QIRT'2022

10.21611/qirt.2022.1013

16th Quantitative InfraRed Thermography Conference

Damage development of initial defects in coated GFRP-structures due to rain exposure

by F. Jensen*, M. Sorg*, A. Fischer*

* University of Bremen, Bremen Institute for Metrology, Automation and Quality Science, 28359 Bremen, Germany

Abstract

Mechanical impacts on the rotor blade leading edge of wind turbines lead to erosion damage, which affects the boundary layer flow and thus the energy production. Initial structural defects like voids further promote the erosion development. In order to investigate the development of structural defects to surface damage, rotor blade-like GFRP specimens with voids introduced are loaded with rain. Thermography, offering the possibility of in-situ measurements, is used to assess the specimen's condition before and after loading. The results show that thermography is able to detect the damage development from sub-surface to surface damage and also to differentiate between them.

1. Introduction

With a speed of over 300 km/h, the leading edge of the wind turbine's rotor blade tip is subject to high loads and exposed to forces from environmental influences like rain impact. This type of stress contributes to the progress of leading edge damage, which has a negative impact on the service life of rotor blades and, by changing the boundary layer flow, also on energy production [1]. Despite protective solutions, erosion damage often occurs premature. Investigations suggest that even small sub-surface defects promote an early development to a surface damage through loading [2]. For non-destructive detection of these initial defects, active thermography is well suited as shown by investigations on modified, coated and curved samples [3]. Also, the damage development at unmodified speciemns caused by compression load and impact weights was investigated by means of thermography [4, 5]. However, the reproduction of damage progression in the laboratory showing the development of an existing near-surface defect to a surface damage has not yet been carried out. In addition, it must be clarified to what extent the different damage states of a rotor blade-like specimen with inserted voids can be recorded and whether the damage development is visible and distinguishable by using active thermography.

2. Measurement approach

Long-pulse thermography is used as a measuring method for documenting the state of damage of the GFRP-specimen, as it can visualise the edge zone of a measuring object non-destructively and in-situ [6]. For this purpose, the measuring object is thermally excited by means of a halogen lamp pulse to cause a heat flow in the material. Due to the material-specific heat transfer behaviour, a characteristic temperature distribution appears on the surface of the measuring object. This temperature response in the form of infrared radiation is recorded with the infrared camera and shown as a thermogram sequence. For the evaluation, the image with the highest contrast is selected from the sequence in order to apply a defect detection algorithm.

3. Experimental set-up

For the investigations, test specimens are produced which, in terms of structural design, materials and geometric dimensions, emulate a leading edge of a rotor blade in the tip area. The basis is a GFRP-laminate consisting of 4 layers in a

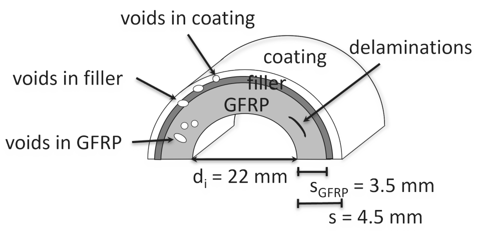

Fig. 1. *Schematic sketch of the GFRP-specimen with different initial defects*

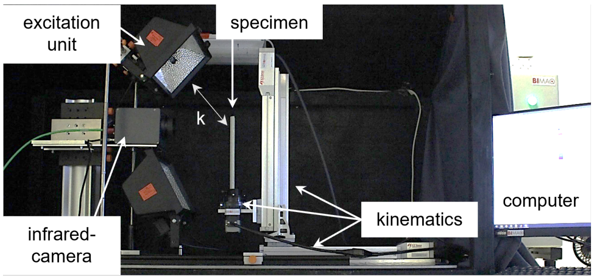

Fig. 2. *Experimental set-up for the thermographic examination of test specimens; k = 204 mm*

semi-tubular shape. A filler and a coating with a thickness of 0.5 mm to 1 mm are applied on top. In order to imitate initial imperfections for first investigations, voids are introduced into the coating by means of polystyrene balls, see Fig. 1. The thermographic test stand where the test specimen is mounted in a kinematic system for optimal positioning, can be seen in Fig. 2. The excitation time lasts 10 s. The thermographic camera used is the Vario CAM hr head from the company Infratec with a 30 mm lens. It has a resolution of 640 px x 480 px with a wavelength range of 7.5 μm - 14 μm. The recording takes place over 30 s with a frequency of 10 Hz and starts after the excitation has ended.

4. Results

In order to show the damage development, the test specimens must first be investigated by means of thermography to document the condition of the unloaded specimen. Subsequently, the specimens are exposed to rain in a rain erosion test stand until the damage has progressed. Afterwards, the specimens are examined again. Figure 3 shows an example of a specimen with voids in the coating, both as a visual image and as a thermographic image normalized to the grey values in the initial state and after 4 h of loading. In the unloaded state, the voids under the surface stand out clearly from their environment as bright dots. With the help of a detection algorithm that searches the thermogram for local maxima, the defects can be detected. By specifying the contrast-to-noise ratio of every detected defect, the detection quality is evaluated. After the four-hour rain exposure, clear changes are visible in the thermogram. While some of the voids remain hidden below the surface and can be seen on the surface as bright dots again, other voids have developed into surface damage. These stand out from their surroundings as dark dots with a light border and can therefore no longer be detected with the existing detection algorithm. The investigations also show that sub-surface defects and surface damage can be distinguished clearly from each other in thermograms by the colouring. At this point, thermography offers the advantage that not only sub-surface defects can be detected but surface damage as well, so that additional investigations with a visual camera are not necessary. In fact, the entire damage development from a sub-surface defect to a rain-induced surface damage can be visualized by means of thermography.

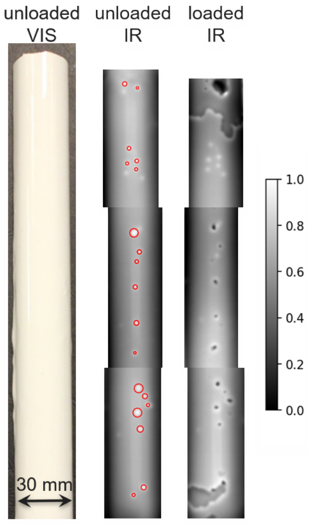

Fig. 3. *Left: visual image of the modified specimen; middle: three thermograms of the modified specimen before loading, red circles are automatically detected voids; right: three thermograms of the modified specimen after 4 hours of rain loading*

5. Conclusion and Outlook

The investigations show that it is possible to reproduce the rain-induced damage evaluation of sub-surface defects to surface damage in the laboratory. In addition, long-pulse thermography can be used to assess the current damage state of a coated and curved specimen. With thermographic edge zone analysis, a clear distinction can be made between surface and sub-surface damage. However, in order to display the course of damage thermographically and, if necessary, to be able to make predictions about a later state of damage, the test specimens must be loaded in several cycles and examined in between.

We thank the German Federation of Industrial Research Association (AiF, 20794 N/2) for funding and the project partners for supporting the specimen preparation and erosion tests.

References

[1] C. Dollinger, N. Balaresque, N. Gaudern, M. Sorg, and A. Fischer. Calculation of the power output loss based on thermographic measurement of the leading edge condition. *Journal of Physics: Conference Series*, 1037:052011, 2018.

[2] M. H. Keegan, D. H. Nash, and M. M. Stack. On erosion issues associated with the leading edge of wind turbine blades. *Journal of Physics D: Applied Physics*, 46(38):383001, 2013.

[3] Friederike Jensen, Marina Terlau, Michael Sorg, and Andreas Fischer. Active thermography for the detection of sub-surface defects on a curved and coated GFRP-structure. *Applied Sciences*, 11(20):9545, 2021.

[4] Hongliang Tuo, Tao Wu, Zhixian Lu, and Xiaoping Ma. Evaluation of damage evolution of impacted composite laminates under fatigue loadings by infrared thermography and ultrasonic methods. *Polymer Testing*, 93:106869, 2021.

[5] Carosena Meola and Giovanni M. Carlomagno. Infrared thermography to evaluate impact damage in glass/epoxy with manufacturing defects. *International Journal of Impact Engineering*, 67:1–11, 2014.

[6] Zijun Wang, Guiyun Tian, Michele Meo, and Francesco Ciampa. Image processing based quantitative damage evaluation in composites with long pulse thermography. *NDT & E International*, 99:93–104, 2018.