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On the development of anti-erosion performance estimators for polymer-based surface multilayer coating systems of wind turbine blades

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Introduction

In the near future, wind power will provide more electricity than any other technology from renewable and low-emission sources. There is a need to improve existing technologies by **increasing the size of offshore wind turbines** to capture more wind energy. Blade manufacturers employ surface coatings to protect the composite structure from exposure to heat, moisture, droplet impact, icing, salinity and/or UV. When considering the **repeated impact of rain droplets**, the high required **tip speed is a key contributor to surface erosion damage** on the blade leading edges.

Figure 1. *Examples of LEP surface erosion across a range of years in offshore service*

The **Leading Edge Protection (LEP)** coating is usually moulded, painted or sprayed onto the blade surface. Industrial processes state that LEP systems can be **outlined as a multi-layered system**, where a sanded putty filler layer between the laminate and the surface LEP coating is included to smooth the composite surface. A primer layer may be also integrated under the coating and over the filler layer to guarantee adhesion circumventing delamination between layers.

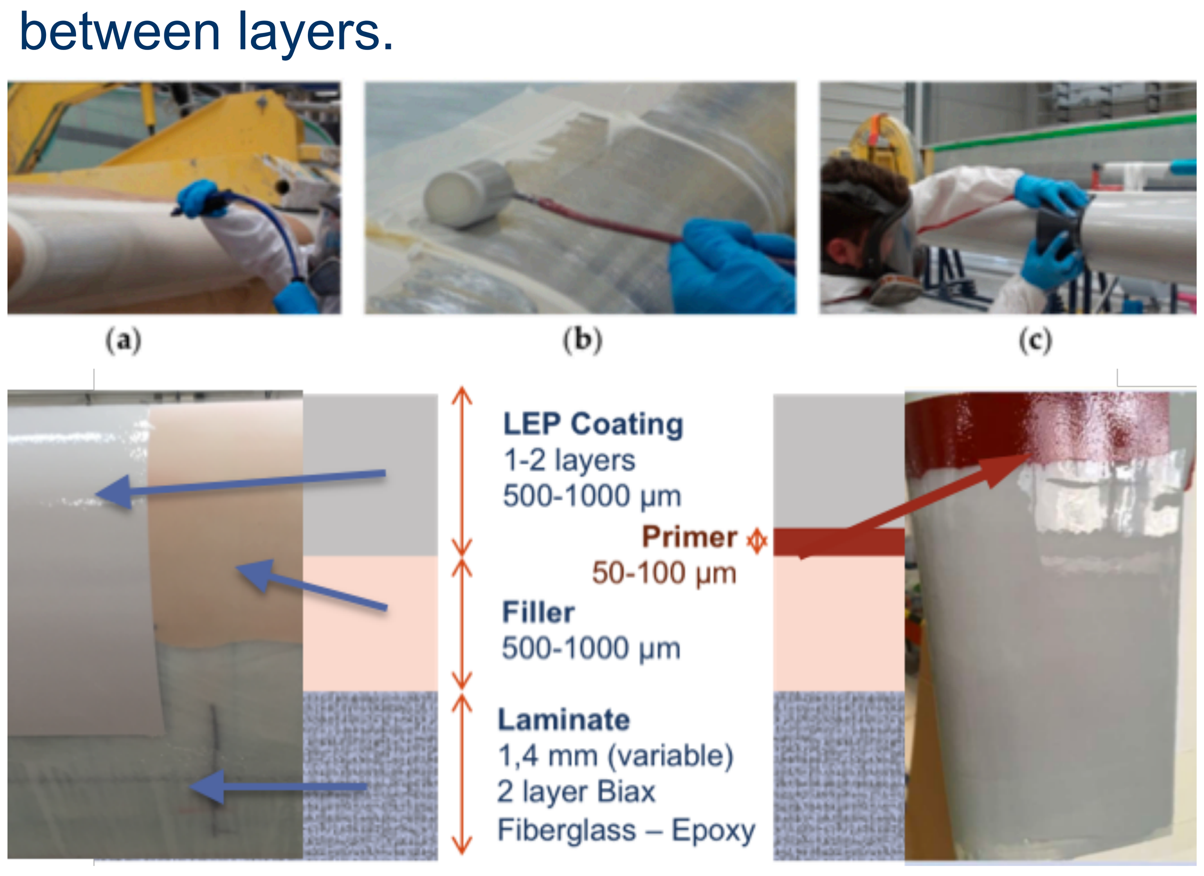

Figure 2. *Leading Edge Protection (LEP) system application procedures, i.e., (a) spray; (b) roller; (c) trowel. Multilayer configuration.*

In the current work, LEP erosion performance at rain erosion **accelerated Rain Erosion Testing (RET) technique is used as the experimental key metric** in an effort to assess the response of the material. **Numerical procedures** to predict both **wear surface erosion and delamination failure** have been proposed to identify suitable coating and composite substrate combinations.

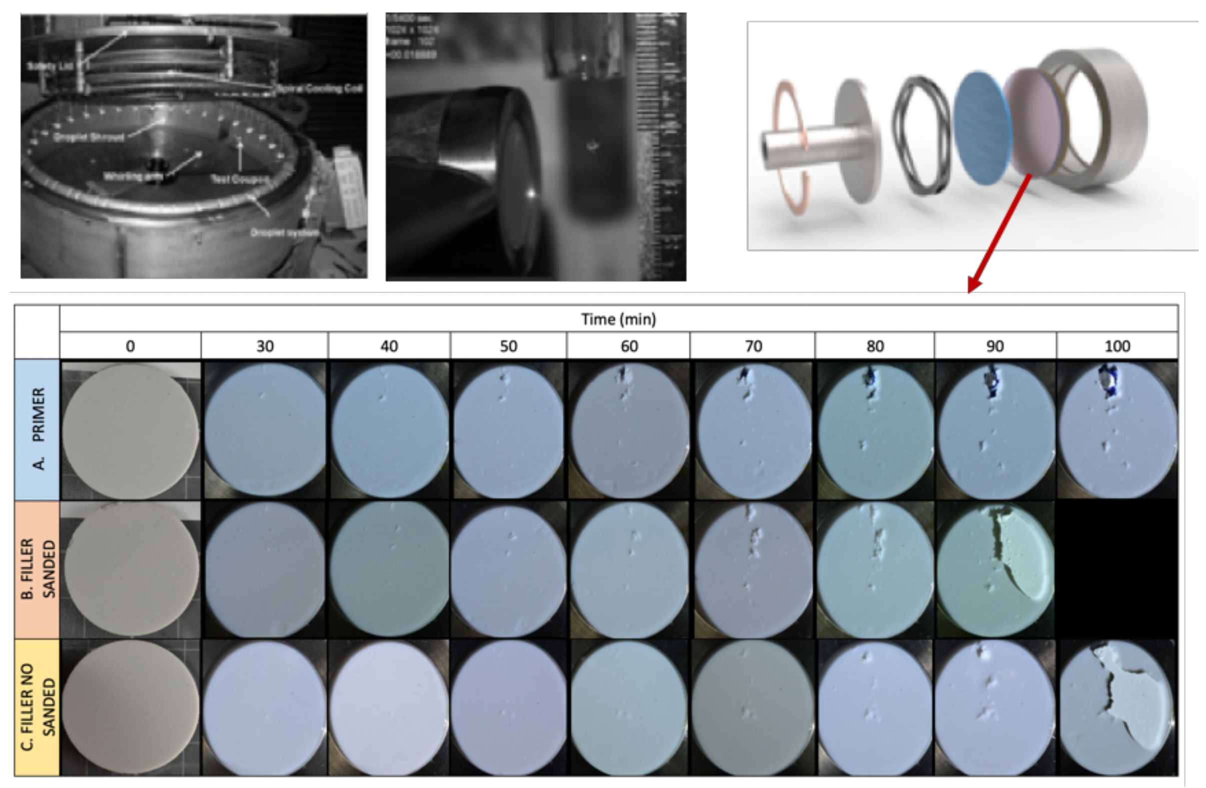

Figure 3. *Whirling arm rain erosion **RET facility** (WARER) at University of Limerick and Images **of wear surface damage and delamination damage** after time interval of testing **comparing LEP coating configurations** with intermediate primer layer (A), No primer application with sanded filler (B) and No primer application with No sanded filler (C)*

Erosion lifetime prediction modelling Part 1: Wear erosion failure

The erosion lifetime prediction model was computationally evaluated and implemented as a model to carry out studies in the optimization of the mechanical parameters involved on the **LEP material performance criteria** due to **wear accumulated damage** and considering **fatigue analysis**. The methodology proposed is founded on Springer's modelling and confronts the modulation of coating properties based on the **analysis of the induced effects of variation for a given fundamental material property** (density, impedance, endurance limit, etc) **and impact conditions** (velocity, droplet size, etc).

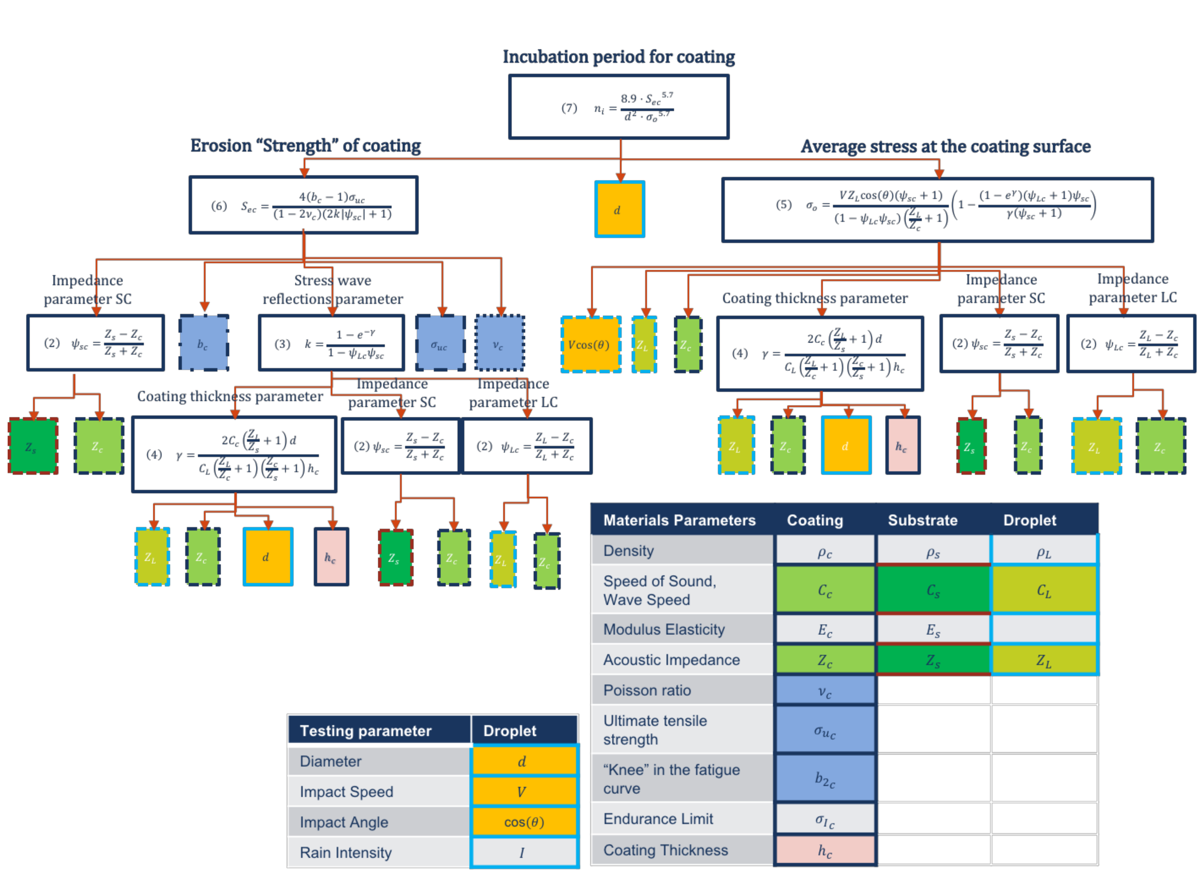

Figure 4. ***Map of material and testing parameters*** *affecting rain erosion performance for **wear failure***

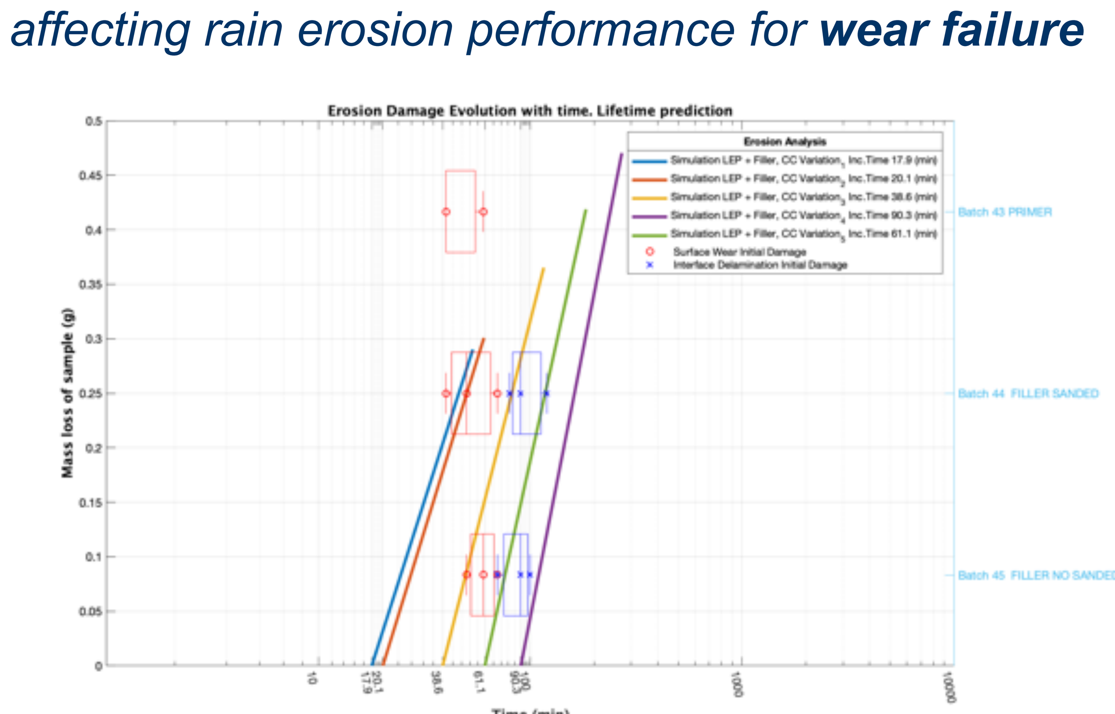

Figure 5. *Results Data for **RET experimental** and **simulated** performance for **wear erosion failure.***

Erosion lifetime prediction modelling Part 2: Interface delamination failure

In order to consider the interface delamination failure in a **multilayer system configuration**, the modelling requires to compute the stress-strain evolution pondering **single droplet impact phenomena** with measured elastic and **viscoelastic properties** at **impact high strain rates**. The **interface contact modelling** is considered with a **cohesive zone formulation CZM** were knowing the **peeling** and the **pull-off** testing, defines the **fracture energy**. The **numerical procedure for the Traction Separation Law (TSL)** considers initial parameter values that vary for subsequent droplet impacts. The **procedure accounts for interface delamination** in case the **remaining Fracture Energy, Ga** vanishes after a given **number of impacts n.** The remaining energy after a series of impacts gives a **Threshold** value **to track for interface Delamination.**

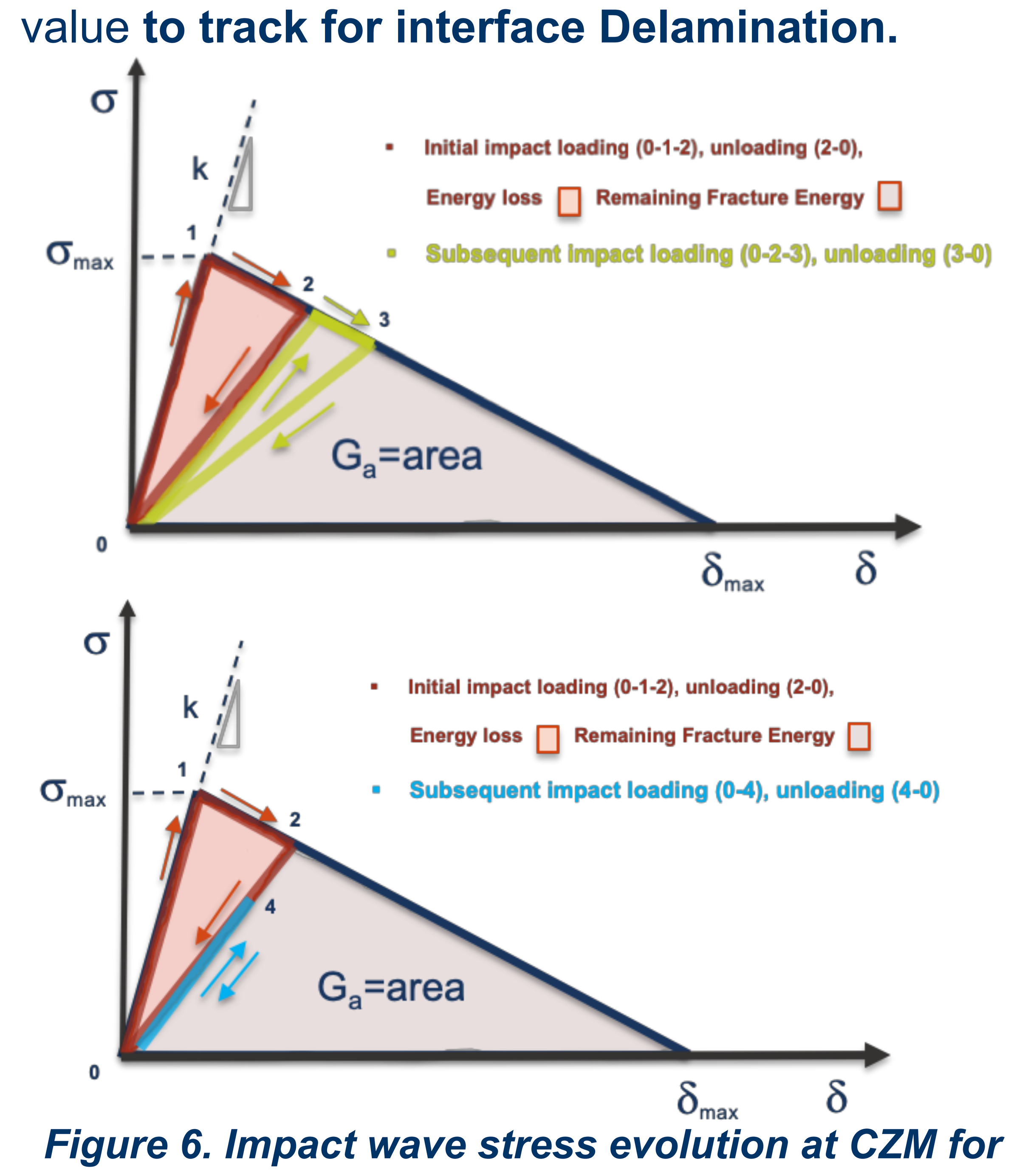

Figure 6. Impact wave stress evolution at CZM for a given TSL *conditioned by the Fracture Energy Ga, the maximum stress at interface, and the slope of parameter k that relates with the deformation δ.*

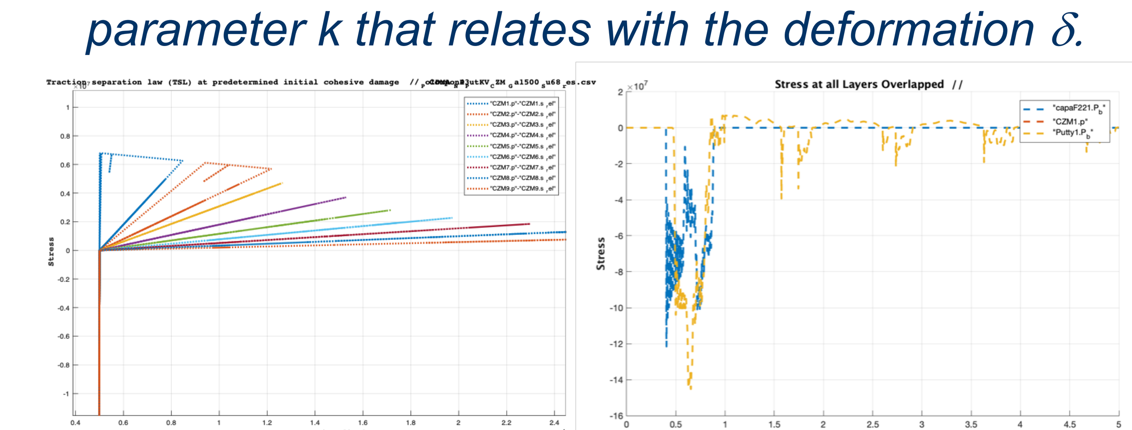

Figure 7. *Fracture Energy **for 10 periods of impacts for the total lifetime** (left) and stress with time (right)*

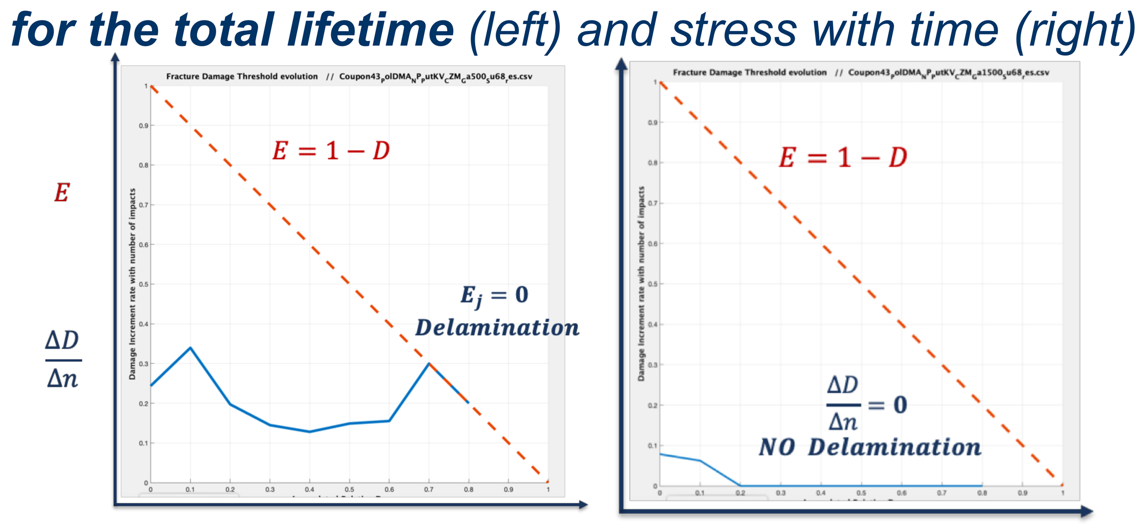

Figure 8. *Estimation for **complete delamination case for sanded Filler** (left) and **No delamination case for Filler + Primer layer** (right)*