EFFECT OF SPECIMEN WIDTH ON STRENGTH IN OFF-AXIS COMPRESSION TESTS

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Abstract

Compression tests have been performed according to ASTM D6641 to check whether 12 mm is a sufficient width for off-axis tests of a unidirectional Non Crimp Fabric (NCF) reinforced carbon-fibre composite. Various off-axis angles are tested in a larger context and it is important to establish a representative material volume. The test matrix consists of two different widths for two off-axis cases, 15° and 20° with a total sample size of 24. A two-sample T-test is performed for each off-axis angle to check if there is a statistically significant difference of the compressive strength between specimens with different widths. The null hypothesis, that there is no difference between the mean values is tested with a double-tailed test on a 5 % significance level. Neither of the cases may be rejected, i.e. there is no statistically significant difference on the 5 % level. The 15° off-axis case returns a p-value of 7.4 % and the 20° off-axis case gives a p-value of 21.3 %. It can be concluded that the effect is small and not statistically significant. It means that remaining off-axis testing in the larger context can proceed with the nominal width of 12 mm.

1. Introduction

Carbon fibre/Epoxy composites reinforced with Non-Crimp Fabric (NCF) textiles offer potential cost savings over tape based prepreg materials, with good mechanical properties - close to that of prepreg type composites. For this reason, NCF-reinforced composites provide an interesting alternative to prepregs for the aerospace industry. One limiting factor for their use in primary structures is their relatively low strength in compression [1]. The overall goal of this research project is to further understand the compressive behaviour of NCF composites and to develop a strength assessment method for the aerospace industry.

A comprehensive test series based on ASTM D6641-14 [2] is performed to investigate the effect of material variations, e.g. laminate thickness and fibre volume fraction, on the compressive strength. This is done with the intention to build a database for further statistical treatments and model development. The strength is tested in compression in the fibre direction (0°) and combined shear/compression by off-axis loadings (5°, 10°, 15°, 20°). The off-axis loading is outside the scope of the standard test [2] and may need some special consideration. Increasing the angle with a constant specimen-width impose a potential problem depicted in Fig. 1. As the off-axis angle is increased, the number of fibres directly loaded in compression is reduced, i.e. fibres attached at both ends. Regions with shear as a longitudinal load-transferring mechanism develop next to fibres which are only clamped on one side and protrude on a free surface. The nominal width for the specimens according to ASTM D6641-14 is 12 mm. This study aims to conclude whether this width is sufficient for this type of textile reinforced composite loaded in off-axis compression.

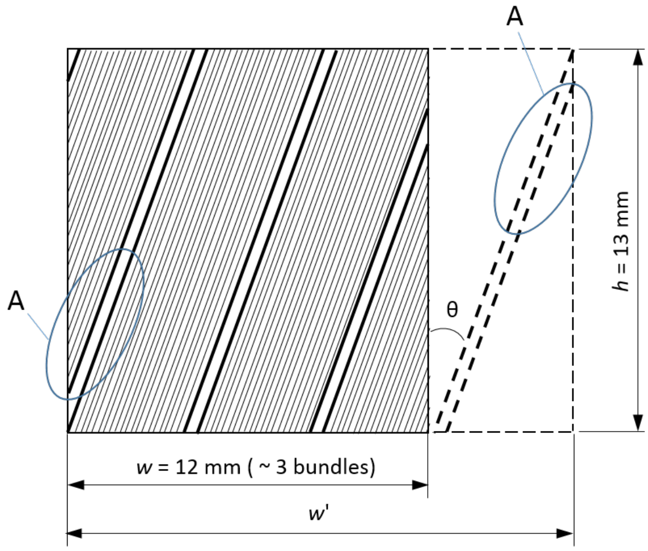

Figure 1. Nominal dimensions of the gauge section with the suggested width increase.

There has been no work found in the literature which address this problem. The closest related study is by Salvi et. al [3] whom investigated the elasto-plastic response for a similar unidirectional tow composite loaded in compression. Two lengths were considered for a 15 degree off-axis case, 38.1 mm and 209.6 mm. Two different failure mechanisms could be observed for these widths. The shorter specimen failing by kinking and the longer by splitting. The current study will instead focus on changing the width and with more moderate alterations to fit standard test fixtures.

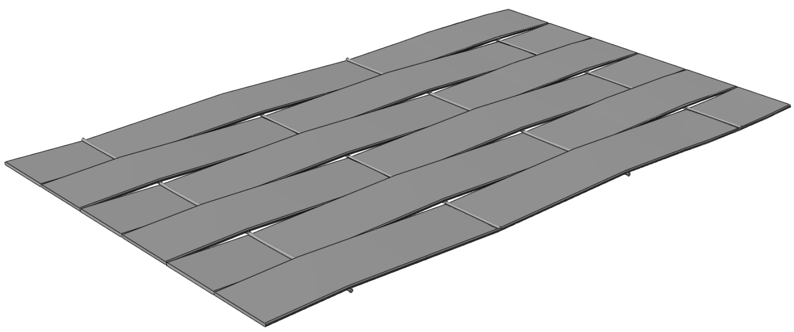

Figure 2. Illustration of the meso-architecture for a ply.

2. Experiments

2.1. Material and specimens

The NCF reinforcement used in this study consists of unidirectional fibre tows (12k) from Tenax HTS45 fibres in the warp direction which are held in place by poly-amide/glass yarns in the weft direction. The plies, depicted in Fig. 2 are stacked with the same fibre orientation to form unidirectional carbon fibre tow composites by the Resin Transfer Moulding (RTM) process. Infusion is done with LY556 epoxy resin. Two different off-axis angles where selected for the study, 15° and 20°. The plates were tabbed with 1.6 mm glass/epoxy laminates on both sides and then cut with water jet according to Table 1. Specimens from the first case are shown in Fig. 3. The gauge section is 13 mm long and the thickness is 2 mm for all the specimens. The number of tested specimens for the nominal width 12 mm is 7 with 2 specimens being tested according to ASTM 3410 [4]. Both test-methods should normally result in similar outcome [5] and is thus having a low contribution to the variance.

Table 1. Testplan for the study.

Off-axis angle (Degrees)	Width (mm)	Number of specimens
15	12	7
15	15.5	5
20	12	7
20	16.7	5

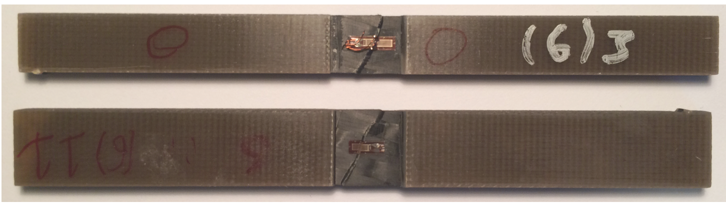

Figure 3. Fractured specimens with 15° off-axis angle in two widths, 12 mm and 15.5 mm.

The suggested width increase is based on the height of the gauge-section and off-axis angle as depicted in Fig. 1. The nominal width w of 12 mm is modified to become $w' = w + h{\cdot}\tan(\theta)$ and the reasoning behind this is simply to have a structured way of altering the width.

2.2. Test setup

Compressive testing is carried out according to ASTM D6641-14 [2] but deviates on one major point. The specimens should according to the standard be symmetric and balanced and these off-axis specimens are naturally not balanced. The specimens are compressed in a Combined Loading Compression (CLC) fixture where load is introduced to the specimen both by shear due to frictional forces from clamping and from end-loading. The in-house made fixture seen in Fig. 4 has been verified for alignment by testing of an aluminium specimen with back-to-back strain measurement.

The specimens are loaded in compression at a rate of 1.3 mm /min with displacement control until failure occurs. The load at failure is easily detected with a sudden drop in applied load. Strain is measured with

5 mm strain gauges for all specimens and on both sides to quantify bending during the test.

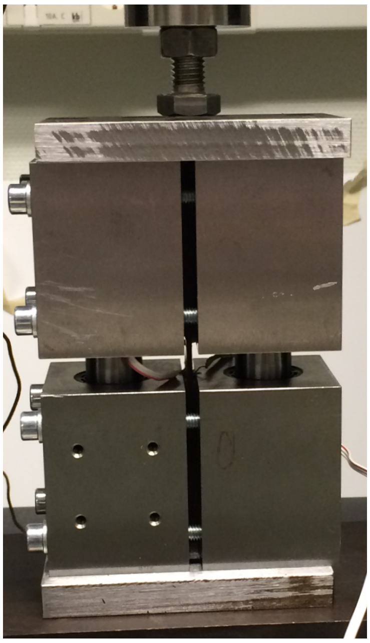

Figure 4. The Combined Loading Compression (CLC) fixture.

3. Results

The main results are presented in Table 2 where $\overline{X_c}$ is the mean compressive strength, B_y is the percent bending at failure, S is the sample standard deviation and n is the number of samples for each specimen type. All tested specimens fail by kinking and the 15° cases have a kink of the laminate out-of-plane visible to the naked eye. The fracture in-plane spreads across the specimen in a direction normal to the fibres. There is no splitting observed for any of the specimens. These results comply with the short specimens from Salvi et. al [3] and the study by [6] to support the fact of kinking for such high off-axis angles.

A two-sample t-test is performed for each off-axis angle to check if there is a statistically significant difference of the compressive strength between the widths. We assume that the samples are equally distributed with equal variance in the two cases and test the null hypothesis with a double-tailed test on a 5 % significance level. The null hypothesis in this case being that both widths have the same mean value of the compressive strength. The test shows that neither of the cases may be rejected, i.e. there is no statistically significant difference between the widths on the 5 % level. The 15° off-axis case returns a p-value of 7.4 % and the 20° off-axis case gives a p-value of 21.3 %.

4. Discussion

Test results with higher bending than 10 % at failure should be disregarded according to the standard [2] but are still included in this study. The first motivation is a low correlation between measured bending and compressive strength, which is observed in this study and by others [5]. The second motivation is that these samples were produced with higher than normal out-of-plane waviness which is believed to be the main reason for the measured bending. The high bending is thus an artefact for a material that still is of great interest to test. It can be argued whether the strain measurement has been appropriate considering the fluctuating strain field for this type of composite [7].

Table 2. Results from compressive testing.

Specimen θ°	w (mm)	$\overline{X_c}$ (MPa)	S (MPa)	n ($\mathbb{N}$)	B_y (%)
15	12	286.1	13.7	7	1.1, 4.7, 7.4, 8.0, 14.0, 21.2, 27.9
15	15.5	308.0	24.2	5	9.2, 15.3, 17.9, 29.7, 33.0
20	12	256.0	7.5	7	0.7, 3.5, 4.3, 5.6, 10.8, 17.4, 14.7
20	16.7	262.6	9.9	5	3.1, 3.6, 5.8, 8.0, 11.4

The variance for the tests should be considered as acceptable, but still, the t-tests could not prove statistically significant differences on the 5 % level in any of the cases. A p-value of 7.4 % for the 15° case is however not that far off. If the same tests are re-done but with a single-tailed test to check whether the wide specimens have a higher strength than the narrow ones, then the the 15° case obtains a p-value of 3.7 % and the 20° case reach a value of 10.6 %. From the results, we can not say if there is an effect on the off-axis compressive strength from the width change.

A Finite Element model was used to check the stress state for these four different cases for better understanding. The local compressive stress is higher for the fibres attached at both ends as expected. The in-plane shear stresses are highest in the region indicated as 'A' in Fig.1. But the important fact is that the stress distribution is very similar between the widths. This could explain the similar failure modes and low impact on strength of a width increase.

5. Conclusions

A study has been made to check whether 12 mm is a sufficient width for off-axis tests of a UD NCF reinforced composite in compression. It can be concluded that the effect is small and not statistically significant on the 5 % confidence level. It means that remaining off-axis testing in the larger context can proceed with the nominal width of 12 mm. The fluctuating strain field is problematic for strain measurement of a textile and this will be dealt with in a more suitable way for future testing.

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