STUDY OF THE USABILITY OF VARIOUS CRUCIFORM GEOMETRIES FOR BIAXIAL TESTING OF FIBER REINFORCED COMPOSITES

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Summary To investigate the behaviour of fibre reinforced composites as much as possible approximating real life, a biaxially loaded planar cruciform specimen was developed by performing finite element simulations in combination with experiments on different geometries of cruciform specimens.

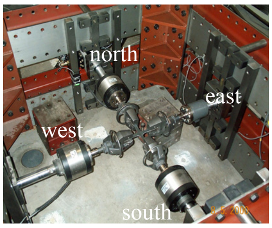
INTRODUCTION

Experimental investigation of fibre reinforced composites was predominantly performed using uniaxially loaded specimens. However, in real applications fibre reinforced composites are hardly ever loaded in one direction. Consequently, experimental investigation of these materials should approximate real life behaviour as much as possible. In an attempt to achieve this goal biaxial tests can be considered [1]. However, these tests are using mainly tubular specimens subjected to torsion in combination with tension or compression [2, 3]. Unfortunately, these highly curved tubular specimens behave different from most fibre reinforced composite components which are often flat or gently curved [4]. For this reason a biaxial testing facility for planar cruciform test specimens was developed at the department of Mechanics of Materials and Constructions of the Free University of Brussels (Figure 1). The design of a suitable cruciform specimen is the subject of this paper.

BIAXIAL TEST BENCH AND CRUCIFORM SPECIMEN REQUIREMENTS

The planar biaxial test bench has a loading capacity of 100kN. In order to fix the central point of the specimen during testing, the force P has to be equal and co-linear to P', F equal and co-linear to F' and the forces P & P' need to be perpendicular to F & F' (Figure 2). To fulfil these requirements four servo-hydraulic cylinders were used. As no cylinders with hydrostatic bearings were used, the test frame is limited to tensile loading. Failure or slip in one arm of the specimen would result in sudden radial forces, which could seriously damage the servo-hydraulic cylinders and load cells. To prevent this, hinges were used to connect the specimen to the cylinders and the cylinders to the test frame.

Figure 1: Biaxial test bench for flat cruciform specimens



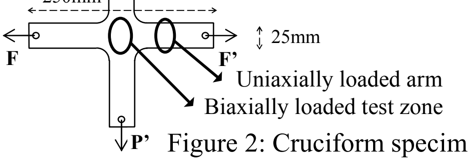


Figure 2: Cruciform specimen

A valid biaxial test avoids premature failure in the uniaxially loaded arms, gives a large region of uniform strain in the biaxially loaded test zone and avoids strain concentrations at the intersection of two perpendicular arms. These conditions are not easily obtained simultaneously. To investigate the influence of parameters like (i) the rounding radius at the intersection of two arms, (ii) the thickness of the biaxial loaded test zone in relation to the thickness of the arms and (iii) the geometry of the test zone on the above mentioned requirements, finite element simulations were performed. Afterwards, these numerical results were compared with experimental results obtained from biaxial tests on selected cruciform geometries.

FINITE ELEMENT SIMULATIONS OF CRUCIFORM GEOMETRIES

Figure 4 shows the finite element results of the first principal strains for three different geometries A, B and C. Due to symmetry, only one quarter is shown. The load ratio between the directions x and y was chosen equal to the strength ratio of both arms (i.e. 3.85/1). The material tested was glass fibre reinforced epoxy with a $[(+45° -45° 0°)_4(+45°-45°)]$-lay-up (zone $\boxed{2}$ on Figure 4 with lay-up $\boxed{2}$ on Figure 3). In the middle of the specimens one layer of (0° +45° -45°) was milled away at each side of the specimen resulting in a$[(45° -45° 0°)_2(+45°-45°)]$-lay-up (zone $\boxed{3}$) for geometries B and C. End-taps were glued on the specimens (zone $\boxed{1}$). The applied load was $F_x/F_y = 46.2kN/12kN$.

For geometry A, strains in the x-direction just after the end taps are higher than in the end-taps, but are less in the direction to the centre of the specimen. This is due to the enlargement of the area taking the load in this region. Consequently, failure of the specimen will occur close to the end taps. In order to increase the strains and the possibility to cause failure in the biaxial loaded zone, a reduction of thickness and/or changing the rounding radius is necessary. In geometry B the first suggestion is shown. The strain results are improved and for this kind of geometry failure can occur at the middle of the specimen. If we use a combination of both suggestions, as shown in geometry C, even higher strains are obtained in the biaxial loaded zone.

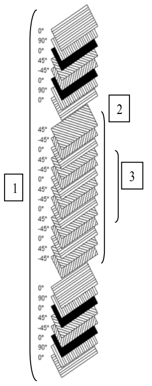


Figure 3: Lay-up of specimens.

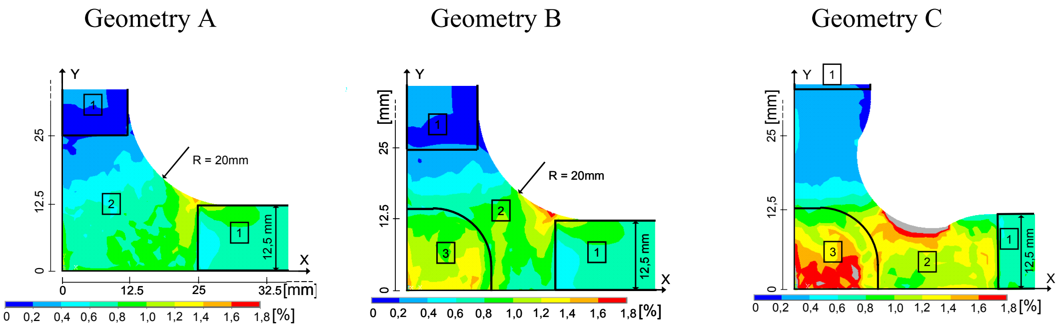


Figure 4: Finite element results for three cruciform geometries. First principal strains are shown.

TENSION TESTS ON CRUCIFORM GEOMETRIES

The experimental results for the three tested geometries A, B and C are shown in Table 1. Each value is an average of at least three experiments. Strain measurements are obtained in x- and y- direction by using strain gauges glued in the centre of each specimen. The failure loads and failure strains are measured in both directions. The failure stresses were calculated using the experimentally obtained failure strains and the stiffness moduli and Poisson's ratios from uniaxially loaded specimens. The highest failure strains are obtained for geometry C, indicating this geometry is the most promising one. For geometry A, failure of the specimen didn't occur in the biaxial loaded test zone, in contrast to geometries B and C (Figure 5). These results confirm the results of the finite element simulations. The high strains at the rounding between the two arms in geometry C do not cause early failure of the specimen as can be seen in the experimental results.

	[kN]		[%]		[MPa]	
	F_x	F_y	ε_x	ε_y	σ_x	σ_y
geometry A	63,2	16,5	1,35	-0,56	395	14
geometry B	60,5	15,8	1,52	-0,66	442	13
geometry C	47,9	12,4	1,68	-0,79	516	56

Table 1: Experimental results on three cruciform geometries.

Figure 5: Failure of cruciform specimen geometry C at 48.2kN. Failure occurs in the biaxial loaded zone.

CONCLUSIONS

The performed finite element simulations in combination with the experiments on three different geometries of cruciform specimens, led to the selection of a suitable geometry for biaxial testing of composite materials. This geometry has a reduced thickness in the central region of the specimen in combination with a rounding radius between two arms inside the material. In that way failure occurs in the biaxially loaded test zone.

References

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