Specimen design and instrumentation for monitoring fatigue crack growth initiating at ply drops

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Introduction

Unpredictable and excessive loads, for example caused by aerodynamic interaction between different turbines, can accelerate fatigue damage in wind turbine blades (Ghosal et. al (2000)). Fatigue damage can also initiate in the early service life of a wind turbine blade in regions of stress concentration, such as those caused by ply drops (Cairns et al. (1999)). Due to these issues, the design philosophy is based on conservative analysis methods and inspections at certain time intervals are required to assess the damage in the wind blades.

An alternative approach is to use damage tolerant materials and a structural health monitoring system (McGugan et al. (2015)). In this approach, a distribution of damage types within the blades is accepted as long as they can be detected by structural health monitoring techniques and their severity evaluated by material damage models.

Experimental details

The present work aims to demonstrate this design philosophy at the laboratory level. A test specimen, which includes ply drops at different distances from each other, is tested under static and fatigue loading. The specimen geometry is shown in Fig. 1, where it can be seen that a slip foil is placed at one of the ply drops to initiate the crack. A second geometry without a slip foil and an additional ±45^o laminate on the top surface is also tested. The aim is to investigate if cracks starting from these locations are stable (damage tolerant) and if the cracks and their location can be detected by non-destructive methods (detection of damage initiation and evolution).

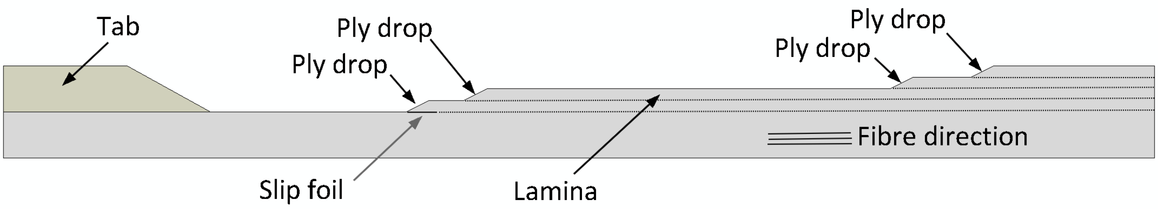


Figure 1: Ply drop specimen geometry with a slip foil (not in scale).

The focus of the paper is on the experimental details and set-up: a) Design of the specimen based on a finite element model. b) Manufacturing of the ply drop specimens including manufacturing issues when embedding fibre Bragg grating sensors. c) Instrumentation of the test specimen e.g. strain gauges, acoustic emission sensors, fibre Bragg grating sensors.
The fibre Bragg grating sensors are placed within the ply drop specimens when the laminates are laid out on the infusion table (see Fig. 2). A difficulty arises with the fibre Bragg grating sensors wires, which should not be damaged during infusion but also should not create leaks in the infusion vacuum bag (see Fig. 3).

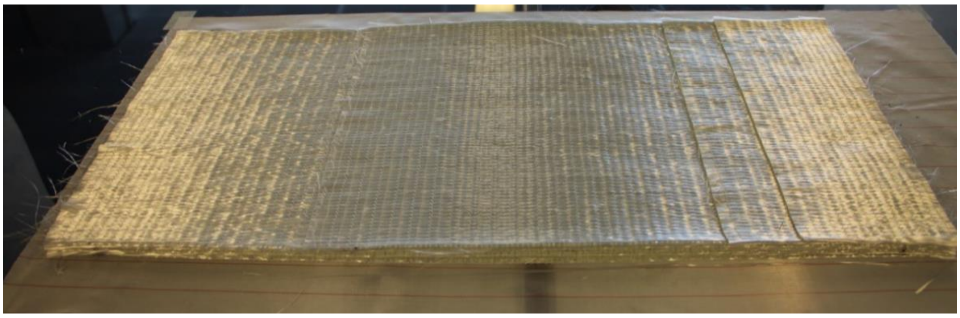


Figure 2: Lay-up of the laminates before vacuum infusion showing the ply drops.

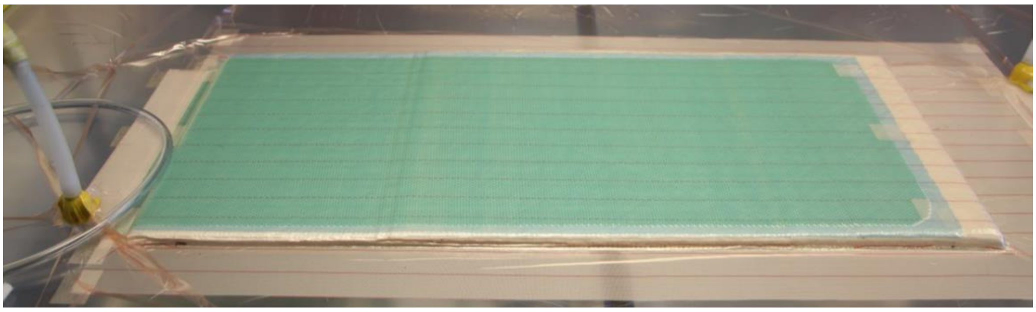


Figure 3: Vacuum infusion of the ply drop specimens.

Two acoustic emission (AE) sensors are mounted on the specimen for both static and fatigue tests as shown in Fig. 4. The aim is not only detect crack initiation and growth, but also to localise the damage.

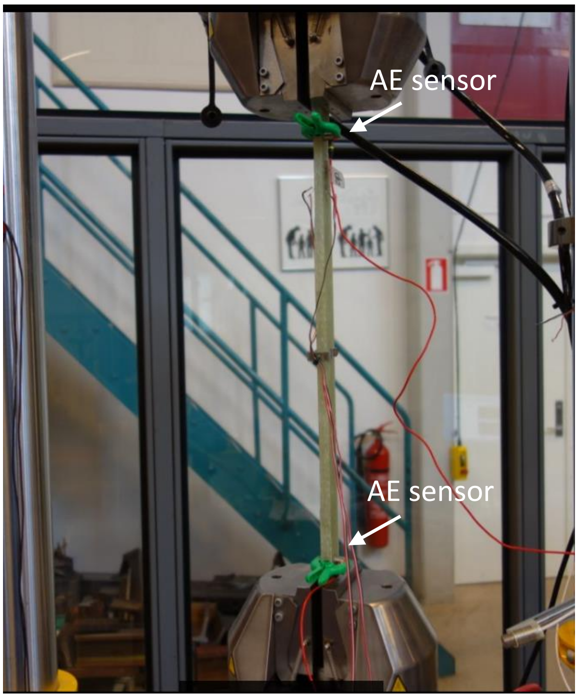
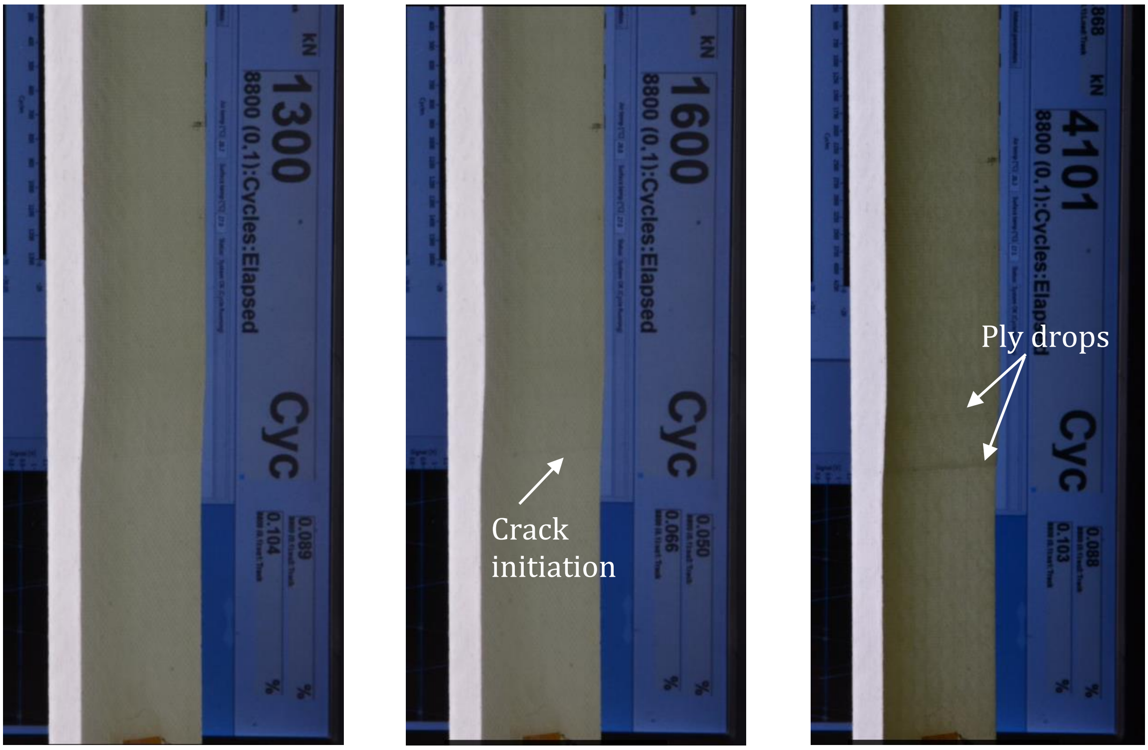


Figure 4: Location of the acoustic emission (AE) sensors for static and fatigue tests.

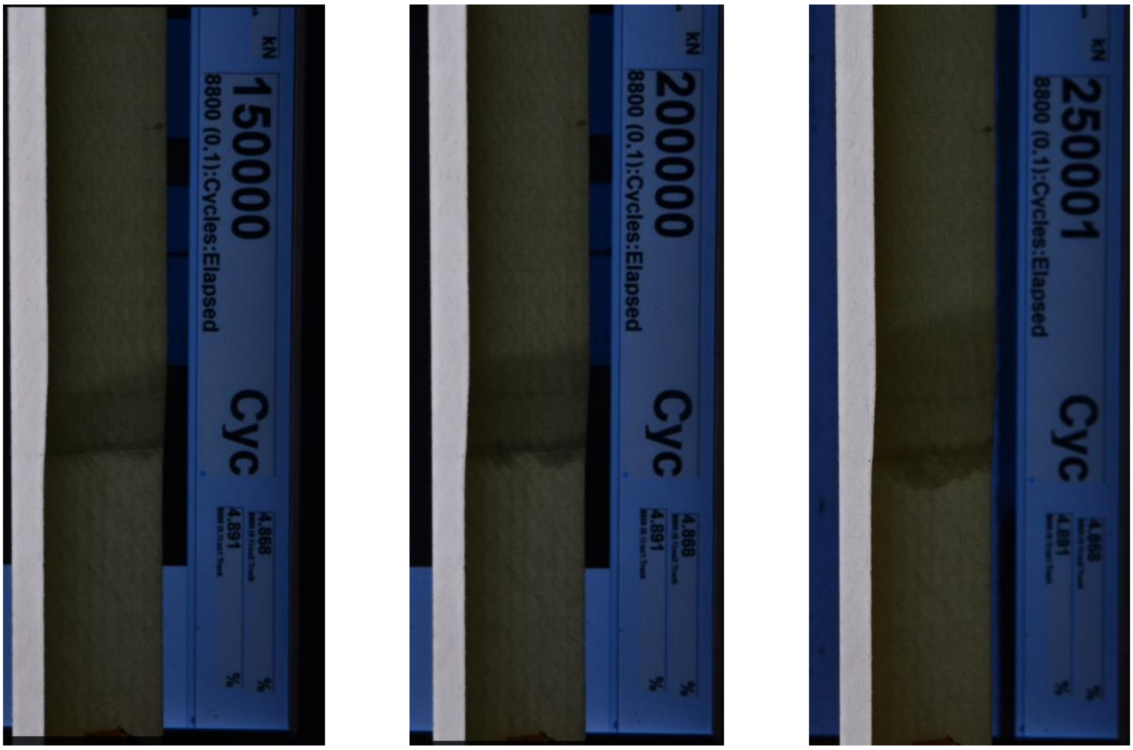
Preliminary results

Selected static and cyclic results will be presented showing that certain damage types (cracks at ply drops) are stable and thus not critical for the integrity of a structure (wind turbine blade) and that structural health monitoring techniques (acoustic emission and fibre Bragg grating sensors) can detect damage initiation and monitor the damage evolution.
Preliminary results are shown in Figs. 5 and 6 where fatigue crack initiation and growth are monitored with photos taken during fatigue testing.



(a) 1300 cycles (b) 1600 cycles (c) 4101 cycles

Figure 5: Fatigue crack initiation and growth at the ply drop for a specimen without slip foil.



(a) 150000 cycles (b) 200000 cycles (c) 250001 cycles

Figure 6: Fatigue crack growth in the constant thickness section (specimen of Fig. 5).

Fig. 5 shows fatigue crack initiation in the first ply drop (Fig. 5b) and then in the second ply drop (Fig. 5c). With further increasing the number of cycles, the crack grows in the constant thickness section of the specimen (see Fig. 1). Fig. 6 shows the fatigue crack growth in this region. From these measurements, the fatigue crack growth rate can be determined.

References

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