Wind Turbine Blade
Service & Maintenance
2019

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MATERIAL AND PROCESS FEATURES IN SERVICE APPLICATIONS THAT AFFECT ANTI-EROSION LEADING EDGE PROTECTION OF WIND TURBINE BLADES

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LEP 4BLADESPROJECT

This Project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 811473

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GDESwind

CEU Universidad Cardenal Herrera

CONTENT OUTLOOK

Introduction.

- **Company overview**
- **Project 'LEP4**BLADES**'.** European Union's Horizon 2020 research and innovation program.

1. Motivation. Leading Edge Protection problem

- **Industrialization** process **vs Service** conditions**.** A **multilayer** system

2. Service application processing parameters

- **LEP application procedure and related defectology**

3. Analysis of LEP Performance depending on application induced issues.

- **Material** and **operational** durability **factors**
- Modelling to **identify suitable coating and substrate**. Acoustic mismatch
- **Void content** affecting erosion damage anticipation

4. Conclusions and Further Work

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protecting the future

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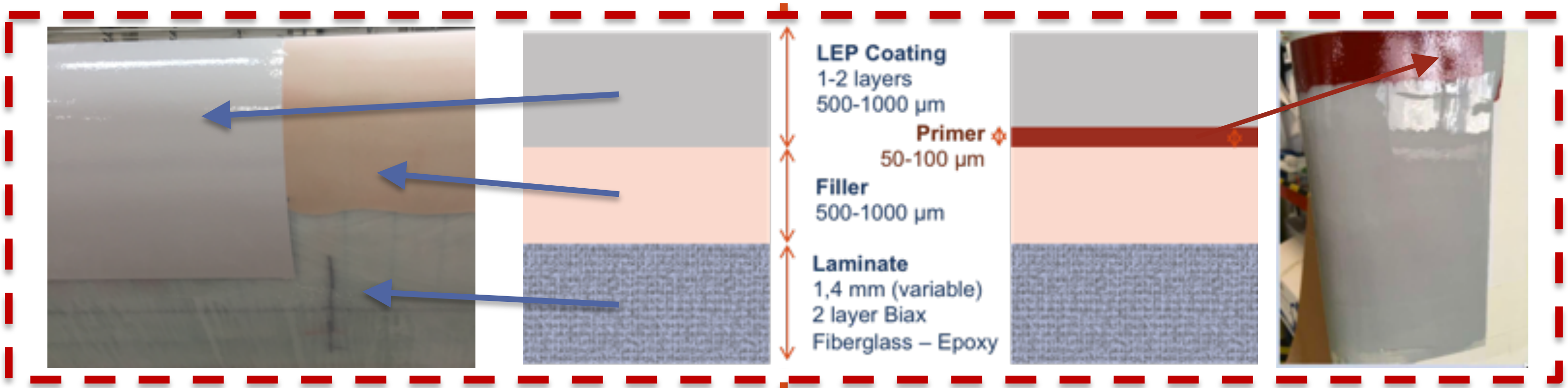
- ❑ A typical wind **turbine may be expected to operate continuously** over its service life.

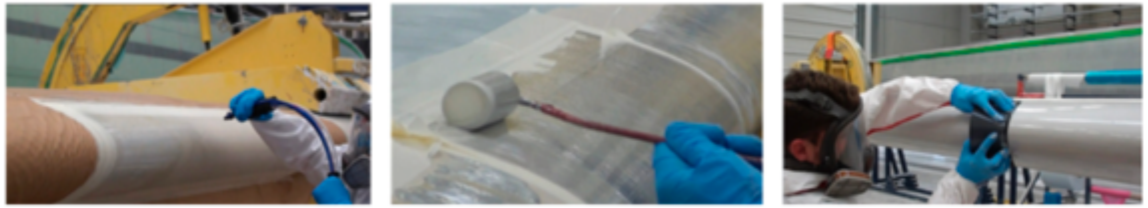
- ❑ We are all observing **blades that only after a few years of operation need to repaired**.

- ❑ Mostly, these performance problems are coming from **the in plant application by the OEM** or from the application under service conditions. The sector is in the **need for a robust product and application process**

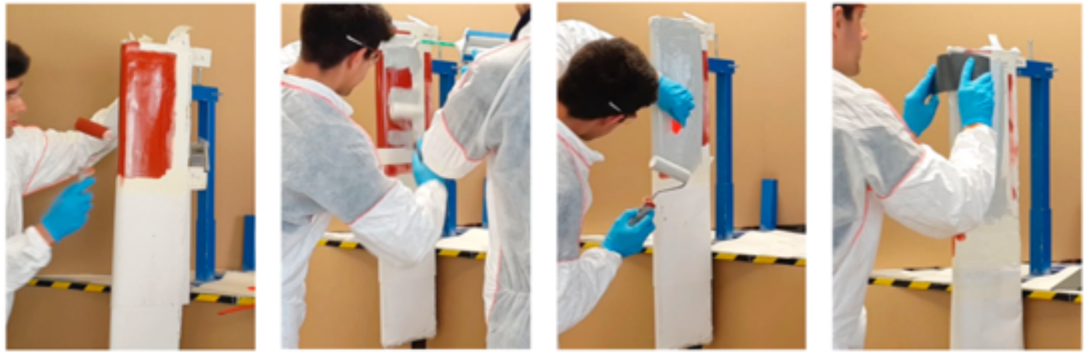
❑ **Motivation.** Leading Edge Protection problem



(a) (b)



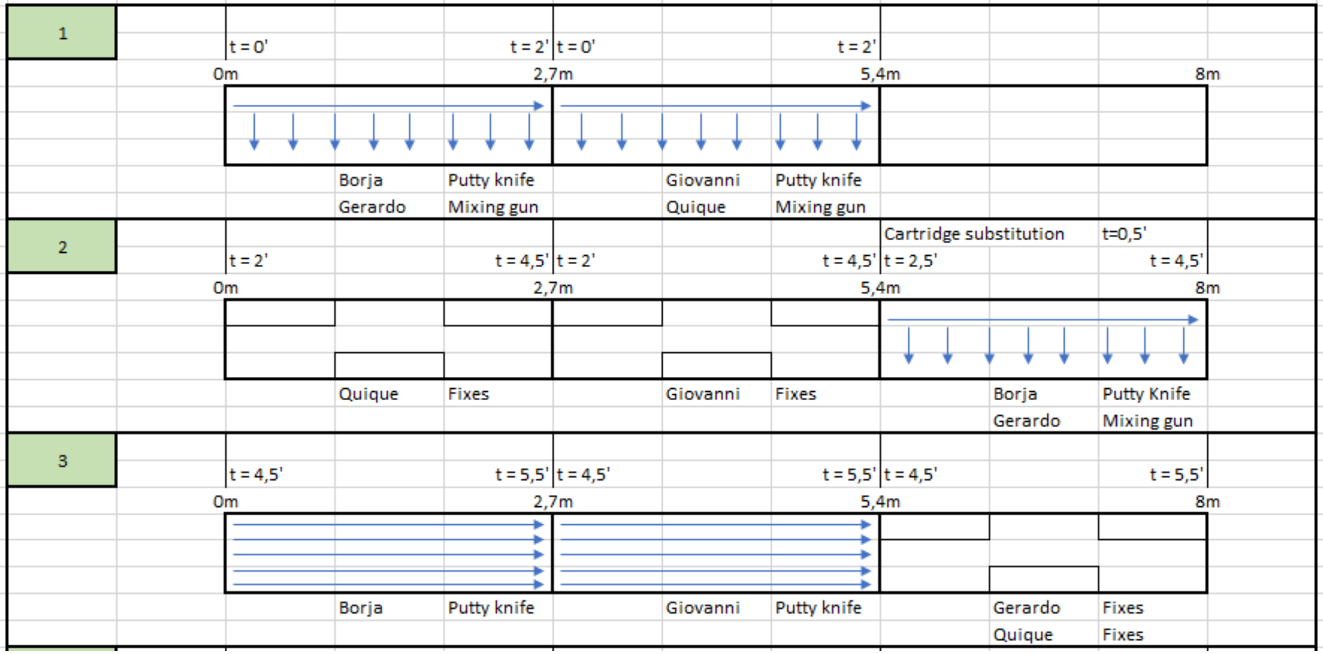
(a) (b) (c)



(a) (b) (c) (d)

Program and plan the particular application:

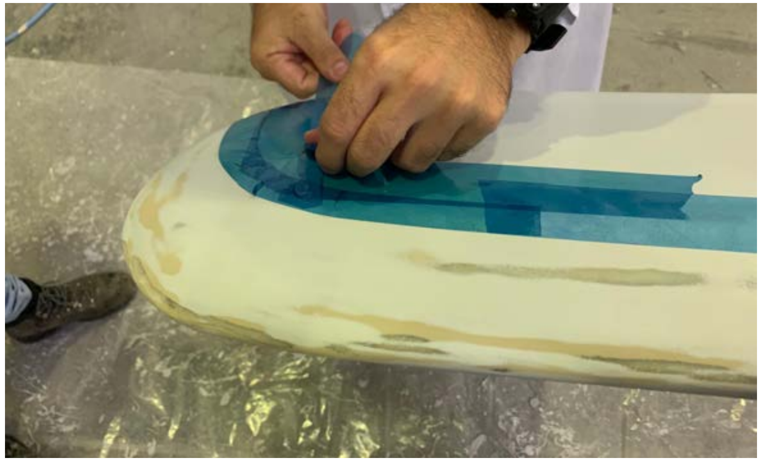
- Geometrical and environmental considerations
- Measure times, distances and quantities
- Practice and act with skilful operators

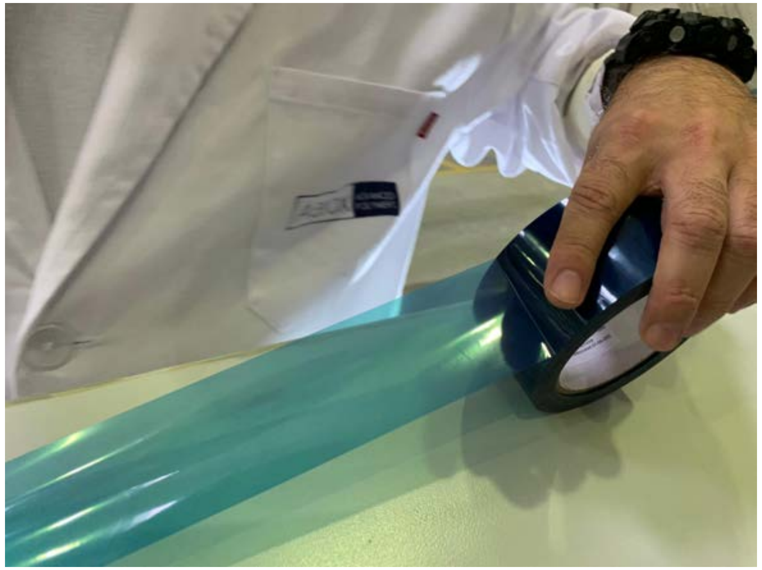


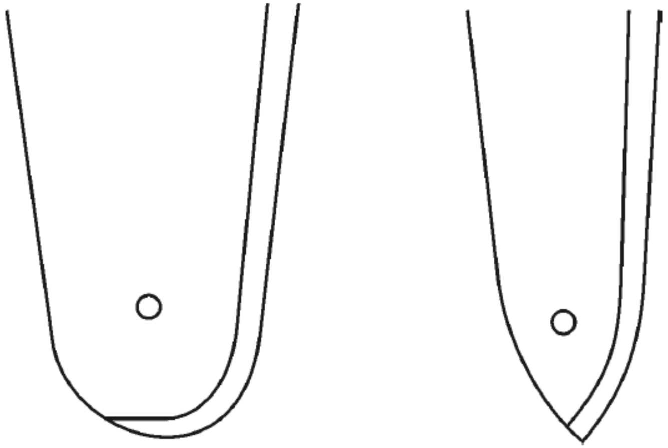
❑ Service application processing parameters

- LEP application **procedure** and related defectology

Surface preparation and masking







❑ Service application processing parameters

- LEP application **procedure** and related defectology

Primer layer application

LEP application

Final LEP system multilayer configuration: AEROX AHP LEP 920 + AEROX AHP PR 202+ Filler+Laminate

Potential defectology:

- Surface irregularities, bubbles
- Lack of levelling. Sagging
- Thickness variability

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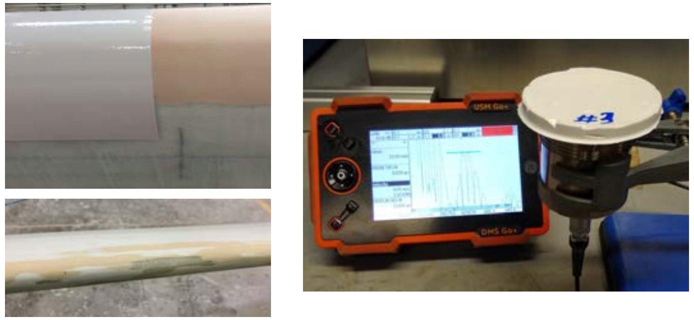
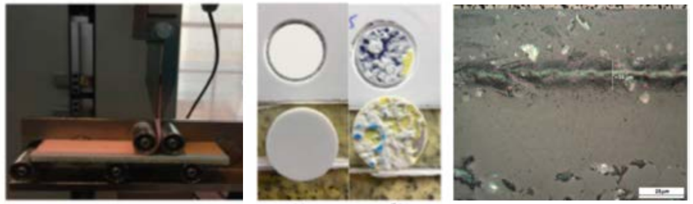
❑ Analysis of LEP Performance depending on application induced issues.

▪ Methodology & Technology inputs

Material & process characterization



Multilayer fundamental properties



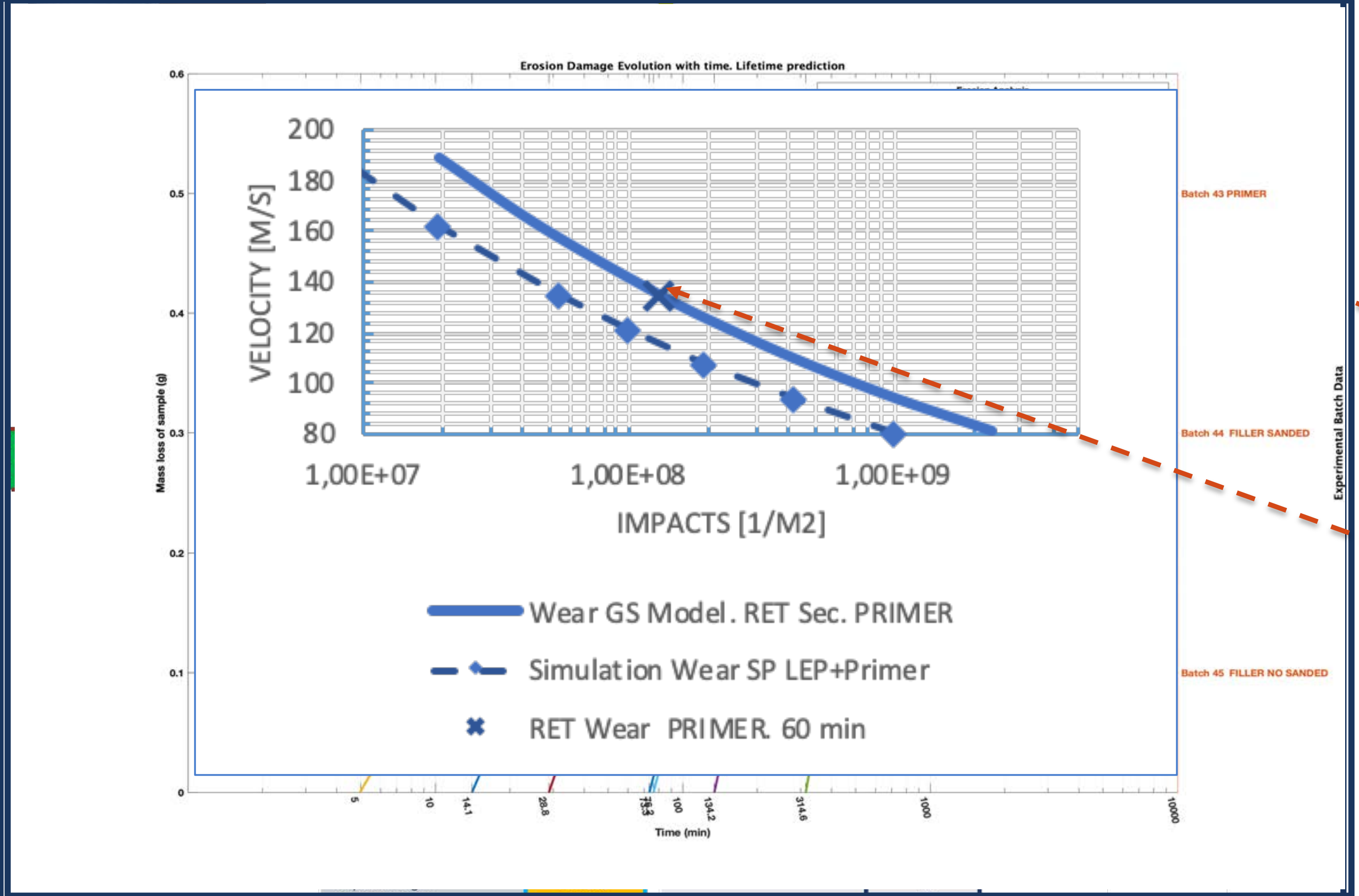
Interface characterization

Manufacturing and Service application processes

- ❑ Identifying and **controlling the <u>material capabilities to withstand failure modes</u>** (Wear & Debonding) of selected LEP system by means of the definition of **<u>mechanical testing</u>** and sample coupons preparation.
  - ✓ To consider: **Tensile-Compression** tests (Evaluation at different **strain rates**), **Viscoelastic characterization** DMTA, DETA (10E2Hz – 10E7Hz), **Impedance** analysis at working frequency with **Ultrasonic testing.**
- ❑ **<u>Adhesion</u> between LEP layers** is a parameter that ensures that **<u>loads are transferred</u>** to the substrate **guarantying <u>interface continuity</u>** .
  - ✓ To consider: **Peeling and pull-off** for interface adhesion, and **nanoindentation** for impedance matching between layers
- ❑ **<u>Processing quality checks</u> parameters** have to be **examined analytically** to quantify its impact on the strength of the LEP system..
  - ✓ To consider: Size and number of **<u>bubbles</u>** in each layer and interfaces may be characterized with optical **microscopy and microCT**. Layer **<u>thickness</u>** can be determined with **Ultrasonic** testing and **<u>surface roughness</u>** with **nanoindentation**

Material & process characterization

Numerical modelling & parametric analysis



Rain Intensity I Coating Thickness h_c

- A modelling **framework** based on 1D Springer' allows to examine the effect of the selected coating properties and operational conditions **on the <u>wear erosion performance</u>**

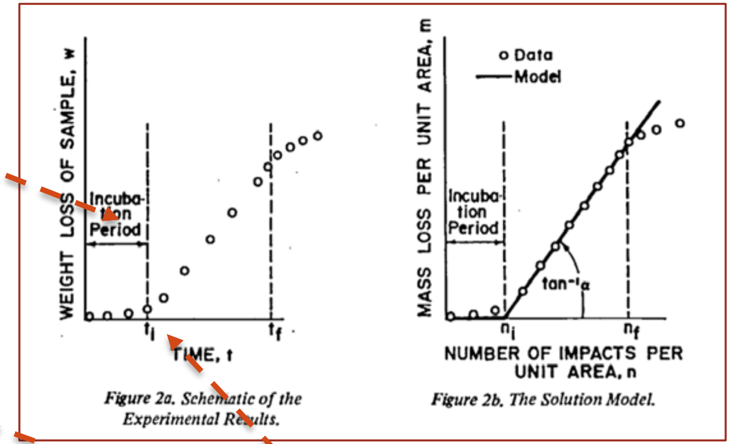
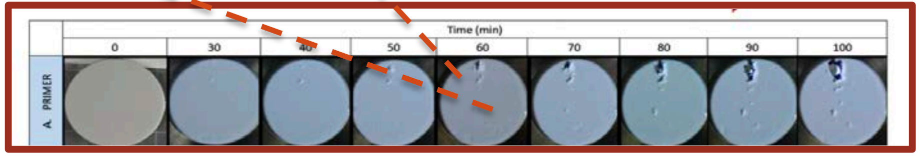


Figure 2a. Schematic of the Experimental Results.
Figure 2b. The Solution Model.



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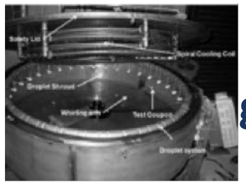
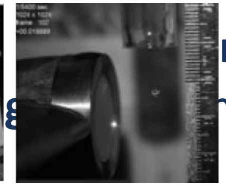
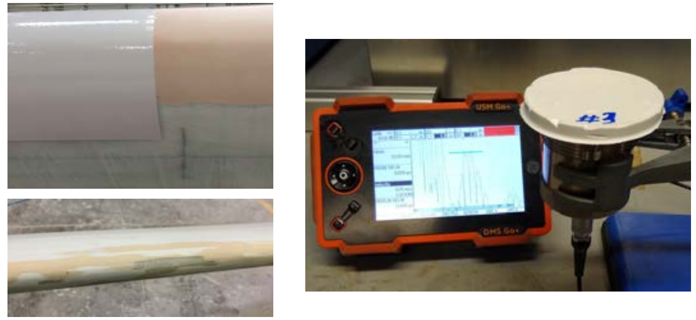




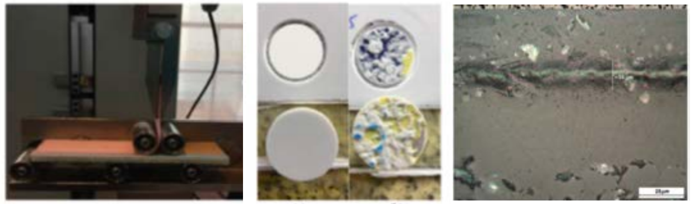
❑ Analysis of LEP Performance depending on application induced issues.

▪ Methodology & Technology inputs

Material & process characterization



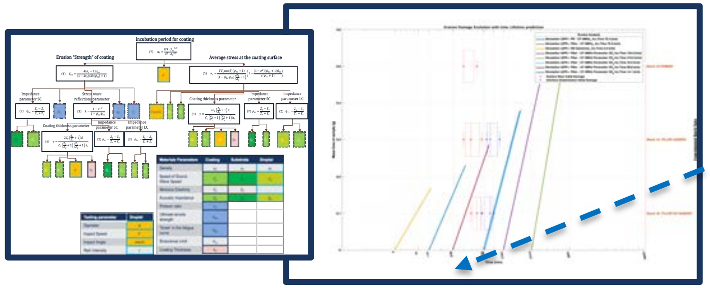
Multilayer fundamental properties



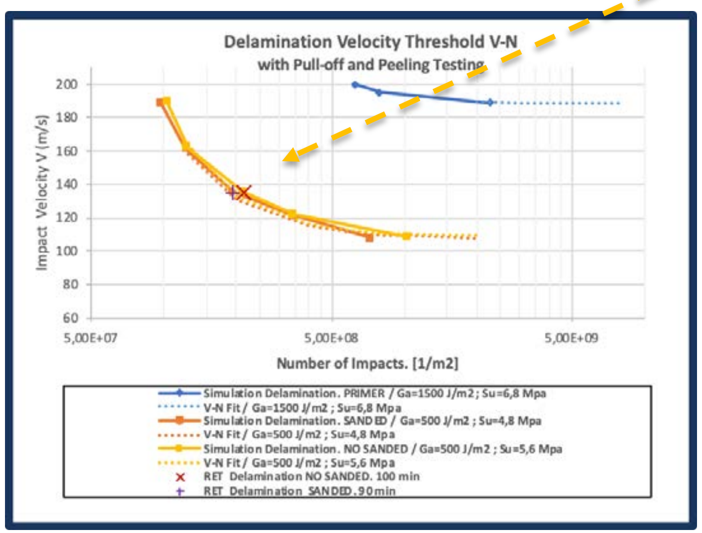
Interface characterization

Manufacturing and Service application processes

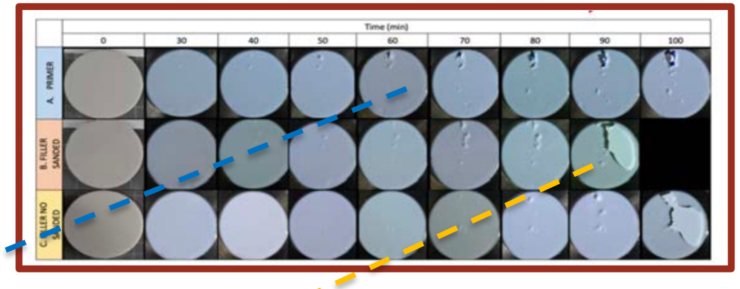
Numerical modelling & parametric analysis



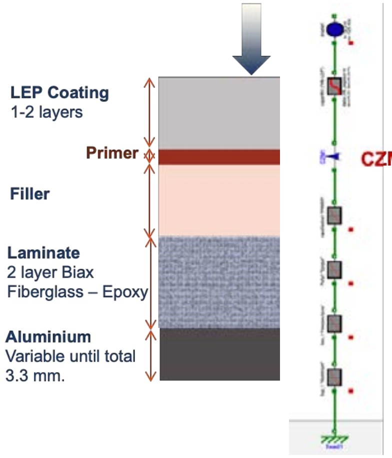
Surface Wear

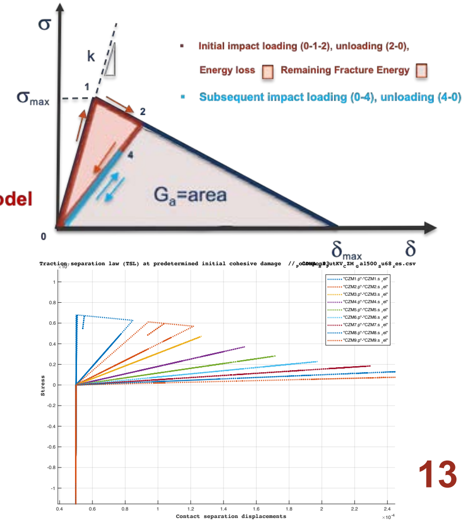


Interface Delamination



❑ The interface modelling is based on a **cohesive zone formulation CZM,** were knowing the experimental **peeling force and pull-off,** estimate the delamination failure **at interface** for a complete V-N curve

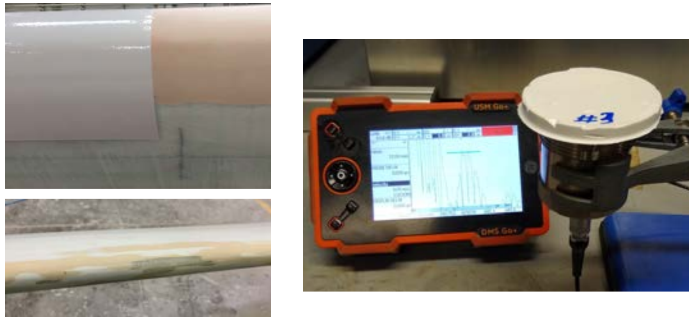




❑ Analysis of LEP Performance depending on application induced issues.

▪ Methodology & Technology inputs

Material & process characterization



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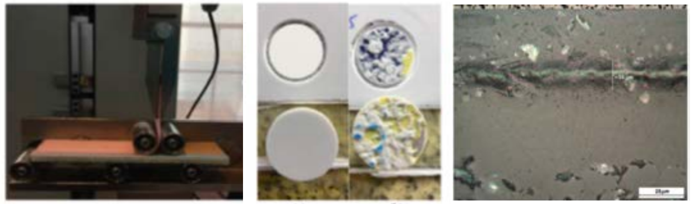
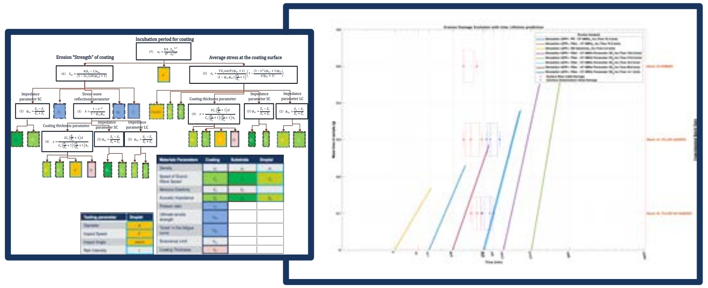


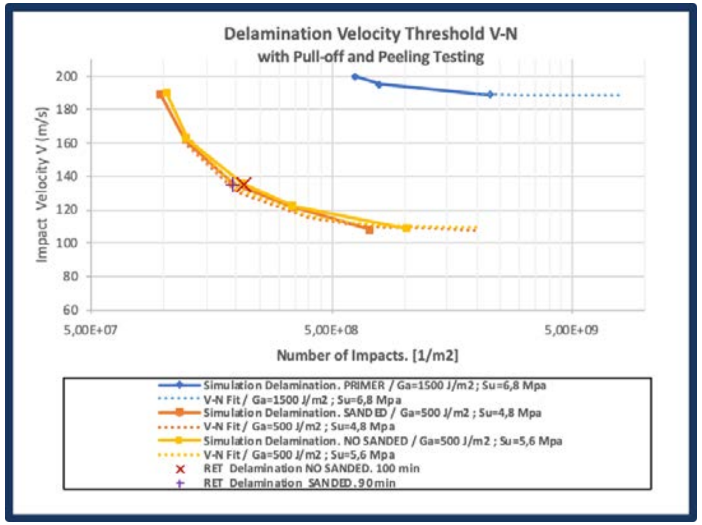
Interface characterization

Manufacturing and Service application processes

Numerical modelling & parametric analysis

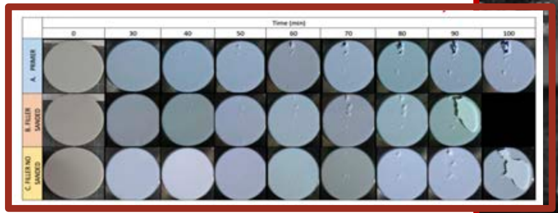


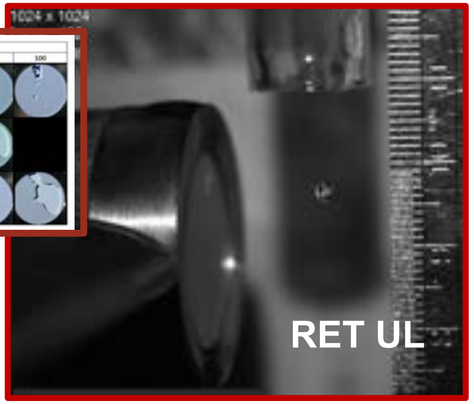
Surface Wear



Interface Delamination

Performance estimation Rain Erosion Testing vs Field





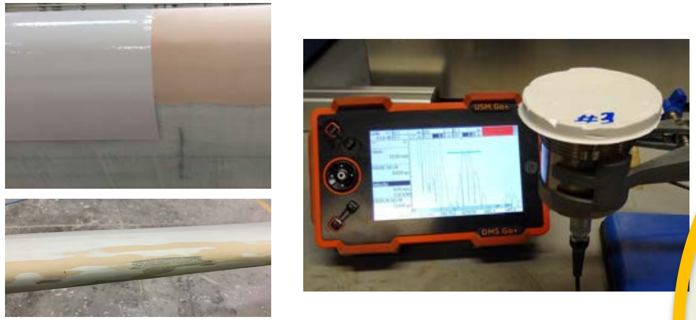
RET ASTM G73-10
Mass loss & Inc.Time

RET V-N. DNVGL-RP-0171

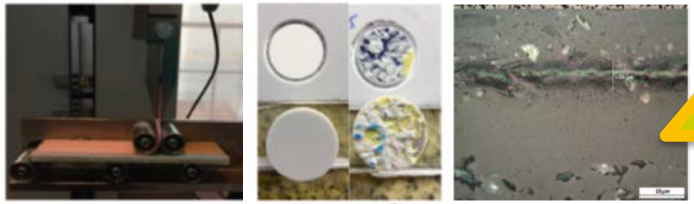
❑ Analysis of LEP Performance depending on application induced issues.

- **Methodology &** Technology inputs

Material & process characterization



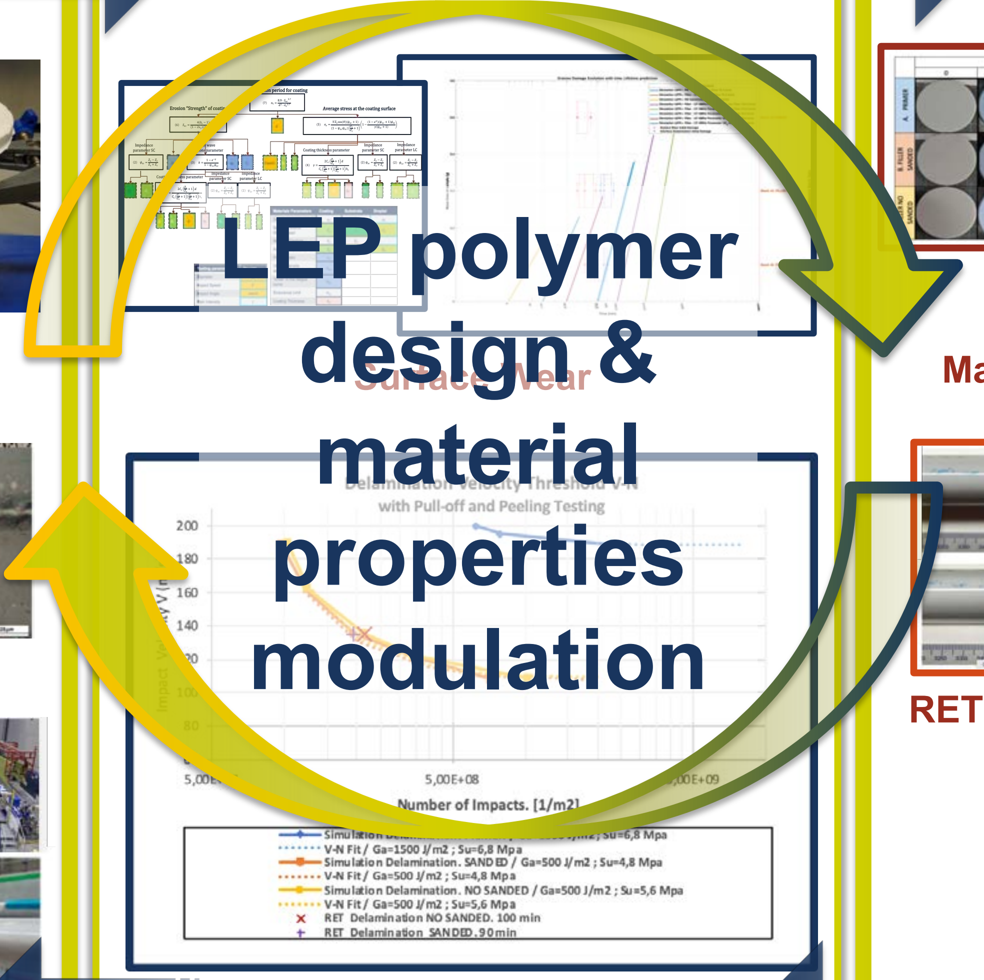
Multilayer fundamental properties



Interface characterization

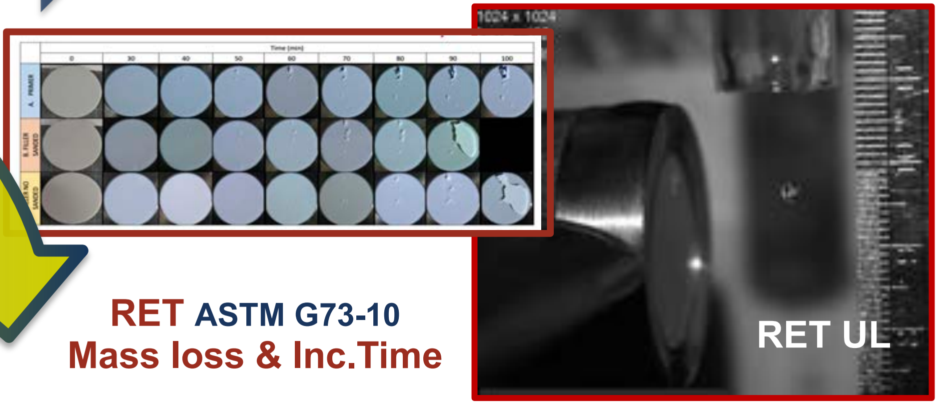
Manufacturing and Service application processes

Numerical modelling & parametric analysis



Interface Delamination

Performance estimation Rain Erosion Testing vs Field



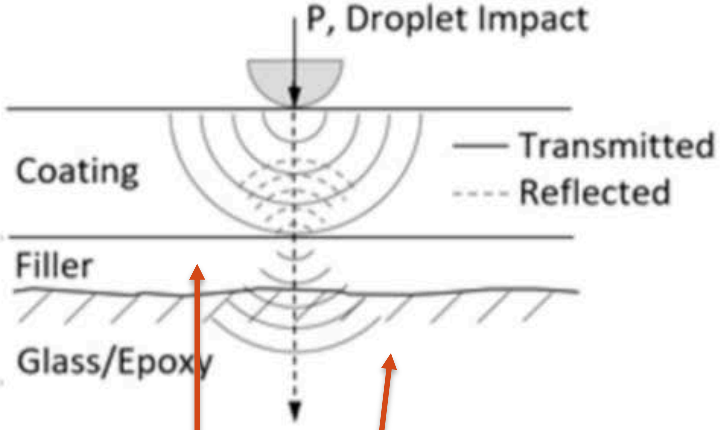
RET ASTM G73-10
Mass loss & Inc.Time

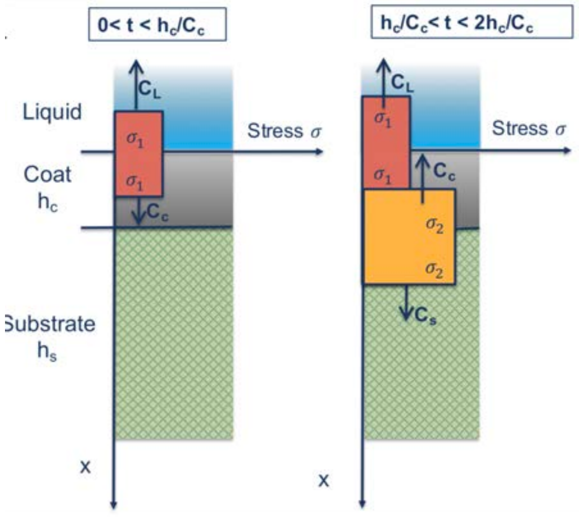
RET V-N. DNVGL-RP-0171

Analysis of LEP Performance depending on application induced issues.

- Modelling to **identify suitable coating and substrate**. Acoustic mismatch

- Upon impingement, the wave front in the top coating further advances towards the coating-substrate interface, where a portion of the **stress wave is reflected back into the coating** with a different amplitude **depending on the relative material acoustic impedances** and the remaining part is **transmitted to the substrate**.





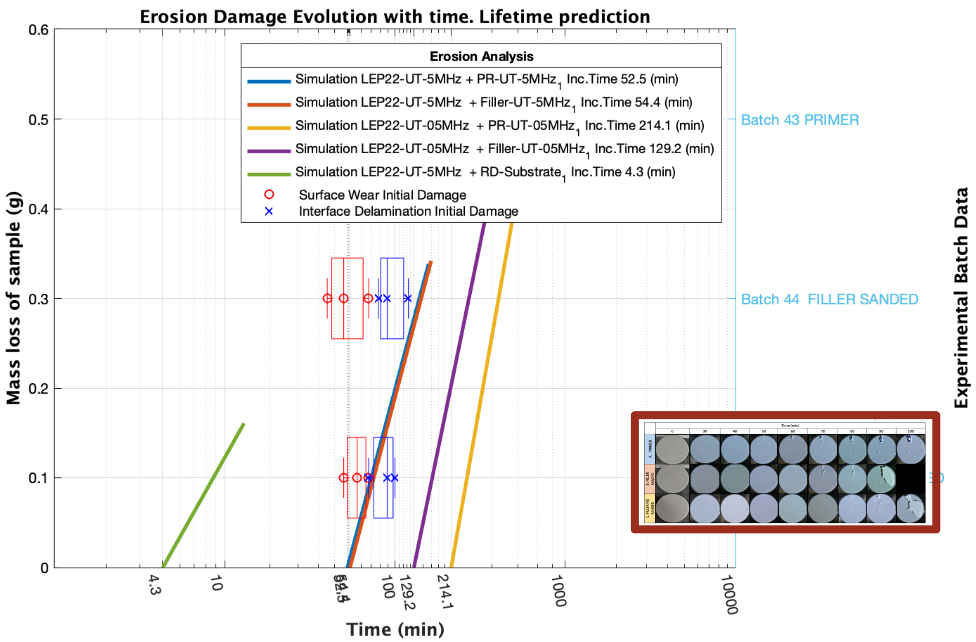
$$\frac{\sigma_{RLC}}{\sigma_{ILC}} = \frac{Z_L - Z_C}{Z_L + Z_C} \; ; \; \frac{\sigma_{TLC}}{\sigma_{ILC}} = \frac{2Z_C}{Z_L + Z_C}$$

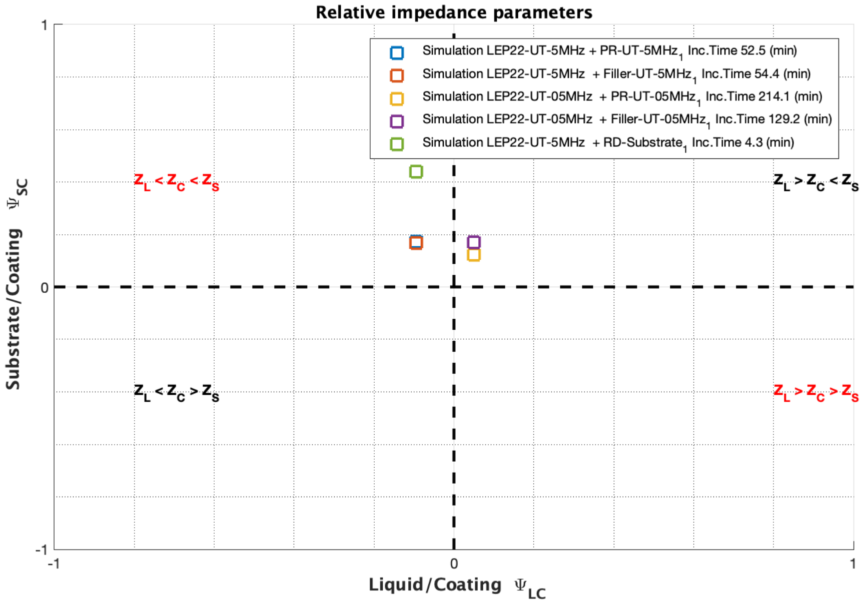
$$\frac{\sigma_{RCS}}{\sigma_{ICS}} = \frac{Z_C - Z_S}{Z_C + Z_S} \; ; \; \frac{\sigma_{TCS}}{\sigma_{ICS}} = \frac{2Z_S}{Z_C + Z_S}$$

- Depending on the **relative acoustic properties LEP-Substrate**, the erosion **lifetime can be optimized**

❑ Analysis of LEP Performance depending on application induced issues.

- Modelling to **identify suitable coating and substrate**. Acoustic mismatch



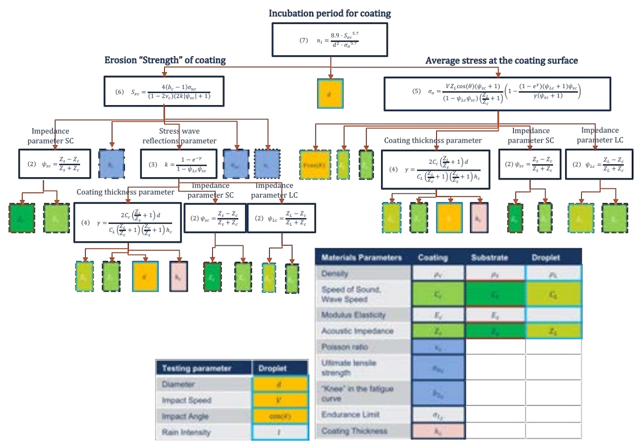


❑ Depending on the **relative acoustic properties LEP-Substrate**, the erosion **lifetime can be optimized**

Analysis of Top Coating Performance depending on application issues.

- LEP performance due to **substrate acoustic mismatch**

$$\left.\begin{aligned} n_i &= n_i(d, S_{ec}, \sigma_o) \\ S_{ec} &= S_{ec}(b_c, \sigma_{uc}, \nu_c, k, \psi_{sc}) \\ \sigma_o &= \sigma_o(V, Z_L, \psi_{sc}, \psi_{Lc}, \gamma) \\ &\vdots \end{aligned}\right\} \Longrightarrow n_i = n_i(b_c, \sigma_{uc}, \nu_c, V, C_L, C_c, C_s, \rho_L, \rho_c, \rho_s, h_c, d)$$

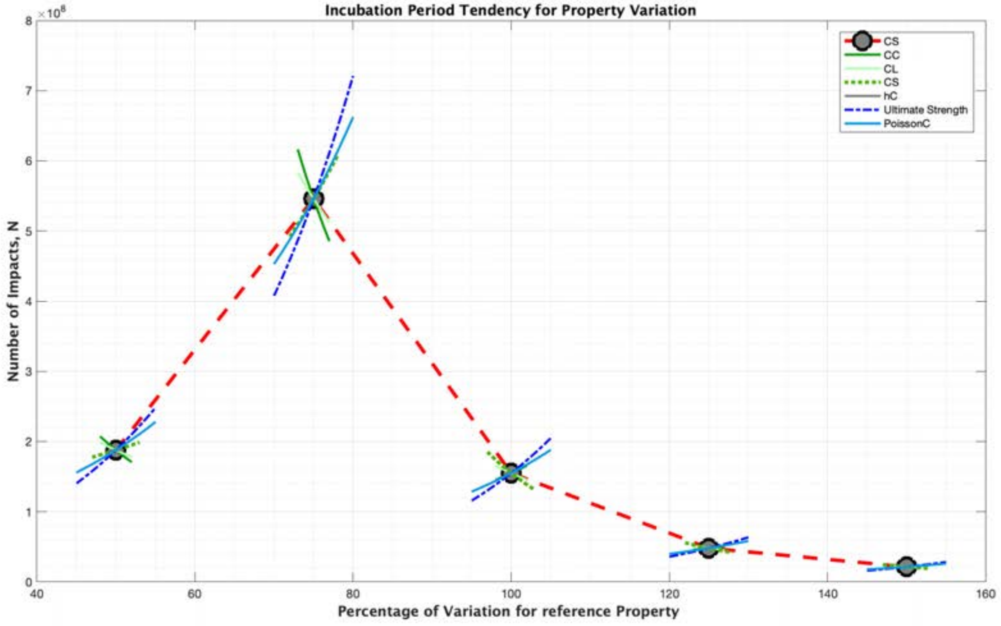


$$dn_i = \frac{\partial n_i}{\partial b_c} db_c + \frac{\partial n_i}{\partial \sigma_{uc}} d\sigma_{uc} + \frac{\partial n_i}{\partial \nu_c} d\nu_c + \frac{\partial n_i}{\partial V} dV + \frac{\partial n_i}{\partial C_L} dC_L + \cdots$$

the variation on the incubation time due to a variation on a given property, for example the **ultimate strength,** may be computed as

$$\frac{\partial n_i}{\partial \sigma_{uc}} = \left(\frac{\partial n_i}{\partial S_{ec}}\right)\left(\frac{\partial S_{ec}}{\partial \sigma_{uc}}\right) = \left(\frac{5.7 n_i}{S_{ec}}\right)\left(\frac{S_{ec}}{\sigma_{uc}}\right) = \left(\frac{5.7 n_i}{\sigma_{uc}}\right)$$

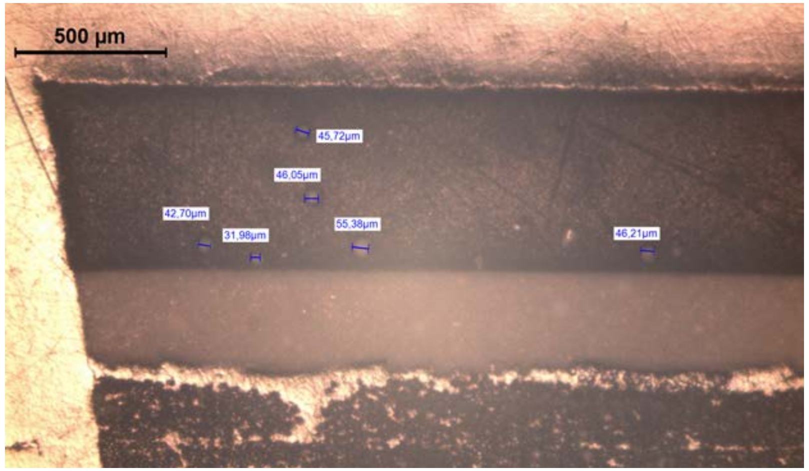
*Analysis of the **variation on substrate wave speed CS due to properties of different material candidates** and also coupled analysis of variation **of a given coating property such is Ultimate strength** with its defined **standard deviation***



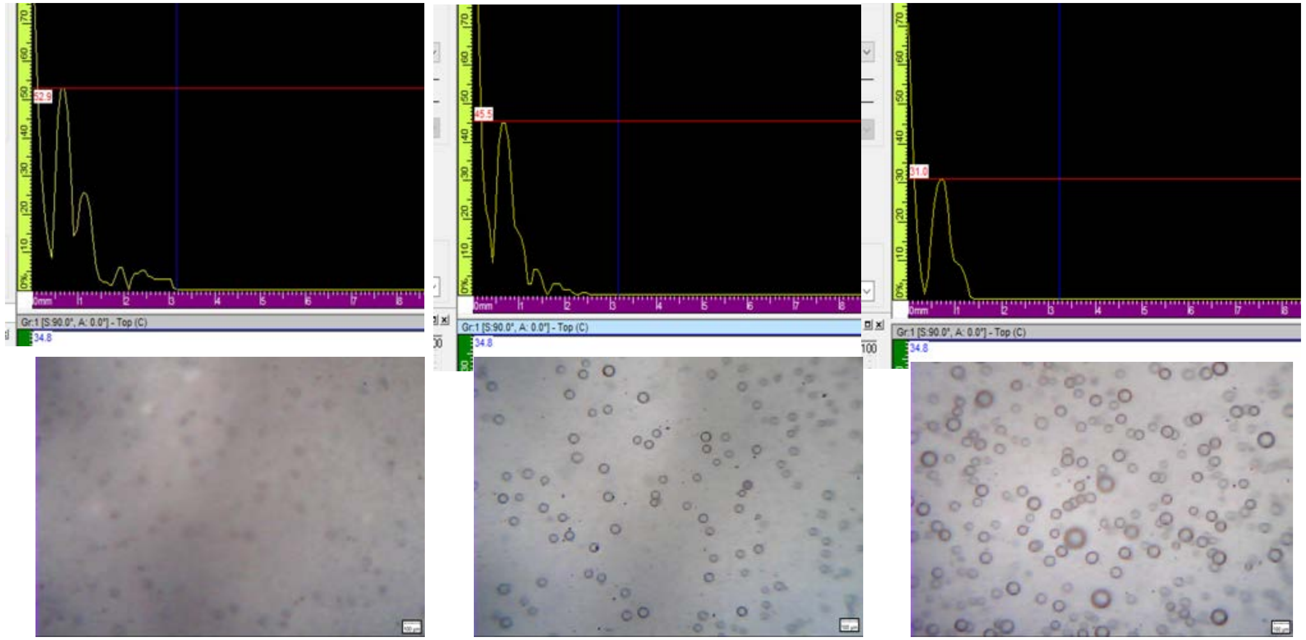
👍 The **optimized selection of the filler** may increase lifetime by means of **stress reduction at interface**

👎 But the same argument of **LEP-substrate impedance mismatch** may **lower the lifetime.**

- ❑ Coating **capability of loss/transfer wave energy** will allow avoid damage
- ❑ **Work in progress**: Determine **variable properties characterization through the thickness** and its vibro-acoustic properties. Develop **reflecting interfaces (void content)** as impact shockwave diminisher.



Coating acoustic reflected wave variation depending on void content

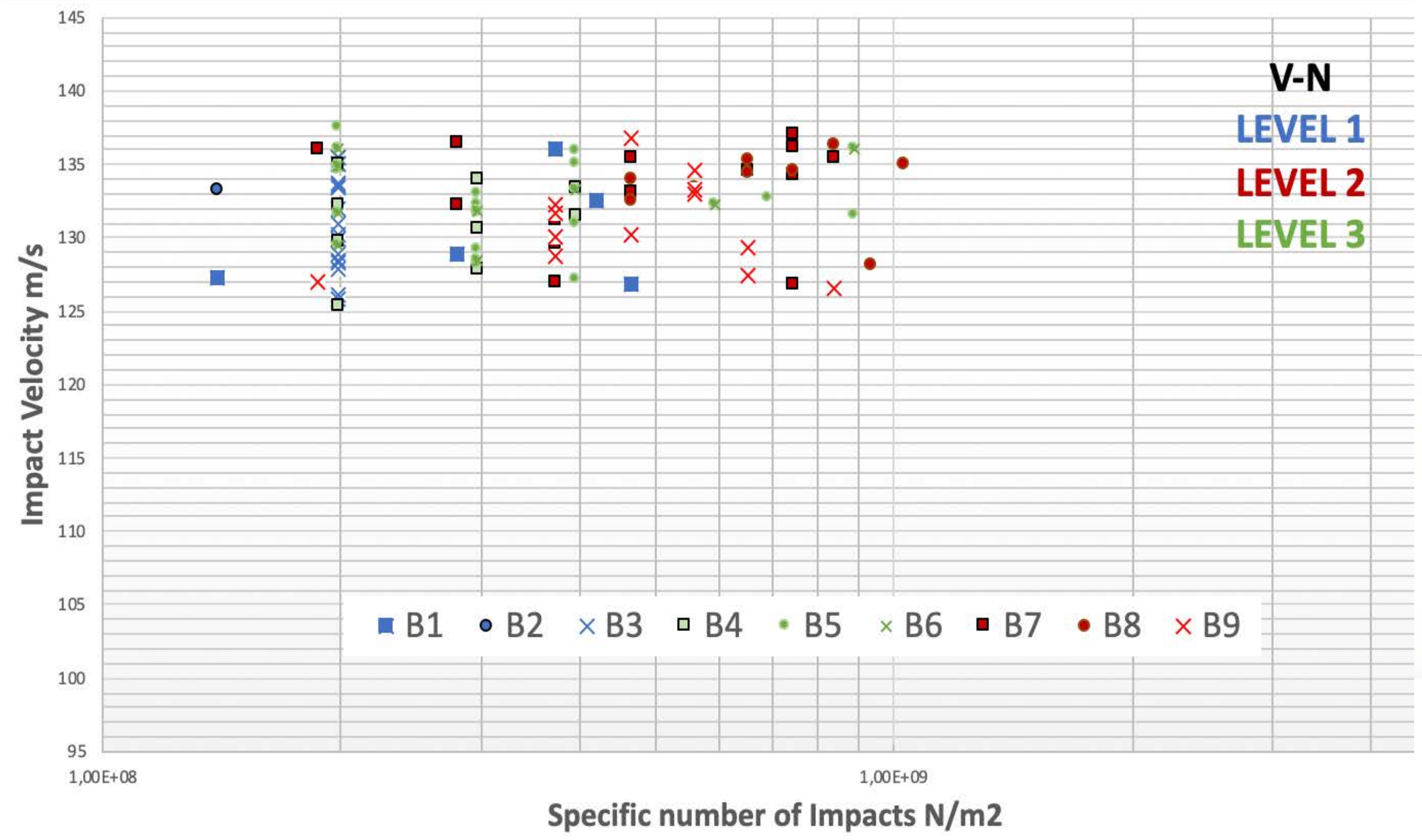


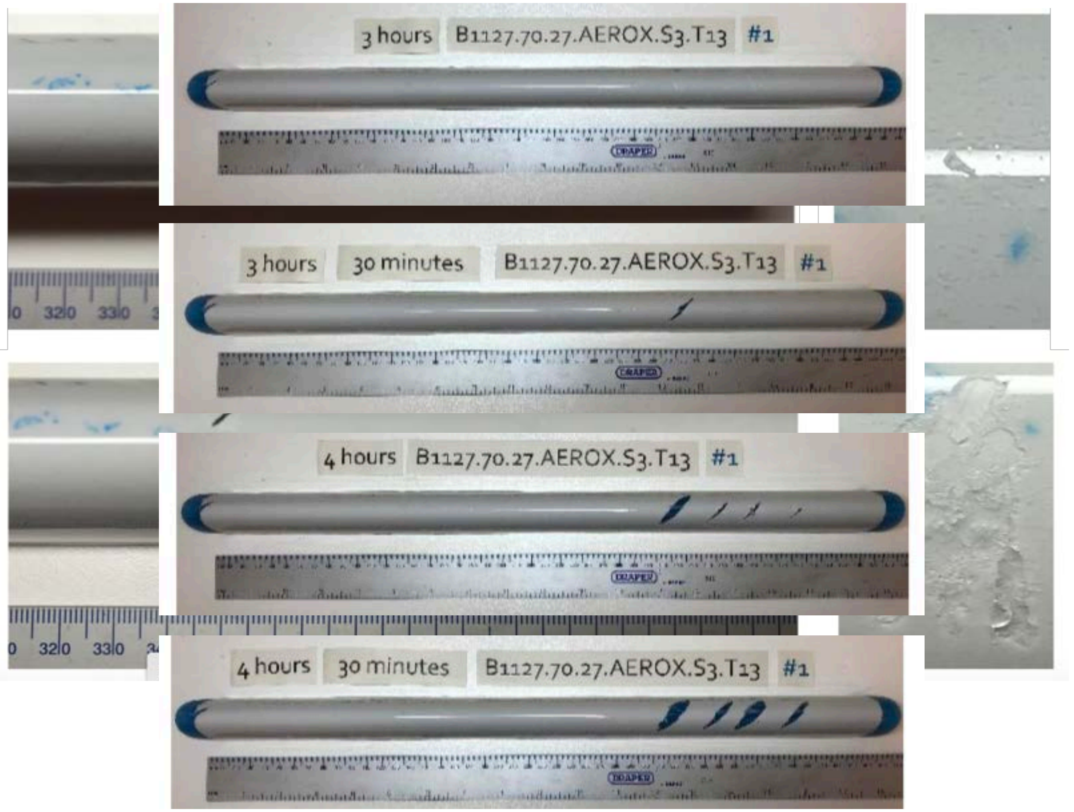
👍 The **more void content** the better for **coating impedance reduction effect for stress attenuation**

👎 But void acts as **stress concentrator** [2], so **cracking initiation and propagation may be** enhanced.

❑ Analysis of Top Coating Performance depending on application issues.

▪ **Void content** affecting erosion damage anticipation





✓ **Number of of bubbles/voids** in a RET sample **does not correlate** with the **Incubation time** for initial failure.

✓ **Number of of bubbles/voids** in a RET sample **correlates** with the **number of failure locations** in same coupon.

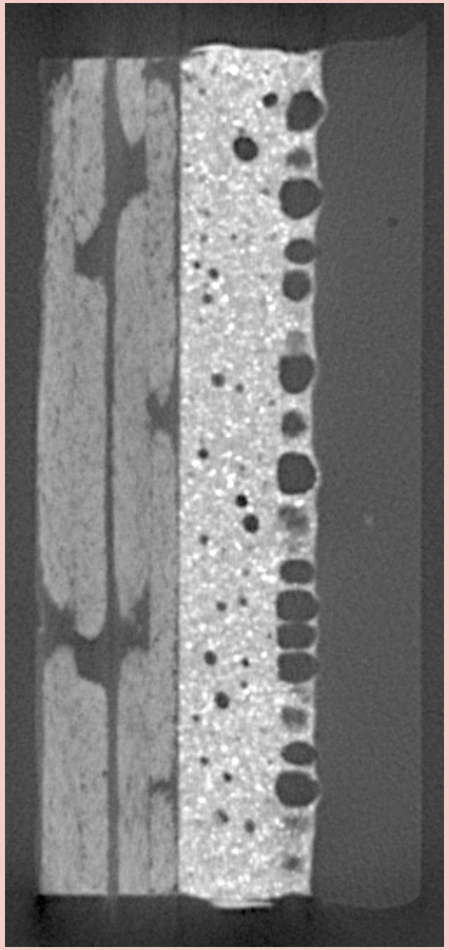
👎 But void acts as **stress concentrator** [2], so **cracking initiation and propagation** may be enhanced.

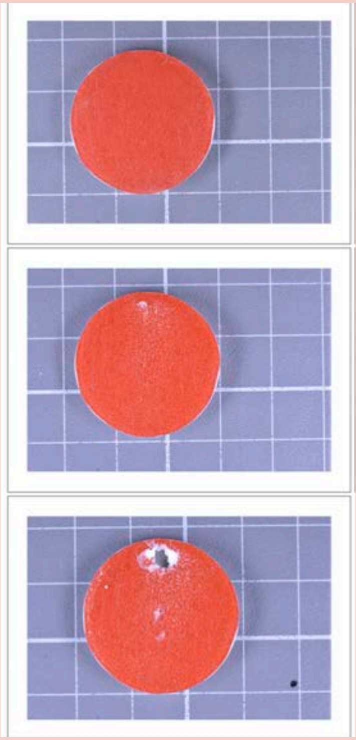
The **capability of LEP thickness** will act **circumventing the negative bubble effect** on surface. **Droplet size-void size ratio** to be analyzed. On going studies

❑ Analysis of Top Coating Performance depending on application issues.

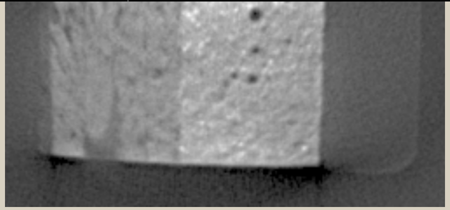
- **Void content** affecting erosion damage anticipation

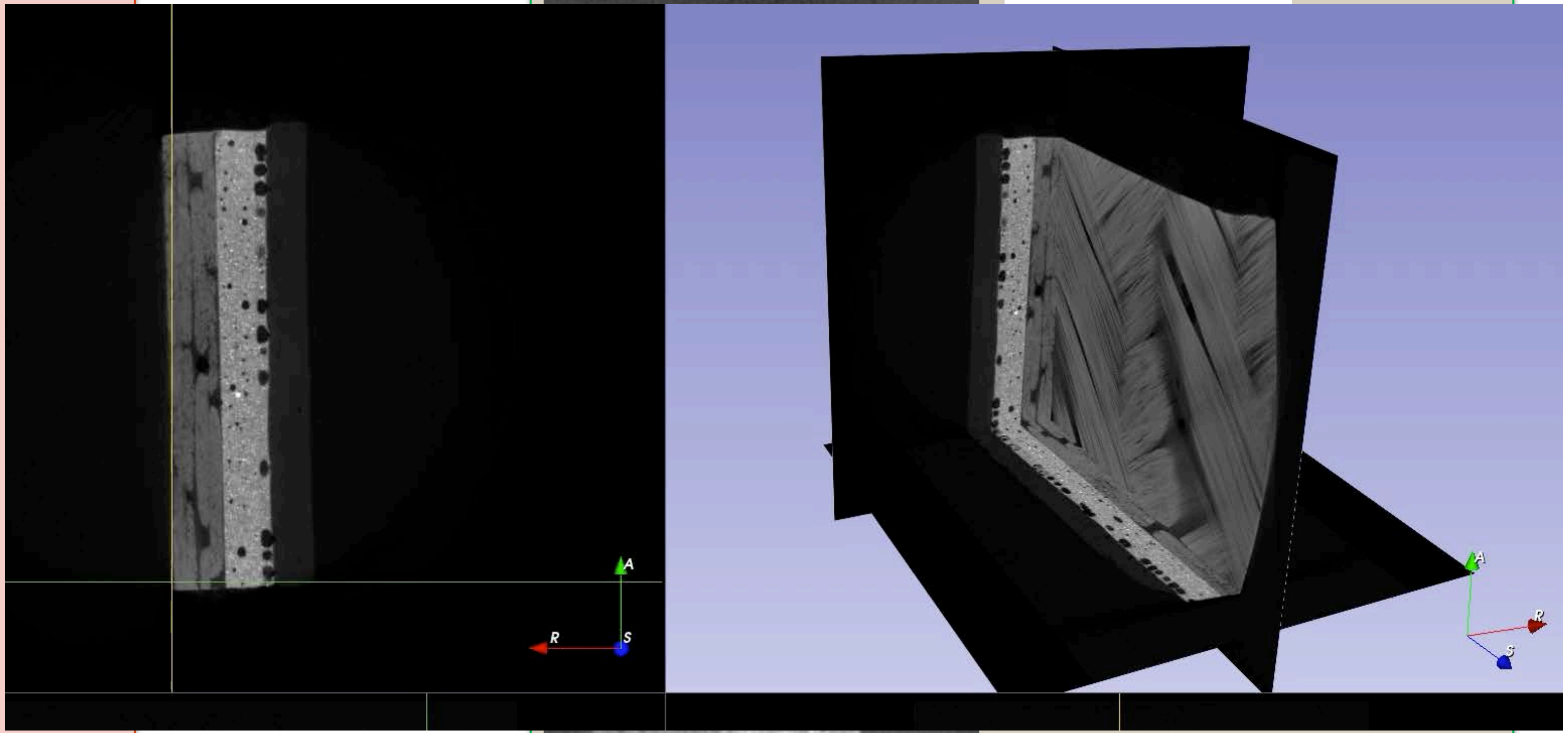
❑ **On the Development Criteria** for **processing defects (Bubbles)** on LEP multilayer system

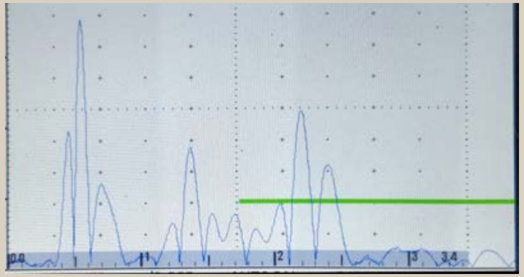




Damaged 45 min RET.







No Damage 900 min RET.

CONCLUSIONS AND FURTHER WORK

- In the current work, an investigation into **various coating application cases** have been undertaken and related with the **rain erosion durability factors** in an **effort to assess the response of changing material** and **processing parameters** involved on its blade application.

- **Diverse cases are** developed throughout the research work **in order to ponder the key issues** on appropriate LEP system definition: Temperature range, gel time, application time, surface preparation, mechanical **substrate characterization**, required **thickness**, undesired **bubbles**, etc.

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

- The LEP application cases have been developed, **analysed and discussed in collaboration with the company GDES Wind.** Different application procedures and LEP material configurations are performed in real service situations. The **in-field erosion performance data feedback of such cases will be analysed in future.**

- Leading Edge Protection systems is an **open Research & Development topic** in Wind Industry

THANKS!

QUESTIONS?