Preventing efficiency loss with enhanced leading edge protection

Words: Dr Adam Nevin

The relentless focus on maximizing efficiency in renewable energy is a key driver in the development of both onshore and offshore wind energy equipment. From increasing blade sizes to minimizing friction in the gearbox, every aspect of wind generation has been optimized to provide maximum efficiency when the turbine is built. Attention is now shifting from efficiency at the point of manufacture, to efficiency over the lifetime of the wind turbine. One critical issue impacting this is erosion of the leading edge of the wind turbine blades by precipitation and spray.

When rotating at maximum speed, offshore wind turbine blades can reach a speed of over 90 meters per second at the tip, turning usually harmless rain droplets into high-speed impactors generating shockwaves that can seriously erode the leading edge of the wind turbine blade. With standard resin and gel coating applied during manufacturing, wind turbine blades operating in areas of high precipitation require regular replacement to prevent the turbine suffering a significant decrease in power output and efficiency.

Replacing blades showing signs of erosion is a credible option to maintain efficiency but is extremely costly, and a trade-off between cost and efficiency is usually considered. Advances in rain erosion protection in the form of sheets or 'skins', which can be applied to the blade post-manufacture, mean that this trade-off can be delayed by many years and could even be avoided completely by finding a solution that can prevent rain erosion. Therefore, it is important to develop high-performance erosion protection to ensure consistent efficiency and power output throughout a windfarm's operational lifetime.

Nanocomposites for next-generation rain erosion solutions

Recognizing that polyurethane holds great promise in protection of wind turbine blade leading edges, Trelleborg's applied technologies operation in Retford, England, developed a novel nanocomposite solution building upon experience manufacturing leading edge protection for aerospace applications that incorporated nanotubes during manufacture. It was predicted that this would reinforce the leading edge of wind turbine blades by bridging potential erosion cracks, preventing future larger pitting and mass loss.

In order to test this hypothesis, a number of sample sheets were manufactured of varying compositions, including standard polyurethane leading-edge protection material, which is currently widely used in aerospace and renewables, and a newly created carbon nanotube impregnated polyurethane.

Each of these sheets was adhered to a fiberglass blade composite substrate as per DNV-RP-0171 standard practice and tested on a state-of-the-art rain erosion rig. An accelerated erosion test, where water droplets added to the test chamber bombarded blades rotating at rapid speeds, enabled accurate comparison of test subjects. This allowed a lifetime analysis based upon precipitation rate, using the incubation period, which is the time elapsed before the first mass loss of the coating or until the damage is visually detectable, of the sample versus number of droplets impacted.

Initial results of the nanocomposite leading edge protection materials were promising; while the incubation period was not significantly positively impacted, the incorporation of the carbon nanotubes led to a mass loss less than half of that of the unmodified leading-edge erosion protection sheet. A reduction in mass loss on its own does not indicate an improvement in erosion, or even in the lifetime of the protection. However, the results obtained from this initial experiment suggested the nanotubes may be acting in the mode hypothesized; reinforcing the

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polymer matrix and preventing significant mass loss during erosion.

In order to fully understand the impact of the nanotubes on the rain erosion performance of the material, it is important

to consider the complexity of rain droplets impacting on rapidly moving objects and the subsequent mechanisms of erosion. Materials need to absorb the shock of a water impact, dissipate it, and recover before the next impact. At high speeds the water impact produces high level localized stress, estimated to be in excess of 100 Megapascals in some epoxy resin systems around the point of impact, which dissipates radially through the material.

Therefore, one important factor that influences the effectiveness of a material for rain erosion protection is the hardness of the material. Increased hardness can reduce the ability of the material to yield when impacted and thereby mitigate the stresses caused by high-speed liquid droplets, worsening erosion performance.

The focus of further analysis to evaluate rain erosion performance was therefore on the hardness of the two materials tested. The hardness of the material was found to increase by roughly 10% upon addition of the carbon nanotubes. Such an increase in hardness would usually be accompanied by a decrease in rain erosion performance, explaining the discrepancy of a decrease in mass loss while maintaining a similar incubation period.

It was therefore theorized that by optimizing the formulation of the polyurethane matrix used in these nanocomposites, the hardness of the material could be controlled and tuned, combining the improvement of nanoscale reinforcement with a highly resilient polymer system in order to create a novel material.

Optimization of high-resilience polymer for peak performance

The final development cycle was the alteration of the polymer backbone to enhance the polyurethane formulation, enabling the hardness, resilience, elastic modulus and toughness of the material to be varied to obtain optimal rain erosion performance.

Constituent polyurethane parts were chosen that offered high cut, chip and tear resistance, while also conveying high tensile properties to the final material when combined with the versatility of a three-component polyurethane. This was to achieve a wide spread of material hardness values, while maintaining consistent results. The system offered the potential to unlock the promising nanocomposite improvements of the carbon nanotube system as demonstrated in the earlier results.

Following the same procedure as before, samples were manufactured and adhered to blade composite structures in accordance with the DNV standard and tested in the same rain erosion rig to enable a direct comparison of results. The new optimized polyurethane material was shown to have a dramatic improvement over both previous samples, with the incubation time doubled by the use of the new high-resilience polymer system.

Furthermore, analysis of the mass loss showed that the use of this system to tune

the hardness of the material was successful, as the material demonstrated a huge improvement in mass loss, with the mass change negligible at the end of the run, successfully combining improvement in polymer reinforcement with rain erosion protection when considering the incubation period.

Further analysis showed the improvement in erosion protection carried on throughout the rest of the test, with the optimized material showing no signs of failure by the end of the rigorous test procedure. By monitoring the rain flow rate and the tip speed throughout the experiment, it was possible to model the impact this material would have on the lifetime of a wind turbine in various precipitation conditions in an offshore environment. It was found that the lifetime of the leading edge protection material increased by over 250%, resulting in a solution predicted to last almost 20 years with a single 300-micron application.

The flexibility and sheet-like nature of the material affords additional benefits as the method of installation is simple and rapid, and the lifetime can be readily increased by a change in thickness. Trelleborg is undertaking further research in this area to examine the impact of the thickness of the material, and investigate the potential of pre-shaped molds, removing any stress imparted to the material during application of a flat sheet over a curved surface.

These unique polyurethane materials hold the potential to dramatically improve the lifetime performance of windfarms, protecting wind turbine blades from efficiency loss due to erosion and the subsequent change in aerodynamics of the blades. Trelleborg hopes these new materials will help wind operators see a consistent return on investment over the lifetime of a windfarm, maintaining the power output by offering complete protection of the wind turbine blade against rain erosion.

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Biography

Dr Adam Nevin is the Innovation Lead within Trelleborg's applied technologies operation. He obtained his doctorate at the University of Nottingham on highly functionalized nanomaterials and their potential for revolutionizing the renewable energy sector, before continuing to a subsequent post-doctoral position developing novel smart polymer materials at Cardiff University.