapted to maximize the potentials of automated manufacturing.

The BladeMaker project will culminate in a demo center capable of automatically building representative parts of current and improved-for-automation rotor blades, delivering a strong tool for both blade manufacturers and automation technology suppliers as well as material suppliers, process experts and research partners to develop even more advanced concepts without disturbing current rotor blade production.

## Blade design with cost model

The project is based on the probably most installed blade size, a 40m rotor blade with a blade root diameter of 1.8m, IKEA bolts, conventional separation between two shells, two pre-manufactured spar caps, two shear webs and a pre-manufactured root section. However, to also take specific difficulties with larger blades into account, a flatback transition region is included in the blade designs, as shown in Figure 3.

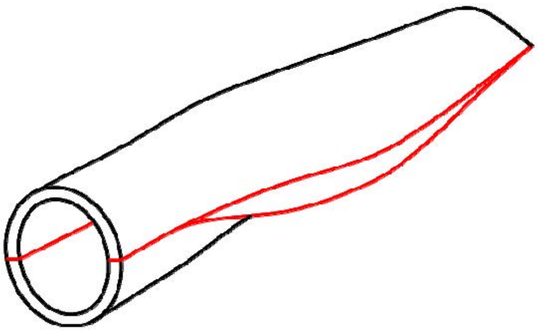


**Figure 3 - Snapshot of BladeMaker blade design**

The BladeMaker research project is based on prior work in [3], detailing costs of current blades in the 40m range. Further analysis based on the blade design shown above leads to a detailed cost model for conventional blade manufacturing, an overview of which is shown in Figure 4.

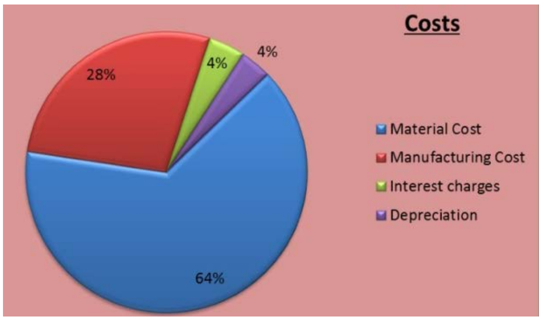



**Figure 4 - Primary cost factors in blade manufacturing**

This overview already demonstrates the potential in decreasing material costs for having an impact on total rotor blade costs. Labor costs are not as dominant as a quick glance on current production sites would suggest.

This fact particularly rules out using special materials like pre-impregnated fabrics which are significantly more expensive and require higher handling costs than conventional materials just to decrease labor costs.

## Materials and Process Technology

Automating certain processes may offer many options to use new or improved materials offering lower prices and/or higher performance than those currently in use. For some processes, the larger possibilities in material selection already pay off the automation investments, whereas in other processes, certain changes to conventional materials will greatly facilitate the automation. The BladeMaker research project integrates all the required material suppliers ready to implement these changes in fibers, fabrics, resin, foam, adhesive, binder etc.

## Continuous fiber placement

For placing non-crimp fabrics into the geometrically complex blade shell directly off the roll, the BladeMaker research project is developing an advanced fabric placement head. This placement head will also constitute a fall-back solution for the spar cap manufacturing within the BladeMaker project.

## Roving placement for the spar caps

Replacing non-crimp fabrics, currently widely in use for making pre-manufactured spar caps, with rovings has a high potential for material cost savings. Two different strategies are being investigated within the BladeMaker project:

1. Dry fiber placement using binders
2. Wet fiber placement

While the second option leads to a wet and dirty process, preliminary infusion tests (specimen shown in Figure 6) show a tendency for tightly packed rovings to make a reliable vacuum infusion very difficult, so currently the project slightly favors the second option.

**Figure 5 - Infusion test on dry rovings**

## Pick and place fiber placement

For placing many pieces of non-crimp fabrics with manageable dimensions into relatively small parts of the blade, e.g. the blade root, the BladeMaker project is investigating concepts for a pick and place process, picking pre-cut materials up and draping them into the mold. A preliminary concept of such a process is shown in Figure 7.

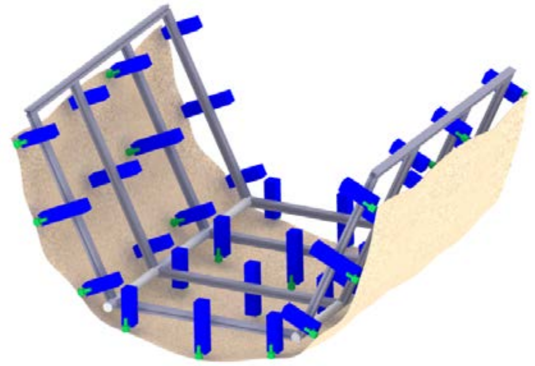


**Figure 6 - Preliminary concept for pick and place fiber placement**

## Surface finishing

BladeMaker also addresses the surface grinding and shaping processes, which – when executed manually as common today – both require many man hours as well as creating a dusty, unhealthy work environment for humans.

**Figure 7 - Belt sander prototype for grinding and polishing (Picture by Jöst GmbH)**

A belt sander as shown in Figure 8 with highly effective geometry adjustment and dust extraction will make these processes less cost-intensive and lead to a higher overall blade quality, especially eliminating the reliance on the form of the day of the workers.

## Automated adhesive application and bonding

Current adhesive application processes require a high amount of excess adhesive to ensure no spots without adhesive. An automated adhesive application as developed within the BladeMaker project helps reducing the waste adhesive through more precise proportioning and will be quicker than manual application, thereby allowing for new adhesives with shorter setting times. Together with improved bonding processes, also developed within BladeMaker, the accuracy of bonding the blade parts will be greatly increased and the effort required in finishing the blade will be reduced significantly.

## New tooling concepts

Another very promising part of the BladeMaker project constitutes of new tooling concepts, in which the blade molds are no longer made from a master part but instead directly milled into a mold material. Onto this raw mold, a carbon fiber heating layer and some additional erosion layers will be laminated. This process promises great savings in mold costs particularly for small series of one blade type, thereby increasing the flexibility of blade manufacturers to make smaller series as well.

## Feedback to blade design

While the BladeMaker research project is based on a blade design that can also be manufactured conventionally, automation technology will probably benefit from slight changes in blade design and the blade design can gain additional degrees of freedom by focusing on automated processes such as roving placement. The BladeMaker research project aims to develop a unified blade design, combining aerodynamic, structural and manufacturing design resulting in optimum Cost of Energy and also building the toolchain required to connect directly into the automation hardware.

**BladeMaker demo center**

Market research conducted in preparation of the BladeMaker project has shown the lack of a demonstration ability to be a big show-stopper for the move to automated rotor blade manufacturing.

Automation suppliers and research projects, often coming from the aerospace industry, have developed many concepts to automate rotor blade production, but very few processes can be demonstrated on or close to full scale. Rotor blade manufacturers are ready to automate their manufacturing (at least in parts) as soon as they are convinced by working prototypes close to the size of a real blade, with realistic layer properties and laminate thicknesses, that the investments are justified.

To overcome this shortness, BladeMaker has developed and will build up a cost-effective demo center at Fraunhofer IWES in Bremerhaven, Germany, a concept of which is shown in Figure 9. It will be capable of building the root section and the transition region of a 40m rotor blade (which are deemed the most critical regions), through any and all steps deemed reasonable for automation.

The demo center can be adapted to demonstrate different processes, though it will not be a production facility, lacking the facilities required to quickly switch between different processes and the storage space to build entire blade series. Upscaling the dimensions to accommodate current and upcoming blade sizes (particularly length, max chord and root-end diameter) has been taken into account in the entire design process, as well as the adaption of the base process technology to different production hall environments.

The BladeMaker demo center is scheduled to open in 2015 and designed to provide an open-access, low-threshold automation demonstration capability to automation suppliers, rotor blade manufacturers and research partners during and after the project duration.

Most of the processes developed within BladeMaker will make use of the heavy-duty z-axis (up to 500kg load capacity) with six degrees of freedom. Even higher loads can be transported on top of the gantry bridge to be close to the process. For maximum flexibility the BladeMaker demo center will also include a medium payload industrial robot, seamlessly included in the control system of the gantry.

**Figure 8 - Planned BladeMaker demo center**

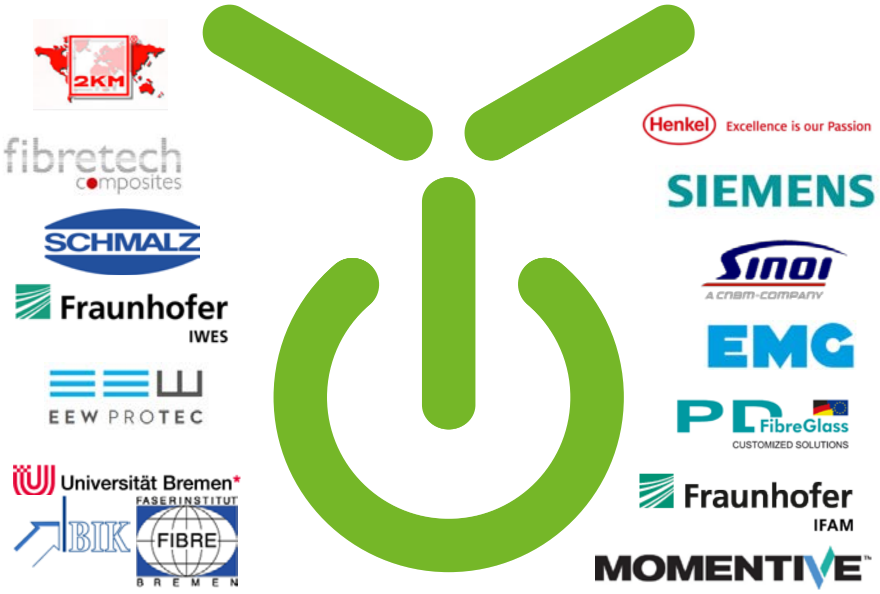
## Conclusion

Automated rotor blade manufacturing offers high potentials for quality increase and cost decrease of rotor blades, significantly decreasing the cost-of-energy of the entire turbine over its lifetime. The BladeMaker research project is the first to bring players from all relevant fields together and develop many different automation aspects, demonstrating the results in the BladeMaker demo center and keeping an overview on the cost, blade design and quality impacts of these aspects.

The BladeMaker demo center will allow blade manufacturers and automation technology suppliers to gather first-hand experience with large-scale automation processes without disturbing the running blade production. It is designed to build the relevant parts of blades with a length of 40m, but the design keeps in mind the need to upscale the dimensions to accommodate blades with a length of 80+m and root end diameters in excess of 4m. It will provide bits and pieces for blade manufacturers to choose the automation steps they benefit the most from.

The growing sizes of today's rotor blades will add pressure to automating parts of the rotor blade production because workers simply have a hard time reaching certain points of large rotor blades coming to market in the next years.

## Project partners

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