Service Application and Manufacturing concerns that influence leading edge protection erosion performance in wind turbine blades

E.Cortés[1], F.Sánchez[2*], L.Domenech[2], A.Olivares[2], B.Madramany[1], A. O'Carroll[3], M.Hardiman[3], T.M.Young[3], and F.Chinesta[4]

[1]Aerox Advanced Polymers, ecortes@aerox.es, web page: http://www.aerox.es

[2] Universidad CEUnCardenal Herrera, Valencia, Spain

fernando.sanchez@uch.ceu.es (*corresponding author), web page: http://www.uchceu.es

[3] Universidad de Limerick, Ireland

[4]Institut de Recherche en Génie Civil et Mécanique, Ecole Centrale Nantes

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ABSTRACT. MOTIVATION

Rain erosion damage on wind turbine blades, is a major cause for maintenance **cost concern**. The problem has been approached by developing new coating systems to diminish the erosion drawback. In this research, **two main coating technologies have been considered**: **In-mould coatings (Gel Coat) applied during moulding on the entire blade surface** and the Post-mould coatings specifically developed for the **Leading Edge Protection (LEP) and usually moulded, painted or sprayed** only on the frontward facing leading edges of the wind turbine blades. The coating adhesion and erosion is affected by the shock wave caused by the collapsing water droplet on impact. The stress waves are reflected and transmitted to the laminate substrate. **It is necessary to optimize the contact adhesion resistance of the multi-layered system interface boundaries in order to avoid failure by delamination**. The experimental investigation has been directed into the resulting rain erosion testing performance depending on the coating-laminate interphase adhesion characterization, which was assessed by pull-off testing, peeling-adhesion testing and nano-indentation testing. The work considers **distinctive coating configurations as study cases:** A first case analyses the effects of the in-mould Gel Coat curing, and a second one ponders the inclusion of a primer layer and a filler layer on a LEP configuration system. **Analytical and numerical models are used to relate lifetime prediction** and to identify suitable coating and composite substrate combinations. 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 for blades into a **knowledge-based guidance for leading edge coating material development**.

CASE STUDIES: EFFECT OF INTERFACE AND ADHESION ISSUES ON RAIN EROSION PERFORMANCE

• Effect of Curing Conditions of In-Mould Blade Coatings

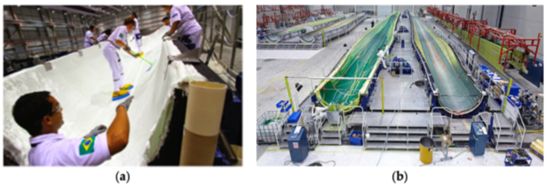

Figure 1: (a) Surface textile material application over the in-mould coating. Depending on the curing conditions of the coated area, its chemical and adhesion relation with the later infused resin Is different. (b) resin infusion process of a large wind turbine blade

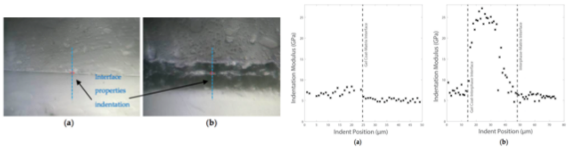

*Figure 2: (**Left**) Layout of the indentation for Gel Coat and interphase properties of the two cases of curing. (a) Coat 1, i.e. Cured and (b) Coat 2, i.e. Semi-cured. (**Right**) Two series of indents across the interface for the two samples of in-mould Gel Coat and the epoxy based matrix of the GFRP laminate with different curing conditions (a) Coat 1, i.e. Cured and (b) Coat 2, i.e. . Semi-cured. A clear interphase is present between the materials, where the interphase has a much larger stiffness than either material. This result correlates well with the erosion testing and also with the acoustic impedance variation due to the interphase.*

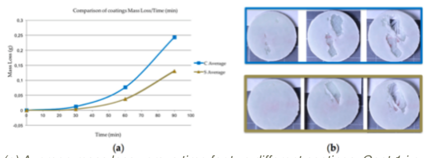

Figure 3 (a) Average mass loss versus time for two different coatings: Coat 1 i.e. Cured (C in blue) and (b) Coat 2 Semi-cured, (S in Green). Images of surface and delamination damage

• Effect of Primer on the Leading Edge Protection (LEP) Coatings

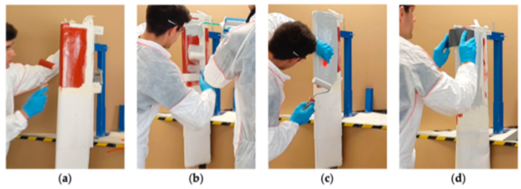

Figure 4: Leading Edge Protection Service application with different techniques. (a) application of the primer layer, (b) the putty/filler/LEP material, (c) thickness needs to be monitored closely,(d) the surface is screened down to ensure a flat, smooth surface following the blade contour

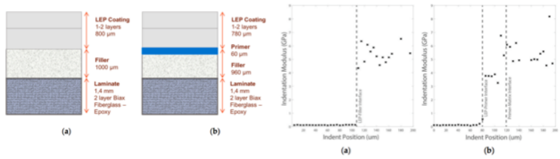

Figure 5: (Left) (a) Leading Edge Protection Coating configuration with an intermediate filler layer. (b) Additional primer layer included to improve adhesion to substrate. (Right)Two series of indents reveals a similar acoustic impedance on Primer-Filler interface and shows also how the primer matches the filler acoustic impedance without pronounced discontinuities.

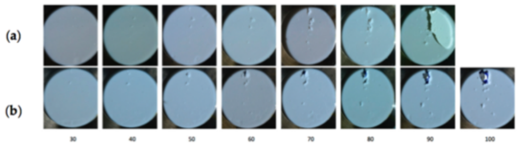

Figure 6. Images of surface and delamination damage after time intervals (in minutes) of testing. (a) LEP coating with No-primer application. (b) LEP with intermediate primer layer. These results correlate well with the similar erosion incubation time observed in both configurations (with and without primer) in the rain erosion testing. The primer layer avoids delamination but no affect erosion incubation time

MODELLING MANUFACTURING FACTORS THAT AFFECT INTERFACE DELAMINATION AND EROSION LIFETIME

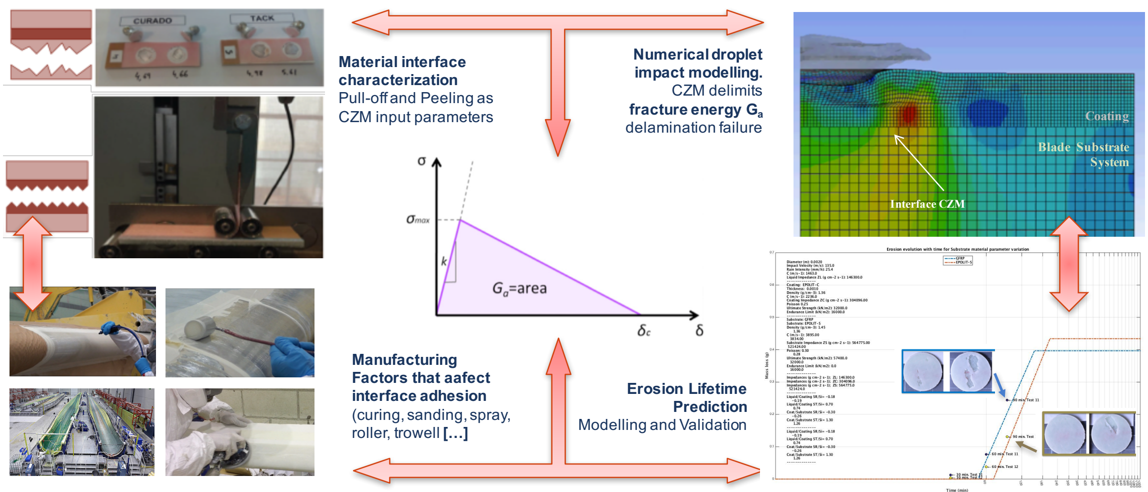

Figure 7: Proposed methodology for the modelling of manufacturing factors that affect erosion performance. The processing conditions may vary interface adhesion capabilities and hence delamination failure. In order to compute the Stress-Strain behaviour of the multi-layered system under impingement , the Input parameters for Cohesive Zone Modelling are determined with Peeling and Pull off testing., etc. Moreover, the erosion lifetime prediction can be modelled considering premature delamination (further work is on its development).