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CHARACTERIZATION OF A FILAMENT WOUND THIN-PLY COMPOSITE FOR A CRYOGENIC TANK FOR LIQUID HYDROGEN

R. Olsson[1], E. Marklund[1], M. Merzkirch[1] and D. Ramantani[2]

RISE Research Institutes of Sweden
[1]Department of Polymers, Fibres and Composites, Box 104, SE-431 22 Mölndal, Sweden
[1]Email: robin.olsson@ri.se, erik.marklund@ri.se, matthias.merzkirch@ri.se
[2]Department of Polymers, Fibres and Composites, Box 271, SE-941 26 Piteå, Sweden
[2]Email: dimitra.ramantani@ri.se
web page: www.ri.se

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ABSTRACT

This paper reviews efforts to characterise the properties of a thin ply composite material for wet winding, Figure 1a, for a linerless tank for storage of liquid hydrogen. The tank is manufactured and tested within the Swedish project "LH2-Tanks" and consists of a cylindrical composite section manufactured by filament winding and two hemispherical end caps in titanium, Figure 1b. The current work is based on our participation in a previous European project on cryogenic composite tanks for a reusable space launcher [1] and previous studies of thin-ply composite materials [2].

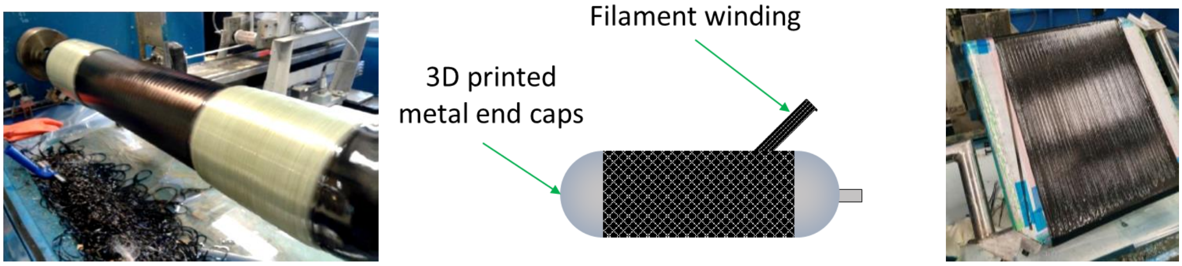

Figure 1: Wet winding of a tank cylinder, a) Overall design of the tank, c) winding of a UD laminate.

Specimens have been manufactured by wet winding of nominally unidirectional laminates on a flat aluminium mandrel, Figure 1c. The material consists of unidirectional (UD) TeXtreme thin-ply bands of carbon fibre with a semi-cured epoxy binder and wet-impregnated by a special epoxy suited for cryogenic applications. Specific challenges include that the filament winding results in a layup of about ±1° for the nominally unidirectional specimens, and that the fibre volume fraction becomes different than for the material in the cylindrical tank walls, which are wound in a $\pm\theta$ layup with a much larger fibre angle. For these reasons, values for the UD material must be recalculated and adjusted before they can be used in design of the tank. The procedure for these calculations will be described.

For this relatively small tank (305 mm diameter), intended to operate at −253°C (20 K), the thermal stresses are significantly larger than the mechanical stresses caused by the internal pressure (<10 bar). For this reason, a specific focus has been on the coefficient of thermal expansion (CTE) and its variation with temperature from curing down to the use temperature. Furthermore, relevant stiffness and strengths have been determined both at room temperature (RT) and at cryogenic temperatures of −253°C or −150°C, Table 1.

Table 1: Overview of tests performed.

Test	Layup	No of tests	Properties determined	Test temp.
Short beam shear[a]	0°	3	ILSS	+22°C, -150°C[b]
Axial tension	0°	5	E_{11}, ν_{12}, X_t	+22°C, -150°C
Transverse tension	90°	5	E_{22}, Y_t	+22°C, -253°C
Off-axis tension	10°	5	XY ($\sigma_2 > 0$)	+22°C, -253°C
Iosipescu	0°	5	XY ($\sigma_2 = 0$)	+22°C
Cross-ply tension	0°/90°	5	In-situ Y_t	+22°C, -150°C
Intralaminar DCB	0°	5	G_{Ic}	+22°C
Intralaminar ENF	0°	5	G_{IIc}	+22°C
CTE		2	$\alpha_1(T)$, $\alpha_2(T)$	-150°C to +100°C

a) Screening test b) Thermal shock at -196°C followed by testing at +22°C

The nonlinear stress-strain response of 10° off-axis specimens at +22°C (RT), which is caused by shear, is virtually non-existent at -253°C (CR) and the failure stress also increases significantly, Figure 2a & 2b. The shear failure strain in the 10° off-axis tests is significantly smaller than in the "pure" shear test (Iosipescu), Figure 2c, due to the superimposed transverse tensile stress.

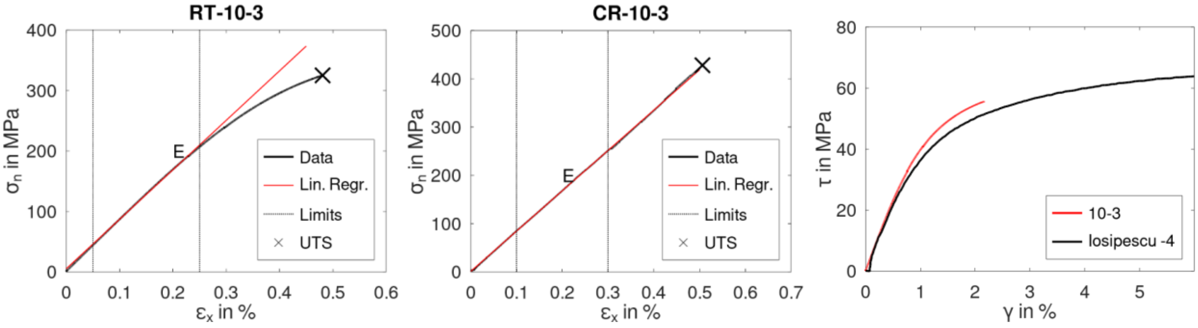

Figure 2: a) σ_x vs ε_x for 10° off-axis at RT, b) σ_x vs ε_x for 10° off-axis at -253C, c) τ_{12} vs γ_{12} at RT

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