Report 2022

Task 46

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Erosion of Wind Turbine Blades

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Erosion of wind turbine blades is primarily driven by rain, hail and other atmospheric factors. It affects the performance of the wind turbines by degrading the power curve and requiring costly repairs.

The purpose of IEA Wind Task 46, Erosion of Wind Turbine Blades, is to further the understanding of factors which contribute to erosion, develop datasets and models that enhance the prediction of leading-edge erosion, define signs of early-stage damage, and advance the development of innovative solutions. The scope of work is divided into the following four technical work packages:

- WP2: Climatic causes of erosion.
- WP3: Wind turbine operations affected by erosion.
- WP4: Laboratory testing.
- WP5: Erosion mechanics and material properties.

The key results of 2022 include two

main deliverables in the form of technical reports and two peer-reviewed journals, as well as dissemination through the first outreach webinar and the third Erosion Symposium. All related material is available on the Task website https://iea-wind.org/task46/.

Thirty-nine participating organisations from twelve countries represent the main wind energy actors engaged in the erosion challenge. These include owners, wind turbine manufacturers, leading-edge protection suppliers, and the research community.

The participants include Engie (Belgium), WEICan (Canada), DTU, Hempel and Ørsted A/S (Denmark), VTT (Finland), Fraunhofer IWES, Covestro, Emil Frei (Freilacke), Nordex Energy, DNV, Mankiewicz and RWE Renewables (Germany), University of Limerick, IT Carlow, and NUI Galway (Ireland), Osaka University, AIST, Tokyo Gas Co. and Asahi Rubber Inc (Japan), TU Delft, Eneco, Suzlon and TNO (the Netherlands), Equinor and University of Bergen (Norway), Aerox, Cener, Nordex Energy Spain, Siemens Gamesa Renewable Energy and University Cardenal Herrera (Spain), ORE Catapult, University of Bristol, Lancaster University, Imperial College London and Vestas Technology UK (United Kingdom), and Cornell University, Sandia National Laboratories and 3M (US).

Introduction

The objective of IEA Wind Task 46 is to attain more profound knowledge about factors causing erosion in wind turbine blades, promote the creation of datasets, methods and tools quantifying the occurrence of erosion and its financial impact, and advance the maturity of solutions. The scope of work covers the following related topics:

- Climatic conditions associated with erosion.
- Wind turbine operations affected by erosion.
- Laboratory testing.
- Erosion mechanics and material properties.

Of the thirty-nine participants, twenty represent industries in the wind energy sector, including OEMs, wind farm developers and operators, and coating companies that deliver coating systems to the wind turbine blades.

Table 1. Countries Participating in Task 46

	COUNTRY	TASK PARTICIPANT
1	**Belgium**	-Engie
2	**Canada**	-WEICan
3	**Denmark**	-DTU -Hempel -Ørsted A/S
4	**Finland**	-VTT
5	**Germany**	-Covestro -DNV -Emil Frei (Freilacke) -Fraunhofer IWES -Mankiewicz -Nordex Energy -RWE Renewables
6	**Ireland**	-IT Carlow -NUI Galway -University of Limerick
7	**Japan**	-AIST -Asahi Rubber Inc. -Osaka University -Toyko Gas Co.
8	**Netherlands**	-Eneco -Suzlon -TU Delft -TNO
9	**Norway**	-Equinor -University of Bergen
10	**Spain**	-Aerox -CENER -Nordex Energy Spain -Siemens Gamesa Renewable Energy -Universidad Cardenal Herrera – CEU
11	**United Kingdom**	-Imperial College London -Lancaster University -ORE Catapult -University of Bristol -Vestas Technology UK
12	**US**	-Cornell University -Sandia National Laboratories -3M

Progress and Achievements

A description of the determining meteorological parameters driving blade erosion, as well as the techniques required for field measurements, was produced in the WP2 [1] IEA Wind Task 46 Technical Report named *"Atmospheric drivers of wind turbine blade leading-edge erosion: Hydrometeors".* This technical report was released with an accompanying spreadsheet describing available public datasets relevant to the characterisation of hydrometeors causing erosion [2].

Continuing on this topic, the participants produced the peer-reviewed publication, *"Atmospheric Drivers of Wind Turbine Blade Leading Edge Erosion: Review and Recommendations for Future Research"* [3].

WP3 progressed on the formulation of a leading-edge erosion classification system, aiming at standardising the assessment of erosion severity in wind turbine blades. The proposed classification was delivered in early 2023 [4].

WP4 produced a technical report on the review and assessment of technologies employed for laboratory testing of erosion, covering rain erosion tests, impact and fatigue tests, characterisation of viscoelastic properties, fracture mechanics of layered properties, and non-destructive and microstructure analysis [5].

Additionally, WP5 participants contributed to the European Conference on Composite Materials (ECCM 2022) with a peer-reviewed publication summarising the multilayer material configurations of Leading-Edge Protection (LEP) used in the wind industry and the modelling techniques used to predict erosion [6].

Task 46 was furthermore acknowledged in the third Erosion Symposium, held in Roskilde between the 1st and 3rd of February 2022, by operating agents who presented the Task objectives and outcomes. In addition to this, Task 46 held its first outreach webinar on the 31st of May 2022, where its progress was presented by the work package leaders and operating agents. The webinar was held online for its thirty-nine attendees.

Highlights

Task 46 was initiated in March 2021, where its operations were largely influenced by the development of the COVID-19 pandemic. It wasn't until

Table 2. Proposed Erosion Classification System for wind turbines blades [4].

	Security Level					
Evaluation Criteria	0	1	2	3	4	5
Visual Condition (LEP)	Initial factory condition	Lightly worn external coating/LEP Instances of reduced LEP adhesion	Notable areas of localised damage on external coating/LEP Individual instances of LEP adhesive failure	LEP is largely compromised over a large area and no longer providing protection to underlying layers	Delamination of topcoat with immediate layer underneath clearly visible and exposed	Notable damage to substrate
Visual Condition (No LEP)		Erosion barely visible or pinholes	Localised pitting	Widespread or coherent pits, some gouges		
Mass-loss		Coating < 10% Laminate 0%	Coating 10 - 50% Laminate 0%	Coating 50 - 100% Laminate < 10%	Coating 100% Laminate 10 - 100%	Coating 100% Laminate 100%
Aerodynamic Performance		Normal surface roughness Region 2 power loss 0 – 1%	Region 2 power loss 1 – 2%	Region 2 power loss 2 – 3%	Region 2 power loss 3 – 4%	Region 2 power loss > 4%
Blade Integrity		Initial erosion of topcoat	Erosion through topcoat	Initial exposure of immediate laminate layers	Erosion through immediate laminate layers	Exposure of structural laminate layers

	RR= 21 mmhr^{1}	
Theoretical distribution	R=1 mm	R=2 mm
Marshall-Palmer	104	1.4
Best	37	2.9
	RR= 21-26 mmhr^{1}	
Observations (probability of precipitation: RR > 0.2 mmhr^{1} in %)	R=1 mm	R=2 mm
Norway: Bergen (13%)	22	0.2
Canada: WEICAN (N/A)	N/A	N/A
USA: SGP-Lamont (2.4% impact, 3.2% laser disdrometer)	81	3.9
USA: SGP-Billings (3.0%)	88	2.9
UK: Cairngorm (14%)	42	5
UK: Reading (6%)	71	1.1
UK: Weybourne (6%)	31	3.2
UK: NOAH (4.2%)	42	0.01
UK: Levenmouth (6.1%)	58	0.03
Denmark: Horns Rev 2 (5.8%)	N/A	N/A
Denmark: DTU-Risø	131	1.7

Table 3. Mean number concentration of rain droplets per unit diameter spectrum (#/m3/mm) for selected sites, compared to theoretical distributions Marshall-Palmer and Best. The large differences between sites show that in-situ measurements are required to accurately estimate the effect of erosion in wind turbine blades [1].

Photo: Task 46 plenary meeting in Copenhagen hosted by Ørsted A/S.

September 2022 that the first in-person plenary meeting could take place. This meeting was hosted in Copenhagen by Ørsted A/S and accommodated twenty-two attendees participating on-site and additional participants who joined remotely.

Regarding work on the characterisation of hydrometeors, a key outcome of the analysis showed that the characteristics of rain vary significantly across all analysed sites. The mean number concentration of droplets at rain rates of 21-26mm/h in droplet radiuses of 1mm – 2mm spans a factor of nearly five [1]. In a general context, the findings indicate a significant deviance from theoretical distributions (Marshall-Palmer, Best).

Outcomes and Significance

The Task has allowed the wind energy community to work together on the complex and multidisciplinary topic of blade erosion. The forum, involving 107 individuals from 39 organisations, produces not only the deliverables but also technical discussions in the periodic meetings of the topical work packages and in the plenary sessions.

The two key outcomes of Task 46 are:

- Deeper knowledge of the topic of erosion by the participants, which trickles down to the wider energy sector through the deliverables and the dissemination sessions.
- A strong and well-aligned research portfolio on the topic of erosion, as a result of the communication and alignment between the 39 organisations involved, enabling challenges such as these to be solved.

Next Steps

Continued activities on the four technical work packages have been planned. This includes the development of a roadmap for creating a methodology to form an atlas for erosion risk. Furthermore, to provide input for best practices on rain-erosion test data analysis to assess the expected lifetime of blade coatings more precisely. Furthermore, the assessment of erosion-safe modes of operation on turbines to limit erosion during control. Finally, to understand the damage processes from experiments and modelling will be continued.

References

[1] Pryor *et al.* 2022 IEA Wind Task 46 Technical Report named *"Atmospheric drivers of wind turbine blade leading-edge erosion: Hydrometeors"*. https://usercontent.one/wp/iea-wind.org/wp-content/uploads/2022/08/IEA_Wind_Task_46_WP2_Deliverable1_5Nov2021_approved.pdf

[2] Pryor *et al.* 2022 IEA Wind Task 46 Technical Report: Atmospheric drivers of wind turbine blade leading edge erosion: Hydrometeors – accompanying spreadsheet. https://zenodo.org/record/5648211

[3] Pryor *et al.* 2022 *Energies*. Atmospheric Drivers of Wind Turbine Blade Leading Edge Erosion: Review and Recommendations for Future Research: https://www.mdpi.com/1996-1073/15/22/8553.

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[6] Alexandros Antoniou et al "Multilayer leading edge protection systems of wind turbine blades: A review of material technology and damage modelling". Proceedings of the 20th European Conference on Composite Materials: Composites Meet Sustainability. ISBN 978-297016140-0). https://orbit.dtu.dk/en/publications/multilayer-leading-edge-protection-systems-of-wind-turbine-blades

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