Manuscript ID: WES-2024-33 Drop-size-dependent effects in leading-edge rain erosion and their impact for erosion-safe mode operation

Nils Barfknecht, Dominic von Terzi

September 2024

Dear reviewers,

We would like to thank you for the time and effort you put into reviewing our manuscript. We believe that your comments have improved the quality of our work. Through this collaboration, we can move toward our common goal of mitigating leading-edge erosion.

Below, you can find your original comment on our work. Where appropriate, we have inserted our answers. We have spent a considerable amount of time carefully reviewing your comments. We hope that we have addressed them to your satisfaction.

Sincerely,

Nils Barfknecht and Dominic von Terzi

Reviewer 1

Comment Accepted as is

We are glad that we could address all points.

Reviewer 2

Comment The authors addressed most of the reviewer comments and made some great improvements to the original submission. It is greatly appreciated that they did take a lot of the suggestions on board.

Thank you.

Before publication there are only minor issues remaining:

Comment The authors added in the abstract and the conclusion: "... for a combination of a typical wind turbine, leading-edge material and site." to convey that this paper is a case study. However the authors are not providing any justification of this to be "typical". They should simply be transparent and mention that they use the IEA 15MW, a site in the Netherlands and material data that is openly available. This work is a case study and cannot be generalised. It could mention in the conclusion that it would be beneficial in the future to expand the analysis by using realistic material and turbine data and multiple sites to see whether the conclusion are indeed generaliseable.

We made the proposed changes in our manuscript. In particular, we wrote:

In the abstract:
Subsequently, their significance for leading-edge erosion is established for the IEA 15MW reference wind turbine, a site in the Netherlands and a commercial leading-edge coating.

In the conclusions:
The importance of these effects was demonstrated for the IEA 15MW reference wind turbine, a site in the Netherlands and a commercial leading-edge coating.

See also the answer to the next comment.

Comment It is understandable that in light of the current length of the paper, the authors do not want to include a sensitivity study, however this should be for sure part of future work. Their model relies

on a multitude of model constants and it would be beneficial to show which model parameters are most important. If there is large uncertainty in some of the driving model constants their conclusions could change significantly. This needs to be mentioned if the authors are not willing to add a sensitivity study at this stage.

We added a discussion about the sensitivity of the results in the conclusions. In particular, we wrote/extended:

The damage model used in this study requires a range of parameters and sub-models. These can influence the outcomes of this study. The largest uncertainty concerns the drop-size dependency of the leading-edge material. Currently, to the authors' best knowledge, Bech et al. (2022) published the only study that independently tested a coating for various drop sizes. The importance of the slowdown effect is projected to grow in the future. The slowdown depends on the aerodynamic nose radius R_c and the tip-speed. Both are expected to increase as wind turbine blades become larger. For future work, it is recommended to perform a sensitivity study that explores the influence of the parameters and sub-models that describe the considered turbine, site and material.

Comment The authors should use SI units everywhere if possible [...]

We use SI units everywhere, but deviate from SI *base* units in two instances.

1) We use SI-derived units in some cases for improved readability. For example, the rainfall intensity is expressed in mm/hr instead of m/s. A typical rainfall of 1 mm/hr in SI base units is $2.78 * 10^{-7}$ m/s, which is clearly impractical.

2) Our work uses results from other studies. This includes equations describing, for example, the terminal velocity of a rain droplet or the erosion lifetime of a coating. We decided to reference these equations and their coefficients in their original (and typical) form. The original coefficients sometimes require the usage of SI-derived units, such as millimeters instead of meters.

We did explain this previously, and in this light, we would like to once again point to the answer we gave to the original L.100 and L.134 comments. Here we repeat Comment L.100 for convenience:

In the original reference, the coefficients of a, b, and ϕ_0 were determined such that ϕ must be substituted in millimeters. It is, of course, possible to adjust these coefficients so that the formulas become consistent with SI [base] units. However, this would also require an explanation in the text so that the reader does not get confused about the apparent inconsistency in the numerical value of the coefficients among references. We, therefore, think that mentioning the original coefficients is more appropriate. [...].

Comment [...] and also normalise their results using some appropriate measure. Changes in certain quantities can then be more easily interpreted. The absolute speed is very much dependant on the type of turbine, controller and blade section, for instance, it would be better to normalise with an appropriate measure. Normally any quantity has some appropriate value that can be used for normalisation. This could also allow transferring some of the results directly to other turbines operating in similar regimes.

In our opinion, we have normalized our results according to the current state-of-the-art and best practices in erosion research. For example, we have normalized the results of Figure 5b and c, 6b and c, 8b, 9, 10, 11a (partly), 12, 13 (see 11a), 14, 15, 16. We interpret the comment(s) of the reviewer such that the reviewer asks to normalize beyond this state-of-the-art so that our results become agnostic to the type of turbine, controller and blade section. However, in our view, this is not straightforward and not in the scope of this work. If such a normalization were to be found, this would be, of course, very exciting and impactful!

Comment This should not hinder the publication of this paper, however in light of the model complexity it is a shame that the authors do not provide a open-source version of the code they used to generate the results.

We are happy to provide the code of this study on request, as noted in the disclaimer of this manuscript.