INFLUENCE OF VOIDS ON THE DEGRADATION OF CFRP UNDER FATIGUE LOADING

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INTRODUCTION

During processing of cfrp-parts defects can arise. One of the mayor defects are voids which occur during the curing process of thermoset matrix systems due to incorrect processing parameters. These prelife damages can have a significant influence on the durability of composites. They act as failure initiator and significantly reduce residual strength and lifetime. Voids are local defects which can be several orders of magnitude larger as the fibre diameter. The voids can lead to stress concentrations which induce premature first ply failure (FPF) and a change in the accumulating fatigue damage. Previous studies showed that under static tensile load voids have minor influences on the strength of CFRP laminates. But it was clearly worked out that FPF started at significantly lower loads as predicted [1].

Prakash et al. were the first to publish a paper on the influence of voids on the damage evolution during tension-tension, tension compression and compression-compression fatigue loading. They proposed fibre kinking as failure mechanism, due to softening of the matrix in the vicinity of void. They explained this by high stress concentrations which lead to a temperature increase in the near by zone which lead to a failure of the fibre [2]. Chambers et al. presented results under bending fatigue on CFRP composites containing voids. It was evident that an amount close to 2% of void volume increased the durability of the composite, but even higher void contents decreased fatigue life. It could be shown later, that both the initial failure and the final failure under cyclic bending were due to the voids [3;4]. Bolted joints of CFRP containing voids were tested by Garett et al. and showed a higher fatigue life as non voided CFRP [5]. However all results were achieved with a variety of test arrangements but could not give a definite answer to the effect of voids on the accumulating damage of CFRP under fatigue. In the present work, the influence of voids on the degradation of CFRP laminates is studied. Many different arrangements of voids are found in a manufactured part. In this study single voids in a single layer and numerous voids distributed in several layers at one location were investigated. Both configurations were created by a blow agent. From this study it can be examined if a single void or if a void field lead to first ply and final failure of a composite under fatigue loading.

EXPERIMENTAL

CFRP-cross-ply laminates were produced from commercial prepreg tape with a ply thickness of t=0,125mm. The curing was performed at 177°C at 7bar in an autoclave process. $NaHCO_3$ was used as blow agent to create artificial voids or voided volumes in the laminates. Both types of void distributions were investigated in cross-ply laminates. The single void was oriented parallel to the load axis in a $[0,90_2,0]_s$-laminate and located in the symmetry plane, always parallel to the fibre direction (see Fig.1.1), while the laminate with voided volumes was in a $[0,90]_{2s}$ configuration with voids created in all plies in a spot with 11mm in diameter (see Fig. 1.2). The maximum loads in the fatigue tests were performed at a stress level of 80% of static tensile strength using a servo-hydraulic test machine at a frequency of f=5Hz and at a load ratio of R=0,1. The degradation process was documented by ZnI_2 enhanced x-ray radiography. The cracks appear in white, fibre and matrix grey and in voids dark grey on the x-ray D2 film.

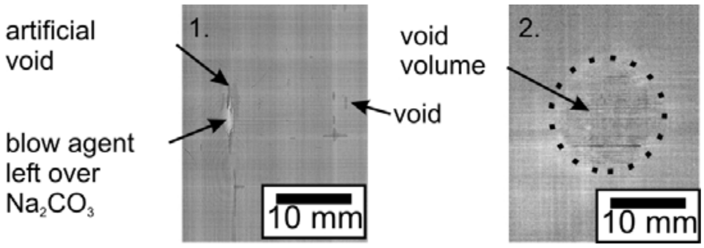

Figure 1: 1. X-ray images of the $[0,90_2,0]_s$ (1.) and the $[0,90]_{2s}$ (2.) laminates. 1. The voids parallel to the load direction were created using $NaHCO_3$. In addition a natural void was created near the blowing agent. 2. Concentrated void volumes in a $[0,90]_{2s}$-laminate.

RESULTS

Fig. 3 shows the damage evolution in the $[0,90_2,0]_s$- laminate containing voids parallel to the loading direction. Already after the first load cycle transverse cracks developed at void locations (see Fig. 3 1 cycle). However after this first failure the propagation or growth of cracks could not be identified as different to cracks formed in void free areas of the coupon. At about 400.000 cycles the growth of longitudinal cracks was observed in the vicinity of artificial and non artificial voids. These cracks showed a deflection with a pronounced waviness when surpassing the artificial voids, while they were straight when propagating through void free areas and areas with voids (see Fig. 1.1).

Delaminations initiated at intersections of transverse and longitudinal cracks or alongside longitudinal cracks respectively, propagated parallel to the longitudinal cracks. However, in the vicinity of the artificial voids larger delaminations with a butterfly shape propagated from the longitudinal cracks towards the void (see Fig.3 400.000 cycles).

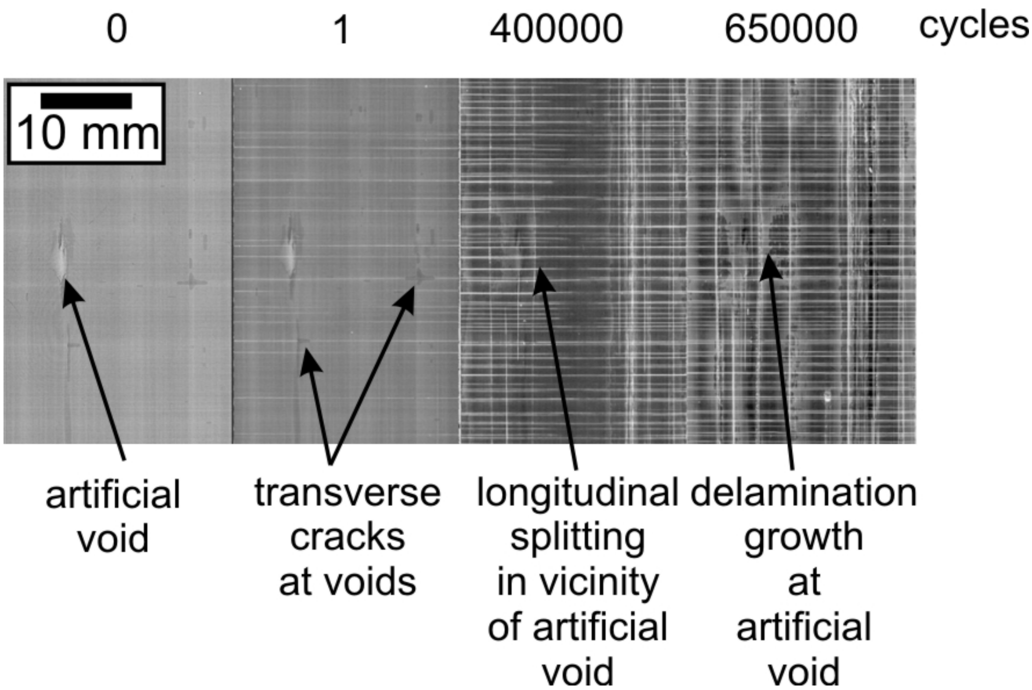

Figure 2: Damage state vs. number of load cycles in a $[0,90_2,0]_s$-laminate containing artificial and non artificial voids under cyclic tensile loading; R=0,1 at 80% of static tensile strength.

However, final failure occurred in void free areas and was not observed at the artificial or non artificial voids.

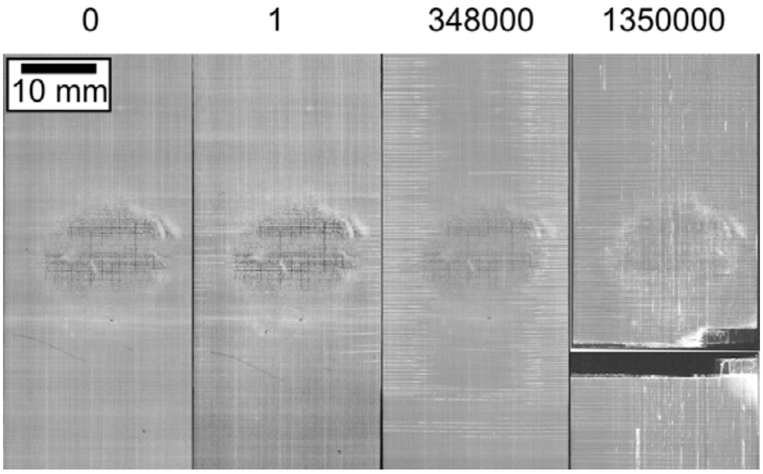

Figure 3: Damage evolution vs. number of load cycles in the $[0,90]_{2s}$-laminate containing voided volumes under cyclic tensile load; R=0,1 at maximum load of 80% of static tensile strength.

The damage evolution of the $[0,90]_{2s}$-laminate is presented in Fig. 3. Already after the first cycle under tensile loading first transverse cracks were formed in the vicinity of the area containing the artificial voids. After 348.000 cycles the cracks show a pronounced waviness. No longitudinal cracks developed during fatigue loading. The longitudinal cracks seen here were bundle failure at the tab area and are assumed as not being connected with the damage evolution in the vicinity of the artificial voids. The final failure occurred after 1.350.000 load cycles close to the void field but not inside. Final failure was not directly linked to the origin of the void. But in the area where the specimens failed a high degree of fibre waviness as well as a higher density of transverse cracks was observed. In Fig. 4 the waviness and the location of the area where the coupon of Fig. 3 fails is shown in more detail. The transverse cracks in white show significant waviness and a higher density at this location after 650.000 load cycles.

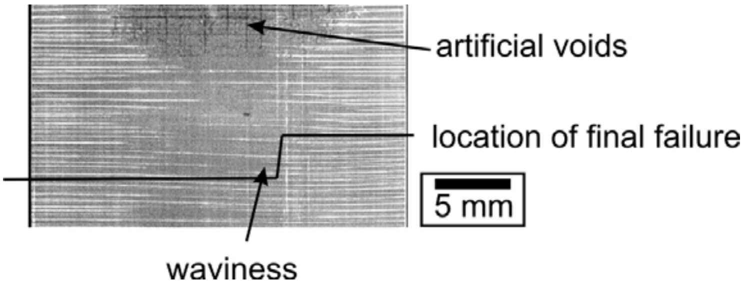

Figure 4: Transverse cracks in the $[0,90]_{2s}$-laminate after 650.000 load cycles. The edge area below the voids shows high degree of waviness.

DISCUSSION

The results presented show that the voids lead to fibre waviness in the adjacent layers and neighbouring fibres. As can be denoted from Fig. 4 the voided area leads to an increase in crack density and in the following to higher local stresses due to a change in the microstructure. The fibres are pressed away from the voids during manufacturing and form an area with higher fibre content and a higher degree of disorder. The single voids showed as well an influence on the fibre misalignment. But in this the degree of disorder was not reached to be critical level to initiate failure in the vicinity of the void.

CONCLUSION

The influence of voids on the damage evolution in CFRP laminates under tension-tension fatigue is evident. The resulting waviness and morphology change in the microstructure leads to a failure in the vicinity of voided areas, but not to final failure in the vicinity of single voids. However, the first-ply failure initiated at the voids as transverse cracks. A void is a volumetric large defect in the composite and leads to a fibre misalignment. This should affect the compressive properties of the laminates, which will be investigated in the future.

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