Key issues in the design and properties modulation of polymeric materials for rain erosion protection systems of wind turbine blades

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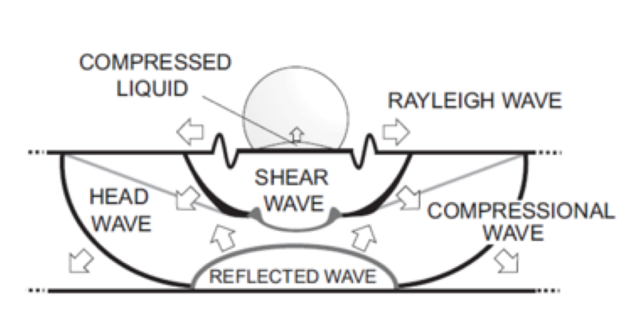
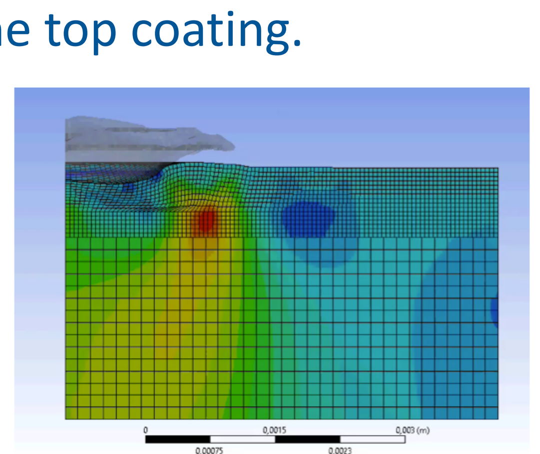
Abstract

Analytical and numerical models are commonly used **to identify suitable top coatings and composite substrate combinations** based on their potential stress reduction on the surface and interfaces **under rain droplet impingement** and also for lifetime **erosion damage prediction**. The numerical models known are limited to a linear elastic response of the polymer subjected to drop impact loads and not consider the multilayer interfaces contact failure. In this research, the polymeric mechanical models are used within a **novel and versatile multi-parametric approach** based on the **viscoelastic material characterization**. Moreover, the appropriate definition of the **Cohesive Zone Modelling (CZM)** allowed one to account for the **interface adhesion** and hence to optimize manufacturing and coating processing.

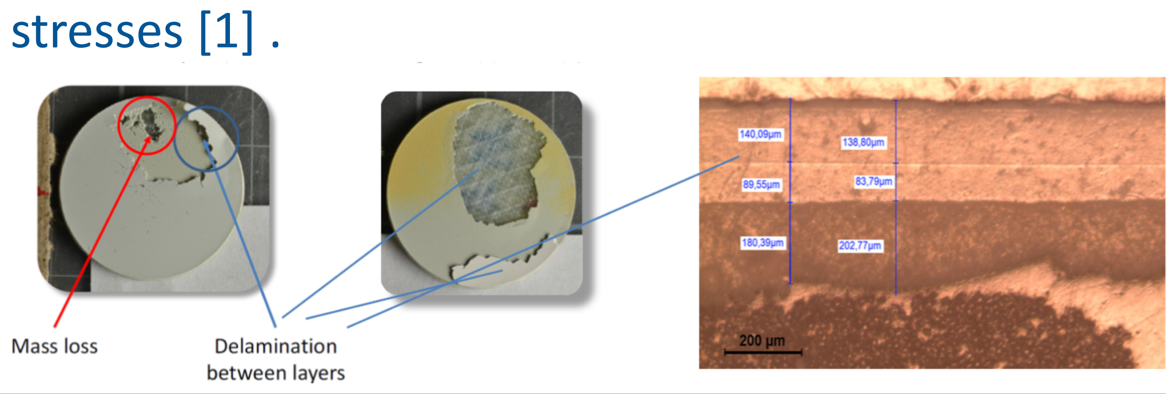
Liquid impact phenomena affecting erosion failure

The analysis of erosion caused by rain droplets shows that the damage is in fact a **3D dynamic event resulting in the propagation of shock waves**. As the water droplet impinges on the surface, a longitudinal compressional normal stress 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 impedance**) and yields a transverse shear wave. The remaining part is transmitted to the substrate. The impact gives rise to a third wave due to the water droplet deformation itself, called the Rayleigh wave, which is confined to the surface of the top coating.



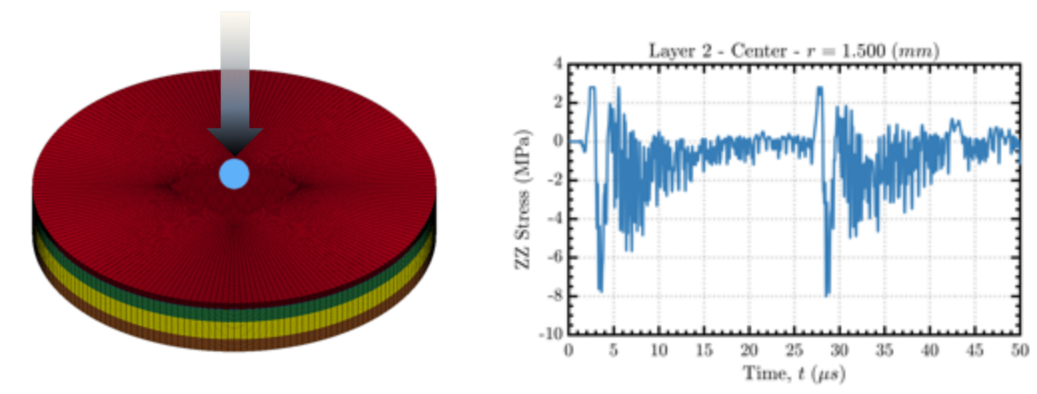


Two main different types of erosion failure are mainly observed in used Rain Erosion Testing coupons: **pits and cracks** that progress with mass loss caused by **direct impact** and stress on surface and **delamination indirectly** caused by the interface stresses [1] .



Versatile computational framework: PGD

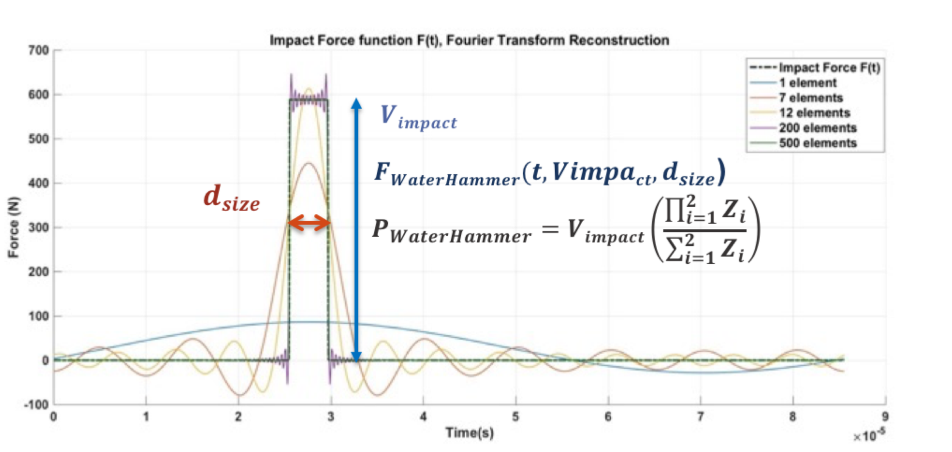
In a **fully conventional 3D FEM simulation**, an exhaustive analysis would require thousands of simulations depending on the geometry, material configuration, impact velocity, droplet size, …

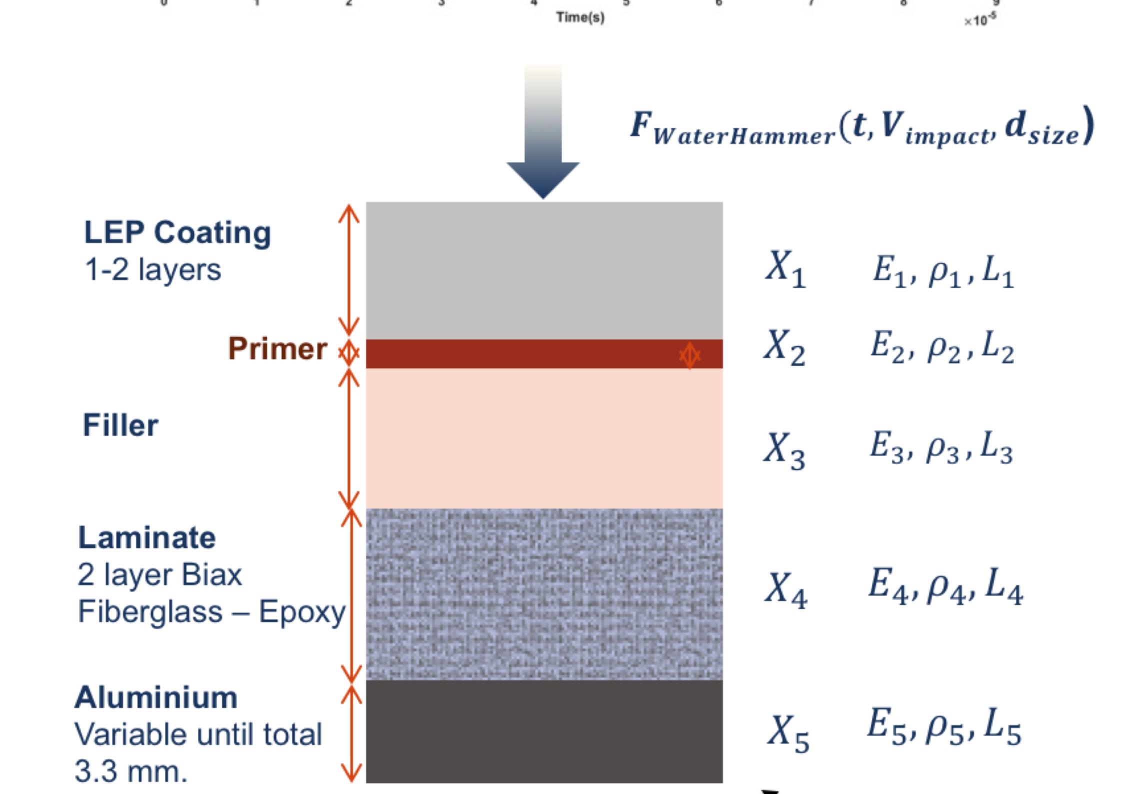


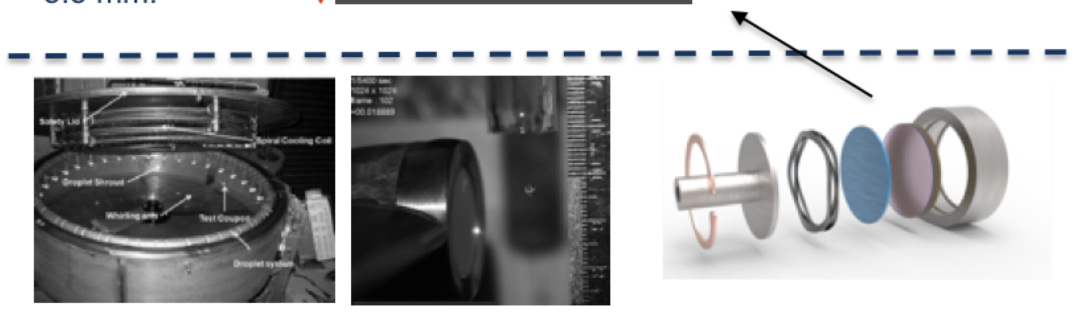
Proper Generalized Decomposition (PGD) is alternatively implemented by the user depending on the **modelling parameters** to be analyzed as objective functions. We consider the **in-plane-out-of-plane** decomposition for solving the 3D elastic displacement field $U = (u, v, w)$, reads:

$$U(x,y,z) = \begin{pmatrix} u(x,y,z) \\ v(x,y,z) \\ w(x,y,z) \end{pmatrix} = \sum_{i=1}^{N} \mathbf{X}^i(x,y) \circ \mathbf{Z}^i(z)$$

Vectors $\mathbf{X}^i$ are the functions in the plane (x, y) and $\mathbf{Z}^i$ are the functions involving the thickness (z). The **PGD method consists** then of introducing unknown fields as **extra coordinates** in addition to the usual coordinates such as space and time. that can be post-processed at will for various purposes, such as **parametric optimization on this research [2].**



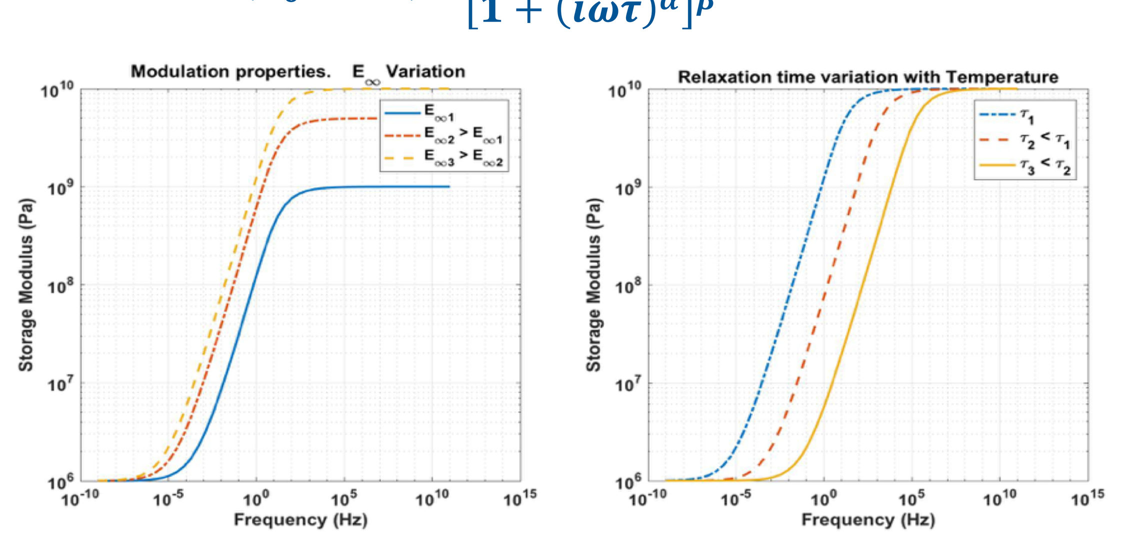




Case: Material Design Factors

The waterdrop impacts on rotor blades are **highly transient** events. A well known method for the modeling of LEP **viscoelastic behavior** is the **Havriliak-Negami Model:**

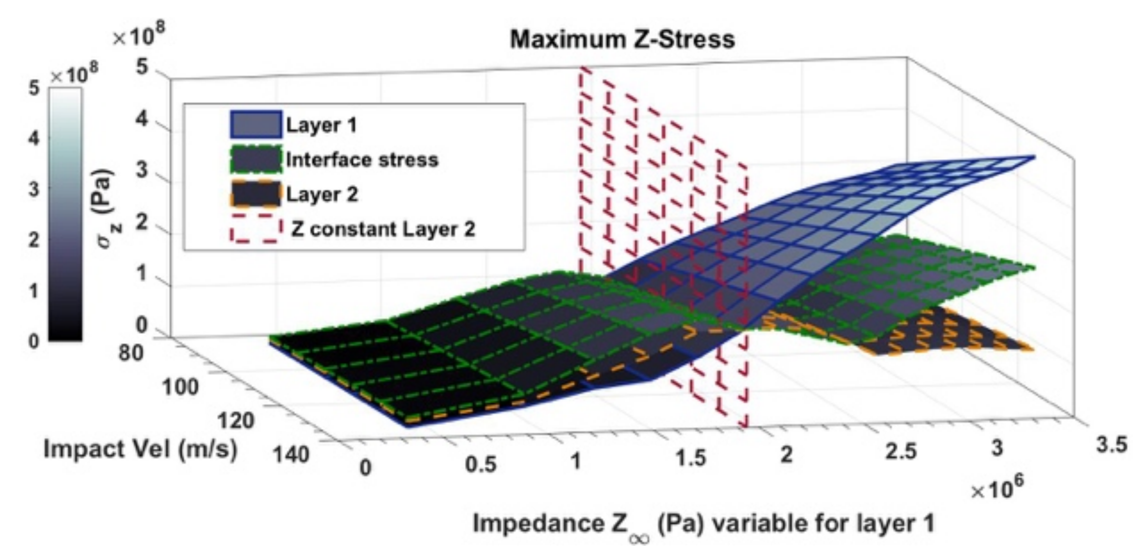
$$E^* = E_\infty + (E_0 - E_\infty) \times \frac{1}{[1 + (i\omega\tau)^\alpha]^\beta} \quad ; \quad E^* = E' - iE''$$



In order to identify suitable coating and substrate combinations, Maximum Normal Stress evolution is computed with the PGD in different layers with the LEP **impedance for a parameter range** for $\mathbf{E_0}$, $\mathbf{E_\infty}$ **, and** τ on the frequencies of interest:

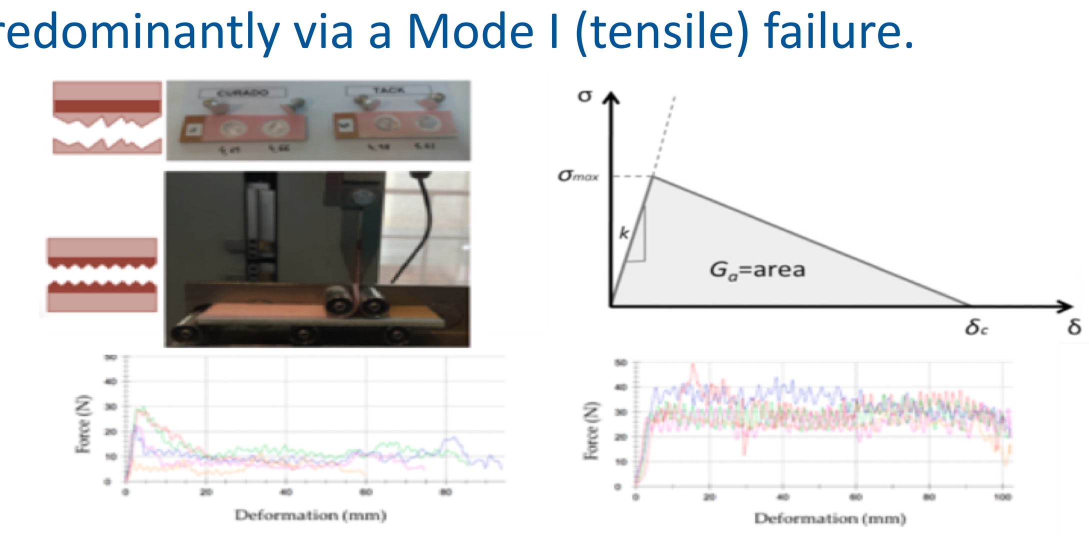
$$u(x,y,z,\omega,E_0,E_\infty,\tau) \approx \sum_{i=1}^{N} \mathbf{X}^i(x,y) \circ \mathbf{Z}^i(z) \circ \mathbf{W}^i(\omega) \circ \mathbf{E}_0^i(E_0) \circ \mathbf{E}_1^i(E_\infty) \circ \mathbf{T}^i(\tau)$$

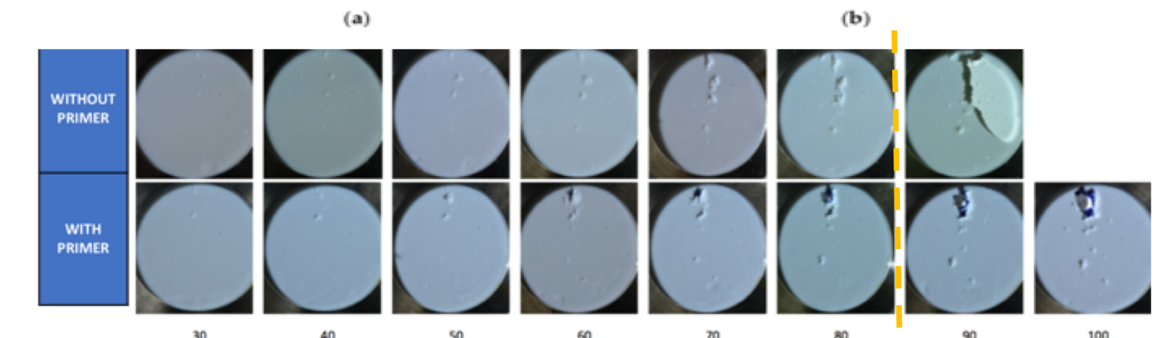
This result **allows one to match the acoustic material properties in order to minimize the stress** reflections and transmissions through the laminate thickness.

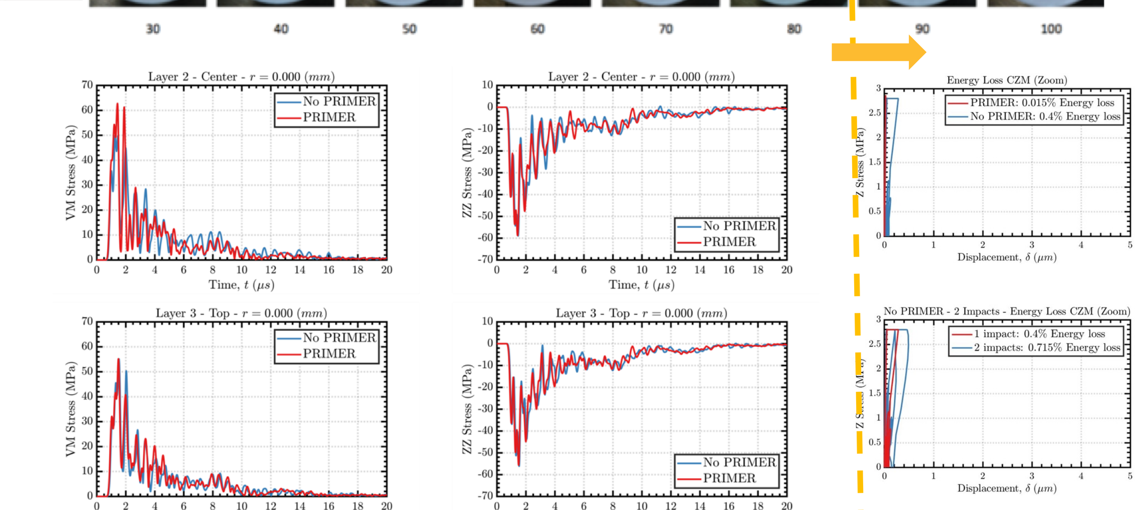


Case: LEP interface failure

The **mechanical characterization** of a multilayer LEP configuration was quantified. Pull-off testing and peeling testing demonstrated the improved interphase coating–laminate adhesion response when a primer layer was included. Treated as the **input parameters for a Cohesive Zone Modelling** algorithm, accounting for the fracture energy, Ga needed for delamination. In all the simulations, it is related as a parameter value the normal traction, σ, to the normal opening displacement, δ, across the crack surface since fracture was assumed to be predominantly via a Mode I (tensile) failure.







References

1. E.Cortés, F.Sánchez, et al; On the material characterization of wind turbine blade coatings: Effect of the interphase adhesion on rain erosion performance, *Materials; September 2017, Vol 10, 1146, doi:10.3390/ma10101146.*
2. C.Germoso, F.Sanchez, et al; Analysis of Liquid Impact Phenomena Affecting Rain Erosion Failure in Wind Turbine Blades. A viscoelastic parametric study, *ECCM18, Athens, 2018*
3. F.Sanchez, A.Olivares, et al; A Numerical Modelling Approach for Interphase Adhesion of Rain Erosion Protection Systems of Wind Turbine Blades, *ECCM18, Athens, June 2018*

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