

WINDING PATTERN AND NUMBER OF LAYERS EFFECTS ON FILAMENT-WOUND CYLINDERS UNDER AXIAL COMPRESSION

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<u>EAW Menezes¹</u>, TV Lisbôa¹, JH Almeida Jr², A Spickenheuer¹, RJ Marczak³, SC Amico³

Leibniz-Institut f
ür Polymerforschung Dresden e. V., Dresden, Germany
 Aerospace Engineering, Queen's University Belfast, UK
 Federal University of Rio Grande do Sul, UFRGS, Porto Alegre, Brazil





- Filament Winding:
 - \rightarrow High fiber content and low void content;
 - \rightarrow Repeatability;
 - \rightarrow Precision in placing fibers;







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Introduction







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- Material and geometrical propert
- Winding angle α;
- Winding pattern WP;



θ



 $\left[-\alpha/+\alpha\right]$



HCO

height

CCO



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- Material and geometrical properties;
- Winding angle *α*;
- Winding pattern WP;
- Number of layers N: —





• Past researches regarding WP influence:

Author (s)	Load case	Approach	Number of	Pattern	Stiffness	Stress /	(%)
			layers $(+\alpha/-\alpha)$	range		Strength	
Claus (1992)	Buckling (axial compression)	Experimental	-	-	Yes	Yes	-
Hahn et al. (1994)	Buckling (axial compression)	Experimental	1	1-26	No	Yes	-
Rousseau et al. (1999)	Axial tension	Experimental	6	2-11	No	Yes	-
	Internal pressure			2-11	-	No	-
Morozov (2006)	Internal pressure	Numerical	1	2-8	-	Yes	33.40
Moreno et al. (2008)	Buckling (external pressure)	Experimental	7	1-5	-	No	-
Mian et al. (2011)	Internal pressure	Numerical	1	2-8	-	Yes	34.87
Wen et al. (2013)	Axial tension	Experimental	7	1-5	-	Yes	
Azevedo et al.(2019)	Buckling (axial compression)	Experimental	1	1-5	Yes	Yes	
Guo et al. (2020)	Buckling (axial compression)	Numerical	7	4-10	-	Yes	4.21
	Buckling (external pressure)	Numerical	7	4-10	-	Yes	1.15
Lisbôa et al. (2020)	Radial compression	Experimental	1	1-10	No	Yes	
Stabla et al. (2021)	Radial compression	Numerical	1	2-7	Yes	Yes	
Stabla et al. (2022)	Radial compression	Experimental	1	1-3	Yes	-	
Lisboa et al. (2022)	Radial compression	Numerical	1	1-3	-	Yes	

Objective



• To numerically investigate the influence of winding pattern as function of the number of layers and winding angle on the mechanical behavior of FW tubes.



- Definition of geometrical properties:
 - \rightarrow Tow height: 0.25 mm;
 - \rightarrow Cylinder length: 250 mm;
 - \rightarrow Mandrel's diameter: 136 mm;
- Material properties:
 - \rightarrow E_1 = 139900 MPa;
 - \rightarrow E_2 = E_3 = 8520 MPa;
 - $\rightarrow G_{12} = G_{13} = G_{23} = 4260$ MPa;
 - $\rightarrow v_{12} = v_{13} = 0.26.$



- Constructive parameters:
 - $\rightarrow \alpha$ (°): 15, 25, 35, 45, 55, and 65;





• Constructive parameters:



ipf

- Constructive parameters:
 - $\rightarrow \alpha$ (°): 15, 25, 35, 45, 55, and 65;
 - → WPs: 0, 1, 3, 5, and 7;
 - \rightarrow N: 1, 2, 4, and 6;
 - \rightarrow 6 × 5 × 4 = 120 models.







N = 4





- Shell elements (SHELL281):
 - \rightarrow 8 nodes (Serendipity);
 - \rightarrow 6 DOF's;
 - \rightarrow 9 integration points;
 - → Triangular shape;
 - → Mindlin-Reissner theory (moderate thickness);



Ansys, 2021

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- Boolean operations;
- Cylindrical (r, θ, z) and local (1, 2, 3) coordinate systems.





- Boundary conditions:
 - → Right edge clamped;
 - \rightarrow Left edge with free translation;
 - \rightarrow Both edges with free expansion/contraction (u_r);
- Load condition:
 - \rightarrow Axial compression load at reference node;
 - \rightarrow Target stress: 500 MPa.





- Stress measurements:
 - \rightarrow Local coordinates;
 - \rightarrow Evaluated along circumferential direction, every 3°;
 - → 1st location: Center line (CL) Along the circumferential crossover (zig-zag lines), at the coordinate z = 0 mm;
 - \rightarrow 2nd location: Shifted Center Line (SCL) 5 mm offset from CL;
 - → 3rd location: Mid-triangle line (MTL) At the midpoint between two CL's (1/4 of diamond's width);
- Stiffness measurement:
 - Directly from displacement considering the deviation relative to the reference configuration (WP = 0);









• Stress concentrations (N = 1, WP = 7, $\alpha = 35^{\circ}$):





• σ_1 as function of WP (N = 1, α = 35°, bottom layer):





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• σ_2 and τ_{12} as function of *WP* (*N* = 1, α = 35°, bottom layer):



21



• σ_1 as function of N (WP = 5, α = 35°, bottom layer):



22



• Stiffness:





• Stiffness deviation from the reference configuration (*WP* = 0):



25



• σ_1 as function of α (N = 1, WP = 7, bottom layer, MTL):



 $---- 15^{\circ} ---- 25^{\circ} ---- 35^{\circ} ---- 45^{\circ} ---- 55^{\circ} ---- 65^{\circ}$

Conclusions



- Stress concentrations observed in the interweaving regions;
- Away from these regions, stress values of regular laminates are observed;
- Stress concentrations of one layer propagate to all the others;
- Their magnitudes are considerably reduced by adding more layers;
- Axial stiffness is sensitive to the size of the HCO region;
- WP's influence on axial stiffness is negligible for more than 2 layers.

Thank you!







