INVESTIGATION OF THE EFFECT OF WATER JET CUTTING AND MACHINING ON CRACK INITIATION IN OFF-AXIS TEST SPECIMENS

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Abstract

Mechanical- and fatigue- properties of fibre composite materials are often obtained by performing tests on coupon test specimens. These specimens are affected by edge-effects, which means that properties obtained through the testing are often lower than the actual properties. In this work, specimens are cut with either a water jet cutter or a diamond saw and some have been polished in order to determine if the cutting technique or the polishing has an influence on the fatigue properties, for instance the crack saturation levels or the stiffness degradation. The cracks are counted using the transmitted light technique, however, the stitching in the specimens blocks more light than the neat material, which causes the dynamic range of the specimens to exceed the range of the camera. Therefore, a transparency with a negative image of the specimen was attached to the specimen to reduce the dynamic range. This corrected one problem and created a new, because the transparency detached during testing, making crack counting in these areas impossible.

1. Introduction

Composite materials such as Glass Fibre Reinforced Polymers (GFRP) are used in many industries due to their high strength and stiffness to weight ratio but also their fatigue resistance. However, there is a large amount of scatter in the results obtained in fatigue testing of GFRP. One reason is the inherent probabilistic and heterogeneous nature of the materials, which cannot be altered. A second reason is that fatigue properties of materials often are obtained through testing of coupon test specimens. These specimens are affected by edge-effects from 3D-effects and manufacturing- and cutting- induces flaws. These effects affect the results and can cause an underestimation of the mechanical and fatigue properties of the tested materials. Therefore, higher measured values can be achieved by reducing the edge-effects, which is more in line with what can be expected from a panel in a structure.

Specimens are usually polished after cutting to reduce manufacturing induced flaws [1–5]. However, it is unclear whether the chosen cutting technique has an influence on the severity of the edge effects. Only few papers have been published on the matter, where it is concluded that polishing of edges being cut by a diamond saw increases the strain at crack onset [6, 7]. Nevertheless, the results are scarce, not very clear, based on static testing, and they do not consider other cutting techniques such as water jet cutting. Furthermore, the increase in strain at crack onset for 0-90 cross laminates, which is the laminate type tested in this work, is close to none [6].

For these reasons, it is of interest to investigate if the cutting technique has an influence on the fatigue results. In this paper, this is investigated by performing fatigue tests on similar off-axis specimens where

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two different cutting techniques will be used, namely water jet cutting and cutting with a diamond saw. Moreover, some of the specimens cut with either technique are polished to determine the effect of the polishing. The crack initiations in the specimens are tracked during testing using the Automatic Crack Counting (ACC) algorithm [8]. Light is emitted through the specimen and a digital camera on the other side of the specimen is used to detect changes in the specimen, the ACC algorithm is then used to track the changes. By using the algorithm, it is possible to count all the cracks that initiate within the specimen. Hereby, a very accurate comparison can be performed of the number of cracks initiating within the specimens cut with different cutting techniques.

2. Specimen Preparation and Test Setup

The specimens are manufactured of Uniaxial 661 H-glass fibres in a GT 105 Polyester. The fibre mats have backing layers of ±80° with ≈8 wt% in total. The specimens are manufactured using Vacuum Assisted Resin Transfer Moulding (VARTM) on a glass table to ensure a smooth surface on the bottom to make it easier to detect the cracks. Standard 2 mm tabs are glued on the plates before cutting. The specimens are cut to dimensions: 250 mm in length and 25 mm in width. The tested lay-up in this work is [0,90,90,0]. The backing layers are placed away from the centre, which means that the mid layer is effectively twice as thick as the constraining layers.

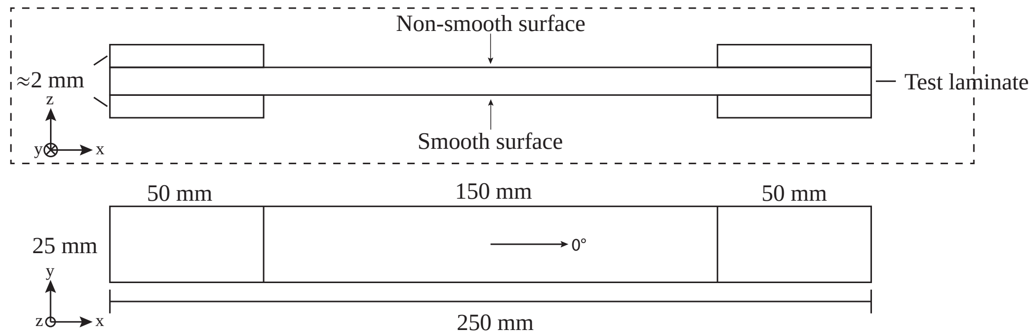

Figure 1. Dimensions of the test specimens.

In this work 3 different types of specimens have been tested with different cutting techniques and surface finishes:

1. Water cooled diamond saw and polished (DSp)
2. Abrasive water jet cutter (WJ)
3. Abrasive water jet cutter and polished (WJp)

The polishing was done with gradually finer grains down to 1μm finish. All specimens were manually sanded on the non-smooth surface and a thin film of lacquer was applied as well to enhance the transparency. The stitching in these specimens block significantly more light than the neat material as shown in Fig. 2, which leads to a high dynamic range in the image. This range is higher than that of the camera. To overcome this issue, specimens 3 to 6 were mounted in the test machine and an image was captured to determine the pattern for the specific specimen. The pattern was inverted, printed on a transparency, and glued to the backside of the specimen by using the applied lacquer. This reduces the observed intensity gradients between stitching areas and non-stitching areas, as shown in Fig. 2, hereby enabling detection of cracks in the stitching areas as well. Detection of cracks in the stitching is difficult for specimen 1 and 2 since this procedure was not done for these. Other methods of attaching the transparency to the specimens are currently being investigated.

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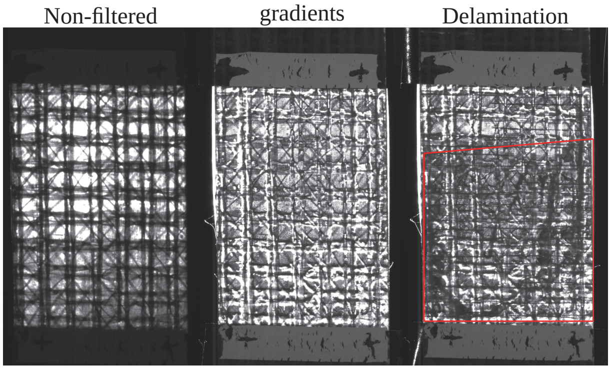

Figure 2. Comparison of specimens with and without light intensity filter and a delaminated filter.

2.1. Test Setup

The fatigue tests in this work are performed on an Instron ElectroPuls E10000 test machine. The load ratio is R=0.1, meaning tension-tension loading is applied to all the specimens with a maximum loading of 3630 N corresponding to a transverse normal stress of ≈31 MPa in the 90° layers.
The test setup is shown in Fig. 3 and it is similar to the one used in [8]. The camera is programmed to take images at even intervals on a logarithmic scale, meaning fewer pictures will be taken per second further along in the test. An extensometer is attached to the specimen to obtain measurements of the stiffness degradation due to the off-axis matrix cracking.

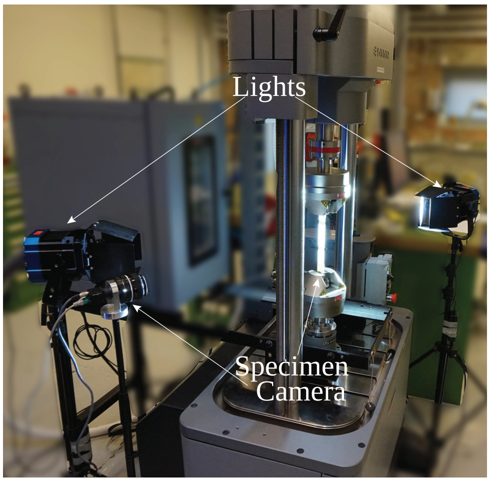

Figure 3. Test setup at Aalborg University.

A gradual degradation process, where multiple cracks initiate, can be captured by using specimens with 0°-constraining layers and acquiring images continuously. The cracks can be considered as independent strength measurements if they initiate so far from each other that they do not interact.

3. Results

The experiments for this paper are currently being conducted at Aalborg University, which means that the complete set of results are to be presented at the ECCM17. However, a preview of the results and the complications with obtaining accurate results are included in this paper in Fig. 4 and 5. It is verified manually that the algorithm has counted the visible cracks correctly for all specimens except specimen 1.

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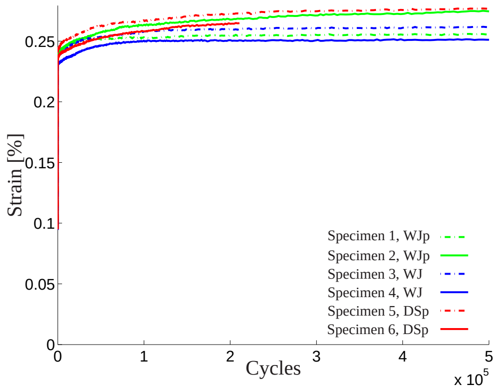

Figure 4. Strain results for all specimens.

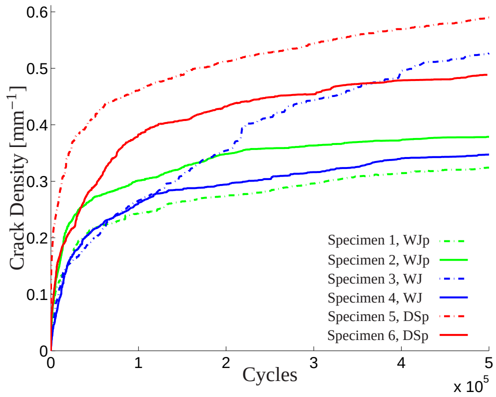

Figure 5. Crack density for all specimens.

4. Discussion

There are variations in the saturated strain levels for the tested specimens as shown in Fig. 4 and this can be seen to have an effect on the crack density in Fig. 5. However, based on the preliminary results presented here it would seem that the specimens cut with water jet cutting and polished afterwards tend to exhibit lower crack densities than the other specimens. This could on the other hand be due to the fact that these specimens were tested without any kind of reduction in the dynamic range and therefore cracks in the stitching areas are difficult to detect. For the specimens where the dynamic range was decreased it came apparent that cracks generally initiated earlier in the stitching than in the rest of the specimens. Hence, this could be one of the reasons why the crack density of these water cut and polished specimens is lower than for the rest of the specimens. The crack density in specimen 1 and 2 is still lower than in the other specimens if it is assumed that there are cracks in all the stitching from one edge to the other in specimen 1 and 2 provided that the saturated strain level is considered as well.
Furthermore, the use of a transparency to reduce the dynamic range introduces a practical difficulty for the method, since the transparencies were found to detach from the specimen during the fatigue tests. The images are altered in the same way as when delaminations are observed, and ACC is limited from counting cracks in delaminated zones as mentioned in [8]. Therefore, it is essential to come up with an other method of attaching the transparency to the specimens to facilitate crack counting both inside and outside of stitching areas, while no delamination occurs to interfere with the ACC. The lacquer turned out to be insufficient for attaching the transparency to the specimens, therefore other adhesives are considered. At the moment, the most promising is super glue.

5. Conclusion

The particular stitching thread used in the tested fiber mats makes crack detection difficult since the intensity difference observed using the transmitted light technique is greater than the dynamic range of the camera system. A method to circumvent this problem has been developed using a transparency and a negative image. The transparency proved to reduce the intensity difference and made it possible to detect cracks otherwise hidden by the stitching thread. However, the transparency was found to peel of during testing and preventing crack counting in these areas. Therefore, another glue type and improved surface preparation is being explored as possible options for reducing the risk of peeling of.

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