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# Leading edge erosion the state of the art research results

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## Abstract

Leading edge erosion at wind turbine blades caused by weather effects dominated by concurrent high-wind, high-rain conditions prevail at several offshore wind farms.

Variations between typical land- and offshore sites explain the degradation speed based on the study of rain and wind climate data [1].

Research to define and characterize the degradation processes investigating materials and the roughness of blades have resulted in new knowledge on droplets in rain erosion tester based on high-speed camera and numerical modelling.

The degradation results in rougher airfoils that causes change in the aerodynamic performance, hence loss of production.

Detailed investigation on the rough surface in wind tunnel testing demonstrate the interplay between surface roughness and aerodynamic performance. These wind tunnel tests showed how surface roughness affected the aerodynamic performance as a function of varying roughness heights.

The roughness of surfaces investigated from detailed observations using X-ray tomography and computational micromechanics simulations.

Interestingly, the micro- and nanoscale structures, including the heterogeneities, particles and voids in the protective coatings, have critical effect on the crack initiation in the coatings under multiple liquid impact.

Based on a systematic finite element simulation on environmental, design, and manufacturing processes, it was revealed what are the desirable coating properties and thicknesses in order to protect leading edges against sharp impacts. This leads to novel coating polymer coating development, relevant for repair of leading edge erosion.

Recently it was proposed to limit leading edge erosion by slowing down turbines during few intense rain events, to prolong lifetime, and reduce cost for repair and even increase the annual energy production [2].

## Acknowledgements

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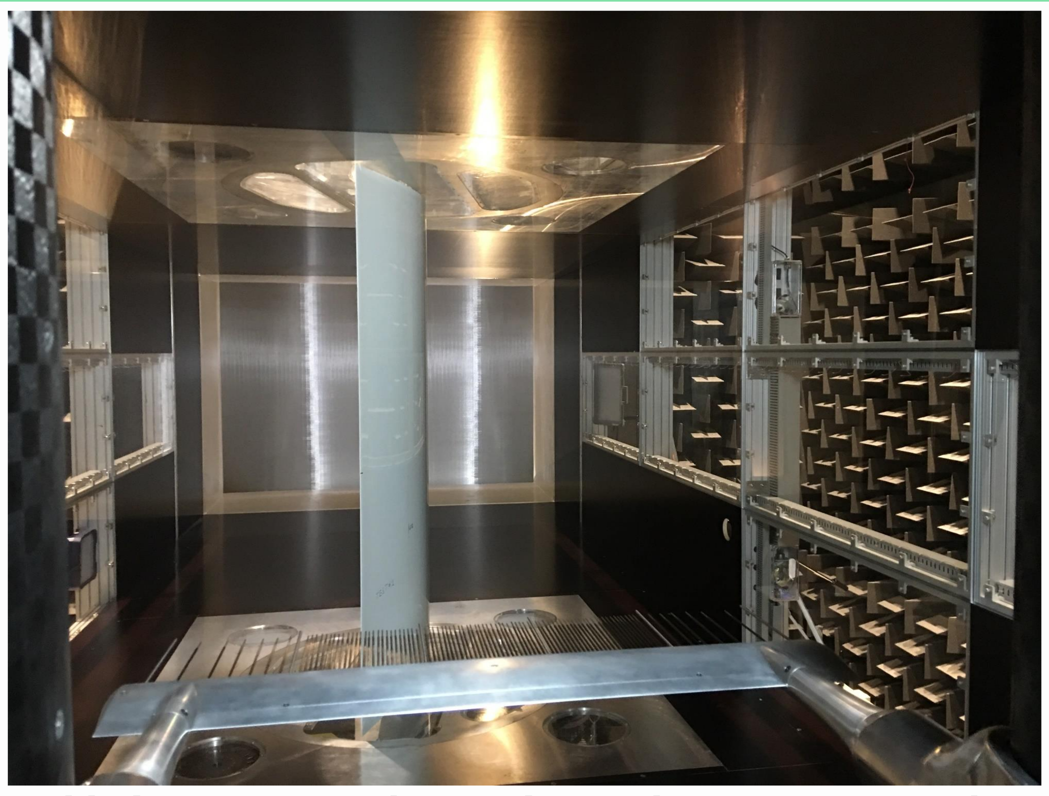
## Methods



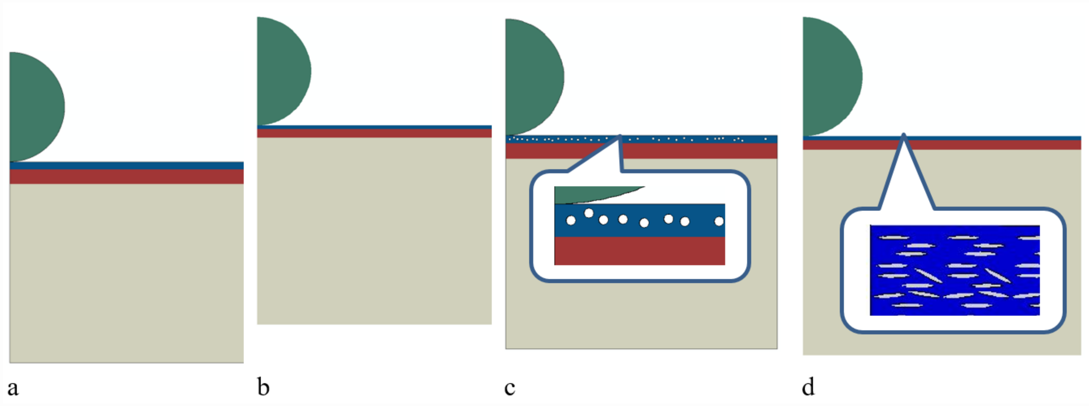
*A blade section in the wind tunnel test section in the Poul la Cour Tunnel being tested for different roughnesses at the leading edge. See www.plct.dk.*

The primarily is based on experimental rmethod used for investigation of leading edge erosion esearch in wind tunnel, in rain erosion tester [3], in x-ray tomography laboratory and from observations at several weather stations of rain intensity and wind speed.

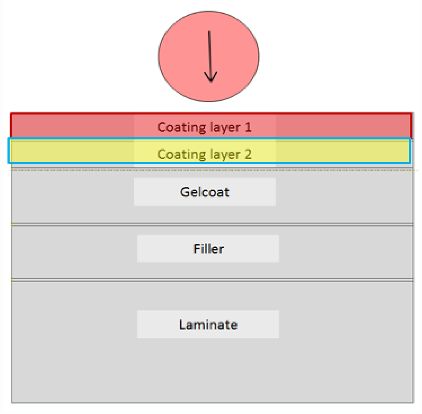
Thus, for all aspects of leading edge erosion from environmental impact, to decrease in aerodynamic performance and structural effects in the materials independent observed evidence are ensured.

The observations are then used in connection with computational modelling of aerodynamic forces from boundary layer modelling, computational fluid dynamic modelling of flow in rain erosion tester and for the materials damages these are modelled using the micromechanical impact modelling finite element [4].

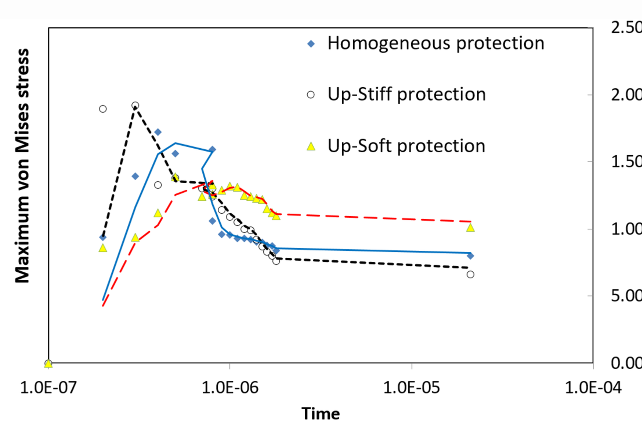
Observations and theory comparison enhance our understanding of leading edge erosion [5].




*Computational models of coated laminates: thick (coating B, a), thin (coating A, b), thick (A) porous (c) and thin (B) with particles coatings (d)*




Multilayer model




*Maximum von Mises stress plotted versus the time for each of 3 models. Black dotted line shows trendline for up-stiff coatings, blue continuous line for homogeneous, and dashed redline for up-soft protection*

## Results

Summary of results are:

1) the wind-rain climate offshore causes faster erosion than on land sites and erosion may be reduced if turbines are curtailed during heavy wind-rain events as the erosion rate is highly dependent upon tip speed.
2) drop-lets falling in the rain erosion tester towards the test specimen are not severely influenced by the complex flow caused by the whirling arm.
3) the blades with leading edge erosion are rougher and aerodynamic performance is degraded, causing loss of production.
4) the damage criterion for the formation of initial defects in the top coating is determined.
5) by increasing the thickness of the polymer coatings it is shown that this reduces the stress amplitude, thus, delaying the damage.

## Conclusions

Leading edge erosion is multi-faceted research area for which highly inter-disciplinary expertise, experimental and theoretical numerical modelling are the key components for advancing state of the art on the topic.

The solutions for repair of damaged blades and future new types of coating that potentially will provide lasting leading edges are what industry is looking for. Also, solutions to reduce the need for repair is relevant in the wind industry.

## References

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