FATIGUE FAILURE OF SANDWICH BEAMS WITH WRINKLE DEFECTS USED FOR WIND TURBINE BLADES

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Abstract

Glass fiber face sheet/balsa wood core sandwich beams with out-of-plane fiber misalignments/wrinkle defects were subjected to in-plane fully reversed fatigue loading and the failure modes were documented. A fatigue life design limit was estimated using finite element analyses and the Northwestern University failure theory. The presence of the wrinkle defect significantly lowered the fatigue strength, but it was found that the test specimens could reach a pre-defined fatigue life with no signs of damage, by applying a fatigue load below 80% of the estimated design limit.

1 Introduction

The fatigue behavior of composite materials and composite sandwich structures has been given much attention by the scientific community [1-5] and it has been demonstrated how structural flaws can have a profound effect on the fatigue strength. A particular severe type of defect is that of out-of-plane fiber misalignments, also called wrinkle defects. The static failure of sandwich beams with these kinds of defects have been studied by Hayman et al [6] and Leong et al [7], but the influence of these defects on the fatigue strength have yet to be investigated further. The current paper briefly presents the investigations conducted on this topic in [8].

2 Materials and experimental methods

The sandwich specimen face sheets consisted of E-glass reinforced epoxy fiber mats, mainly uni-directional with a bi-directional cross ply mat on top and bottom. A balsa wood core was used between each face sheet. Wrinkle defects were induced between the core and the upper face sheet by folding the glass layers on top of a plastic rod, which was removed before casting. Test specimens were manufactured with a VARTM process and cut into slim beam specimens as shown in Fig. 1.

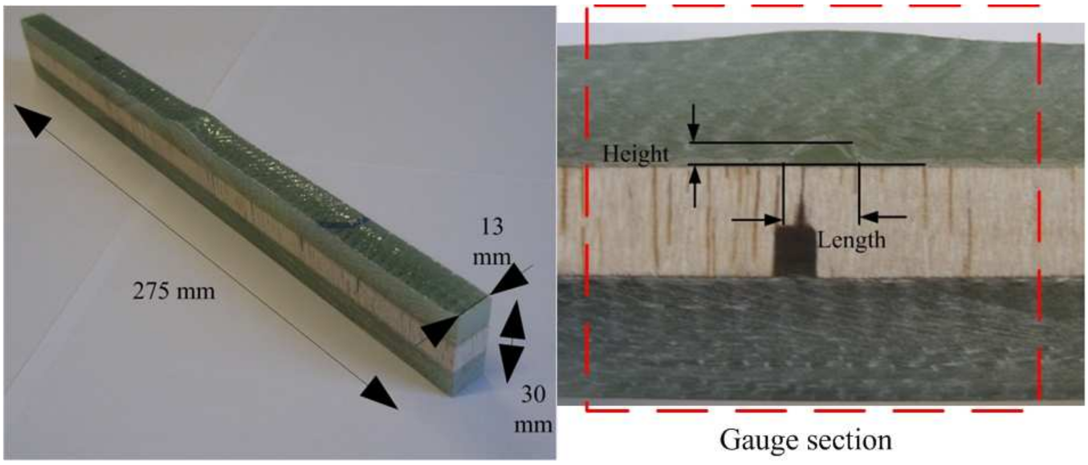

Figure 1. Test specimens and wrinkle geometry.

The specimens were mounted in hydraulic grips and fully reversed (R=-1) fatigue load amplitudes of different magnitudes were applied. A DSLR camera was setup for time-lapse photography to monitor the damage development. All tests were run at a load frequency of 3 Hz at a room temperature of 21 C. A pre-defined target life of $2*10^6$ load cycles was used in the majority of tests. The test setup can be seen in Fig. 2.

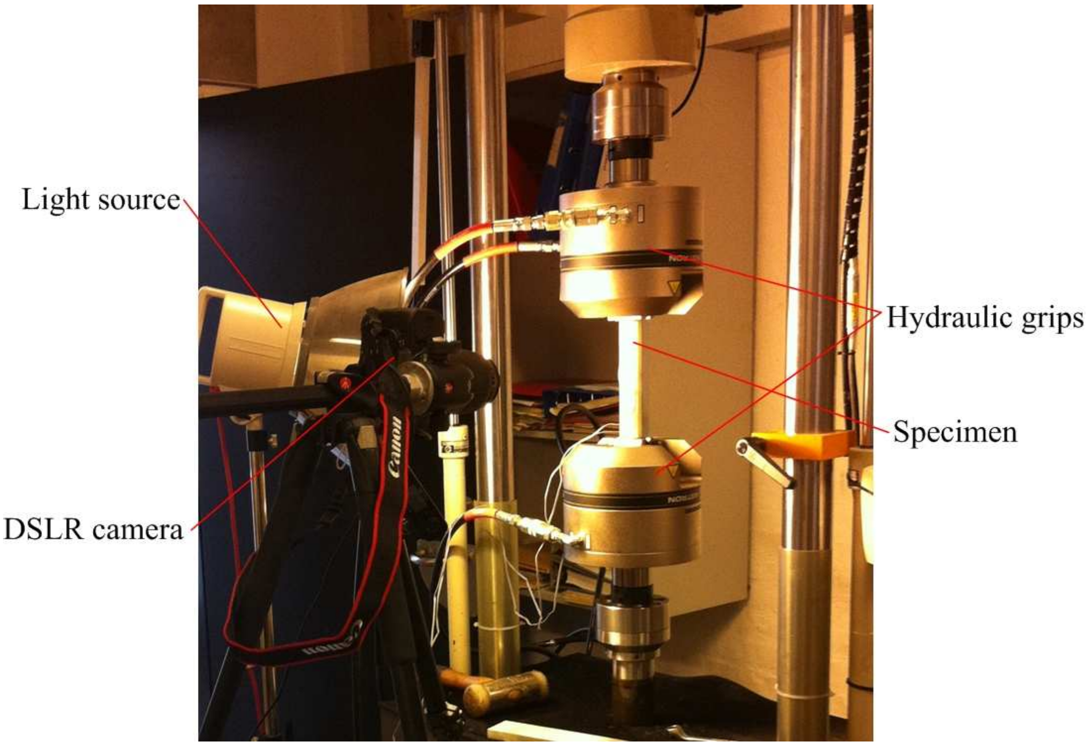

Figure 2. Picture of the fatigue test setup.

3. Determination of design limit

Earlier studies have shown that static compression loaded sandwich beams with wrinkle defects fail by layer wise delamination [7]. It was also shown that the localized strains around the wrinkle defect would exhibit non-linear behavior long before final specimen failure. A method to determine material failure initiation was presented in [9], along with a demonstration of the applicability of the Northwestern University interfiber/interlaminar failure theory [10-12] to predict failure in glass fiber composites subjected to various states of stress. Vallons and co-workers, [13], have shown how the non-linear stress vs. strain behavior in NCF fabrics can be attributed to material micro damage and how an apparent infinite fatigue life can be achieved when loading materials under this micro damage/failure initiation onset point. Using this knowledge, each specimen was modeled using finite elements and the specimen failure initiation was predicted using the approach described in [9] together with the NU failure theory.

4. Results

The stress vs. life (SN) relation of sandwich beams with wrinkle defects was generally lowered significantly, compared to reference data of the face sheet material without a wrinkle defect. The fatigue strength at the target life of $2*10^6$ was in the magnitude of 33% of the reference material, and the strength reduction was much more pronounced at lower numbers of load cycles. Specimens loaded above the estimated design limit generally exhibited fatigue lives between 10^3-10^5 load cycles. An example of the damage development in these specimens is shown in Fig. 3.

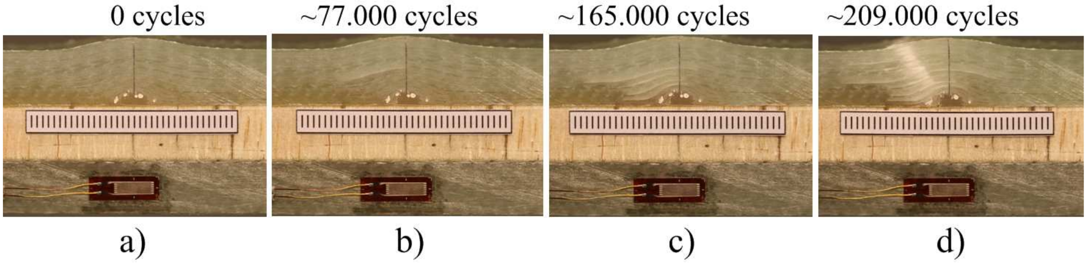

Figure 3. Typical development of interlaminar fracture and damage propagation during fatigue tests. a) Start of test, no visual damage. b) A single delamination becomes visible in the face sheet. c) Several delaminations visible through the specimen face sheet thickness. d) Specimen final failure.

Specimens loaded at and slightly below the estimated design limit would reach the target life but with visual face sheet damage, similar to what is shown in Fig. 3 b) and c). Lowering the fatigue load further would result in specimens reaching the target life and above with no signs of damage.

5. Summary and conclusions

GFRP face sheet/balsa wood core sandwich beams with face sheet wrinkle defects were tested in fatigue. Compared to reference data, the presence of a winkle defect could lower the fatigue strength of the beam specimen with 2/3 or more. A design limit was estimated by using the NU interfiber failure theory and finite element modeling. Specimens loaded below this design limit would not develop any signs of damage up to and beyond the fatigue target life.

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