Renewable Energy
Volume 197, September 2022, Pages 776-789

Experimental study on the effect of drop size in rain erosion test and on lifetime prediction of wind turbine blades

Jakob Ilsted Bech [a], Nicolai Frost-Jensen Johansen [a], Martin Bonde Madsen [b], Ásta Hannesdóttir [a], Charlotte Bay Hasager [a]

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https://doi.org/10.1016/j.renene.2022.06.127

Abstract

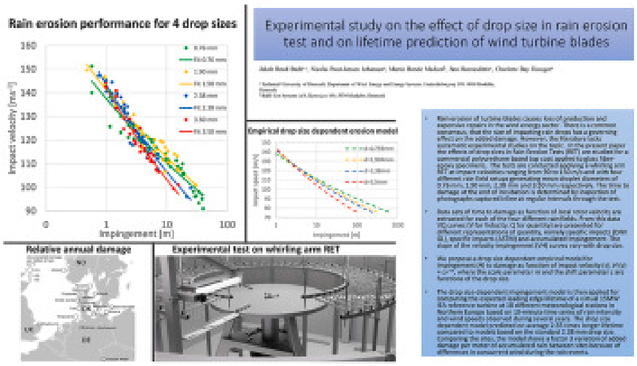
Rain erosion of turbine blades causes loss of production and expensive repairs in the wind energy sector. There is a common consensus, that the size of impacting rain drops has a governing effect on the added damage. However, the literature lacks systematic experimental studies on the topic. In the present paper the effects of drop sizes in Rain Erosion Tests (RET) are studied for a commercial polyurethane based top coat applied to glass fiber-epoxy specimens. The tests are conducted applying a whirling arm RET at impact velocities ranging from 90 to 150 m/s and with four different rain field setups generating mean droplet diameters of 0.76 mm, 1.90 mm, 2.38 mm and 3.50 mm respectively. The time to damage at the end of incubation is determined by inspection of photographs captured inline at regular intervals through the test.

Data sets of time to damage as function of local rotor velocity are extracted for each of the four different rain fields. From this data VQ curves (V for Velocity, Q for Quantity) are presented for different representations of quantity, namely specific impacts (DNV GL), specific impacts (ASTM) and accumulated impingement. The slope of the velocity-impingement (VH) curves vary with drop size.

We propose a drop size dependent empirical model for impingement (H) to damage as function of impact velocity (v), $H(v)=cv^{-m}$, where the scale parameter m and the shift parameter c are functions of the drop size.

The drop size-dependent impingement model is then applied for computing the expected leading edge lifetime of a virtual 15 MW IEA reference turbine at 18 different meteorological stations in Northern Europe based on 10-min time series of rain intensity and wind speeds observed during several years. The drop size dependent model predicted on average 2.35 times longer lifetime compared to models based on the standard 2.38 mm drop size. Comparing the sites, the model shows a factor 3 variation of added damage per meter of accumulated rain between sites because of differences in concurrent wind during the rain events.

Graphical abstract



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Introduction

Rain erosion of wind turbine blades is a prominent challenge for the wind energy industry [1,2]. When erosion occurs, it causes roughening of the blade surfaces, leading to reduction in aerodynamic efficiency, and potentially losses in annual energy production [3,4]. Wind turbine blades may need repeated repairs during a lifetime, and blade repair costs are high, particularly offshore, due to logistics [5]. Consequently, erosion needs to be considered when planning and operating wind parks, designing wind turbines and developing blade coatings and protection systems. The prevalence and progression of leading edge erosion at wind turbines in operation depend on rotor tip speeds, leading edge materials, rain and wind, and other environmental parameters. Erosion shows variability between sites, not only because of different turbines and blade coatings, but also because of different meteorological conditions, where concurrent values of precipitation and wind speed are the main meteorological drivers [6,7]. The drop size distribution of the impinging rain also play a significant role. The drop size distribution varies with rain intensity, but also with type of rain, temperature and humidity [8].

The correlation between drop size of impinging rain and added damage to coated composites is thus of great importance for modelling of rain erosion. Several models take into account the effect of drop size on impingement damage [[9], [10], [11], [12]]. However, no experimental validation and studies are found in literature.

In the current work, the whirling arm rain erosion test [13], is used to study the effect of drop size and impact speed on erosion damage. A new empirical drop size dependent impingement model is proposed and used to predict the expected blade lifetime for a virtual IEA Wind 15MW reference turbine [14] at 18 North European sites using site-specific rain intensity and wind speed time series.

The paper is structured as follows. Section 2 contains a description of the experimental methods and materials, the analysis of tests data, and the meteorological data and wind turbine characteristics used in the lifetime predictions. Section 3 describes different representations of impinging rain and resulting damage and analysis steps. Results are presented in Section 4, followed by Discussion in Section 5, Limitation and proposals for further research in section 6 and conclusion in section 7.

Section snippets

Rain erosion test

The rain erosion tests are conducted with a rain erosion tester (RET) from the company R&D Test Systems A/S. This RET, Fig. 1, has a 3-bladed rotor with one test specimen per blade and a rotor diameter of approximately 2.5m. The RET is capable of rotational speeds ranging from 500 to 1386 RPM, producing tip speeds from 63 to 172m/s, and up to 1790 RPM/224m/s in the aerospace configuration. The rain field is generated from an array of drop dispensing needles. The flow of water is adjustable …

Representations of impinging rain

Rain erosion is commonly considered as a fatigue phenomenon. In classical fatigue theory, the load parameter is denoted *S* for stress, and *N* denotes the number of load cycles. A plot of sustained load cycles to failure as a function of applied stress is called an SN curve or Wöhler curve.

The simplest idealized rain field consists of spherical drops of equal diameter *d*, which are uniformly distributed in space. The volume concentration of water in the rain field, ψ, is calculated as follows:$\psi = \frac{I}{v_{dr}}$ …

Drop size measurements

The rain fields in the RET was characterized applying a disdrometer.

The drop sizes and fall velocities from three of the four needle and flow rate configurations are presented in Fig. 5. Relative frequency curves are shown to the right and above of the coordinate system. The rain fields of G27 at 60l/h (green dots) and G30 at 85l/h (yellow dots) are relatively uniform with narrow distributions while the spray mode G27 at 105l/h (blue dots) shows a much broader distribution both in drop size …

Discussion

Some of the methods, results and assumptions are discussed in the Results section. Additional assessment and considerations are given below. …

Limitations and proposals for further research

1. The present study does not account for other meteorological parameters like UV and temperature and the environmental degradation of coating properties over time. Research on how environmental degradation affects VH curves over time would enable more realistic lifetime predictions. …

2. The Palmgren-Miner assumption for linear damage accumulation is not validated for rain erosion. We do not consider the effects of sequences of loading with differing drop sizes and impact velocities. This could be …

…

Conclusion

The present experimental study focuses on the importance of the drop sizes in rain erosion testing of leading edge protection systems for wind turbine blades. Through rain erosion testing of a modern high performance top coat on glass fiber/epoxy specimens with four different rain fields, representing average drop sizes from 0.76mm to 3.5mm we demonstrate, that the slopes of the VN and VH curves decrease with decreasing drop size, corresponding to an increasing exponent of the fitted power …

Author contributions

JIB created the research concept and research plan for the specimen testing, developed the empirical models together with NF-JJ and calculated the lifetimes. NF-JJ described and compared the standard recommended practice ASTM and DNV-GL methods for specific impact and did the visual inspection analysis of the RET results. MBM ensured the RET was performed and conducted and collected disdrometer measurements in the RET. ÁH implemented the droplet size impingement models in the python code for …

Data availability

The meteorological data used in this study are openly available in the Natural Environment Research Council's Data Repository for Atmospheric Science and Earth Observation (CEDA), the

Danish Meteorological Institute's (DMI) Frie Data repository, the German Weather Service (DWD) Climate Data Center, and The Norwegian Meteorological Institute (NMI) based on data from MET Norway. …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

Acknowledgements

This work was supported by the Innovation Fund Denmark - Grand Solutions projects, Grant 6154-00018B “EROSION” and grant 9067-00008B “Blade Defect Forecast”. Meteorological data from the Open Data Server of Deutscher Wetterdienst, the Norwegian Meteorological Institute, the Meteorological data from Natural Environment Research Council and the Danish Meteorological Institute are acknowledged. We warmly thank Flemming Vejen for quality control and filtering of precipitation data at the DMI …

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