INFLUENCE OF IMPACT DAMAGES ON THE FATIGUE BEHAVIOUR OF COMPOSITES

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Abstract

Defects in composite structures, such as impact damages have a major influence on the fatigue behaviour. Based on the conducted experiments the influence of impact damages on fatigue life of glass fibre based NCF composites was characterised.

1. Introduction

Defects in composite structures, such as impact damages have a major influence on the fatigue behaviour. These defects, which can occur during the lifetime of composite parts, lead to delaminations between adjacent layers with different fibre orientations and to matrix cracks within the layers.

To ensure the service of a component over a long period, it is necessary to exactly know the material-specific fatigue behaviour after impact damage, also known as post-impact fatigue (PIF) [1,2]. If the effects of impact damage on the fatigue behaviour of FRP are well known, more fatigue resistant FRP structures can be developed. Damage caused by an impact can have a negative effect on the fatigue performance of FRP. Generally, the failure mode of impact damage is very complex, including matrix cracks, delaminations and fibre fracture [3]. Therefore an impact often leads to a steep increase of material degradation. The stability and the residual strength of the entire laminate are reduced and cause even earlier final failure of the FRP structure [4–7].

In this work, the relationship between impact damage and fatigue lifetime is investigated. Specimens made of a glass fibre non crimp fabric (NCF) are produced by vacuum assisted resin transfer moulding (VARTM). Impact damage is introduced using a drop weight with a hemispherical head. It is purposed to characterise the damage development in fatigue of fibre reinforced polymers as a function of impact damage, lifetime and stress level (which one) as precise as possible. Therefore, the stiffness degradation during fatigue due to matrix cracks, delaminations, fibre failure and temperature development of the specimens is plotted vs. the number of load cycles. In interrupted fatigue tests at defined numbers of load cycles the influence of defects on the matrix crack development is determined and correlated with the stiffness degradation. Furthermore, thermoelastic stress analysis was performed during the interrupted tests in order to determine the stress concentrations in the area of the impact damage. The specimens are tested under fatigue loading using a stress ratio of R=10 (compression-compression).

2. Material and experimental procedure

2.1 Material

Specimens were prepared from laminates consisting of two glass fibre non crimp fabrics (GF-NCF) made of the roving OC 111A from Owens Corning infiltrated with epoxy resin Epikote MGS RIM 135 and curing agent Epikure MGS RIMH 137 from Momentive by vacuum assisted resin transfer moulding (VARTM) and cured for 48h at 30°C. The laminates consist of eight plies [0° -45° 90° 45°]s, with a fibre volume content of 34.3 % ±3 %. Each ply has different quantities in the laminate: [0°: 49 %, -45°: 23 %, 90°: 5 %, 45°: 23 %]. The mechanical properties of matrix and fibres are given in [8]. Aluminium/GFRP end tabs were attached to ensure homogenous load introduction. Specimens with dimensions of 250 mm x 30 mm x 3 mm were cut with a diamond saw in 0° direction of the GF-NCF, which is the main reinforcement direction. To avoid edge delamination, the specimen edges were polished with siliciumcarbid sandpaper. After specimen preparation a post-curing of 15 h at 80°C was performed to obtain a glass transition temperature of about 85°C. The specimens were then stored at standard conditions of 23°C and 50 % humidity for at least one week until testing to reduce internal stresses

2.2 Cyclic loading

All tests were performed with a test frequency of 4 Hz on a servo-hydraulic test machine. The stress ratio was R = 10 which is compression, compression loading. All specimens were loaded stress-controlled. An anti-buckling device consisting of two aluminium halves, placed on both sides of the specimens was used to avoid global buckling. A slot in the anti-buckling device allowed local buckling, strain measurements with a laser extensometer and observation of the specimen.
Cyclic loading of specimens was interrupted after 50 cycles to introduce an impact damage. To obtain detailed data about the fatigue behaviour, some impacted specimens were tested in repeatedly interrupted fatigue tests after defined numbers of cycles for application of NDT methods like TSA and optical scan. TSA was used to visualise the stress distribution in the area of the impact damage on the specimen surface.

2.3 Introducing impact damage

Specimens were removed from the fatigue test machine to introduce impact damage with a drop weight having a semi hemispherical head and a diameter of 20 mm. The mass of the impactor was constantly m = 1.3 kg. To obtain different energy levels the drop height was changed. The energy was calculated from the potential energy of the impactor. All introduced impacts were low velocity impacts (LVI) as defined in [9–11] (see fig. 1). After impacting, specimens were tested in the servo hydraulic testing machine as described above.

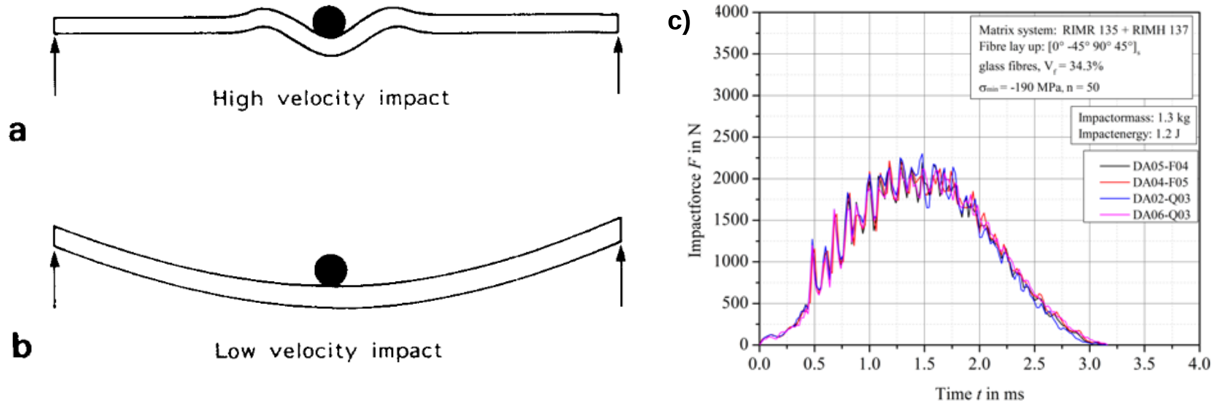

Figure 1. Material response (a) HVI und (b) LVI [9] (c) Force-time curves of specimens preloaded at -190 MPa for 50 cycles and impacted with 1.2 J

3. Results

In fig. 2 all test results from the fatigue tests are shown in a stress - life - diagram (S/N-diagram). For each impact energy one line connects the mean values of the cycles to failure at different load levels. The mean values are based on a log- normal distribution of the fatigue test results. The different slopes of the lines indicate the varying influence of the impact damage on the fatigue results depending on the load level. It is conspicuous that on a load level of -250 MPa and -220 MPa small impacts (e.g. 1.2 J) already cause a strong decrease of the samples fatigue life while at a load level of -190 MPa a higher impact energy (e.g. 2.1 J) is required to cause a comparable loss of fatigue life.

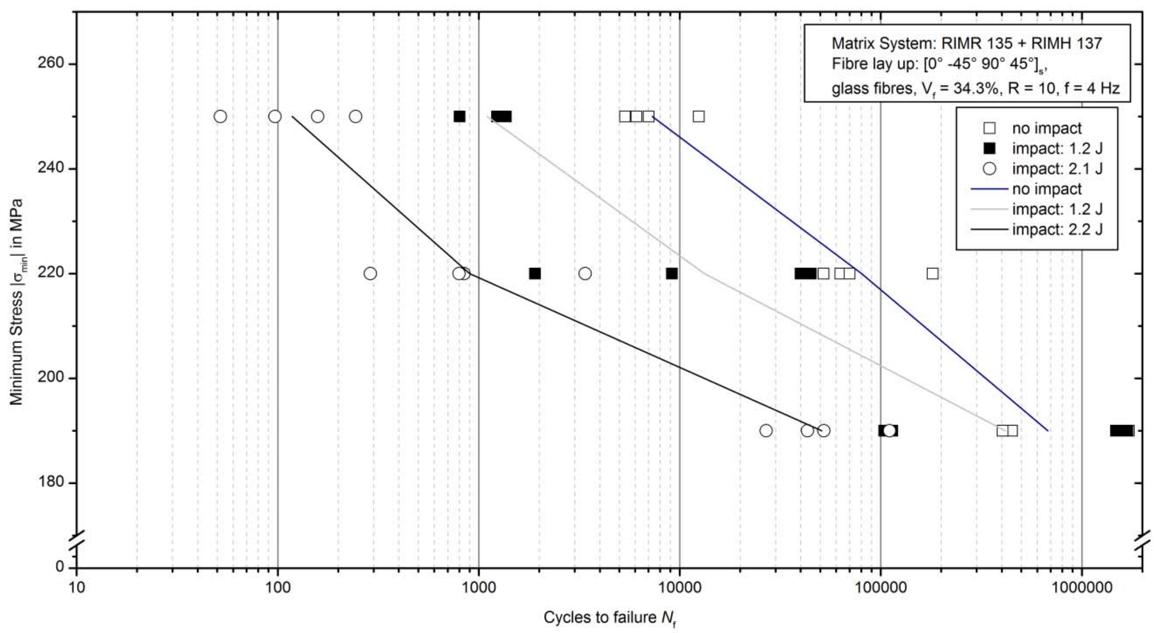

Figure 2. Stress - life - diagram of all tested specimens, the lines connect the logarithmic mean values of the different load levels

It seems that for each load level there is a difference concerning the influence of the impact energy on the fatigue life. Fig. 3 shows the correlation of fatigue life and impact energy. The mean values and the standard deviation of the cycles to failure, based on a log- normal distribution, are shown for each load level. Based on the diagram for each of the three investigated load levels a unique relation between the samples' fatigue life and impact energy and thus a specific critical impact energy level is obtained.

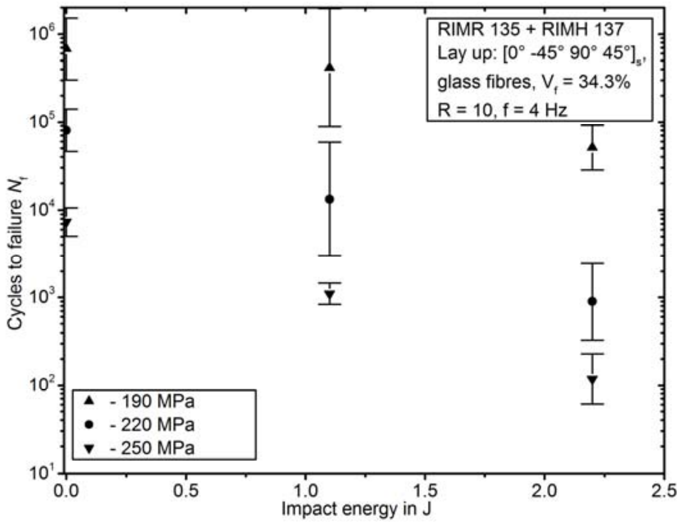

Figure 3. Mean values of cycles to failure plotted against impact energy

Locally increased material damage is shown well by a temperature hotspot, as can be seen in the images taken by the IR camera. A hotspot occurs during mechanical testing in the area of impact damage and in most cases it also constitutes the place of the macroscopic sample failure. Thus, by the use of thermography it is possible to predict the location of the sample failure early during mechanical testing and with high probability. Fig. 4 shows such a case where an early hotpot appears (at about 50 % of the fatigue life). For samples with impact damage, specimen failure caused by further mechanical loading always occurred in the area of the impact damage. Thus, impact damage causes an accumulation of further material damage.

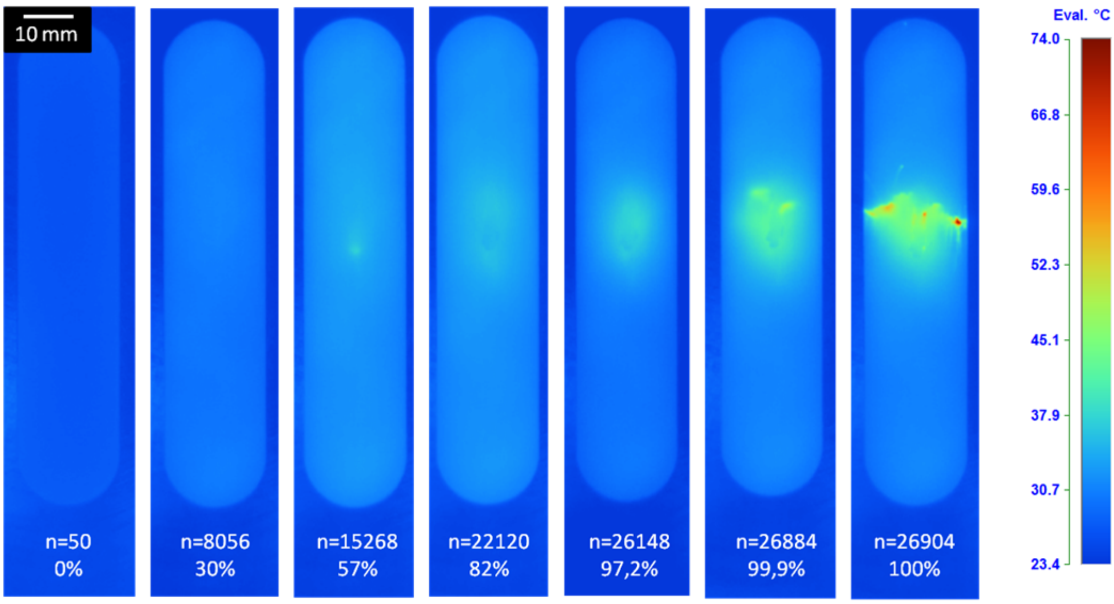

Figure 4. IR images of the specimen with an impact of 2.1 J tested at -190 MPa with use of an anti-buckling device

4. Conlusion

In this work, the relationship between impact damage and fatigue lifetime was investigated. The experiments were conducted under cyclic loading conditions with a stress-ratio of R = 10 at three different stress levels. A multiaxial GFRP was pre damaged by impact with different impact energy levels after 50 fatigue load cycles. Impact damage had an accumulating effect on material damage. More than 83 % of the samples failed directly in the area of impact damage. The location of the final failure of the specimens can be seen in IR-images beginning at about 50 % of the specimens' fatigue lifetime.
For the tested material there is a critical value of impact energy which is dependent on the stress level.

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