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Evaluation of the elastic stiffnesses of multi-directional laminates by bending tests

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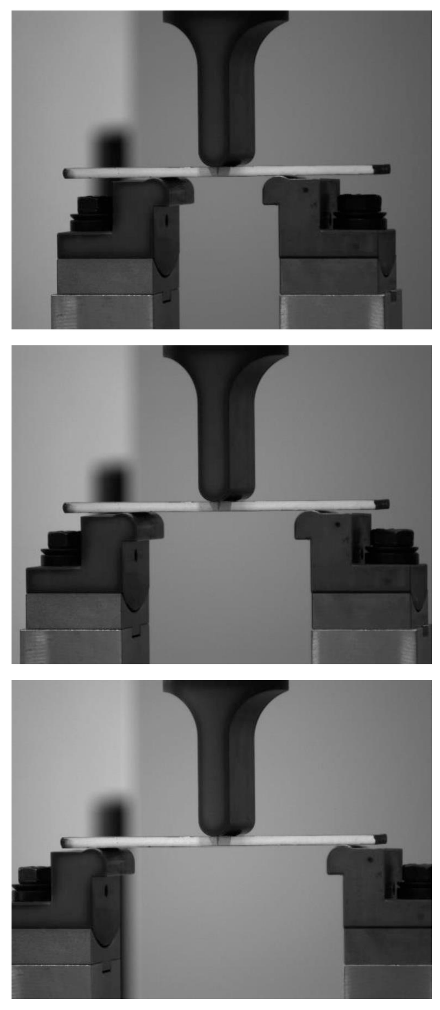
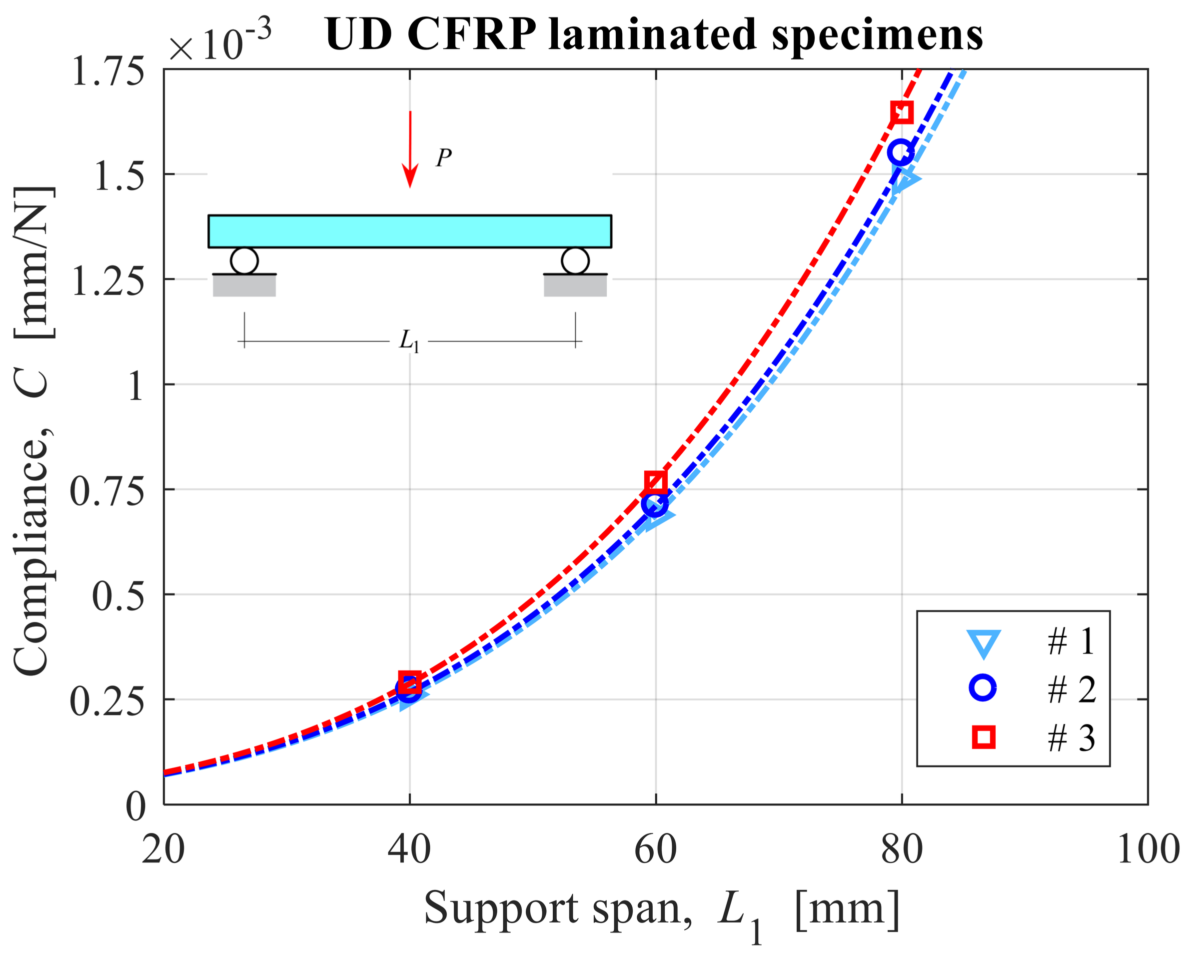
Situations may arise in which the elastic stiffnesses of composite laminates are to be evaluated with a limited quantity of available material. Besides, tensile testing may not be possible due to inadequate geometries of the available samples with respect to the laboratory equipment, etc. In such cases, three-point bending (3PB) or four-point bending (4PB) tests may result as a simple and effective alternative to tensile tests [1]. ASTM D7264 specifies how to evaluate the flexural properties of polymer matrix composite materials by bending tests. In the literature, it has been proposed to evaluate also the shear stiffnesses of unidirectional (UD) laminates by executing an adequate number of non-destructive 3PB tests at different span lengths [2].



3PB tests on UD CFRP laminates



We improve the above procedure and extend it to multidirectional (MD) laminates, whose geometry and stacking sequence are known. By assuming that the specimen behaves as a Timoshenko beam [3], we determine its compliance as

$$C = \frac{\delta}{P} = \frac{L_1 - L_2}{2B} c + \frac{(L_1 - L_2)^2 (L_1 + 2L_2)}{48B} d$$

where B is the width of the specimen, $\boldsymbol{c}$ and $\boldsymbol{d}$ are the bending and shear compliances of the specimen [4], and L_1 and L_2 are the support and load spans, respectively. The given expression holds for both 3PB and 4PB test specimens, provided that a zero value is granted to L_2 in the first ones.

We executed 3PB tests on carbon-epoxy UD specimens for three values of the support span at Musam Lab, IMT [5]. We performed also 4PB tests on glass-polyester MD specimens, used in the strengthening of road bridges [6], at several span lengths, for the same support length, at the Laboratorio Ufficiale per le Esperienze sui Materiali da Costruzione, University of Pisa.

4PB tests on MD GFRP laminates

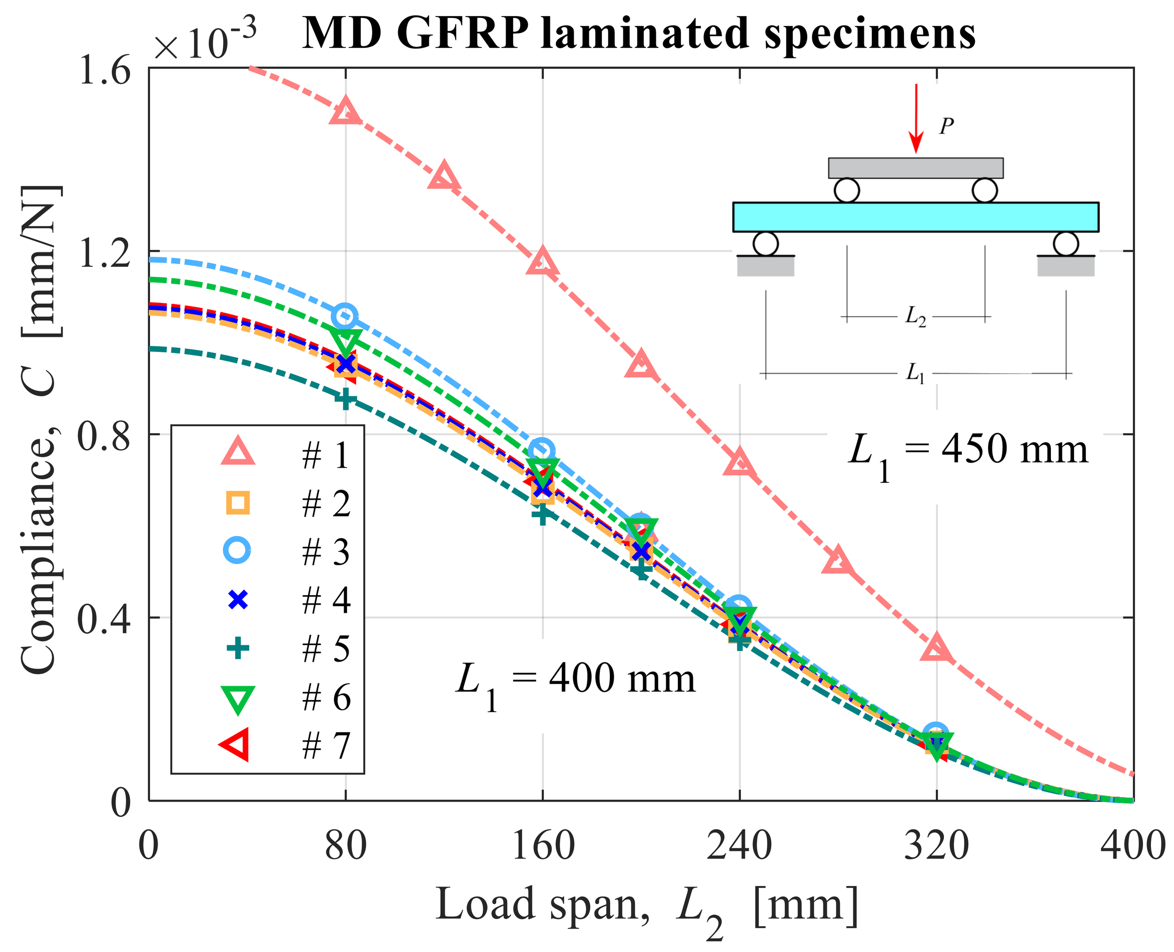
For each test, we calculate the compliance as the inverse of the slope of the regression line which best fits the experimental data obtained during the loading phase. Then, we apply the least squares method to determine the values of the bending and shear compliances, which best fit the experimental data obtained for each specimen. The homogenized shear and flexural moduli of the laminate are calculated as

$$G_{zx} = \frac{6}{5H}\frac{1}{c} \quad \text{and} \quad E_x \cong \frac{12}{H^3}\frac{1}{d}$$

where H is the thickness of the specimen.

The procedure turns out to be effective for both UD and MD laminates, provided that the bending-extension coupling is negligible for the stacking sequence considered. The determined values are reported in the following table.

	G_{zx} [GPa]	E_x [GPa]
CFRP	1.4	117.7
GFRP	1.2	30.9



[1] Lasn K. *et al*. Mech Compos Mater (2015) 51: 55.
[2] Mujika F. Polym Test (2007), 26: 869.
[3] Timoshenko S. P. Strength of materials (1955).
[4] Jones R. M. Mechanics of composites materials (1999).
[5] Bennati S. *et al*. Proc XXIII AIMETA (2017): 2119.
[6] Valvo P. S. *et al*. Proc XXIII AIMETA (2017): 1998.

The European research project SUREBridge (Sustainable Refurbishment of Existing Bridges) is developing a new concept for the structural strengthening of road bridges. The target is to exploit the remaining capacity of the superstructure of concrete and steel-concrete bridges, preserving the structural elements of the deck (girders and slab) and increasing the load-carrying capacity to the desired level. This is achieved by using light-weight, tailor-made glass fibre-reinforced polymer (GFRP) sandwich panels, installed on top of the existing concrete slab, and carbon fibre-reinforced polymer (CFRP) laminates applied to the bottom side of the girders.

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