An experimental approach to analysing rain droplet impingement on wind turbine blade materials

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1 Introduction

Leading edge erosion is an important issue in the wind turbine industry, and many examples of eroding blades have been seen in the past, an example of which can be seen in Figure 1. The issue is of the up-most importance as the energy yield from the turbine can be majorly reduced as shown by Sareen et al [1]. If left unattended, the structural integrity of the blade could also be at risk. In reality however, this is not the case and wind turbine blades are regularly maintained to prevent any loss in potential revenue to the owner. Whilst onshore this is much less of an issue, offshore turbines suffer from considerable logistical constraints, meaning that operators want to minimise the frequency and severity of maintenance on their turbines, in order to reduce costs.

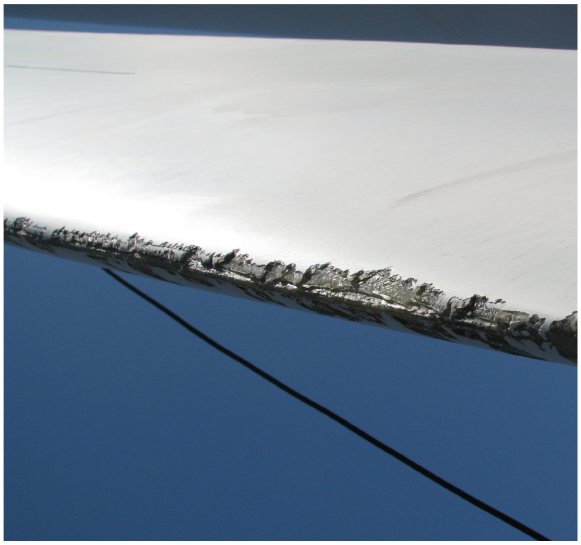

Figure 1: An example of leading edge erosion [2]

Higher tip speeds are sought after due to the potential to reduce the overall loading on the drive-train at a given power output. A lack of constraint on acoustic emissions offshore also encourages greater tip speeds. At this time the erosion on the leading edge of the blade is a major limiting factor for the operation of the wind turbine, but other constraints do also exist: effects on the rotor solidity by operating at a higher speed has an impact on the overall optimal rotor design and thus would need to be taken into consideration [3].

Some literature has been conducted in the area: Slot et al [4] conducted a review of wind turbine coating models and Keegan et. al [5] conducted a broader literature review in the area of leading edge erosion, as well as using explicit dynamics software to model the impact of rain droplets. The material modelled was an epoxy resin plate and was impacted at speeds from 40 m/s to 140 m/s. The work of Liersch and Zhang [6, 7] represent their respective efforts to experimentally evaluate the erosion on wind turbine blades.

The University of Strathclyde constructed a rain droplet erosion rig for the purposes of testing erosion on wind turbine blades. It is mounted on a vertical axis and is a "whirling arm" type rig, the impingement method is via syringes of which can be switched in order to modify the droplet diameter. The delivery method is a simple pump whereby the rainfall rate can be modified by adjusting its settings. The University of Limerick constructed a similar rig for erosion testing purposes, however much of the testing undertaken was for the aerospace industry and no work has been performed relating to the leading edge of wind turbine blades [8].

2 Approach

ASTM guidelines for "liquid impingement erosion using rotating apparatus" were used as a basic guideline where applicable; the standards have many guidelines and recommendations relating to composite material testing [9].

Experiments were carried out to map the erosion effects of the rainfall rate against tip velocity, This ranged from 40m/s to 60m/s and rain flow rate from 20mm/h to 40mm/h. The droplet diameter was held constant at 2.5mm and each test lasted for a duration of 40 minutes. This was performed in order to gain an insight into the recovery time of the composite material used.

The composite used was uncoated and had two main constituents; an epoxy matrix supported by glass fibres, this type of material is typically used on wind turbine shells. The material was constructed by layering up the fibres in specific orientations, namely 0°, 45° and -45°.

Polymer composite can be tested for liquid impact erosion in a fairly similar way to metals however, one key difference with composites is that they absorb moisture relative to the local humidity. This has significant impact on the weight loss measurements after the duration of the test, which is the main evaluation method for erosion in this case [9]. This was resolved by measuring the weight loss 24 hours after the testing had finished, which was found to be an adequate resting period.

2.1 Outputting mass loss- time curves

As the weight loss could not be continuously measured at set intervals during the experiment due to the gained moisture content, a separate experiment was proposed. The weight loss relationship over time, a key erosion indicator as explained in Springer [10] would be determined in this case. In the test, a single sample was exposed for discrete 10 minute intervals in the rig, left to dry for 24 hours and then weighed before being exposed in the test chamber yet again. The scales used for weighing were accurate to +/- 0.1mg. This process was found to be adequate without the use of a high temperature desiccator, which could have caused damage on the material surface [11].

3 Main abstract body

Figure 2 shows a wastage map representing the relationship of rainfall rate to sample velocity, the corresponding table classifies the boundary conditions for mass loss.

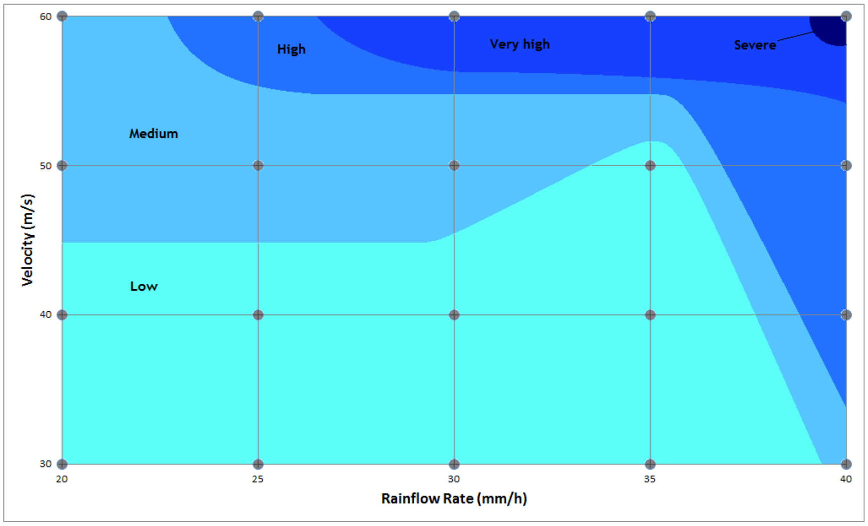

Figure 2: Wastage map showing mass loss for velocity against rainfall rate. The duration of each test was 40 minutes and the droplet diameter was 2.5mm

Table 1: Classification of the parameters of mass loss for Figure 2

Classification	Mass loss (mg)
Low	<2
Medium	2-5
High	5-15
Very high	10-100
Severe	>100

As expected, the overall severity of the erosion becomes more severe towards the higher velocities and rainfall rates. A slight discrepancy can be seen at 35mm/h and 50m/s however, this can be considered an anomalous result as a general trend can be seen on the map. It can also be seen that the influence of velocity has a much greater effect on the severity of erosion than the rainfall rate.

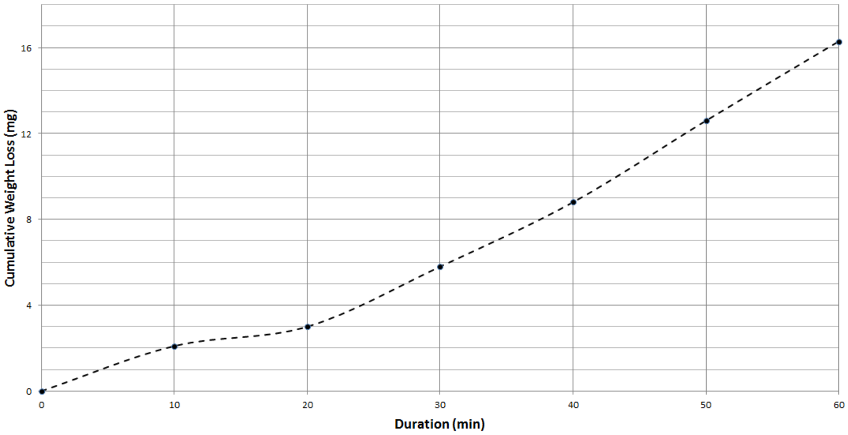

Figure 3: Results after stopping the tests a set intervals and waiting for the sample to dry.

Figure 3 shows the wastage effects over the duration of a test for a sample subject to a droplet diameter of 2.5mm, at 60 m/s velocity with a rainfall rate of 25.4 mm/h. It can be seen that no incubation period is present, meaning that damage resulting from liquid impingement is immediately reflected as mass lost on the sample.

The purpose of this test was to negate the wet-ability property of the composite, which on average accounted for twice the overall mass lost on the samples. This emphasises the importance of properly accounting for the wetability aspect of composites.

4 Conclusion

Erosion of the leading edge of the blade occurs with far greater severity for increasing velocity and rainflow rates. It can be seen from the wastage map produced that an increase in the velocity of the impact has a greater mass loss than an increase in the rainflow rate, suggesting that the velocity of the wind turbine blade plays a greater role than the relevant conditions the turbine is situated in. It also suggests that the recovery rate of the material is not as significant as previously thought.

5 Learning objectives

1. Contact velocity is much more damaging than rainfall rate as shown in the results, highlighting the importance of tip speed.
2. Composite wet-ability makes liquid impact testing difficult, and should be adequately dealt with.
3. Wind turbine designers and control engineers face a number on constraints on the rated tip speed, including leading edge erosion.

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