RELIABLE OPTIMAL USE OF MATERIALS FOR WIND TURBINE ROTOR BLADES

OPTIMAT BLADES
(ENK6-CT-2001-00552)

Proposal for UD coupon tests

TASK GROUP 2: Investigation of blade material behavior under complex stress states

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Introduction

In the frame of TG2 & 5, three different series of coupon tests on UD reference material are foreseen, as delineated in the attached file `OB_TG2_001_UP.pdf`. Each series, in turn, comprises a number of tensile, compressive tests in the fiber direction and transversely to it, as well as tensile tests of [±45] coupons for characterizing in-plane shear modulus and shear strength respectively.

The test series BT1, BT2 and BT3 refer to static, CA fatigue and residual strength tests respectively. As it is well known, test coupon geometry, at least for the two first series, varies in a wide range, depending on load direction, type of loading etc. A compilation of applicable international standards for these types of tests, previously followed more or less in our experimental studies, is presented in the appendix. **(TGL's and any other interested partner are kindly asked to review this compilation and correct or supplement omissions)**

There are several contradicting issues in UD coupon geometry (this is also the case for the multidirectional laminated specimens also), especially with concern to TG2 & TG5 aims:

1. Residual strength tests are in essence CA fatigue tests followed after a predetermined number of cycles by static tests, either tension or compression, to failure. However, as it can be seen in the table of the appendix, fatigue coupon tests have different geometry from those used in static tests, especially in combinations such as e.g. CA fatigue @ R=10 and then residual strength test in tension, or CA fatigue @ R=0.1 and then residual strength test in compression. The fact that residual strength test results must be compared and eventually correlated with static test results complicates even more the situation
2. In TG5, residual strength test coupons loaded in CA fatigue containing compression must be of reduced gauge length, to avoid buckling, while they should leave enough space for NDT sensor mounting (which is hampered by the use of antibuckling jigs)

The above hold also true for the case of laminated coupons with different fiber orientation in each ply, i.e. multidirectional lay-up. Again, static and fatigue test coupons are usually of different geometry and it is exactly the residual strength tests series that creates the contradiction, in parallel with the need for NDT sensor placement.

In the past 5-6 years, our group was involved in a research study for fatigue life evaluation of multidirectional laminates, e.g. $[0_2/\pm45]_S$, loaded under complex stress by using on- and off-axis coupons cut from the plate. Straight edge coupon nominal dimensions were 250 x 25 x 2.7 mm with aluminum tabs, 2 mm thick and 45 mm in length, leaving a gauge length of 160 mm. In cases where the load program was containing compressive cycles, the antibuckling jig shown below was used. However, although the performance of this arrangement was deemed satisfactory for fatigue testing, it cannot be used for static compressive tests, or residual strength tests, nor it can accommodate NDT sensors due to the antibuckling jig.

Conclusions

Manufacturing of test coupons according to relevant standards will create problems in comparing strength results from ordinary static tests and residual strength tests, in one hand, and will increase the burden on the preparation of these coupons since several plates of different thickness will be necessary, coupons of different dimensions etc. Further, it is still an issue to decide specimen geometry for cases where no known test standard is applicable.

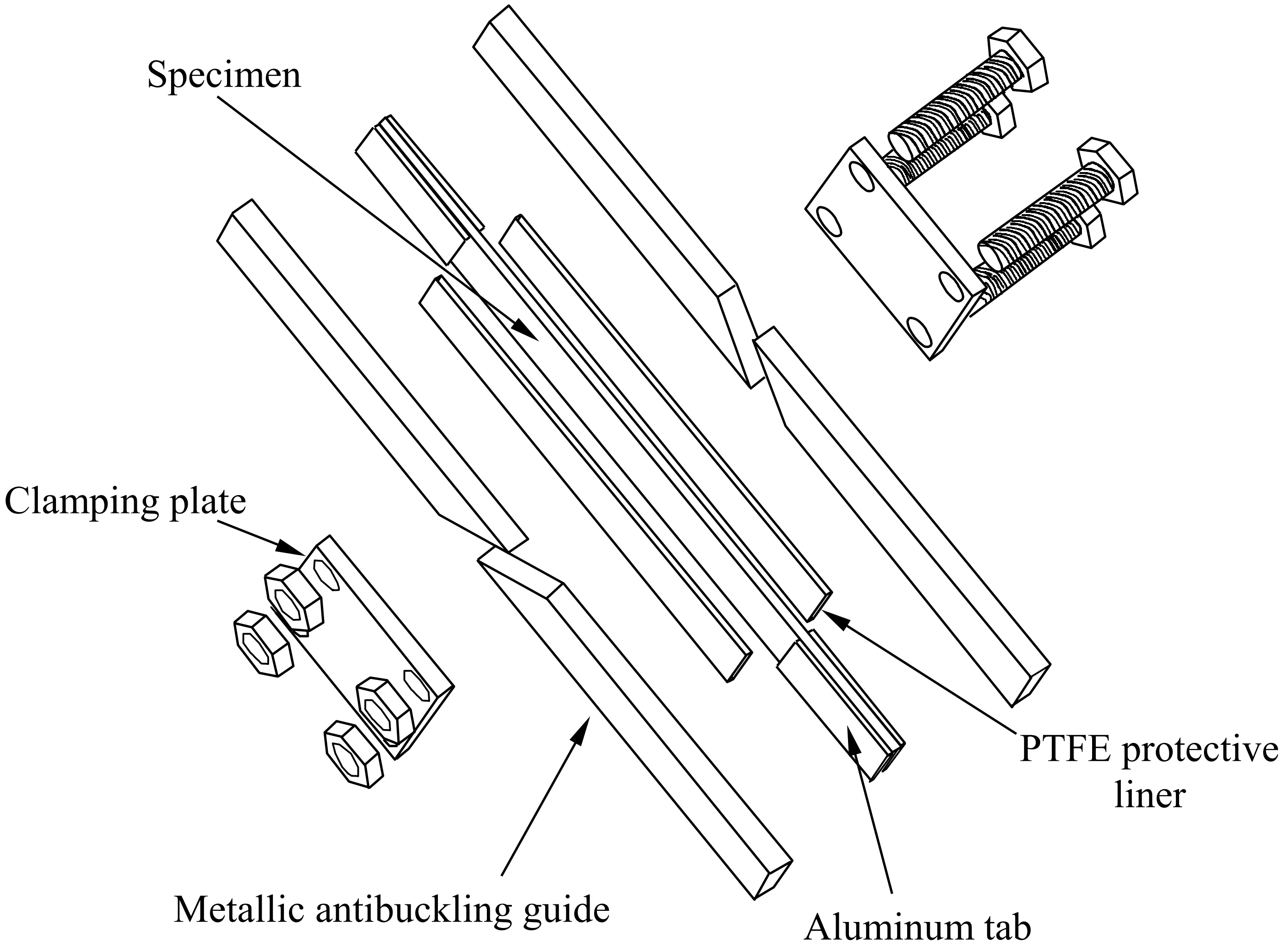

Fig.1 Test coupon and antibuckling jig used in University of Patras for MD-laminates

The idea of a single specimen geometry for all test series BT1, BT2 and BT3 seems attractive for its simplicity and obviously for the ease it offers in comparing test results, failure modes etc. In addition, the same geometry could be used for the verification test coupons, i.e. those with a multidirectional lay-up.

Christoph has recently indicated[1] to me the successful use of a relatively short specimen, straight edge L x w x t = 160 x 25 x 3 mm, tabs made of fiberglass, 60 mm long and 1.5 mm thick, leaving a gauge length of 40 mm (unsupported). Of course, the thickness to avoid buckling in case of compressive cycles is a function of material stiffness. The aforementioned coupons were used for fatigue, R=-1 as well as for static compressive strength measurements. We have also used in the past a similar

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[1] Ch.W. Kensche, P. A. Joosse, “Mechanical Properties of Panex/Epoxy”, LCB-DLR-70 (22.03.2002)

geometry with 30 mm unsupported gauge length at a thickness of 3 mm approximately for static compressive tests of GRP MD coupons with fair results.

I therefore propose to use the following four different coupon geometries (straight edge):

1. In the fiber direction, [0]: 160 x 15 x 6 mm, tabs made of [±45] glass/epoxy, 1.5-2 mm thick, 60 mm long, leaving 40 mm of gauge length
2. Transverse to the fiber, [90]: 160 x 25 x 8 mm, tabs made of [±45] glass/epoxy, 1.5-2 mm thick, 60 mm long, leaving 40 mm of gauge length
3. Keep the geometry and stacking sequence of [±45] coupons for shear properties as shown in the table of the appendix
4. For MD laminated coupons, e.g. [0/±45]: 160 x 25 x 8 mm, tabs made of [±45] glass/epoxy, 1.5-2 mm thick, 60 mm long, leaving 40 mm of gauge length

Coupons from 1, 2 and 4 will be used in all three test series, BT1, BT2, BT3, tension and compression (unsupported), while [±45] coupons will be subjected only to tensile loads in each test series.

The gauge length of 40 mm is marginal to allow NDT sensor mounting and resist buckling at the proposed thickness. However, this must be verified with preliminary static tests, at least.

Appendix

Test coupon geometry for UD Glass Fiber Reinforced Plastics

	Test code name	Description	Applicable standards	L x w x t in (mm)	Tab specification	Comment
1	**BT1_AT**	Static tension (∥)	ISO 527-5 (1997), type A	250 x 15 x 1	Tab 1	
2	**BT1_AC**	Static compression (∥)	ISO 14126 (1999), type B1	110 x 10 x 3	Tab 1	
3	**BT1_BT**	Static tension (⊥)	ISO 527-5 (1997), type B	250 x 25 x 2	Tab 1	
4	**BT1_BC**	Static compression (⊥)	ISO 14126 (1999), type B2	125 x 25 x 5	Tab 1	
5	**BT1_S**	Static In-plane shear	ASTM D3518M-94 ISO 14129 (1997)	250 x 25 x **	Tab 1	** = $[45/-45]_{4S}$
6	**BT2_AT**	CA fatigue, T-T, (∥)	ASTM D3479-76	250 x 12.7 x 1	Tab 2	Geometry according to ASTM D3039
7	**BT2_AC**	CA fatigue, T-C or C-C, (∥)				
8	**BT2_BT**	CA fatigue, T-T, (⊥)	ASTM D3479-76	250 x 25.4 x 2	Tab 2	Geometry according to ASTM D3039
9	**BT2_BC**	CA fatigue, T-C or C-C, (⊥)				
10	**BT2_S**	CA fatigue, in-plane shear				
11	**BT3_AT**	Residual tensile strength (∥)				After CA fatigue in T-T, T-C, C-C
12	**BT3_AC**	Residual compressive strength (∥)				After CA fatigue in T-T, T-C, C-C
13	**BT3_BT**	Residual tensile strength (⊥)				After CA fatigue in T-T, T-C, C-C
14	**BT3_BC**	Residual compressive strength (⊥)				After CA fatigue in T-T, T-C, C-C
15	**BT3_S**	Residual shear strength				After CA fatigue in T-T

Notes

1. Length x width x thickness = L x w x t
2. Tab 1 = GFRP [±45], L ≥ 50 mm, t ≤ 2 mm, not tapered
3. Tab 2 = GFRP [±45], L ≥ 38 mm, t = 1.5 to 4 times the thickness of the test composite, tapered at an angle ≥ 5°
4. T-T = Tension-Tension
5. T-C = Tension - Compression
6. C-C = Compression - Compression
7. All specimens are straight edge