Webinar – Task 46 Erosion of wind turbine blades

IEA Wind TCP

31 May 2022 , 16:00 CEST

Raul Prieto (VTT) and Charlotte Hasager (DTU),
Sara Pryor (Cornell Univ.) and Marijn Veraart (Ørsted) ,
David Maniaci (Sandia), Jakob Ilsted Bech (DTU), Maral Rahimi (Hempel),
Fernando Sánchez López (UCH-CEU) and Bodil Holst (Univ. of Bergen)

Please mute your mic
unless presenting :-)

Agenda

- Welcome & Introduction to Task 46 Erosion of wind turbine blades. Charlotte Hasager (DTU) and Raul Prieto (VTT). 5’
- Key challenge questions to the audience (Interactive poll with Mentimeter). 5’
- Atmospheric properties of relevance to leading edge erosion. Marijn Veraart (Ørsted) and Sara Pryor (Cornell University). 20’
- Development of a Standard Erosion Classification System. David C. Maniaci (Sandia National Laboratories). 20’
- Break 10’
- Test methods for properties and performance of LE protection systems. Jakob I. Bech (DTU) and Maral Rahimi (Hempel). 20’
- On the material technology & damage modelling of multilayer leading edge protection systems. Fernando Sánchez López (UCHCEU) and Bodil Holst (UiB). 20’
- Wrap-up of key challenge results. Charlotte Hasager (DTU) and Raul Prieto (VTT). 10’

IEA Wind Technology Collaboration Programme

- The International Energy Agency Wind Technology Collaboration Programme is an international co-operation that shares information and research to advance wind energy research, development and deployment in member countries.
- The consortium operates under auspices of the International Energy Agency (IEA).
- Founded in 1977, It is formed by 24 countries which represent 84% of wind capacity.
- Website: https://iea-wind.org/

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Task 46 - Background and goals

- The purpose of this IEA Wind Task is to improve understanding of the erosion driving factors, develop datasets and model tools to enhance prediction of leading edge erosion likelihood, identify damage at the earliest possible stage and advance potential solutions.
- 35 participants from 12 countries

Task 46 work packages

Climatic conditions driving erosion (wp2)

Sara C. Pryor (Cornell University) & Marijn Veraart (Ørsted)

Wind turbine operations with erosion (wp3)

David C. Maniaci (Sandia National Laboratory)

Laboratory testing of erosion (wp4)

Jakob I. Bech (DTU) & Maral Rahimi (Hempel)

Erosion mechanics & material properties (wp5)

Fernando Sánchez López (Univ. Cardenal Herrera CEU) & Bodil Holst (Univ. Bergen)

Management (wp1) - Raul Prieto (VTT) & Charlotte Hasager (DTU)

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Towards solving blade erosion

Task 46 - WP2 Climatic conditions

Goals

- Provide assessment for wind farms regarding the potential for LEE damage
- Inform wind farm operation to optimize blade lifetime

Objectives

- Understand atmospheric drivers for LEE
- Evaluate datasets and models
- Develop roadmap for LEE atlas
  (including erosion classes)

Sara C Pryor
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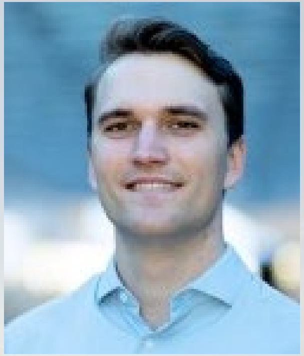

Marijn Veraart
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Task 46 - WP2 Climatic conditions

1. Priority areas for mapping LEE potential – focus on hydrometeors

2. Identify other crucial parameters

(dust, freezing rain, sea-spray, UV, temperature variation)

3. Lit rev: Hail, rain & dust in priority areas

4. Lit. rev: Hydrometeor size dist. As f(climate)

5. Data quality/availability update

6. Roadmap for LEE atlas

7. Recommended Practice for measurement of LEE drivers

8. Methods to perform model V&V on LEE drivers

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Task 46 - WP2 Climatic conditions

Active participants

Belgium	Engie
Canada	WEICan
Denmark	DTU, Ørsted A/S
Finland	VTT
Germany	Fraunhofer IWES
the Netherlands	TU Delft, TNO, ENECO
Norway	University of Bergen
Spain	Cardenal Herrera University
United Kingdom	ORE Catapult
United States	Cornell University
Japan	AIST, Osaka University

Task 46 - WP2 Climatic conditions: Work in year #1

1. Priority areas for mapping LEE potential – focus on hydrometeors

2. Identify (other) crucial parameters

(e.g. dust, freezing rain, sea-spray, UV, temperature variation)

3. Lit rev: Hail, rain & dust in priority areas

4. Lit. rev: Hydrometeor size dist. As f(climate)

5. Data quality/availability update

6. Roadmap for LEE atlas

7. Recommended Practice for measurement of LEE drivers

8. Methods to perform model V&V on LEE drivers

Task 1

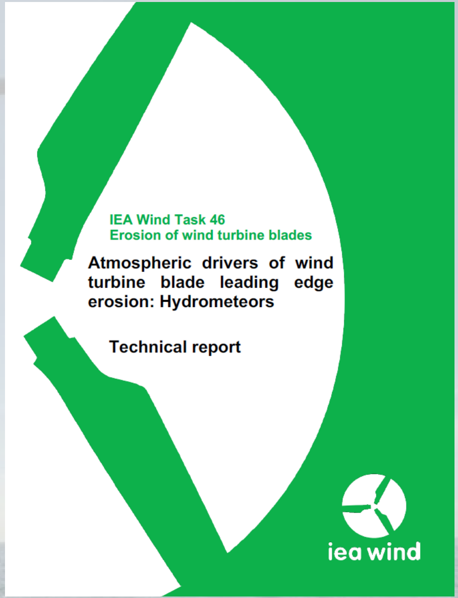
- Collated meta-data and analyzed hydrometeor measurements in wind resource rich areas
- Deliverables:
    - Report & spreadsheet to TCP
    - Journal paper under development

Task 46 - WP2 Climatic conditions: Work in year #1

First deliverable ready (technical report & spreadsheet)

Atmospheric drivers of wind turbine blade leading edge erosion: Hydrometeors

- Describe **crucial meteorological parameters** for wind turbine blade leading edge erosion
- Describe **technologies appropriate to measurement** of hydroclimates and specifically hydrometeor size distributions
- Identify **available data sets** to describe hydrometeor size distributions, and phase and compile their meta-data. These data sets are available for use in mapping wind turbine blade leading edge erosion potential
  - Summary analyses based on these key datasets
  - Spreadsheet summarizing meta-data. **Doi:** 10.5281/zenodo.5648211
- Identify **priority geographic areas** for geospatial mapping of wind turbine blade leading edge erosion potential



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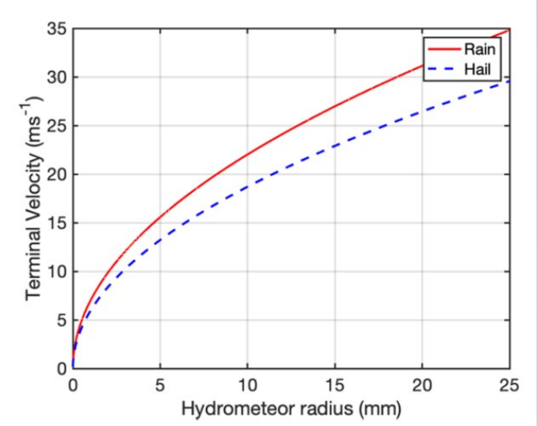
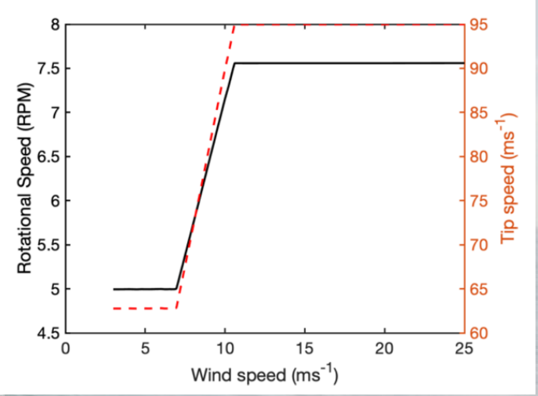
Task 46 - WP2 Climatic conditions: Work in year #1

Crucial meteorological parameters

1. The closing velocity between the hydrometeor and the blade





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Task 46 - WP2 Climatic conditions: Work in year #1

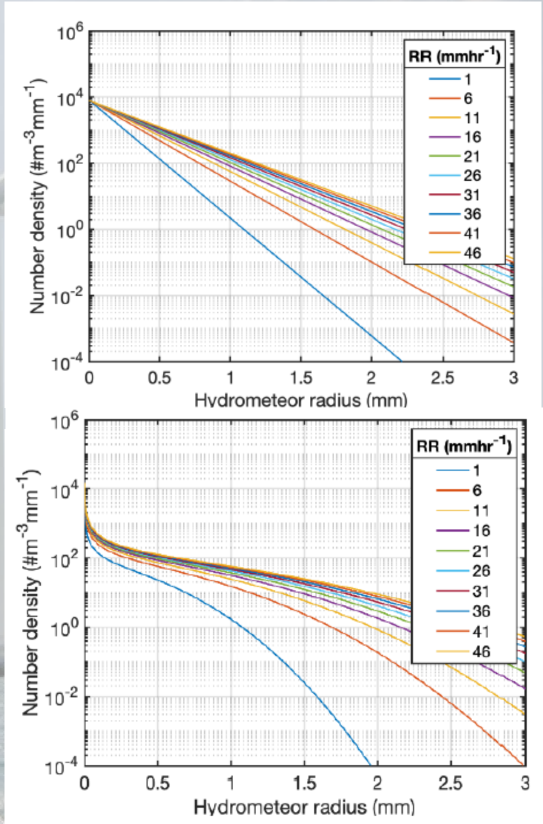
Crucial meteorological parameters

1. The closing velocity between the hydrometeor and the blade
2. The number of hydrometeor impacts

Task 46 - WP2 Climatic conditions: Work in year #1

Crucial meteorological parameters

1. The closing velocity between the hydrometeor and the blade
2. The number of hydrometeor impacts
3. The nature of the hydrometeors (size and phase)



Rain droplet size distributions described by Marshall-Palmer (top) & Best (bottom)

Task 46 - WP2 Climatic conditions: Work in year #1

Crucial meteorological parameters

1. The closing velocity between the hydrometeor and the blade
2. The number of hydrometeor impacts
3. The nature of the hydrometeors (size and phase)
4. The impact efficiency

Task 46 - WP2 Climatic conditions: Work in year #1

Measurement techniques

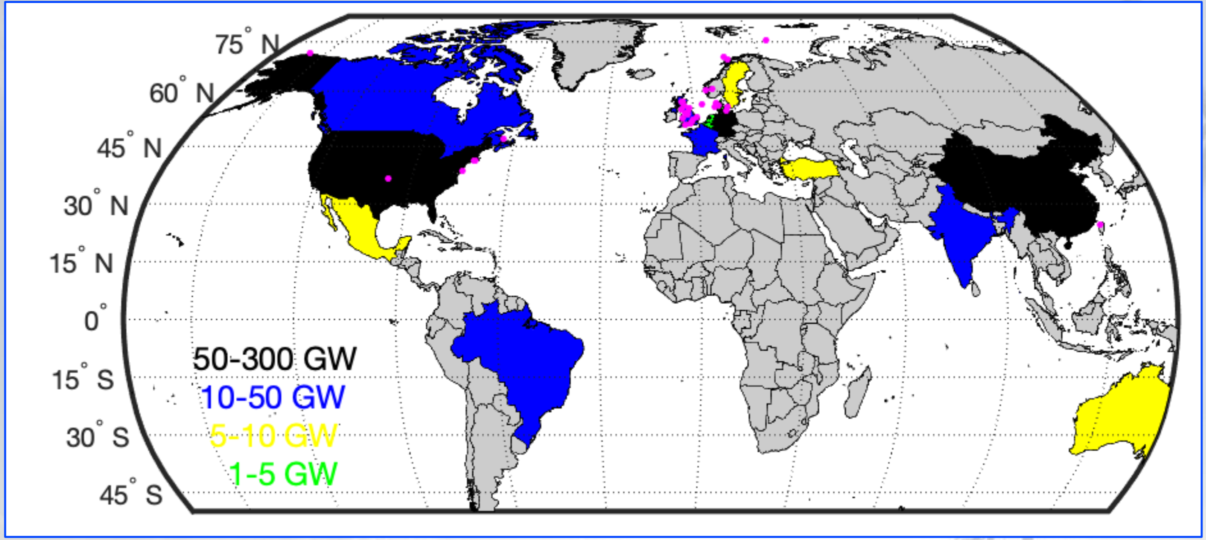
- Direct *in situ* measurement:
  - Tipping bucket rain gauges
  - Disdrometers
  - Hail sensors
- Remote sensing:
  - Single polarization radar
  - Dual polarization radar
  - Micro-rain radar
  - Satellite-derived products
  - Gridded datasets
  - Numerical weather prediction models

Task 46 - WP2 Climatic conditions: Work in year #1

Measurement techniques

Task 46 - WP2 Climatic conditions: Work in year #1

Priority geographic areas



Lamont Southern Great Plains, USA – high hail freq. high WT IC
WEICAN, eastern Canada – high frequency of freezing rain
Weybourne, UK – close to abundant UK offshore
Horns Rev 2, Denmark – offshore
Risø, Denmark – heavily instrumented, comparison with HR2
Bergen, Norway – freq. precipitation

Task 46 - WP2 Climatic conditions: Work in year #1

Priority geographic areas (key takeaways)

- Profound **variations in rainfall rate**, mean **droplet size distributions** and **hail frequency**
- The **differences in the hydroclimates**; probability of precipitation and hail, intensity of precipitation and the size distributions of hydrometeors have profound implications for the number of hydrometeor impacts on the blades
- Pronounced **regional differences** in terms of the relative importance to total accumulated kinetic energy transfer to the blades of;
    1. **hail versus rain**
    2. **low intensity** but sustained precipitation periods versus high intensity but relatively short duration precipitation periods
- There are **important gradients in hail frequency** at the regional and sub-regional scale
- **Hail frequency** in the USA greatly exceed those in Europe
- The **specific instrument** (i.e. type of disdrometer) from which droplet size distribution are drawn has a profound influence on the resulting droplet size distribution

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Task 46 - WP2 Climatic conditions: Work in year #1

Joint Probability Distributions Lamont Southern Great Plains, USA

Journal paper

Rainfall rate (mmhr^{-1})	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	12.5-25
50-100	0.01	0.02	0.07	0.07	0.06	0.12
20-50	0.06	0.19	0.40	0.26	0.24	0.39
10-20	0.09	0.20	0.56	0.43	0.32	0.39
5-10	0.19	0.59	1.09	0.94	0.54	0.81
2-5	0.46	1.94	3.17	2.78	1.37	1.86
1-2	0.66	2.32	3.19	3.50	1.86	1.46
0.5-1	0.66	2.46	3.53	3.50	2.19	1.38
0.2-0.5	0.92	3.00	4.47	4.45	3.05	1.92
<0.2	1.72	6.29	7.15	6.75	5.06	6.06

Wind speed @ 90 m (ms^{-1})

	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	12.5-25
Hail	4.78	17.01	23.64	22.69	14.69	14.39

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Task 46 - WP2 Climatic conditions: Work in year #2

Task 1
Journal paper

1. Priority areas for mapping LEE potential – focus on hydrometeors

Task 2
For 'focus sites' identified in #1
Include data co-stressors

2. Identify (other) crucial parameters

(dust, freezing rain, sea-spray, <u>UV</u>, <u>temperature variation</u>)

Tasks 3&4
Review literature

3. Lit rev: Hail, rain & dust in priority areas

4. Lit. rev. Hydrometeor size dist. As f(climate)

5. Data quality/availability update

6. Roadmap for LEE atlas

7. Recommended Practice for measurement of LEE drivers

8. Methods to perform model V&V on LEE drivers

Task 46 Erosion of Wind Turbine Blades

Work Package #3: Wind turbine operation with erosion

Development of a Standard Erosion Classification System

David Maniaci (Sandia National Laboratories)

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Public Webinar - 31 May 2022

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SAND2022-7171 PE

Technology Collaboration Programme

by iea

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WP 3 : Wind turbine operation with erosion

This work package has three key overarching objectives:

1. Promote collaborative research to mitigate erosion by means of wind turbine control, assessing the viability of erosion safe mode.
2. Improve the understanding of droplet impingement in the context of erosion.
3. Improve the understanding of wind turbine performance in the context of erosion, specifically the effect of LEE surface roughness on aerodynamics.

	Activity	WP code
Year 1	Model to predict annual energy production loss on blade erosion class	WP3.1
	Report on standardization of damage reports based on erosion observations	WP3.2
Year 2	Droplet impingement model for use in fatigue analysis	WP3.3
	Potential for erosion safe-mode operation	WP3.4
	Accuracy of LEE performance loss model based on field observations (validation)	WP3.5

Please reach out if interested in collaborating!

David C. Maniaci
dcmania@sandia.gov

Sandia National Laboratories (U.S.)

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WP 3: Activity Description

WP3.1: Model to predict annual energy production loss on blade erosion class

- Develop a common model of aerodynamic performance loss due to leading edge roughness and erosion standardized classes.

WP3.2: Report on standardization of damage reports based on erosion observations

- Standardization of damage reports for validation of any erosion potential assessment and to allow effective integration of data from operators with laboratory derived estimates.

WP3.3: Droplet impingement model for use in fatigue analysis

- Develop a standard model for droplet impingement, validated with wind tunnel experimental data.

WP3.4: Potential for erosion safe-mode operation

- Report describing potential for leading edge erosion safe mode operation. This report will be used for seeking participation from industry and research funders towards a coordinated project designed to assess viability and cost-benefit of leading edge erosion safe mode operation.

WP3.5: Accuracy of LEE performance loss model based on field observations (validation)

- Carry out iterative aerodynamic loss benchmarks with model development and new wind tunnel testing for calibration and validation. Validation of complete performance loss model using probabilistic analysis of field observations.

Specific Technical Activities in Work Package 3

- Collaboration through monthly meetings focused on specific topics
  - Fundamental aerodynamic knowledge and testing for LEE.
  - Needs for AEP performance model.
  - Available sites and partners for field validation.
  - Coordination with IEA Task 43 Digitalization on topic of Risk-Based Maintenance for Blades.
  - Focus group to benchmark aerodynamic models for AEP loss. (CENER facilitating)
- WP3.1 Model to predict annual energy production loss based on blade erosion class.
  - Shared background information on existing erosion models and papers (online repository).
  - Defined turbine information needs for validation of LEE performance models.
- WP3.2 Report on standardization of damage reports based on erosion observations. (ORE CATAPULT facilitating)
  - Reviewed existing erosion classification systems and methods.
  - Discussed what existing partners do now for field identification and repair decisions.
  - Held a workshop to develop a common **erosion classification system** for the task.
  - Tested the classification on sample images and working on AEP estimates now.

Erosion Classification System Example

Observation Category	Erosion Class
Visual data definition	3
Mass-loss or Depth	3
Aerodynamics/Perf.	3
Structural	3

Workshop: IEA Wind Task 46 Proposed Solution – Considerations

Assessment Method
- Methodology
  - Drone, Rope access, Ground based cameras
- Potential for difficulties in interpretation
- Technology
  - Visual
  - NDT, Other

Assessment Type
- Research – CFD, Wind Tunnel
- Operational Turbine

Blade Geometry
- Area
- Blade location (span and chordwise)
- Depth of erosion
- Distinguishing different locations of erosion

Subsequent Action
- Damage progression
- Point of intervention
  - Considered with other types of damage
- Separate categorisation for repair

Structural Integrity
- Location on blade
- Erosion depth

Categorisation

Performance
- Mass Loss
- Roughness
- AEP
- LEP Failure
  - Adhesion
  - Degradation
- End of incubation period

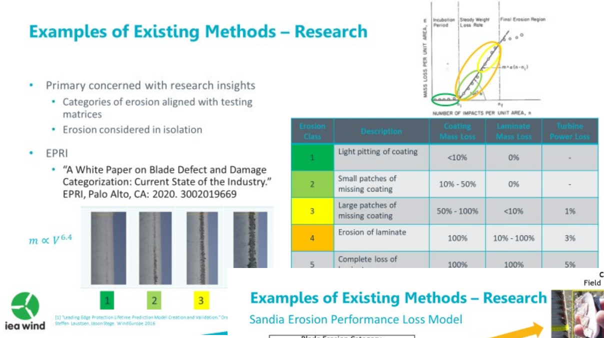
Additional Context
- Number of blades affected
- Age of blades
  - Lifetime extension
- Previously known damages
- Expected erosion rate (lifetime of LEP)

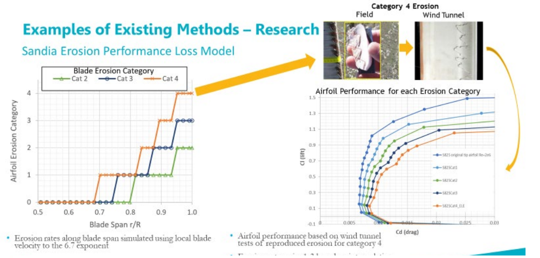
Damage Mechanism
- Different Material
  - LEP - Tape, Softshell, Coating, other…
  - Unprotected blades
- Root cause
- Type of failure/damage
  - Erosion/Degradation
  - LEP adhesion failure

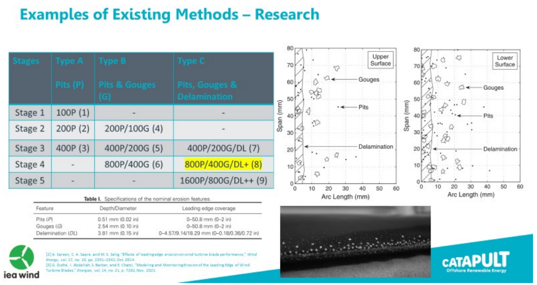
Stakeholder Scenarios for Blade Damage Classification

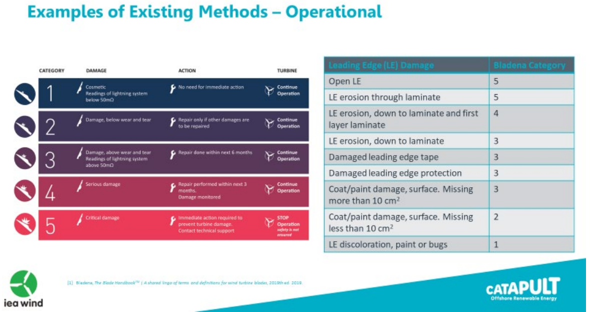
- There are different techniques for categorizing wind turbine blade damage.
- There can also be specific motivations for individual organizations and stakeholders depending on the situation that the assessment is being carried out.

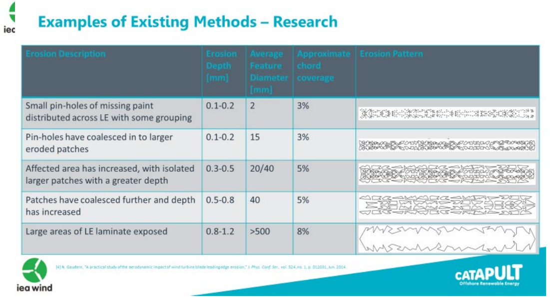
Assessment	Primary motivation
Research	Novel insights and understanding
Testing	Replicating in-situ conditions to predict expected performance
Manufacturing	Quality control
Operational	Performance and structural integrity of wind turbine assets









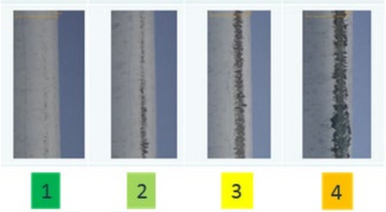


Initial Draft Erosion Classification System

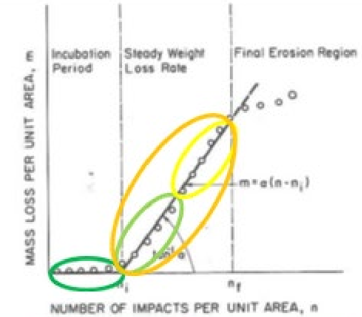
	Erosion Class based on Observations					
Observations	0	1	2	3	4	5
Visual data definition		Light pitting of coating	Small patches of missing coating	Large patches of missing coating	Large exposed surfaces of fiberglass. Signs of damage to the underlying fiberglass.	Complete loss of laminate, holes in surface material.
Mass-loss or Depth*Length		Coating mass loss <10%, Laminate mass loss 0%	Coating mass loss 10-50%, Laminate mass loss 0%	Coating mass loss 50-100%, Laminate mass loss <10%	Coating mass loss 100% , Laminate mass loss 10-100%	Coating mass loss 100%, Laminate mass loss 100%
Aerodynamics/Performance	Idealized as-built blade	Normal operating surface roughness, no or little damage	Power loss 1%, Moderate loss to L/D and CL_max, (-20% and -5%)	Power Loss 2%, Noticeable loss to L/D and CL_max (-30% and -5-10%)	Power loss >3%, Significant loss to L/D (> -40%) and CL_max (> -10%)	Power loss >4%, Severe loss to L/D and CL_max
Structural		Light dirt, oil, grease, or insects on the blade surface.	Early stages of leading edge erosion or other increased surface roughness.	Coating damage, crack in structure at the leading edge.	Leading edge erosion through shells, exposing blade internal structure.	Significant chordwise or spanwise cracks or large delaminations in shells.

Blade erosion class vs. local class: When 5% of blade span is in a given class the blade is considered that class or if a higher class changes the response, the blade class is increased.

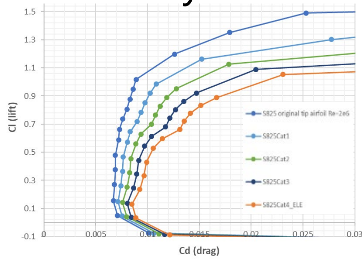
Visual[1]



Mass-loss[2]



Aerodynamics[3]



[1] "Leading Edge Protection Lifetime Prediction Model Creation and Validation." Drew Eisenberg, Steffen Laustsen, Jason Stege. Wind Europe 2016
[2] Springer, G. S. Erosion by Liquid Impact. Scripta Publishing Co. Washington D.C., 1976.
[3] "Uncertainty Quantification of Leading Edge Erosion Impacts on Wind Turbine Performance." Maniaci, D.C., Westergaard, C., Hsieh, A., and Paquette, J.A.,, in Torque 2020.

Erosion Classification System Example

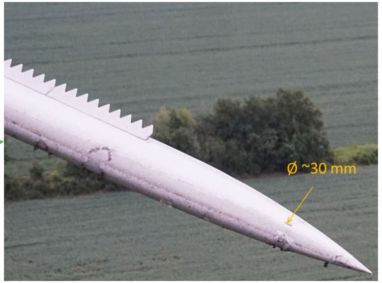
- Participants were asked to test the draft classification system on a sample of images.

Information to Categorize	Erosion Class	Note
Visual data definition	4	Large exposed surfaces of fiberglass. Signs of damage to the underlying fiberglass.
Mass-loss or Depth	4	
Aerodynamics/Performance	4	
Structural	3	

Parameter (Specified by Service Provider)	Value
Material	Laminate
Blade Length	37 m
Distance from Root	37.3 m
Length of damage	4.1 m
Width of damage	0.15 m

Erosion Classification System Test

Organisation Type		RTO	Owner/Operator	University	Turbine OEM	University	RTO	University	RTO	Owner/Operator	Turbine OEM	Median	Variance
Image 1	Visual data definition	2	1		2	0	2.5	2		2	3	2	0.85
	Mass-loss or Depth	1	1			2	1			1	4	1	1.47
	Aerodynamics/Performance	2	1	5	2.5	2	2		2	1	3	2	1.44
	Structural	1	1			0	2.5		2	2	3	2	1.06
Image 2	Visual data definition	4	4		4	3	4	5	4	4	5	4	0.36
	Mass-loss or Depth	4	4			3	3			3	5	3.5	0.67
	Aerodynamics/Performance	4	4	5	4.5	3	3.5		4	3	5	4	0.56
	Structural	4	3			0	4		3	4	5	4	2.57
Image 3	Visual data definition	1	2		2	1	2		2	1	2	2	0.27
	Mass-loss or Depth	1	1			0	1			1	1	1	0.17
	Aerodynamics/Performance	1	1		2	1	2		2	1	3	1.5	0.55
	Structural	2	1			0	2		3	1	2	2	0.95
Image 4 - Part 1	Visual data definition	3	1		2	1	2	1	2	1	2	2	0.50
	Mass-loss or Depth	2	1			1	1			1	4	1	1.47
	Aerodynamics/Performance	3	1	3	2	1	1.5		2	1	2	2	0.63
	Structural	2	1			0	2		3	2	3	2	1.14
Image 4 - Part 2	Visual data definition	2	2		1	1	2.5	1	2	1	1	1	0.38
	Mass-loss or Depth	1	2			1	1.5			1	1	1	0.18
	Aerodynamics/Performance	2	1	2	1	1	1.5		2	1	2	1.5	0.25
	Structural	2	1			0	2		3	2	1	2	0.95
Image 5	Visual data definition	1	1		1	0	0.5	2		1	0	1	0.42
	Mass-loss or Depth	1	1			0	0			1	1	1	0.27
	Aerodynamics/Performance	2	1	2	2.5	2	1		1	2	2	2	0.32
	Structural	1	1			0	1			1	0	1	0.27
Image 6	Visual data definition	1	1		1	1	1.5	1	1	1	1	1	0.03
	Mass-loss or Depth	1	1			1	1			1	1	1	0.00
	Aerodynamics/Performance	1	1		1	1	1		1	1	0	1	0.13
	Structural	2	1			0	2		2	1	1	1	0.57
Image 7	Visual data definition	2	1		1.5	0	1	1	1	1	3	1	0.69
	Mass-loss or Depth	1	1			1	0			1	2	1	0.40
	Aerodynamics/Performance	2	1		3	2	1		2	2	4	2	0.98
	Structural	1	1			0	1		2	1	1	1	0.33



- Classification is in draft form and could be refined based on discussions and feedback.

Work Package 3 Plans for the Next Year

Next steps:

- Collect images to create archive of how to use the erosion classification system
- Technical summary of erosion classification system, background and proposed system, results from testing it
- Apply system and test images to AEP estimate
  - Model to predict annual energy production loss based on blade erosion class
  - Select common turbine model(s) for initial performance loss exercise

Year 2 focus areas:

- Aerodynamic benchmarks, detailed aerodynamic studies on common datasets
  - Compare AEP predictions to pre aero-benchmarks. Have the AEP models changed significantly?
- Droplet impingement model for use in fatigue analysis: Develop a standard model for droplet impingement, validated with wind tunnel experimental data.
  - Characterization of aerodynamics for droplet impingement probability.

IEA Wind task 46 WP4

Laboratory testing for LEE

Public webinar 31/5-2022

Jakob Ilsted Bech – DTU Wind & Energy Systems
Maral Rahimi – Hempel A/S

WP4. Laboratory testing of erosion

WP4.1: Available **technologies** (report) M1-M10 - extended

WP4.2: Erosion **failure modes (**literature review) M11-M16

WP4.3: Normalization of test **substrates (**Recommended practice - input) M17-M22

WP4.4: Pre-evaluation of test specimens M23-M28

WP4.5: Test data analysis, damage accumulation and **VN curves** (RP) M29-M34

WP4.6: “Simple” **mechanical test** for screening of key parameters (report) M35-M40

WP4.7: Correlation between **RET** data and expected **field service life** (report + model) M41-M46

WP4.8: Aging – unloaded and during testing (literature review + RP)

WP4.1 Available technologies
Review on lab testing related to wind blade erosion

Edit: Jakob+William Finnegan – NUI Galway et al.

1. Introduction
2. Rain erosion test
3. Impact test and fatigue
4. Viscoelastic properties
5. Fracture - delamination
6. Micro structure
7. Ageing

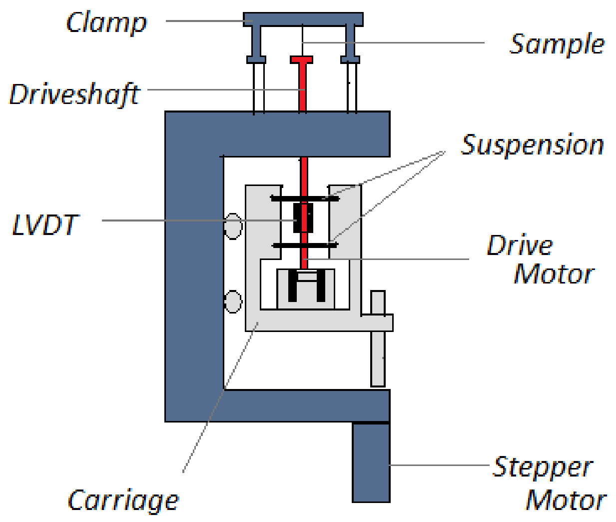
- https://share.dtu.dk/sites/IEA_WIND_T46_493900/SitePages/Home.aspx

Review of each test method

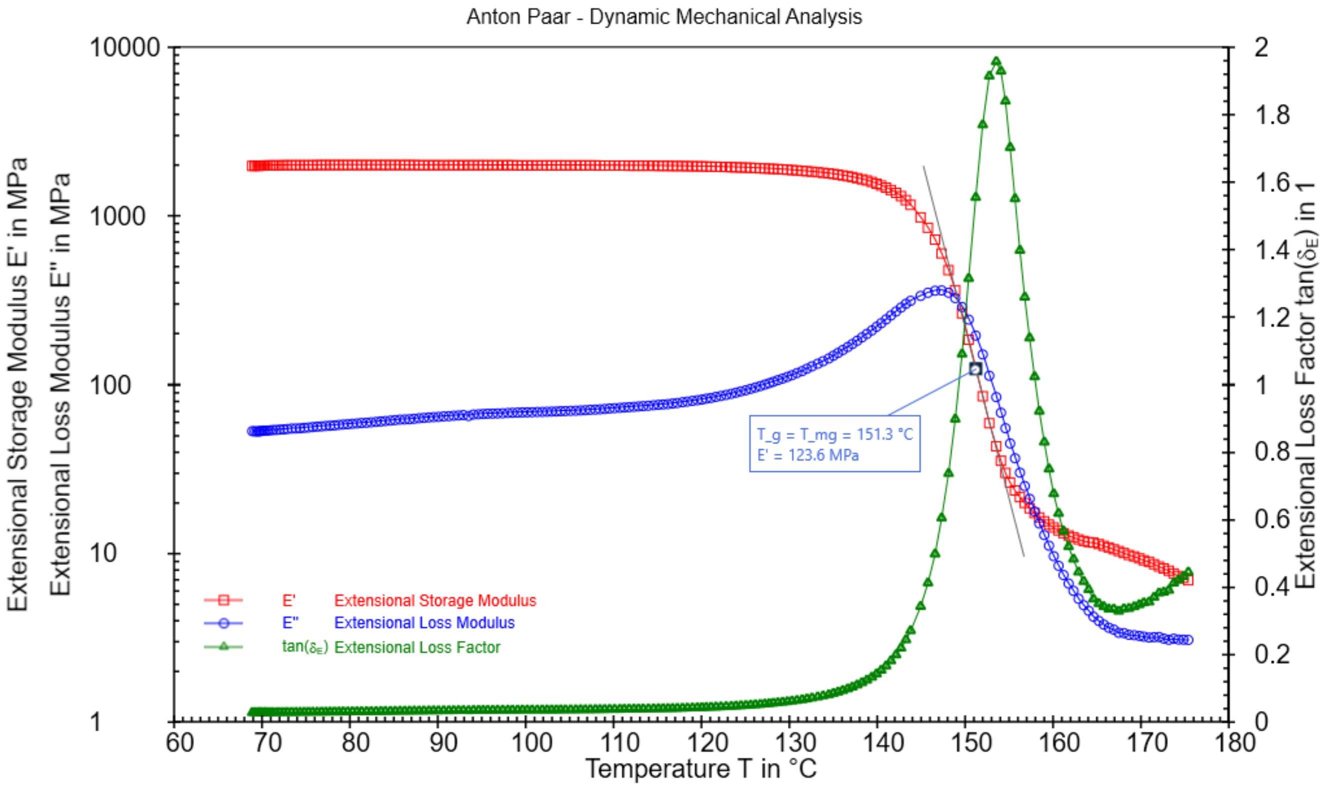
- State of the art/available technologies
- test results/observations (and failure modes where relevant)
- Relevance and current use for LEE
- Opportunities & strengths/Limitations & weaknesses
- Availability & access
- Future work & challenges
- Potential project ideas

4.1.4. Viscoelastic properties

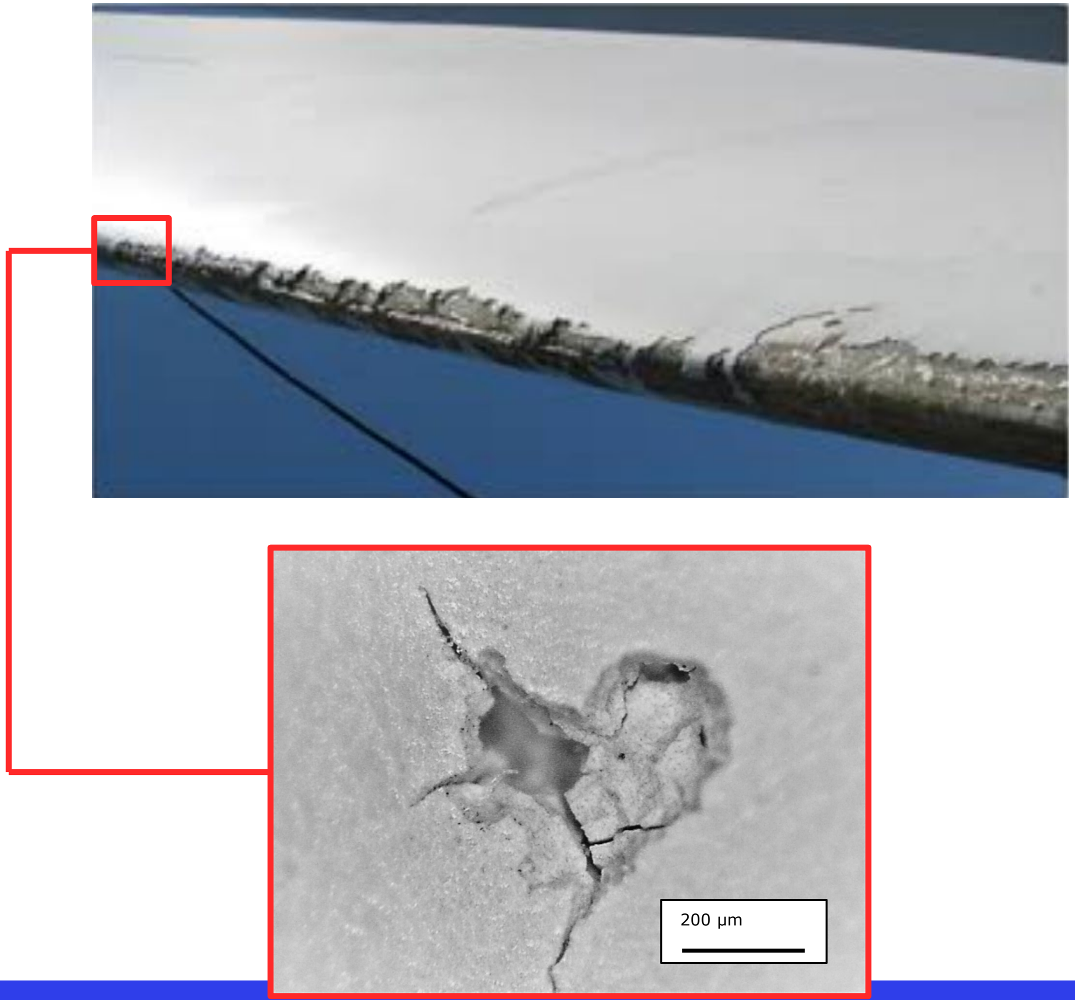
Jakob (DTU)

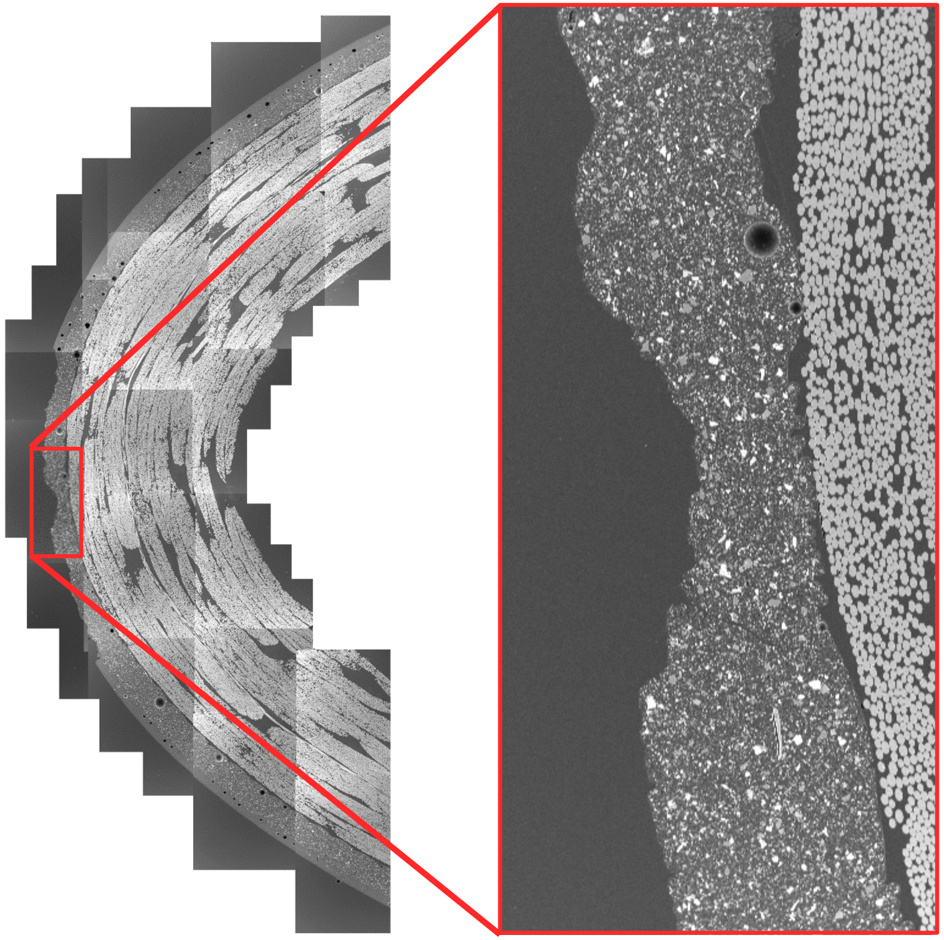


By Chem538w10grp1 - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=9715576



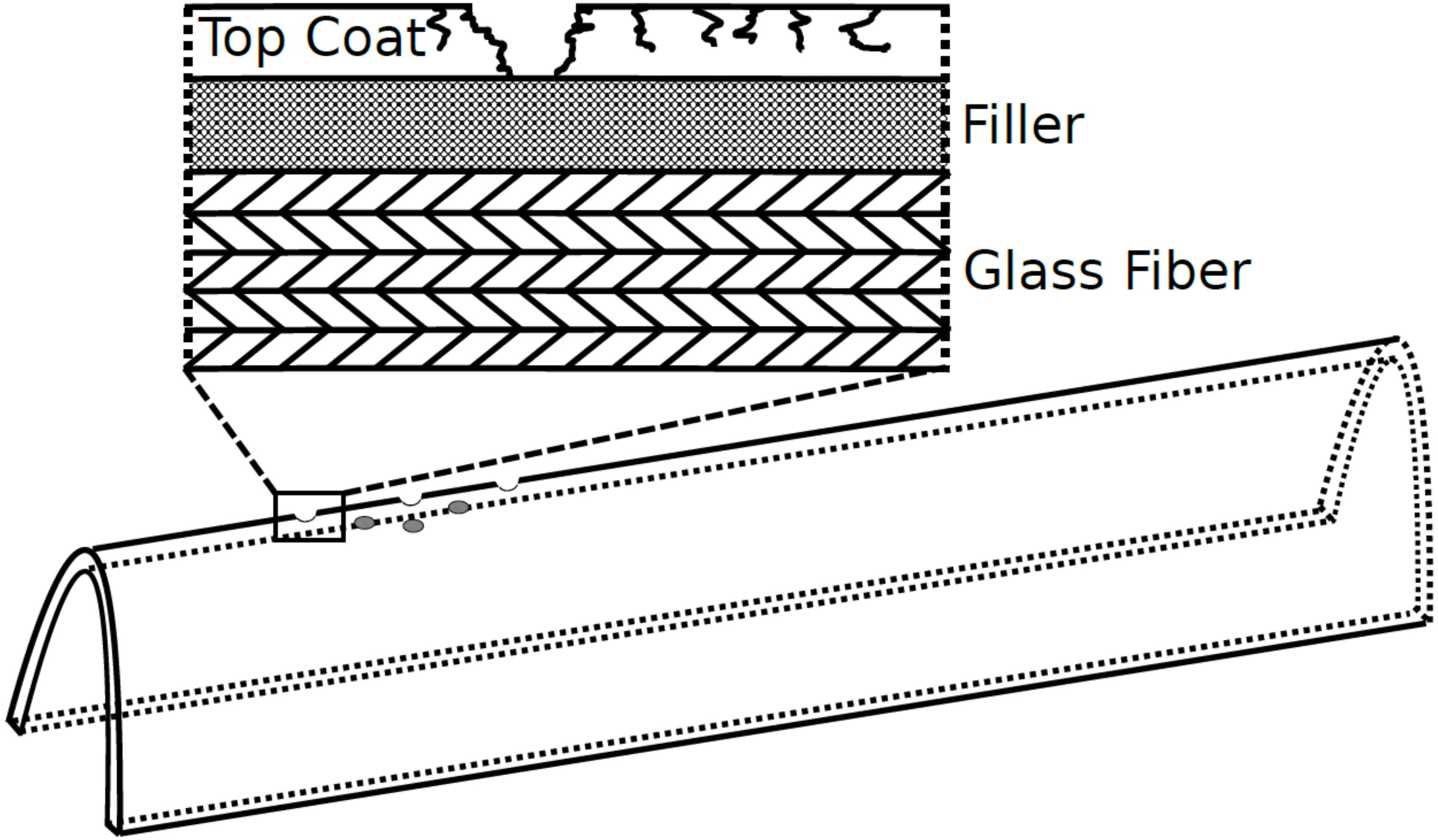
WP 4.2 Erosion failure modes in LE systems - Review





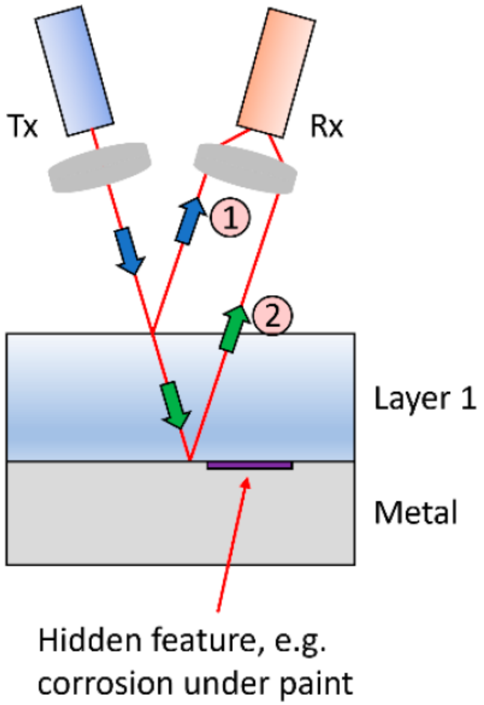
WP4.3: Normalization of test substrates Recommended practice M17-M22

- Specification of test substrate
- Role of composite lay-up; putty; prim
- Stress waves, reflections, interface

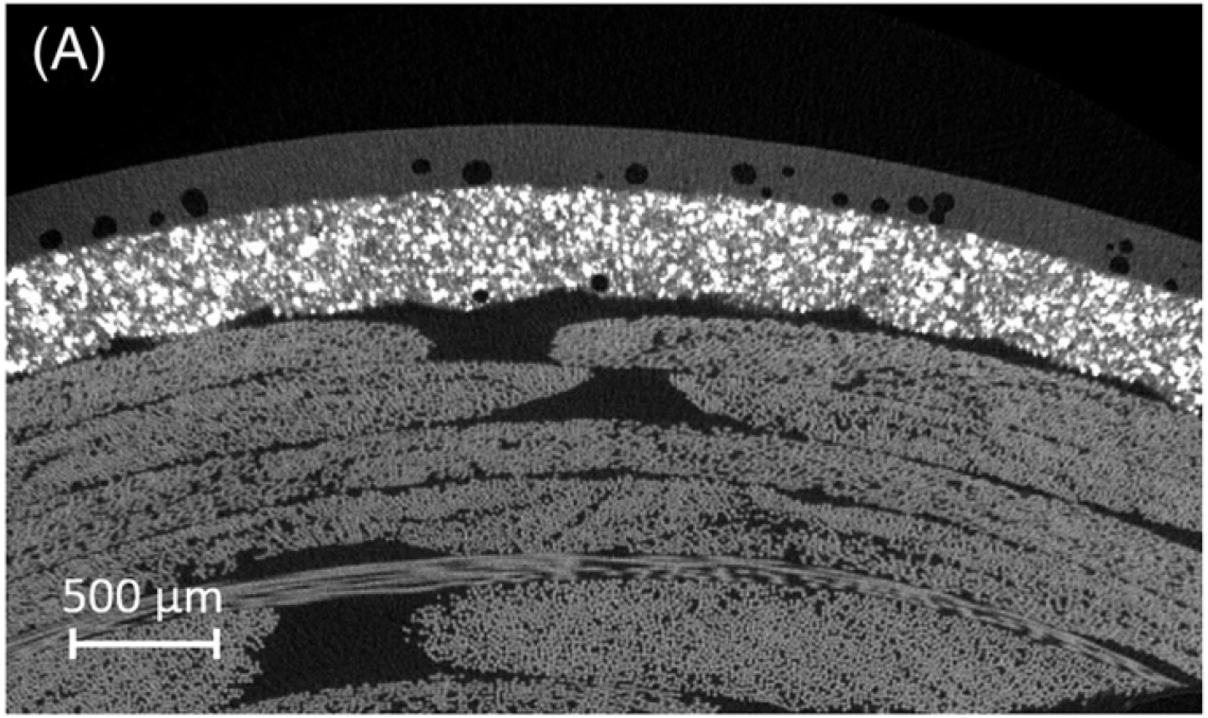


WP4.4: Pre-evaluation of test specimens M23-M28

- QA
- thickness (variation); curing; adhesion, air inclusions, surface defects etc.
- characterization methods, NDA
- Acceptance criteria

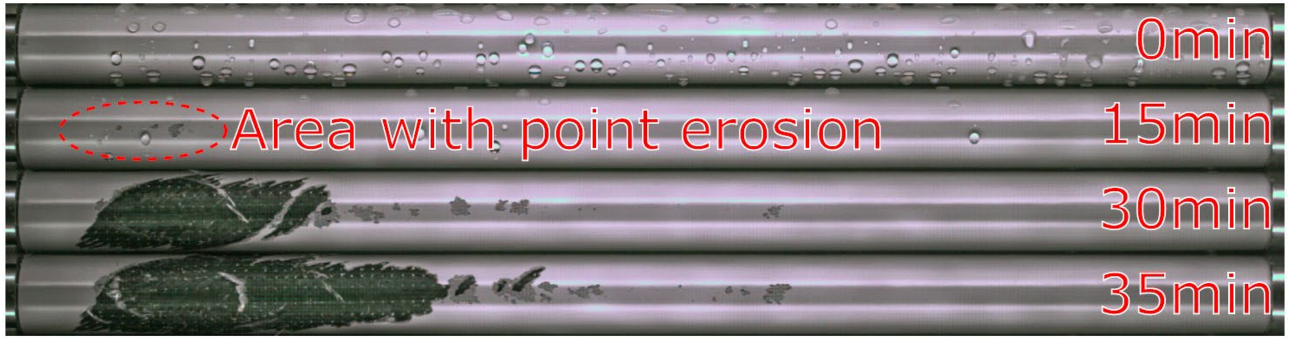


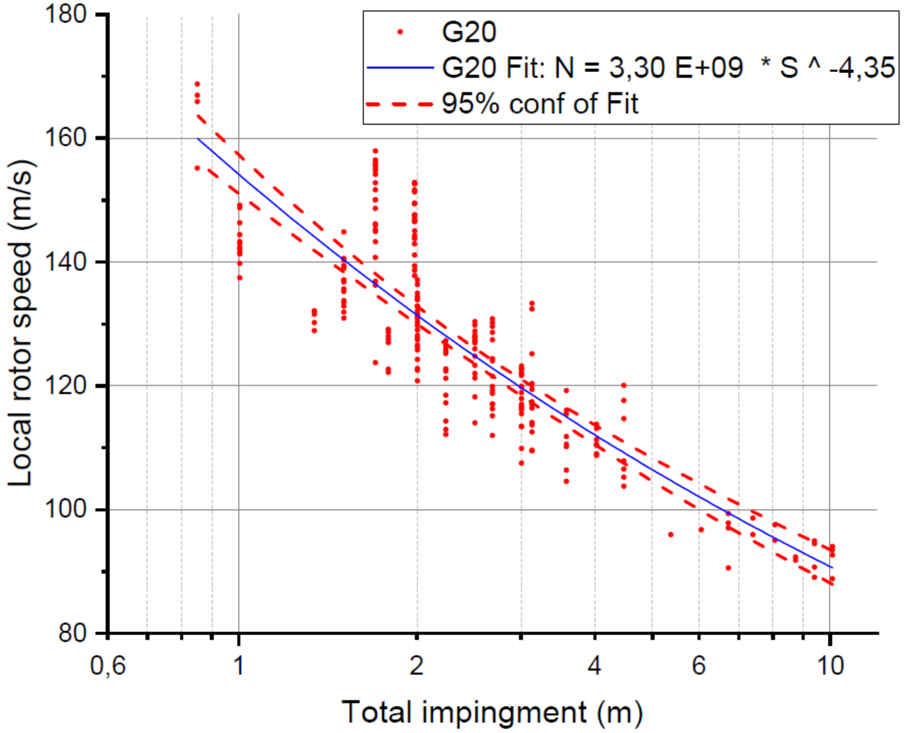
Courtesy of DTU Photonics



WP4.5: Test data analysis, damage accumulation and VN curves (RP) M29-M34

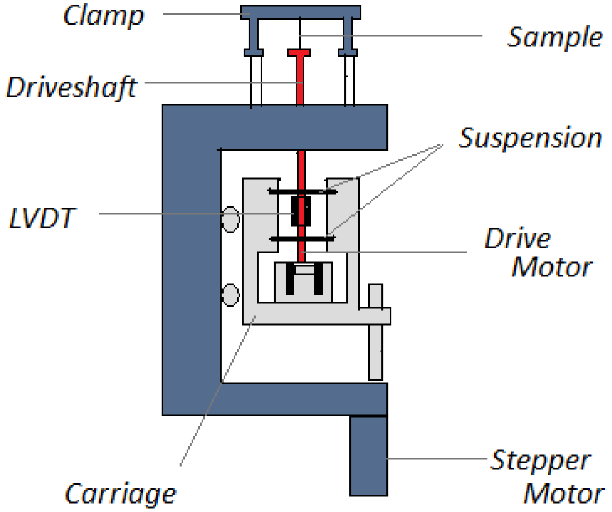
- initiate from DNV GL RP 0171 and 0573
- Take into account defect dominated damage
- Stochastic failure – probabilistic approach?





WP4.6: “Simple” mechanical test for screening of key parameters (report) M35-M40

DMTA

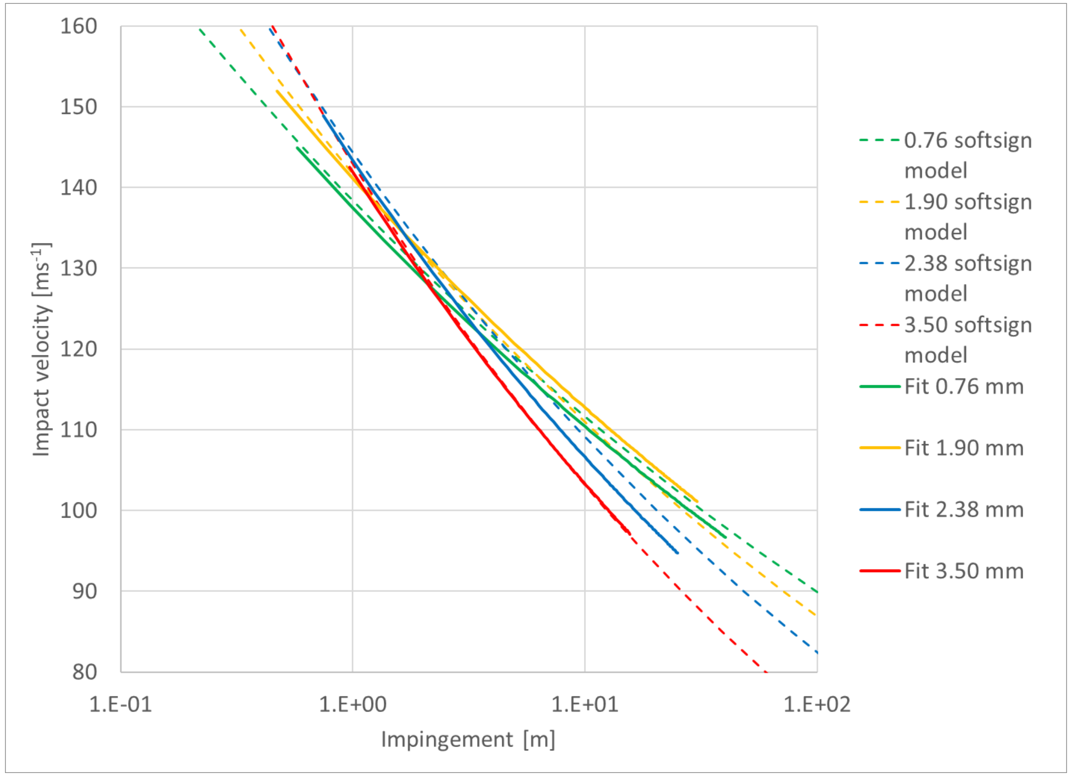


Tensile test

www.shutterstock.com · 1820939435

And others…

WP4.7: Correlation between RET data and expected field service life (report + model) M41-M46



WP4.8: Aging – unloaded and during testing (literature review + RP)

- UV Photo oxidation
- H2O Hydrolysis
- Thermal degradation
- Time
- Change of properties
- etc

WP4 partners

- Engie (BE)
- DTU (DK)
- Hempel (DK)
- VTT (FI)
- Fraunhofer IWES (GE)
- Covestro (GE)
- Emil Frei Lacke (GE)
- Delft University of Technology (NL)
- University of Bergen (NO)
- Equinor (NO)
- Aerox (ES)
- CEU Cardenal Herrera University (ES)
- Nordex (ES)
- SGRE (ES)
- ORE Catapult (UK)
- University of Bristol (UK)
- 3M (US)
- Uni. Limerick (IR)
- Uni. Galway (IR)
- Uni. Carlow (IR)
- AIST (JP)
- Uni. Niigata (JP)

IEA Wind TCP

Task 46 Erosion of Wind Turbine Blades

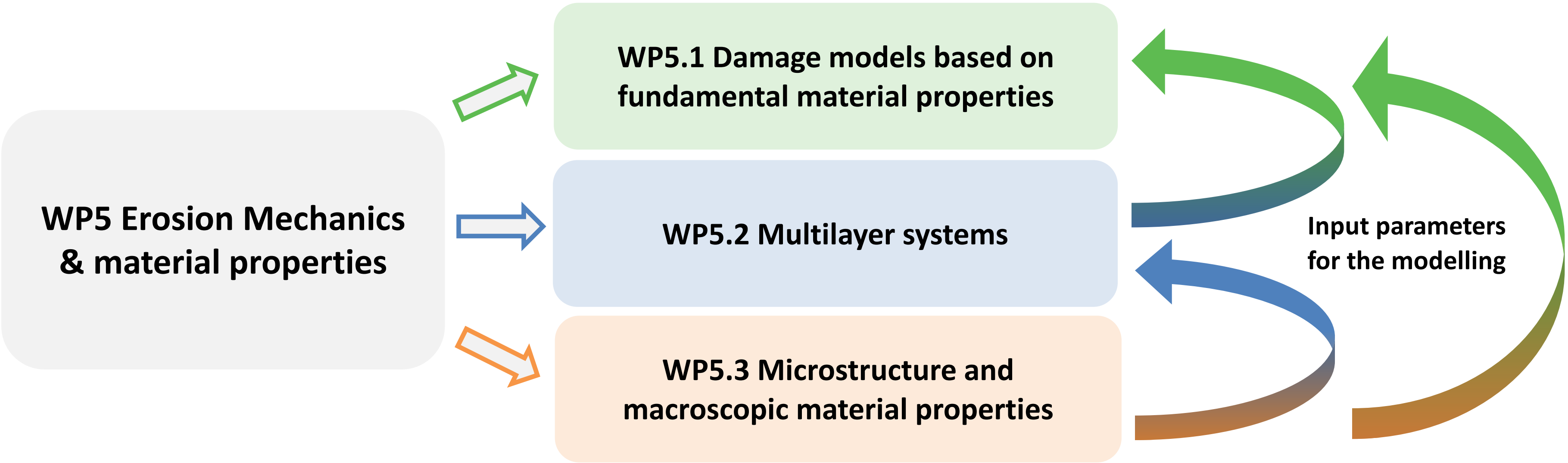
Work Package #5 Erosion Mechanics and material properties

ON THE MATERIAL TECHNOLOGY AND DAMAGE MODELLING OF MULTILAYER LEADING EDGE PROTECTION SYSTEMS

Fernando Sánchez (CEU)
fernando.sanchez@uchceu.es

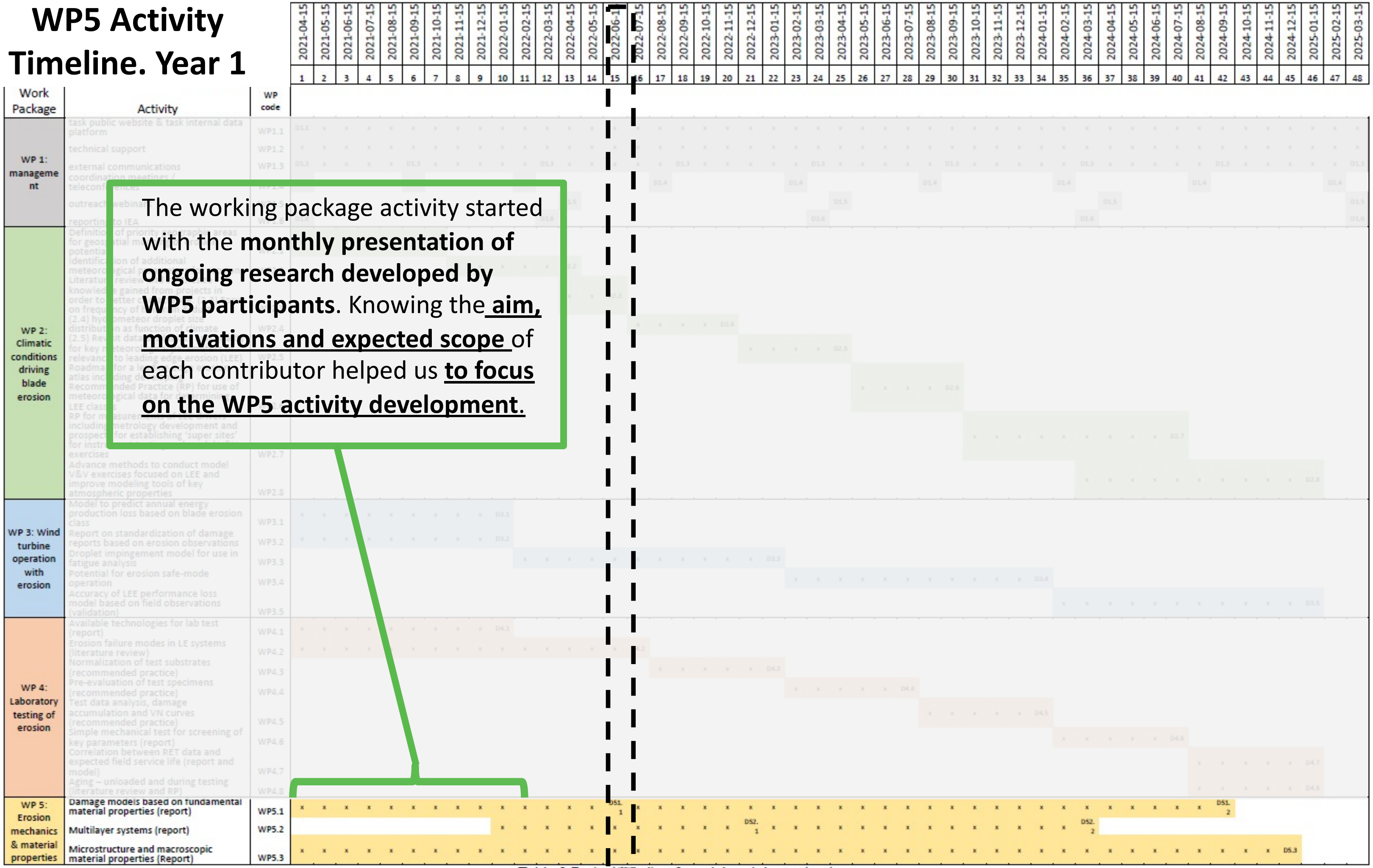
Public Webinar- 31 May 2022

WP5 Aim & Scope: Appropriate **modelling techniques and material properties** characterization methods will be defined and used to understand erosion mechanics for LEP system technologies and **to quantify the influence on the performance**.



- **Report literature reviews and** alternative/complementary **studies** including partner's experiences
- **Focused on** better **understanding** of 3 key factors:
  - ✓ damage mechanisms,
  - ✓ influence of material behavior,
  - ✓ and performance analysis.
- **Based on Modelling techniques** and related **input material parameters**

WP5 Activity Timeline. Year 1

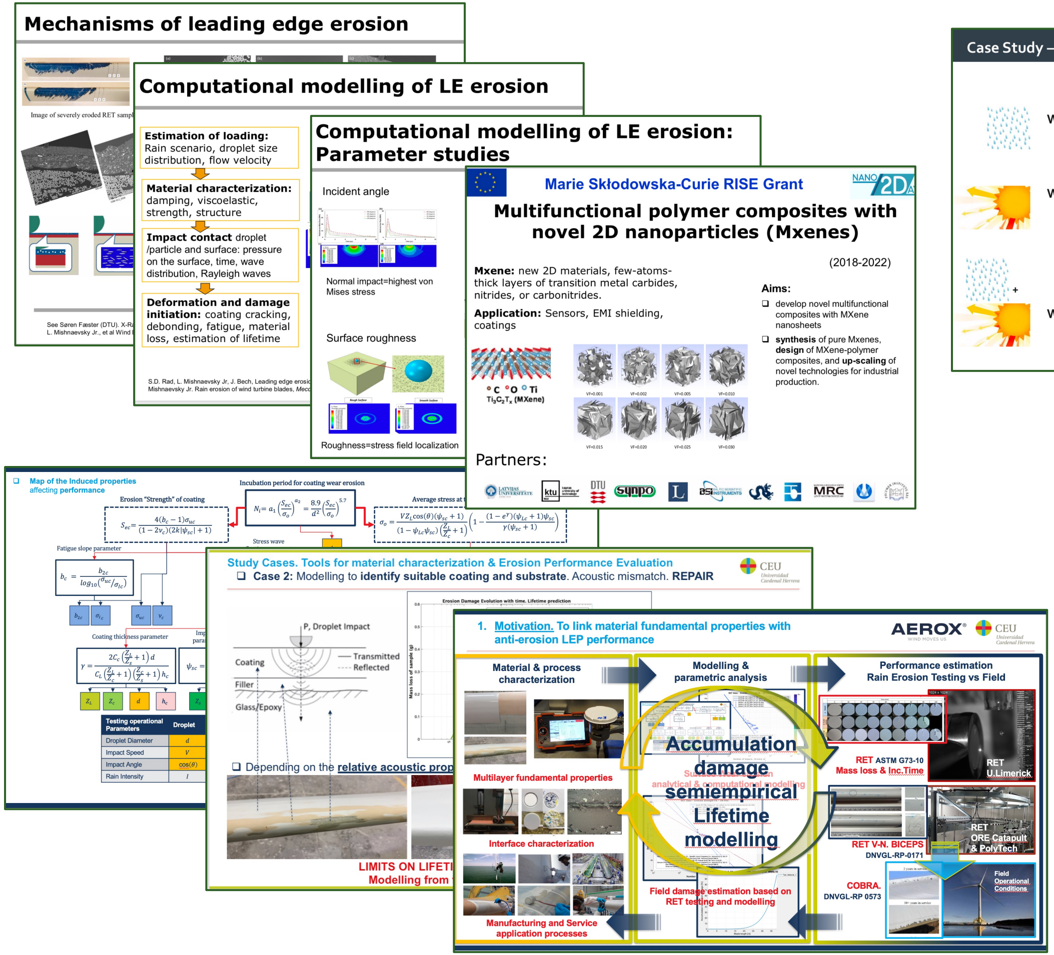


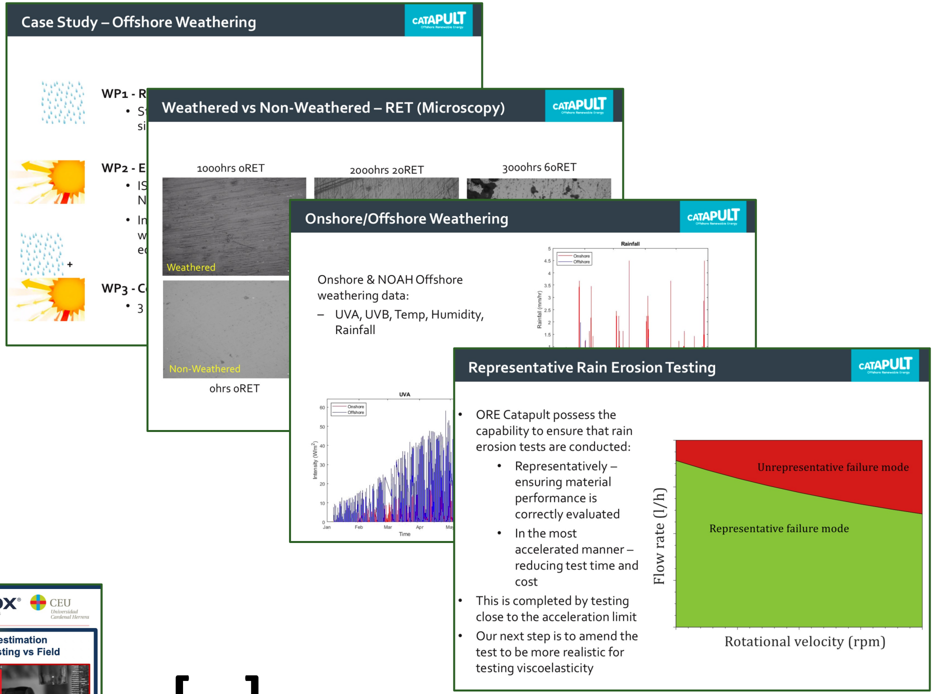
The working package activity started with the **monthly presentation of ongoing research developed by WP5 participants**. Knowing the **aim, motivations and expected scope** of each contributor helped us **to focus on the WP5 activity development.**

Table 3 Project timeline & work breakdown structure

Specific Technical Activities WP5. Year 1

WP5.1 Damage models based on fundamental material properties





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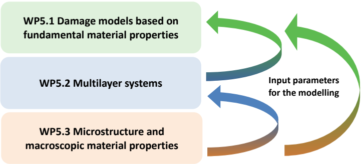
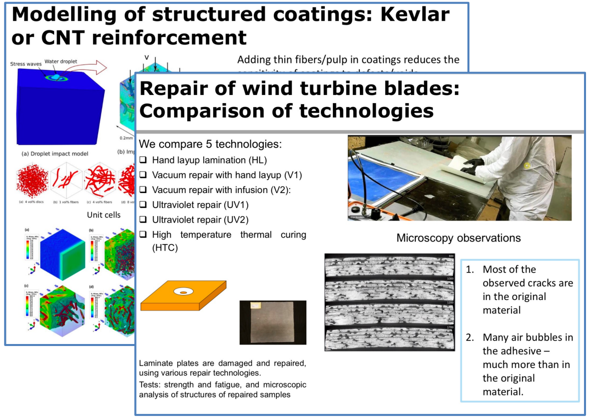
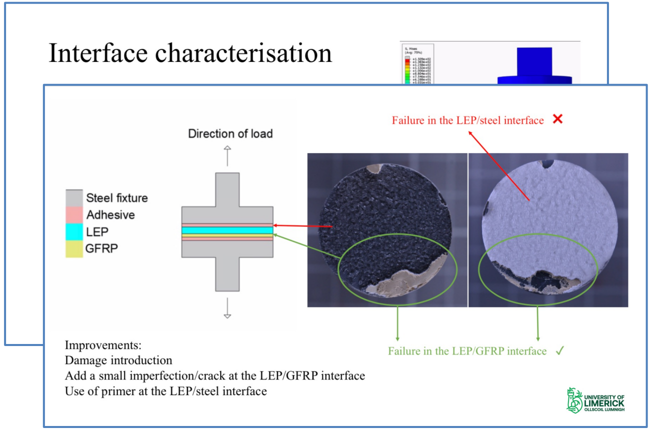
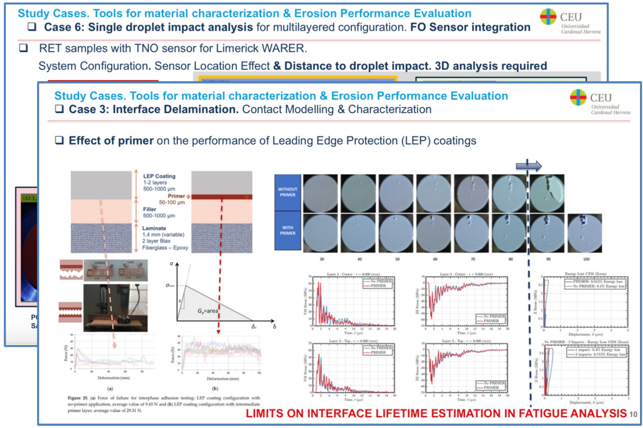


Specific Technical Activities WP5. Year 1

WP5.2 Multilayer systems

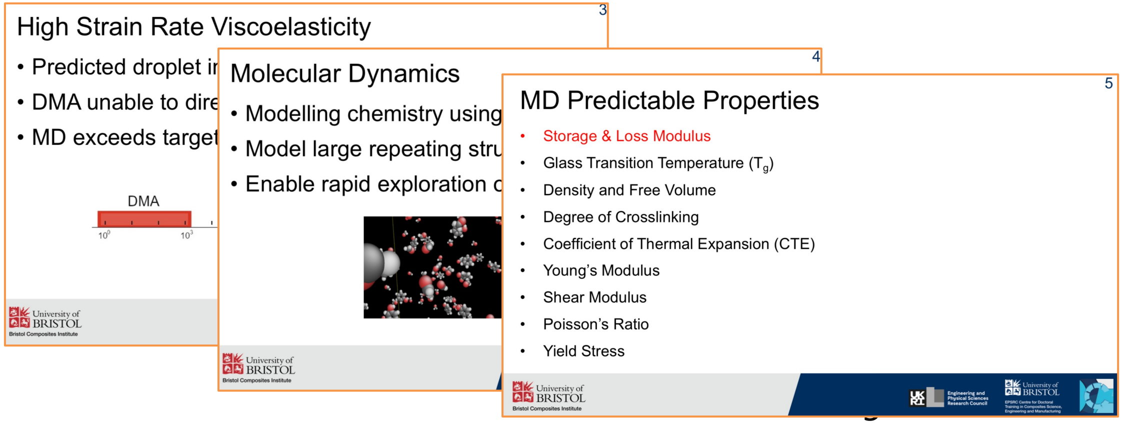






Specific Technical Activities WP5. Year 1

WP5.3 Microstructure and macroscopic material properties



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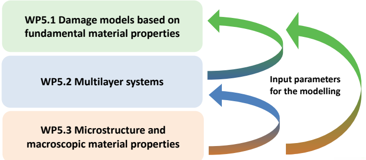


iea wind

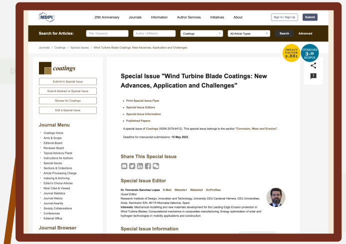
WP5 Activity Timeline. Year 2

The working package activity started with the **monthly presentation of ongoing research developed by WP5 participants**. Knowing the **aim, motivations and expected scope** of each contributor helped us **to focus on the WP5 activity development.**

Work Package	Activity	WP code
WP 1: management	task public website & task internal data platform	WP1.1
	technical support	WP1.2
	external communications	WP1.3
	coordination meetings / teleconferences	WP1.4
	outreach webinars	WP1.5
	reporting to IEA	WP1.6
WP 2: Climatic conditions driving blade erosion	Definition of priority geographic areas for geospatial mapping of potential	WP2.1
	Identification of additional meteorological ... Literature review ... knowledge gained from projects in order to better ... on frequency of ...	WP2.2
	(2.4) hydrometeor droplet size distribution as function of climate	WP2.4
	(2.5) Revisit data ... for key meteorological ... relevance to leading edge erosion (LEE)	WP2.5
	Roadmap for a ... atlas including ... Recommended Practice (RP) for use of meteorological data for determining LEE classes	WP2.6
	RP for measurement of LEE drivers including metrology development and prospects for establishing 'super sites' for instrument ... exercises	WP2.7
	Advance methods to conduct model V&V exercises focused on LEE and improve modeling tools of key atmospheric properties	WP2.8
WP 3: Wind turbine operation with erosion	Model to predict annual energy production loss based on blade erosion class	WP3.1
	Report on standardization of damage reports based on erosion observations	WP3.2
	Droplet impingement model for use in fatigue analysis	WP3.3
	Potential for erosion safe-mode operation	WP3.4
	Accuracy of LEE performance loss model based on field observations (validation)	WP3.5
WP 4: Laboratory testing of erosion	Available technologies for lab test (report)	WP4.1
	Erosion failure modes in LE systems (literature review)	WP4.2
	Normalization of test substrates (recommended practice)	WP4.3
	Pre-evaluation of test specimens (recommended practice)	WP4.4
	Test data analysis, damage accumulation and VN curves (recommended practice)	WP4.5
	Simple mechanical test for screening of key parameters (report)	WP4.6
	Correlation between RET data and expected field service life (report and model)	WP4.7
	Aging – unloaded and during testing (literature review and RP)	WP4.8

Work Package	Activity	WP code	2021-04-15 (1)	2021-05-15 (2)	2021-06-15 (3)	2021-07-15 (4)	2021-08-15 (5)	2021-09-15 (6)	2021-10-15 (7)	2021-11-15 (8)	2021-12-15 (9)	2022-01-15 (10)	2022-02-15 (11)	2022-03-15 (12)	2022-04-15 (13)	2022-05-15 (14)	2022-06-1 (15)	2022-07-15 (16)	2022-08-15 (17)	2022-09-15 (18)	2022-10-15 (19)	2022-11-15 (20)	2022-12-15 (21)	2023-01-15 (22)	2023-02-15 (23)	2023-03-15 (24)	2023-04-15 (25)	2023-05-15 (26)	2023-06-15 (27)	2023-07-15 (28)	2023-08-15 (29)	2023-09-15 (30)	2023-10-15 (31)	2023-11-15 (32)	2023-12-15 (33)	2024-01-15 (34)	2024-02-15 (35)	2024-03-15 (36)	2024-04-15 (37)	2024-05-15 (38)	2024-06-15 (39)	2024-07-15 (40)	2024-08-15 (41)	2024-09-15 (42)	2024-10-15 (43)	2024-11-15 (44)	2024-12-15 (45)	2025-01-15 (46)	2025-02-15 (47)	2025-03-15 (48)
WP 5: Erosion mechanics & material properties	Damage models based on fundamental material properties (report)	WP5.1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	D5.1.1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	D5.1.2						
	Multilayer systems (report)	WP5.2										x	x	x	x	x	x	x	x	x	x	x	D5.2.1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	D5.2.2												
	Microstructure and macroscopic material properties (Report)	WP5.3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	D5.3			

Table 3 Project timeline & work breakdown structure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Special Issue "Wind Turbine Blade Coatings: New Advances, Application and Challenges"

- Print Special Issue Flyer
- Special Issue Editors
- Special Issue Information
- Published Papers

A special issue of Coatings (ISSN 2079-6412). This special issue belongs to the section "Corrosion, Wear and Erosion".

Deadline for manuscript submissions: **15 May 2022**.

Share This Special Issue

Special Issue Editor

Dr. Fernando Sanchez Lopez E-Mail Website1 Website2 SciProfiles
Guest Editor
Research Institute of Design, Innovation and Technology, University CEU Cardenal Herrera, CEU Universities, Avda. Seminario S/N, 46115 Moncada-Valencia, Spain
Interests: Mechanical modelling and new materials development for the Leading Edge Erosion protection in Wind Turbine Blades; Computational mechanics in composites manufacturing; Energy optimization of solar and hydrogen technologies in mobility applications and construction

Special Issue Information

Composites Meet Sustainability – Proceedings of the 20th European Conference on Composite Materials, ECCM20. 26-30 June, 2022, Lausanne, Switzerland

MULTILAYER LEADING EDGE PROTECTION SYSTEMS OF WIND TURBINE BLADES: A REVIEW OF MATERIAL TECHNOLOGY AND DAMAGE MODELLING

Alexandros Antoniou[a], Kirsten Dyer[b], William Finnegan[c], Robbie Herring[b], Bodil Holst[d], Jakob Ilsted Bech[e], Ioannis Katsivalis[f], Tazefidan Kutlualp[a], Leon Mishnaevsky Jr.[e], Asta Šakalytė[g], Fernando Sánchez[h], Julie Teuwen[i], Trevor Young[f]*

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i: Aerospace Manufacturing Technologies, Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, Delft 2629HS, the Netherlands

Abstract: *The use of composites opens great prospects in the design and manufacture of the wind turbine blades due to their optimization versatility. Blade manufacturers employ polymeric surface materials to protect the composite structure from exposure to repeated impact of rain droplets which are mostly contributing to the leading edge erosion of wind turbine blades. Modelling tools considering multicomplex stress states and the material degradation are required for design purposes toward protection performance. This investigation summarizes a initial review based on two main issues: firstly, the LEP material configuration used in industry as a multilayer system considering the blade integration technology and, secondly, the modelling techniques and numerical procedures currently used to predict both wear surface erosion and interface delamination failure. The work is conducted in the framework of the IEA Wind TCP (International Energy Agency Wind Technology Collaboration Programme) - Task 46 Erosion of wind turbine blades.*

Keywords: Wind turbine blades; leading edge protection; droplet impact computational modelling; multilayer systems

1. **Introduction**

In the immediate future, wind power will provide more electricity than any other technology based on renewable and low-emission energy sources. As a result, the size of offshore wind turbines has increased to harvest more wind energy in order to achieve the 2050 EU carbon neutral targets. The use of composites opens great prospects due to their optimization versatility. However, composites perform poorly under rain droplet impact, perpendicular to the reinforcement direction and are sensitive to environmental factors such as heat, moisture, icing, salinity and UV.

IEA Reports based on Literature Review:

1. **Identify lacks and drawbacks** on state-of-the-art erosion damage **modelling techniques** and corresponding material characterization including partner's experiences.
2. **LEP multilayer** technology and **interface modelling** methodologies

Specific Technical Activities WP5. Year 1-2

WP5.1 Damage models based on fundamental material properties. Identify appropriate **damage models and define appropriate testing methodologies** for the material properties defined **as input parameters** in the modelling. Work will be performed in alignment with WP2.8 and 3.3 (modelling including droplet impingement aerodynamics and key atmospheric issues) and WP4.7 (modelling from RET Data).

- **Report 1** based on **Literature Review:** To write a scientific paper as a review and extend to IEA Report

✓ Identify **lacks and drawbacks on state-of-the-art** erosion damage modelling techniques and corresponding material characterization including partner's experiences.

Next steps:

- ❑ **To compile available test data relevant to the erosion damage models**, state of the art in models for the accumulation of damage, and its relationship with fundamental material properties. To link with WP4 Lab Testing.
- ❑ To explore further analysis of **combined weathering and RET** and inclusion in **Lifetime Prediction Models.** Analysis of **UV effect on material base fundamental properties** and hence a key issue on erosion mechanics. Research to be focused on how to relate weathering cycles with **RET and in-field performance modelling analysis**. In Relation with WP2

Specific Technical Activities WP5. Year 1-2

WP5.2 Multilayer systems. Consider the leading edge as a multilayer system, and the different modelling approaches (in relation with 5.1). Appropriate analysis for **Manufacturing issues** due to **LEP configuration**, application procedure, LEP **blade integration** technology.

- **Report 2** based on **Literature Review**: LEP multilayer **technology and interface modelling** methodologies. To write&present conference paper as a review and to extend to IEA Report
  - ✓ Develop **comprehensive literature reviews** on multilayer / interface damage and underline different SoA **modelling approaches** with required input parameters.

Next steps:

- ❑ Develop a report for **performance testing analysis methodology** to extract **material/interfacial modelling inputs** such as the interfacial **fracture toughness quantification** and the critical **traction/separation** of the interfaces. This work is closely connected to the experimental **fracture mechanics approaches discussed in WP4**.
- ❑ To develop an **interface performance testing & modelling analysis methodology** which will take into account the effect of:
  - the different **layers** of each **configuration**
  - the **strain rate sensitivity** of the interfaces
  - the **gradual property degradation** due to rain erosion

Specific Technical Activities WP5. Year 1-2

WP5.3 Microstructure and macroscopic material properties. Connecting the observed macroscopic mechanical behavior with the polymer composition and microstructure. Investigating the effect of fillers, additives, **polymer chemistry, on erosion mechanics** and accumulation damage. To investigate testing techniques for polymer system analysis linked with the erosion damage progression. **To explore** how material **properties** derived at an **atomistic level can feed into mesoscale and macroscale simulations**.

✓ Develop comprehensive literature reviews on polymer composition and microstructure and underline different LEP technology approaches

Next steps:

❑ **Report 3** on the material microstructure and macroscopic material fundamental properties in relation with erosion performance. SoA to **predict high strain rate viscoelastic properties of LEP systems computationally** with molecular dynamics, and the materials properties to evaluate models. To **analyse temperature effects** in **terms of viscoelasticity relation with erosion mechanics**. In relation with WP2

Webinar – Task 46 Erosion of wind turbine blades

IEA Wind TCP

Poll & mentimeter© results

31 May 2022 , 16:00 CEST

Raul Prieto (VTT) and Charlotte Hasager (DTU),
Sara Pryor (Cornell Univ.) and Marijn Veraart (Ørsted) ,
David Maniaci (Sandia), Jakob Ilsted Bech (DTU), Maral Rahimi (Hempel),
Fernando Sánchez López (UCH-CEU) and Bodil Holst (Univ. of Bergen)

Blade erosion: What are key research challenges?

Mentimeter

34

Blade erosion: What are key challenges in the wind industry?

Mentimeter

lab results vs real life
offshore maintenance
aging of materials
new blades without it
apply product - defects
reliable-repairable lep
find safe mode settings
find easy fix 4 old blade
blade o and m planning
lep tapes
wind data
lep materials
increasing velocity
repair solutions
requirements unclear
rain data
risk evaluation
performance loss
financials
aerodynamic influence
aerodynamic loss
lep durability in field
damage categorization
processability
selection of lep
long-lasting-materials
collaboration
lep installability
lep variability
aep loss
offshore repair
geographies
inspection and repair
lep
confidentiality
lifetime prediction
process feasibility
cost reduction
low-cost-operation
repair
prediction
inspection interval
quality of repairs
characterize
lcoe
approval procedure
reliability
rain erosion
maintenance strtategy
damage quantification
site specific prediction
human resources
appropriate coating
select products
material ret and cost
offshore field repair
quality assessment
quantify economic loss

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Poll – Question #1

IEA task 46 webinar 31 May 2022

5:11 | 2 questions | 33 of 39 (84%) participated

1. What challenges do you foresee on blade erosion 10 years from now? (Multiple Choice) *

33/33 (100%) answered

Weather conditions in emerging markets poorly known	(13/33) 39%
Higher tip speeds of novel turbines will increase blade erosion	(20/33) 61%
Cost effective coating solutions will not be available	(7/33) 21%
O&M costs increase for the fleet of existing wind farms	(16/33) 48%
Blade aerodynamic performance cause loss of energy production due to erosion	(16/33) 48%
Scaling up offshore wind installations rapidly will increase blade erosion	(20/33) 61%

Poll – Question #2

2. Which concepts have the highest potential to tackle blade erosion? (Multiple Choice) *

33/33 (100%) answered

Wind farm planning, e.g. site specific erosion assessment maps	(10/33) 30%
Blade design, e. g. new coating materials	(32/33) 97%
Blade design, e. g. blade design for lower tip speed	(5/33) 15%
O&M, e. g. cost effective inspection	(6/33) 18%
O&M, e. g. cost effective service and repair	(16/33) 48%
Wind turbine control, e. g. erosion safe operation	(11/33) 33%
Disruptive innovation tackling blade erosion 100%	(14/33) 42%

End Poll

Operating agents:

Charlotte Bay Hasager (cbha@dtu.dk) and Raul Prieto (raul.Prieto@vtt.fi)

Country	IEA Wind Contracting party	Task Participant
Belgium	Belgian Ministry of Economy	Engie
Canada	Natural Resources Canada	WEICan
Denmark	Danish Energy Agency	DTU
		Hempel
		Ørsted A/S
Finland	Business Finland	VTT
Germany	Federal Ministry for Economic Affairs and Energy	Fraunhofer IWES
		Covestro
		Emil Frei
		Nordex Energy
		DNV
Ireland	Sustainable Energy Authority of Ireland	NUI Galway
		University of Limerick
		IT Carlow
Japan	New Energy and Industrial Technology Development Organization (NEDO)	AIST
		Osaka University
		Tokyo Gas Co.
		Asahi Ruber Inc.
Netherlands	RVO	TU Delft
		Suzlon
		TNO
		Eneco
Norway	NVE	Equinor
		University of Bergen
Spain	CIEMAT	Aerox
		Universidad Cardenal Herrera – CEU
		CENER
		Siemens Gamesa Renewable Energy
		Nordex Energy Spain
		DNV Iberica
United Kingdom	ORE Catapult	ORE Catapult
		University of Bristol
		Lancaster University
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