Homogenised stiffness coefficients of unloaded endoscope shafts

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EXTENDED ABSTRACT

1 Introduction

When modelling slender structures made of composite materials using a beam theory, effective or homogenised stiffness coefficients must be obtained. However, these are difficult to define due to uncertainties and the complex behaviour of the mixed materials. In this work, we aim to identify a homogenization procedure of the stiffness coefficients of circular multi-layered beam cross-sections. This will help in the study of the constitutive behaviour of unloaded shafts of flexible endoscopes. An experimental campaign was carried out at ITWM Fraunhofer (Kaiserslautern, Germany) in order to evaluate the bending and torsion stiffness coefficients of such devices. Experimental results will be showed and used to build a proper cross-section model.

2 Description of the samples and the cross-section model

Flexible endoscopes are medical devices with a complex structure that can be separated into an external part and an internal cavity where the instruments are housed. In order to study the mechanical behaviour, only the outer part, denominated *unloaded shaft*, is taken into account here. The unloaded shafts are characterised by a hollow slender cylindrical geometry, shown in Figure 1, and made out of composite materials, i.e. starting from the outer side, two layers of plastic, one layer of stainless steel mesh, and one inner layer of stainless steel coil. Due to uncertainties introduced by the production process and general difficulty of modelling such complex cross-sections, experimental campaigns are fundamental for mechanical-parameter characterisation.

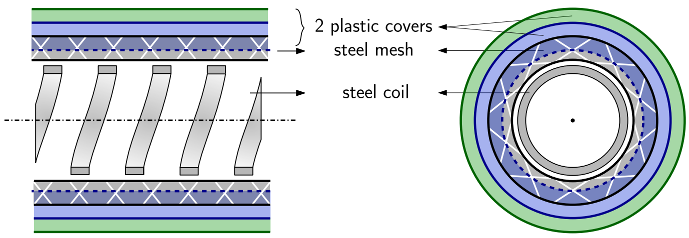

Figure 1: Longitudinal (left) and transversal (right) sections of an unloaded shaft

Since the coil is only attached to the overall structure at the ends of the shaft and can move relative to the other layers, its contribution to the mechanical properties of the cross-section can be considered later on, as additive on top of the rest. Thus, one can model the shaft as a fused three-layered cross-section, see Figure 2. One can distinguish the hollow interior (considered as layer 1) and a steel mesh as layer 2. Due to difficulties in properly characterizing and differentiating the two outermost layers of plastic, they considered as a single one (layer 3 in Figure 2).

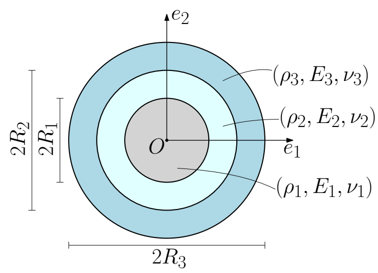

Figure 2: Three-layers piecewise homogeneous cross-section

3 Theoretical homogenization

Assuming linear homogeneous material behaviour, the effective stiffness coefficients of the resulting beam to be determined are the axial, shear, bending and torsional stiffnesses. In the case of a single simple material, these reduce to EA, κGA, EI and GJ respectively. Here, A is the cross-sectional area, I is the second moment of area of the circular cross-section, $J = 2I$ is the polar moment of inertia, E is Young's modulus, $G = E/[2(1+\nu)]$ is the shear modulus, ν is Poisson's ratio, and κ is a shear correction factor [1]. In case of beams made of composite materials welded together with different Poisson's ratios, the homogenization procedure to obtain the stiffness coefficients is more complex due to coupling effects [2, 3]. In this work, we compute homogenized stiffness coefficients for axisymmetric bars of piecewise-isotropic materials. This new formulation takes into account the coupling effects at the interface level between the layers.

4 Experimental characterization of the constitutive properties of unloaded shafts

MeSOMICS[1] is a measurement system developed at Fraunhofer ITWM to determine the mechanical properties of flexible slender structures. In this work, we use the system to carry out bending and torsional experiments on four different shaft models provided by Karl Storz Video Endoscopy Estonia (KSEE). Figure 3 shows the obtained results for one of the endoscope models.

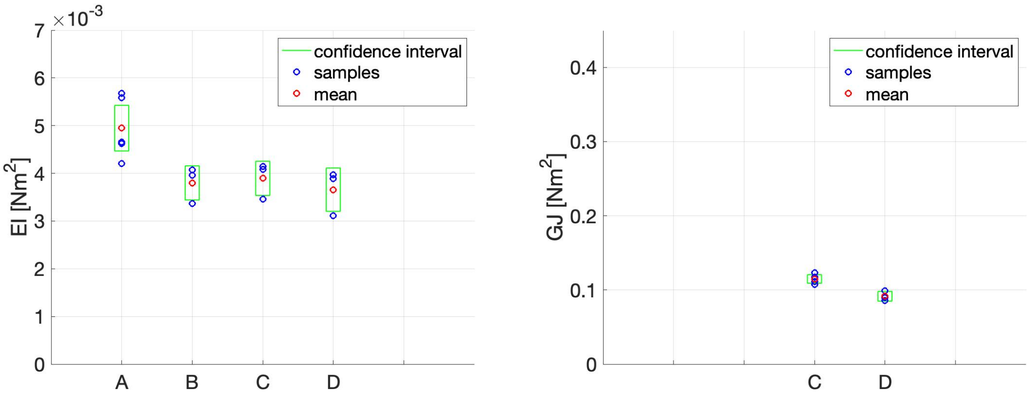

Figure 3: Bending and torsional stiffnesses of the endoscope shaft model 1. The complete results for the four models and the different test types represented by A, B, C, D will be explained in details during the talk

5 Conclusion and discussion

Currently, performing experiments on composite materials in general, and in endoscopes in particular, is fundamental to better understand their mechanical behaviour. In this work, on one hand, we experimentally characterize the mechanical properties of these materials. On the other hand, we attempt to predict effective stiffness coefficients of similar models via theoretical homogenization.

Acknowledgments

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References

[1] G. R. Cowper. The Shear Coefficient in Timoshenko's Beam Theory. Journal of Applied Mechanics, Vol. 33, 2:335-340, 1966.

[2] N. I. Muskhelishvili. Some basic problems of the mathematical theory of elasticity. Fundamental equations, plane theory of elasticity, torsion and bending, translated from the fourth, corrected and augmented Russian edition by J. R. M. Radok. Noordhoff International Publishing, Vol. 15, 1977.

[3] D. Ieşan. Classical and generalized models of elastic rods. CRC Press, Boca Raton, FL, 2009.

[1] More details about MeSOMICS here: www.mesomics.eu