PO.ID 127

# Very large wind turbine rotor blades require damage tolerance and damage monitoring

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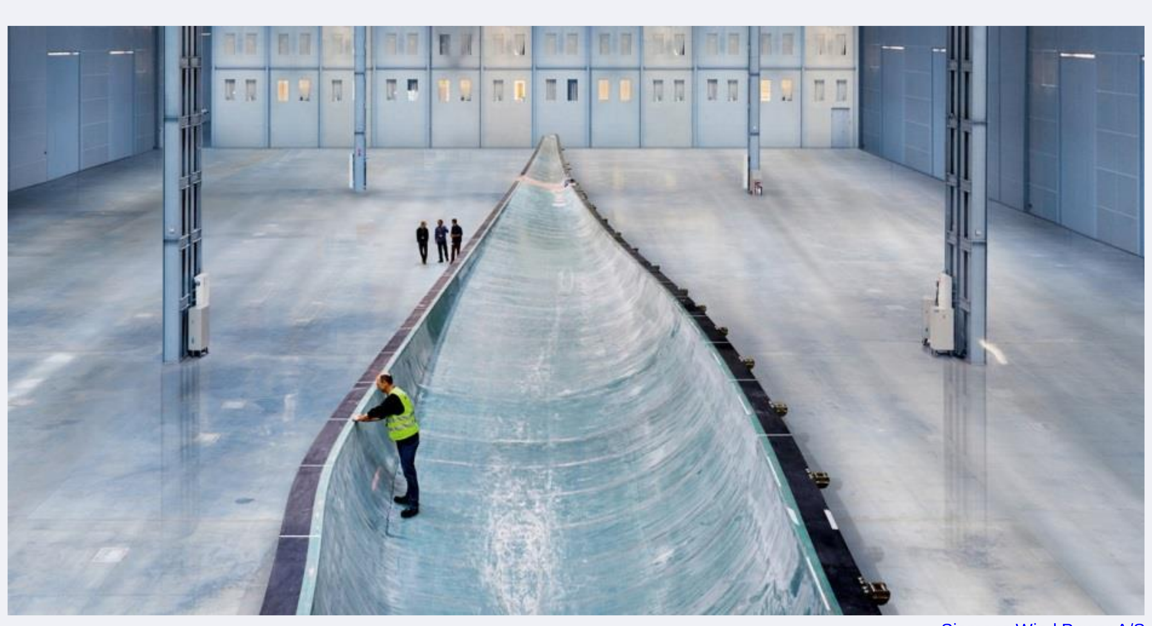
## Background and introduction

The most effective way of increasing the power produced per wind turbine is to **increase the length of the rotor blades** as the produced energy is proportional to the swept area. A major challenge is to design future very large rotor blades so that they can endure minimum 20 years of service in a harsh off-shore environment.

Rotor blades are made as **very large parts** using relative low-cost fibre composite materials and low-cost manufacturing methods. It is not possible to manufacture "perfect" blades. Setting high quality control (allowing only blades with small manufacturing defects) leads to a high rejection rate, which is not attractive since large blades are costly.

Since each blade will have different **manufacturing defects** and will be subjected to different loading histories, it will undergo its own unique damage evolution. Having no detailed information about the manufacturing defects and loading history of each blade, it is **not possible to make accurate prediction of the lifetime** of blades individually.

Regular manual inspection is neither an economical nor a technical efficient solution, since **manual inspection** of off-shore wind turbines is costly and difficult.



Siemens Wind Power A/S

**Mold for the manufacturing of a 75 m long wind turbine rotor blade made of glass fiber / epoxy resin and balsa (above). The rotor blade casted as a single component (below).**

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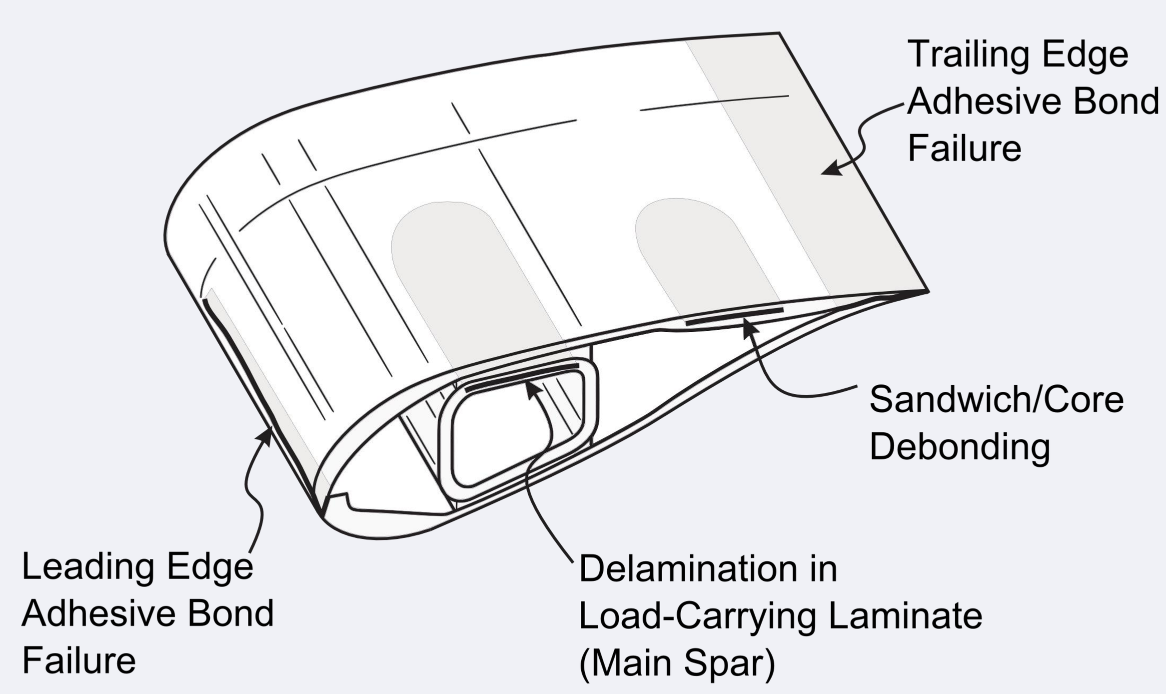
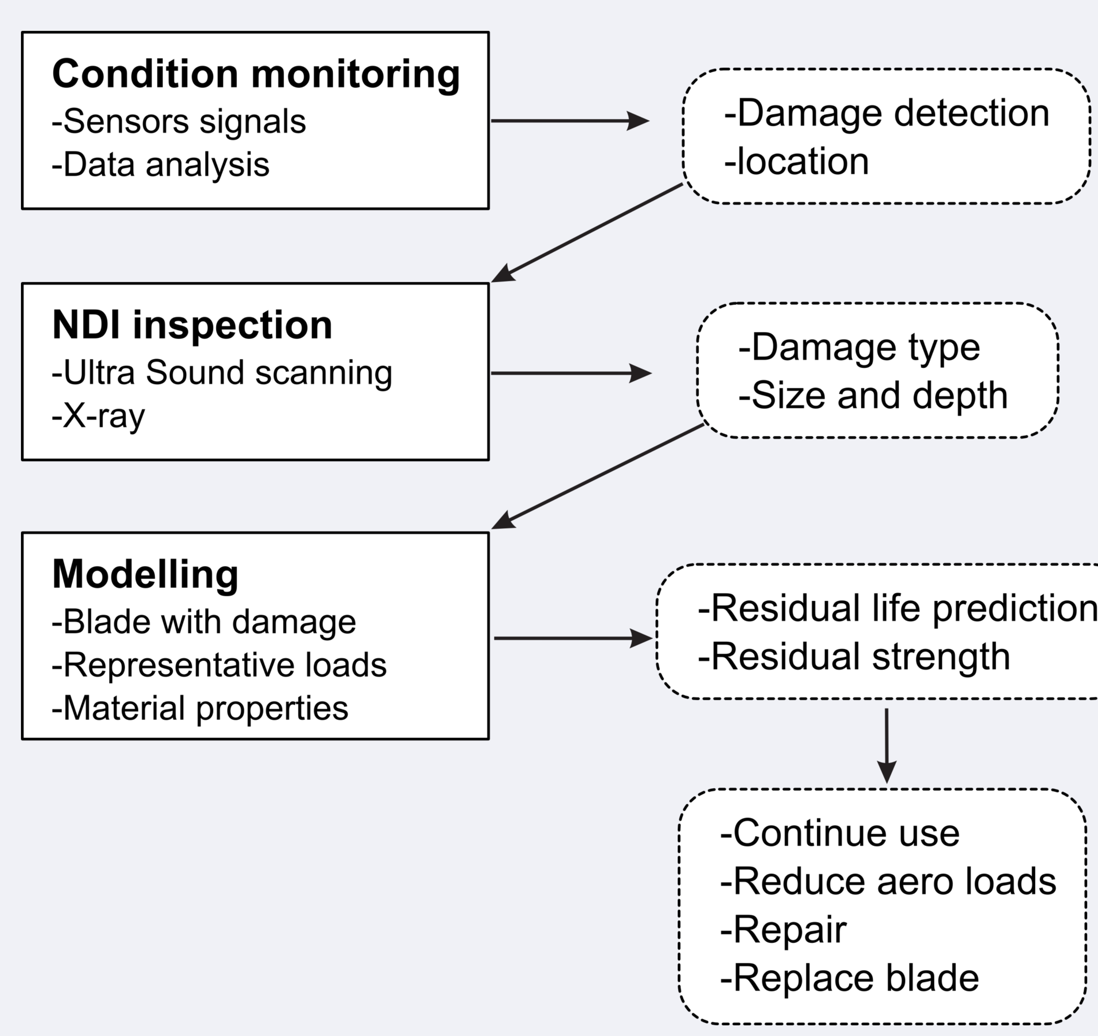
## Major failure modes of a rotor blade




**Schematics of the major failure modes in a part of a wind turbine rotor blade. The shaded areas indicate cracked internal regions.**

## The new approach

We propose a novel approach that allows blades to contain **defects** and develop stable **damage** under operation [1]. The key idea is to use **damage tolerant materials** and **design methods** which ensure that defects do not develop into unstable damage leading to blade failure.




**Major elements of conditional-based maintenance approach.**

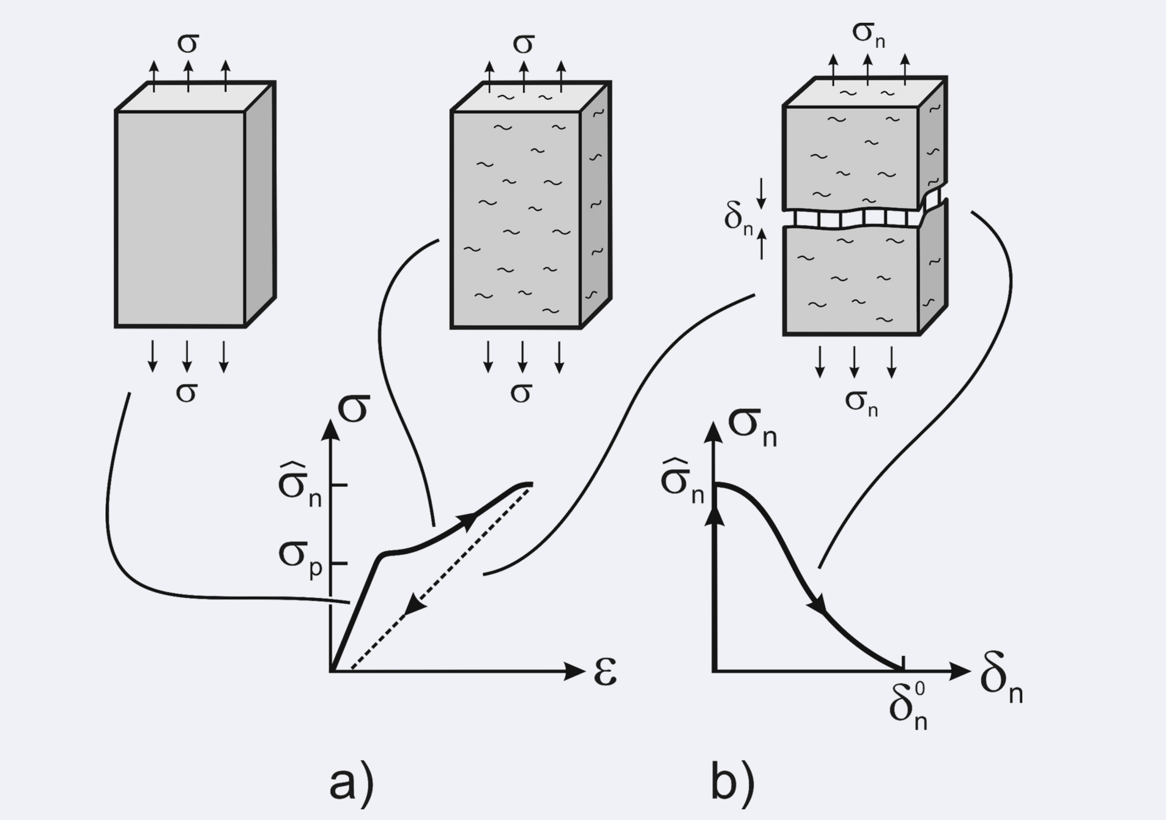
The approach involves **damage monitoring**, i.e., the use of built-in sensors that can detect damage in a wind turbine rotor blade. **Sensors**, built-in during the blade manufacturing, should be able to detect the location of damage in a blade and send a warning to an on-shore surveillance center. A maintenance team will be sent out to inspect the damaged area of the blade using **non-destructive inspection** techniques to identify the type of damage, it size and depth. Models will be used to **predict the residual fatigue life and residual strength** of the damaged blade.

The criticality of the detected damage is assessed. A decision is made about whether:

- the damaged blade can be used as it is
- its operational loads should be reduced (to meet the targeted lifetime)
- the blade should be repaired
- the blade should be replaced by another blade

## Increasing reliability by damage tolerance

A key issue is to create damage tolerance, meaning that damage from defects must always **progress stably**, i.e. slowly under increasing load, while at the same time be **detectable by sensors**. Damage tolerant design can be obtained by structural design optimization and by the use of **damage tolerant materials**, e.g. materials that possesses increasing fracture resistance with increasing crack extension.




**The relationship between stress, σ, and strain, ε, is used to characterize deformation of undamaged material (linear stress–strain response) and material with distributed damage (nonlinear stress–strain response), while the relationship between stress (traction), $\sigma_n$, and separation, $\delta_n$, describes localized damage (fracture).**

## Perspectives

This new approach enables the service life of each blade to be decided individually on the damage state of each blade. It then becomes possible to **extend the lifetime of healthy blades** beyond their originally planned service life. It is not critical to be able to calculate the loads for each wind turbine with high accuracy since the damage evolution can be assessed on the basis of sensor signals.

## Conclusions

The development of more damage tolerant structures and materials together with damage monitoring can be the technological opportunity that enables the safe development of future **very large wind turbine rotor blades** approaching 100 meters in length.

## Acknowledgements

The work was partially supported by the Danish Centre for Composite Structures and Materials for Wind Turbines (DCCSM), grant no. 09-067212 from the Danish Strategic Research Council. G.P. acknowledges the Seventh Framework Programme (FP7) for funding the project MareWint (Project reference: 309395) as Marie-Curie Initial Training Network.

## References

1. McGugan, M., Pereira, G., Sørensen, B. F., Toftegaard, H., and Branner, K., 2015, "Damage tolerance and structural monitoring for wind turbine blades", *Philosophical Transactions of the Royal Society A*, Vol. 373: 20140077.