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Quantitative study of the impact of biaxial test protocols on the derived material parameters for a PVC coated polyester fabric

Maarten Van Craenenbroeck^{1,*}, Silke Puystiens^{1,2}, Lars De Laet¹, Danny Van Hemelrijck², Marijke Mollaert¹

¹ *Departement of Architectural Engineering, Vrije Universiteit Brussel, Pleinlaan 2 B-1050 Brussels, Belgium*

² *Department of Mechanics of Materials and Constructions, Vrije Universiteit Brussel, Pleinlaan 2 B-1050 Brussels, Belgium*

Abstract

Fabrics have been used in tensile surface structures for over 50 years. Their unique properties, such as their high flexibility and low self-weight, make that these materials can be used in very efficient and architecturally unique constructions.

However, due to these materials consisting of woven fibres and different interacting layers, deriving their mechanical properties unambiguously has proven difficult. Current biaxial testing methodologies differ between institutes and much discussion exists as to how the obtained test results should be interpreted or to which extend these variations have a possible impact on the design and analysis of tensile fabric structures.

To quantify the impact of the used testing protocols on the obtained results as well as the method for deriving the elastic constants from said results, we tested fabrics using various test methodologies so that the direct impact on the test results could be quantified. Following these tests, material parameters were derived using various methods to show the impact of both the used test methodology as well as the method of deriving the material's constants. These results were then deployed in various computational models to quantify the actual structural impact of these variations.

This paper describes the analysis conducted on biaxial test results from a PVC coated polyester fabric (Sioen T2107), quantifying differences in the deviated material parameters and the resulting predicted stress-strain behaviour. The results show that taking different data sets can lead to significant different results, which then lead to a difference in the strains and displacements derived from the computational simulations.

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* Corresponding author. Tel.: +32 2 629 28 30

E-mail address: maarten.van.craenenbroeck@vub.ac.be

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1. Introduction

Coated fabrics show a highly nonlinear behaviour when subjected to uniaxial and biaxial loads. Despite this, common practice still often relies on characterising this behaviour by means of elastic constants, typically two Young's moduli and two Poisson's coefficients, which are obtained through biaxial tests. However, currently there is no agreement on how these tests should be conducted [1] [2] [3] [4] or on the post-processing of the test data and the interpretation of the results [2] [3] [5] [6] [7]. This lack of unification leads to a possible big differentiation when it comes to the material parameters found through biaxial testing of fabrics.

Until recently, the Japanese code MSAJ M-02-1995 [2] "Testing Method for Elastic Constants of Membrane Materials" (further referred to as "the MSAJ standard") has often been used as reference for testing fabrics and determining material constants. The method described in this standard consists of applying a least-square fitting of a planar surface to the biaxial stress-strain data to predict the global stress-strain behaviour. In order to conduct this fitting, the non-linear stress-strain behaviour of the fabric is simplified and approximated by two Young's moduli and two Poisson's ration. By implying the plane-stress condition, the equations used to derive the material parameters reduce themselves to contain only three unknowns to predict the behaviour of the fabric for the whole spectrum of possible load ratios and stress levels (up to 25% UTS).

Containing an elaborate discussion on the used test procedure and the mathematical method to derive the material constants, the MSAJ standard has proven very valuable for fabric manufacturers, contractors and designers alike. It does however make a number of assumptions, such as the 1:1 ratio being the "default state" for the structure, and leaves room for interpretation when it comes to, for instance, the data considered during the least-squares fitting.

Where previous research [6] [7] [8] has provided valuable insight in the effect of considering the residual strains, the plane stress assumption, the impact of various test profiles and limiting the fitting to a certain set of load ratios, the research in this paper specifically looks at the effect of the amount of considered data points as well as the impact of specific post processing methods on the resulting material constants. The material parameters derived from different data sets from the same test were compared to each other as well as to results from "specialised" data sets, which limit themselves to load ratios of practical interest, a method frequently applied in practice. A selected set of results was then compared to the actual stress-strain behaviour found during the tests and was applied in two numerical models: a hyper structure with a symmetric prestress and a conical structure. This final step relates the results to practice and makes an estimate to what extend the found variations could influence the design process.

2. Material and test procedure

The material used in this research is a Type II PVC coated polyester fabric made by Sioen Industries [www.sioen.com]. The material, designated as T2107, has a symmetric tensile strength of 80kN/m and an average thickness of 0.80mm.

Biaxial samples with a central area of 30cm x 30cm were subjected to a load profile which is a modification of the profile described in the MSAJ standard [8] (Figure 1). Similar to the profile describe in the MSAJ standard, this profile cycles through various load ratios, each separated from each other by a 1:1 normalisation ratio. However, unlike the methodology described in the MSAJ, this profile repeats each ratio three times, starts by holding the prestress level for 30 minutes to allow the fabric to settle and replaces the 1:0 and 0:1 ratios with respectively 5:1 and 1:5 ratios. This latter has been done for practical reasons: the controller used to balance the loads had difficulties maintaining load symmetry when running the 1:0 and 0:1 ratios, causing results from tests containing these ratios to have a low repeatability.

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