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Microstructure and Deformation Properties of CFRP – UD Tubes, an Acoustic Emission Study

Final Report

AKTION project no. 56p3
1. 1. 2010 – 31. 12. 2010

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1. Overview and Results

The project was focused on the study of deformation behaviour of unidirectional carbon fibre reinforced plastic (CFRP – UD) tubes produced by pultrusion (endless fibres pulled through a two-component liquid matrix, continuously cured in a long furnace) with the help of the acoustic emission (AE) technique.

The CFRP is a very strong, light, and expensive fibre-reinforced polymer, which has many applications in aerospace and automotive fields, as well as in sailboats, and notably in modern bicycles and motorcycles, where its high strength-to-weight ratio is of importance.
AE stems from transient elastic waves, which are generated within deformed material due to sudden localized structure changes. AE is also a non-destructive *in situ* method, which offers integral information about the evolution of the dynamic state of the material.

All experimental procedures, described in project proposal, were performed. Additional to the proposed tests on tubes, bending tests were carried out on CFRP unidirectional laminates in order to gain a better understanding of the fibre-matrix interaction with respect to the deformation response of a material under flexural load. Correlation of AE signals (parameterized according to their amplitude, energy, etc.) with the degree of deformation indicates the progress of the delamination, crack formation and fibre fracture.

Tab. 1: Geometries, components and manufacturing processes of studied UD-CFRP materials

CFRP	Fibres	Fibre vol. fraction	Matix	Produced	Dimensions	Porosity
Laminates (L_0)	HS AS4	66%	Epoxy	Hot Press	b=15mm,h=2mm	2.7%
Laminates (L_1)	HS AS4	66%	Epoxy	Hot Press	b=15mm,h=2mm	1.1%
Tubes (T_0)	Tenax STS	65%	Epoxy	Pultrusion	$Ø_o$=10mm,$Ø_i$=8mm	<1%

Briefly explanation our experiments will be done on a CFRP tube during torsion test (see Fig.1, where the AE count rate – time *vs.* torque – twist angle dependence is given by applied twist speed). CFRP tubes were twisted clockwise with a rotational speed of about 6°/min, a piezoelectric sensor was placed on the sample to detect AE response. Three different zones are observed, for which the intensity of the AE activity is connected with successive degradation processes within the material. Low AE activity represents a fibre-matrix debonding in the material. Very high AE activity in later stage of deformation (angle about 40°) is due to crack propagation followed by fibre fracture and specimen failure. To verify this statement it was necessary to analyze the sample before and after mechanical testing by means of both light and scanning electron microscopy (see Fig.2). Another very helpful tool for three-dimensional characterisation is computed X-ray tomography (see Fig.3).

These three different stages of the AE activity (till first AE signals, low and AE activity) were observed in all twisted UD-CFRP samples and were related to the degradation process occurring in the material, which afterwards was confirmed with the above mentioned materialographical techniques (LOM, SEM and XCT).

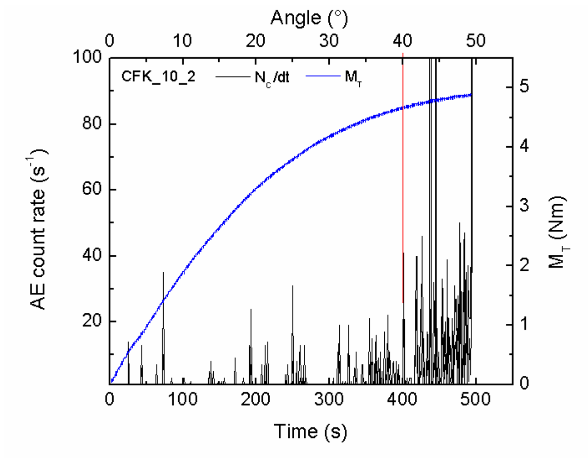

Fig. 2: Count rate / Torque vs. Time / Angle diagram for a torsion tested UD-tube (T_0_2).

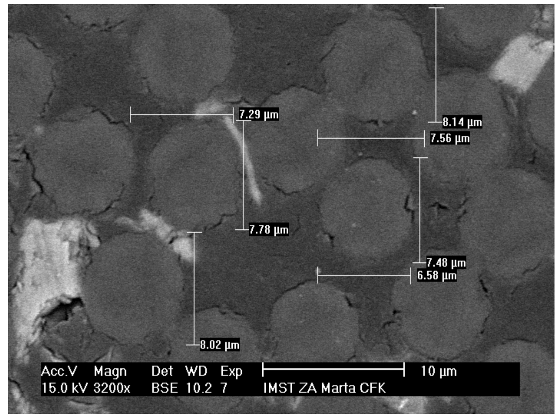

Fig. 1: SEM micrograph of a UD-CFRP tube after mechanical testing showing micro cracks.

In a similar way, bending tests were also performed to study the mechanical response of the UD-CFRP laminates. These tests were made in the fibre direction (0°) and perpendicular to it (90°).

Mechanical characterisation of the samples:
Torsion: using the recorded values of torque and angle of twist, a shear stress-strain curve is plotted taking into account the geometry of the specimens and the gauge length (the slope on the elastic range gives out the shear modulus G; the ultimate torsional shearing strength or modulus of rupture τ_u was also calculated using $M_{T\,max}$)
Bending: deflection and force values recorded during the test are converted into flexural strain-stress curves taking the geometry of the samples and the span lengths into account (the slope on the elastic range gives out the bending modulus E_b)

Tab. 2: Bending: flexural properties for both laminate types. Torsion: shear properties of the tubes with and without hysteresis cycles.

4-point-Bending				Torsion					
Laminates	E_b (GPa)	σ_b (MPa)	ε_b (%)	Tubes	Cycl.	G (GPa)	τ_u (MPa)	$M_{T\,max}$ (Nm)	θ_{max}
L_0 0°	124	1592	1.5	T_0_2	No	2.4	38.0	4.9	49.9°
L_1 0°	134	1956	1.9	T_0_5	x3	3.3 - 3.1 - 2.9	interrupted		→25°
L_1 90°	10	96	0.9	T_0_6	x4	3.4 - 2.9 - 2.7 - 2.6	interrupted		→35°

For all the studied UD-CFRP tubes tested in torsion with load-unload cycles, it was observed an increase of the AE activity coupled with a decrease of the shear modulus (G) on the stress-strain diagram. This behaviour was not observed in the case of the laminates, for which the E_b values remained constant after repeated load-unload cycling.

Obtained results can be used for an improvement of the composites manufacturing technology and for modelling of deformation processes in CFRP materials.

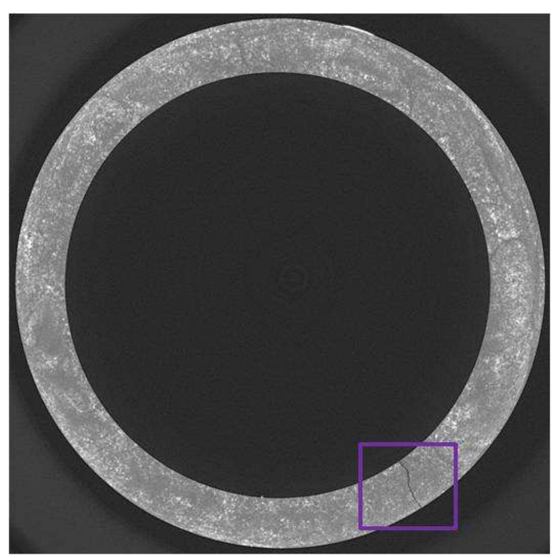

Fig. 3: CT slice of a CFRP tube after torsion test showing crack formed during failure.

Part of our results was presented on:
5th Seminar for PhD students - Research in progress on metallic materials at
Institute for Materials Science and Welding Graz University of Technology,
Graz (Austria), November 8 – 9, 2010

Speaker: Mag.rer.nat. Marta Rodríguez-Hortalá
Acoustic emission signals produced during deformation of carbon fibre reinforced polymers (CFRP)

2. Visits

Mag.rer.nat. Marta Rodriguez-Hortalá

Stays in Prague:
17. 05. – 20. 05. 2010

09. 08. – 16. 08. 2010

10. 11. – 14. 11. 2010

03. 12. – 04. 12. 2010

Ing. Patrik Dobroň, Ph.D.

Stays in Vienna:
12. 04. – 16. 04. 2010

19. 07. – 28. 07. 2010

07. 11. – 10. 11. 2010

30. 11. – 01. 12. 2010

3. The financial statement

The overview of the costs in CZK, spent in 2010 and reprinted from the economical department of Faculty of Mathematics and Physics at Charles University Prague, is shown in the Appendix.

We would like to thank AKTION for the financial support to our project and also for giving us the possibility to deepen the cooperation between Department of Physics of Materials and Institute of Materials Science and Technology.

Ing. Patrik Dobroň, Ph.D. and Mag.rer.nat. Marta Rodríguez-Hortalá

Prague, January 12, 2011