IEA Wind Task 46

Erosion of wind turbine blades

Simple laboratory test

Mechanical characterization of LEP materials

Technical report

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Purpose

Leading edge erosion (LEE) of wind turbine blades has been identified as a major factor in decreased wind turbine blade lifetimes and energy output over time. Accordingly, the International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) has created the Task 46 to undertake cooperative research in the key topic of blade erosion. Participants in the task are given in Table 1.

The Task 46 under IEA Wind TCP is designed to improve understanding of the drivers of LEE, the geospatial and temporal variability in erosive events; the impact of LEE on the performance of wind plants and the cost/benefit of proposed mitigation strategies. Furthermore Task 46 seeks to increase the knowledge about erosion mechanics and the material properties at different scales, which drive the observable erosion resistance. Finally, the Task aims to identify the laboratory test setups which reproduce faithfully the failure modes observed in the field in the different protective solutions.

This report is a product of Work Package 4 Laboratory testing of erosion.

The objectives of the work summarized in this report are to:

- Describe the characterization of the viscoelastic parameters of LEP materials using dynamic mechanical thermal analysis (DMTA).
- Investigate if these mechanical properties correlate with rain erosion test performance.

Table 1 IEA Wind Task 46 Participants.

Country	Contracting Party	Active Organizations
Belgium	The Federal Public Service of Economy, SMEs, Self-Employed and Energy	Engie
Canada	Natural Resources Canada	WEICan
Denmark	Danish Energy Agency	DTU (OA), Hempel, Ørsted A/S, PowerCurve, Siemens Gamesa Renewable Energy
Finland	Business Finland	VTT
Germany	Federal Ministry for Economic Affairs and Energy	Fraunhofer IWES, Covestro, Emil Frei (Freilacke), Nordex Energy SE, RWE, DNV, Mankiewicz, Henkel
Ireland	Sustainable Energy Authority of Ireland	South East Technology University, University of Galway, University of Limerick
Japan	New Energy and Industrial Technology Development Organization	AIST, Asahi Rubber Inc., Osaka University, Tokyo Gas Co.
Netherlands	Netherlands Enterprise Agency	TU Delft, TNO
Norway	Norwegian Water Resources and Energy Directorate	Equinor, University of Bergen, Statkraft
Spain	CIEMAT	CENER, Aerox, CEU Cardenal Herrera University, Nordex Energy Spain
United Kingdom	Offshore Renewable Energy Catapult	ORE Catapult, University of Bristol, Lancaster University, Imperial College London, Ilosta, Vestas
United States	U. S. Department of Energy	Cornell University, Sandia National Laboratories, 3M

Table of Contents

Figures

Executive Summary

Dynamic Mechanical Thermal Analysis (DMTA) testing was explored as a means to quantify the visco-elastic mechanical properties of the coating materials. Correlations between the visco-elastic properties and behavior in Rain Erosion Test (RET) were investigated.

1. Introduction

When a droplet impacts the surface of a wind turbine blade, the visco-elastic properties of the blade coating layers determine the stresses and strains as functions of the impact velocity and droplet size.

In this subtask, Dynamic Mechanical Thermal Analysis (DMTA) testing was explored as a means to get a quantification of the mechanical properties of polymer based blade protection coating materials. Several types of DMTA test fixtures are available. For testing coatings, typically tensile clamps are considered the most suitable, due to the small thickness of the bulk PU samples [2]. In the tests, a static and dynamic load can be set and both frequency and/or temperature scans can be performed.

2. Dynamic Mechanical Thermal Analysis (DMTA)

To establish the full visco-elastic behaviour, both frequency and temperature scans are required to construct the mechanical properties over a full range of frequencies, applying the time-temperature-superposition principle (for instance using William Landel Ferrel, WLF). The curves thus generated are denoted Master curves. They are used to predict the material behavior at frequencies beyond the range of actual testing. This is important for LEP materials because droplet impacts on wind turbine blades are associated with very high frequencies and rates of deformation, orders of magnitude beyond what can be achieved in normal DMTA. The frequency has a large effect on the mechanical properties of the coating – where higher frequencies typically result in more elastic behaviour, and lower frequencies in more viscous behaviour. The extrapolation of the frequency scans to higher frequencies will be more accurate when temperature scans at different frequencies have been performed as well. The test results from the DMTA include: storage modulus (elastic behaviour of the material) and loss modulus (viscous behaviour of the material). From the data, the tan(δ) which is the loss modulus divided by the elastic modulus, and the glass transition temperature (transition between glassy and rubbery state of a material) can be derived [3]. One definition of the glass transition temperature is the temperature where tan(δ) has its peak. It is has been hypothesised that the higher the tan(δ) for a given coating material at the frequency of impact (range: 10^4-10^5) the better the LEE erosion behaviour. Frequency sweeps in the DMA are typically in the order of 10^{-6}-10^2 Hz [4], therefore the time-temperature superposition is needed in the analysis. This relies on the fact that behaviour at lower temperatures corresponds to behaviour expected at higher frequencies. The correlations between frequency and temperature can be quantified by shift factors, as outlined by WLF.

3. Pulsating jet erosion testing and DMTA

In [1] DMTA tests were performed to characterize the material and observe the visco-elastic behavior of bulk PU samples. Relating LEE erosion data with DMA data within the scope of this report was first done on PJET (pulsating jet erosion testing) of two types of coatings: PA and PD (collaboration between TUDelft and UCHCEU). The results for tan(δ) for a temperature sweep at 1Hz are shown in Figure 1. The tan(δ) for the PD material peaks at its highest value at approximately 10°C and for PA at 15°C. For the temperature range of -3°C to 12°C PD has a higher tan(δ), while for the lower temperature range (T<-3°C) and higher temperature range (T>12°C) PA has a higher tan(δ) – see Figure 1 and Figure 2. The erosion behaviour of these two materials is seen in Figure 3. It can be seen that there is a cross-over between the two materials at an impact velocity of 150m/s. At high impact velocities (and therefore frequencies) the behaviour of PA and PD is similar (as can be explained by the similar tan(δ) at very low temperatures). At impact velocities of 150m/s, PA seems to outperform PD (having a higher tan(δ) in the lower temperature range), after which for a lower impact velocity (140m/s), PD shows the better behaviour, which can be explained by the cross-over point in the temperature sweep. However, this can’t be verified as no frequency sweep was done.

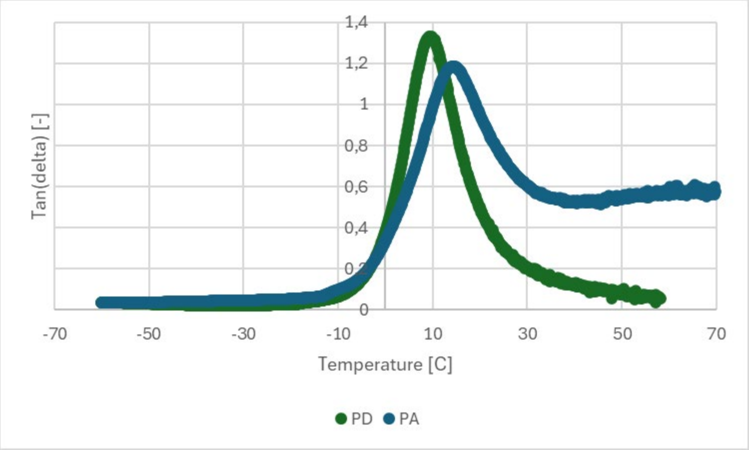


Figure 1 Temperature sweep at 1Hz for PA and PD coating materials.

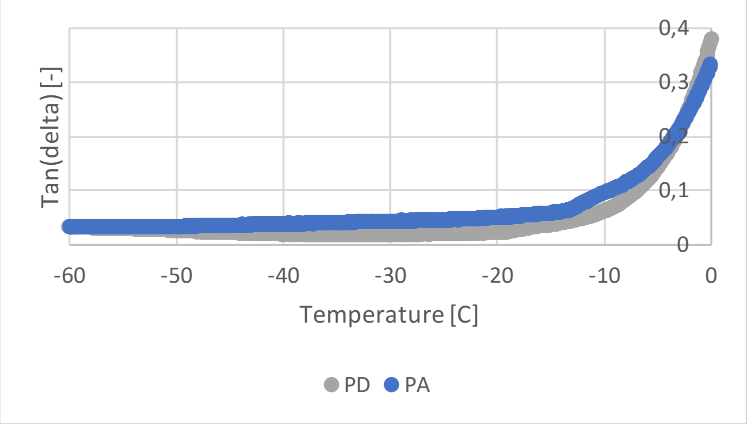
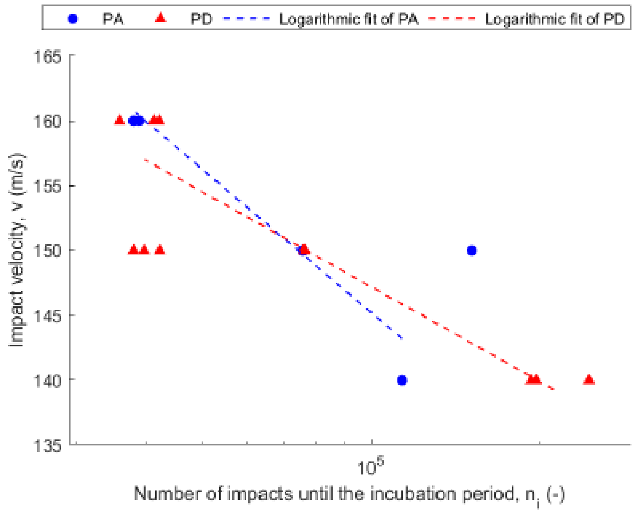


Figure 2 Zoom in at lower temperatures of temperature sweep data (1Hz) for PA and PD coating materials.



(a) $v - n_i$ curve

Figure 3 Velocity- number of impacts till incubation during PJET for coatings PA and PD.

4. Whirling arm rain erosion testing and DMTA

Polymers with a wider range of properties were studied in the Duraledge project Datasets were provided for six different materials [5]. tan(δ) curves for the six materials, obtained by temperature scans at a fixed frequency, are shown in Figure 4. The temperature where tan(δ) has its peak, known as the glass transition temperature, (visible in the graph) range from -30°C for TPU to 80°C for coating 3. It is clear that at lower temperatures, TPU has the highest tan(δ), followed by coating 2, which also retained some of its viscous behaviour below 0°C, while the other coatings quickly drop in viscous behaviour below 0°C.

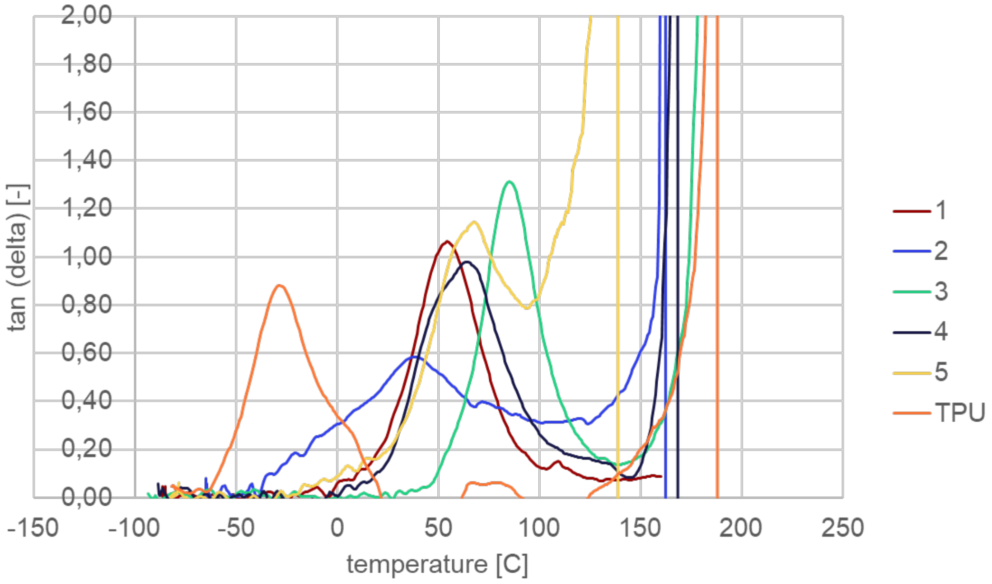


Figure 4 Tan(delta) for 6 different coatings over a temperature sweep at a given DMA frequency.

The master curves for these coatings were generated using time-temperature shifting, and are shown in Figure 5. The tan(δ) peaks on the master curve may be interpreted as glass transition frequency or rate of deformation. It can be seen that in the expected range of rate of deformation in LEE testing (10^4-10^5 Hz), TPU has the highest tan(δ), followed by coating 2, 5, and 1. Coating 3 and 4 have almost similar behaviours, showing very low tan(δ) at high frequencies (10^4-10^5Hz).

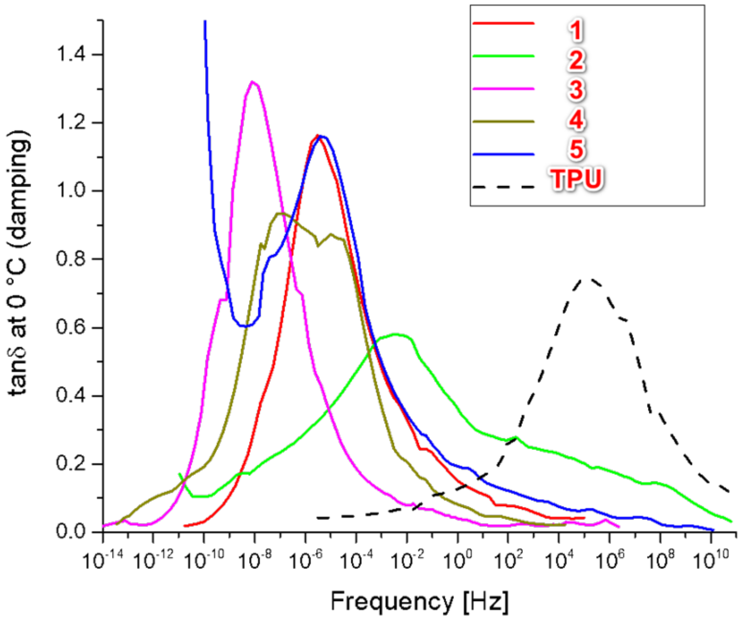


Figure 5 Master curves for the 6 different coatings with T_ref at 0°C.

Figure 6 shows the power function curves fitted to V-N data for coatings 1 to 5, tested in a whirling arm RET. The five coatings perform very differently. Indeed it is interesting to see that a life time rating at e.g. an impact velocity of 120m/s at room temperature, is not in line with the expected behaviour according to the glass transition frequencies or tan(δ) values at high frequencies. The order of worst to best performance is here coatings 5-1-4-3-2. Therefore, this seems to indicate that not only the tan(δ) plays a role in the coating behaviour and that more extensive mechanical testing would be needed to get the full picture of the coating behaviour.

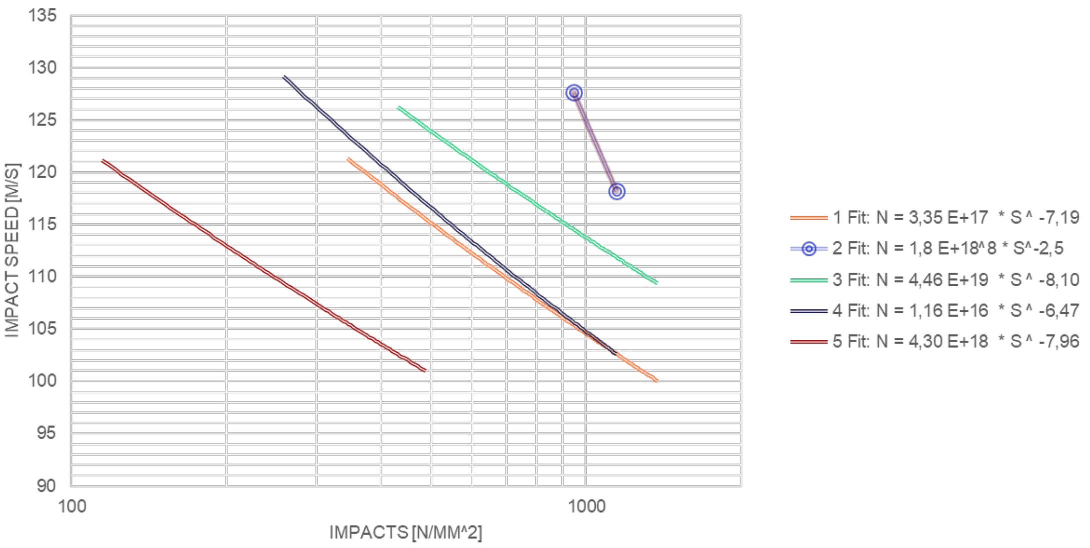


Figure 6 Impact speed versus numbers of impacts until incubation (whirling arm test) for 5 different coatings.

5. Notes, conclusions and recommendations

Visco-elastic properties govern material loads and deformations, which are important parameters in liquid impact erosion. Hower, no conclusive trends were found between glass trasition values or tan(δ) at high rates of deformation and the performance in rain erosion tests. A missing link may very likely be material degradation and damage progression, which need to be taken into account as well in order to correlate loads with failure. Thus the role of materials properties related to fatigue, crack propagation and fracture need to be adressed in future research.

A few other notes must be made for future work: the effect of frequency on the strain at break in tensile test has not been taken into account. The conversion between transient strain rates and corresponding DMTA frequencies should be fully understood, as well as the fact that the material goes through a range of strain rates upon impact. Local adiabatic hysteresis heating may also shift the master curves during impact.

References

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