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Date 14.02.2019

Report on Biaxial Test and Young's Modulus determination

Client:

Sattler PRO-TEX GmbH

Sattlerstraße 45

A-8077 Gössendorf

Index

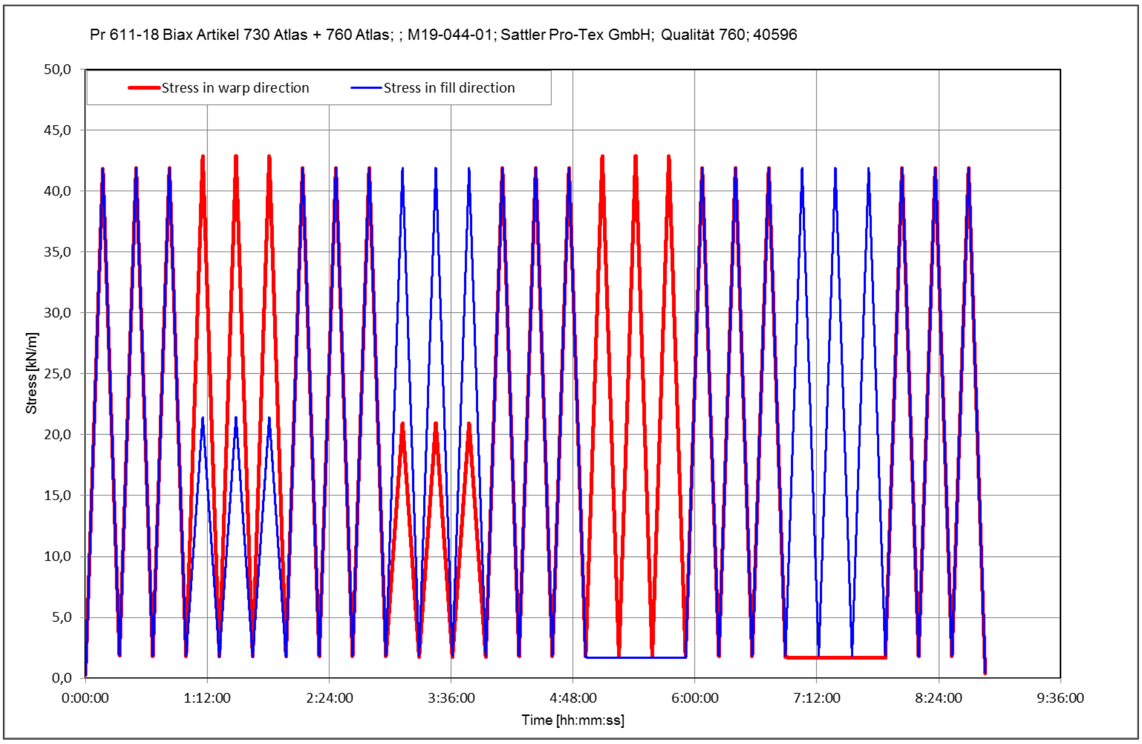
1. Task

The following biaxial tests has been executed in the lab of DEKRA Technical Textiles and Films according to the client's test requirements and according to DIN EN 17117-1.
This test was done to determine the Young's Modulus.

Testing temperature:	23 °C ± 2 K
Date of receipt:	07.02.2019
Date of test:	08.02.2019
Supplier of sample:	Sattler PRO-TEX GmbH, Gössendorf, Austria
Material manufacturer:	Sattler PRO-TEX GmbH, Gössendorf, Austria
Material type:	PVC coated Polyester fibre fabric
Material application type:	760 ATLAS Architecture Type IV
Batch no:	40596
Production no.:	
Internal sample no.:	M19/044
Load regime:	611-18 LG 760 Atlas
Load conditions:	warp to weft stresses 1:1, 2:1, 1:2, 1:0, 0:1
	pre stress 2.0 kN/m

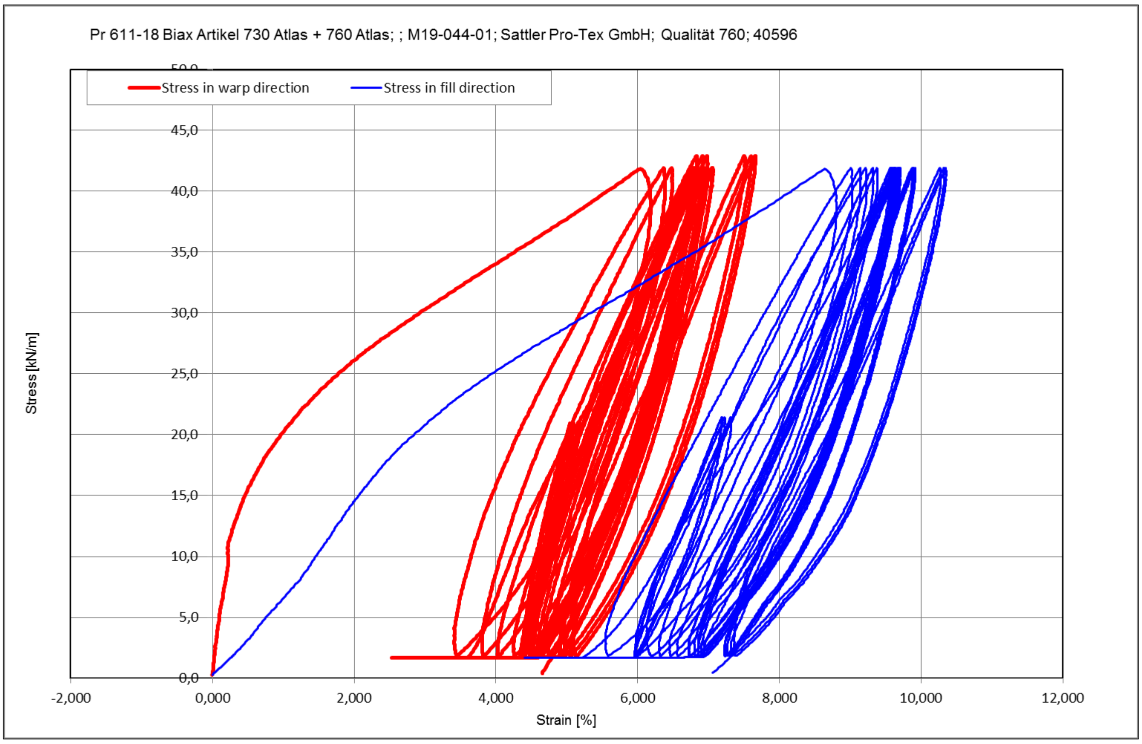
2. Introduction

There are different methods to determine the elastic moduli of a coated fabric.
First we have to mention that we want to establish a linear elastic approximation for a non-linear non-elastic behaviour. Furthermore we assume that a fabric behaves as an orthotropic two dimensional material. And we want to simulate only the behaviour under stresses the mean axes of which are parallel to warp and weft.
In the following picture 2.1 a normal load regime to determine the elastic moduli is shown.



Picture 2.1: Load regime for the determination of the elastic moduli

In the second picture we will show a usual diagram for the stress-strain-relations. In many cases the moduli are now calculated as the gradient of a tangent in a chosen working point, normally the prestress which is sketched here.



Picture 2.2: Stress strain diagram

We will show that this procedure can be critical in some cases and that we propose another procedure.

3. Theory

In linear elastic approximation for orthotropic behaviour we have the following relations:

$$\begin{bmatrix} n_{11} \\ n_{22} \end{bmatrix} = \begin{bmatrix} E_{1111} E_{1122} \\ E_{1122} E_{2222} \end{bmatrix} \begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \end{bmatrix}$$

with the inversion:

$$\begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \end{bmatrix} = \begin{bmatrix} C_{1111} C_{1122} \\ C_{1122} C_{2222} \end{bmatrix} \begin{bmatrix} n_{11} \\ n_{22} \end{bmatrix}$$

or, explicitly:

$n_{11} = E_{1111}\, \varepsilon_{11} + E_{1122}\, \varepsilon_{22} = E_{1111}\, (\varepsilon_{11} + \nu_{12}\, \varepsilon_{22})$

$n_{22} = E_{1122}\, \varepsilon_{11} + E_{2222}\, \varepsilon_{22} = E_{2222}\, (\nu_{21}\, \varepsilon_{11} + \varepsilon_{22})$

with the inversion:

$\varepsilon_{11} = C_{1111}\, n_{11} + C_{1122}\, n_{22}$

$\varepsilon_{22} = C_{1122}\, n_{11} + C_{2222}\, n_{22}$.

Index 11 is used for warp direction, index 22 for fill (weft) direction. For stresses n is used, ε for strains, E is used for Young’s modulus in the respective direction and C is used for compliance.

The following abbreviations are used:

- n_{11} stress in warp direction,
- n_{22} stress in fill direction
- ε_{11} strain in warp direction,
- ε_{22} strain in fill direction
- E_{1111} stiffness in warp direction,
- E_{2222} stiffness in fill direction,
- E_{1122} stiffness interaction between warp and fill,
- $\nu_{12} = E_{1122}/E_{1111}$ Poisson ratio for the interaction between warp and fill
- $\nu_{21} = E_{1122}/E_{2222}$ Poisson ratio for the interaction between fill and warp
- C_{1111} compliance in warp direction,
- C_{2222} compliance in fill direction,
- C_{1122} compliance interaction between warp and fill.

We have used four indices both for stiffness and compliance to manifest that these terms are tensors of fourth order which link two tensors of second order, the stresses **n** and the deformations ε linearly. With this statement the behaviour under transformation is well defined.

4. Practical Calculations

When the slopes of each load cycle is taken, using the equation:

$$\begin{bmatrix} \Delta\varepsilon_{11} \\ \Delta\varepsilon_{22} \end{bmatrix} = \begin{bmatrix} C_{1111} C_{1122} \\ C_{1122} C_{2222} \end{bmatrix} \begin{bmatrix} \Delta n_{11} \\ \Delta n_{22} \end{bmatrix}$$

the following two equations are obtained:

$$\Delta\varepsilon_{11} = C_{1111} \cdot \Delta n_{11} + C_{1122} \cdot \Delta n_{22}$$

and

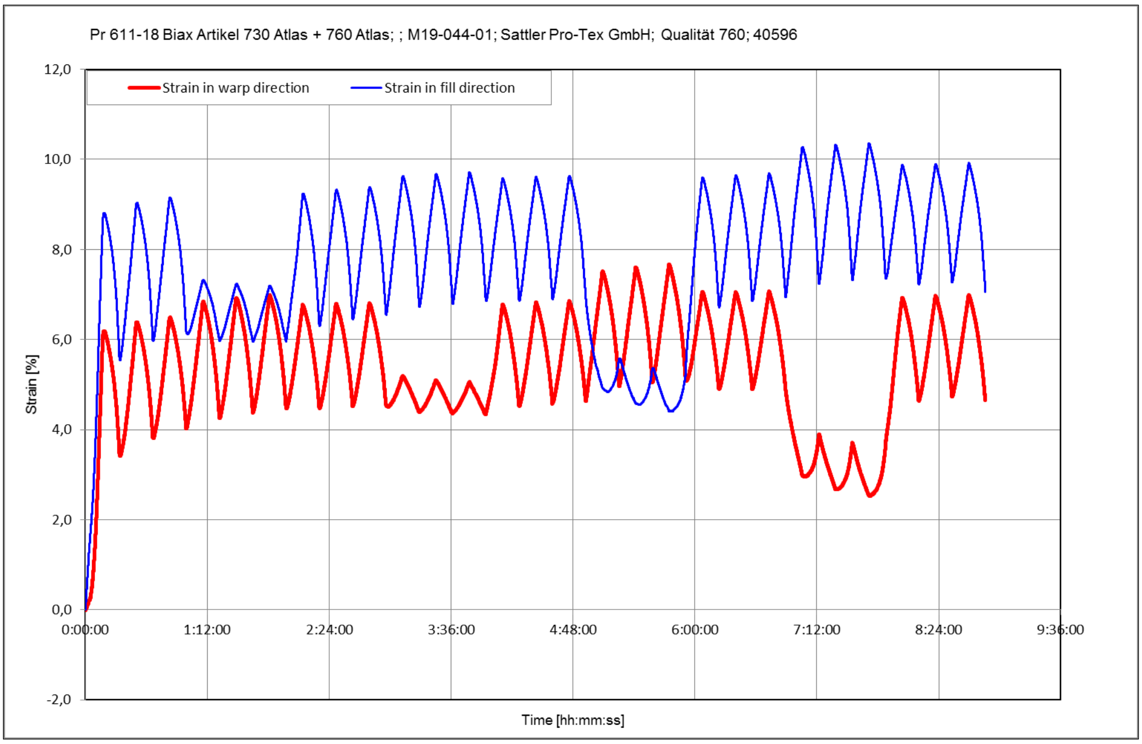
$$\Delta\varepsilon_{22} = C_{1122} \cdot \Delta n_{11} + C_{2222} \cdot \Delta n_{22} .$$

The elastic modulus is then:

$$\overline{E} = \frac{1}{\det C} \begin{bmatrix} C_{2222} - C_{1122} \\ - C_{1122} C_{1111} \end{bmatrix} .$$

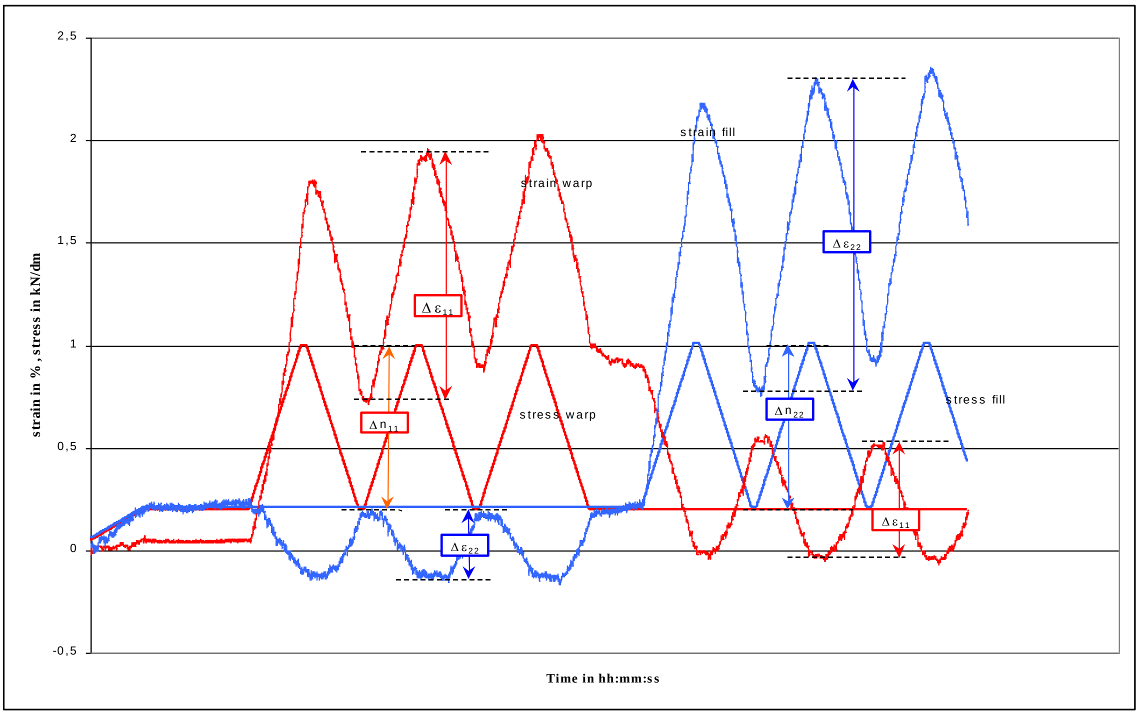
5. Measuring, Definition of load regime, Calculation of Moduli

Now we have applied the load regime shown above in picture 2.1. The resulting strains are shown in picture 5.1.



Picture 5.1: Resulting Strains

In Picture 5.2 the evaluation of the results is shown for example.



Picture 5.2: Evaluation of elastic moduli

Evaluating is made with the strain results as shown in picture 5.1. The differences of stress values and of strain values will be taken for each relationship of ratio (Δn11, $\Delta\varepsilon$11, Δn22, $\Delta\varepsilon$22…) The results are written down in table 5.1. Then calculation will be done for relation of stress combination as shown in the following table 5.2.

The classical formulation of stress – strain in table 5.2 are taking into account the Poisson’s ration, they will be often used in appropriate known calculation programs (finite elements analysis).

For comparison, the evaluations of the individual cycles are also listed, where it should be shown that these are not to be regarded as representative.

Table 5.1: Differences of stress and strain and average values for different stress ratio

warp to weft stress ratio	last 2 cycles				averages			
	Δn_{11}	Δn_{22}	$\Delta\varepsilon_{11}$	$\Delta\varepsilon_{22}$	Δn_{11}	Δn_{22}	$\Delta\varepsilon_{11}$	$\Delta\varepsilon_{22}$
	kN/dm *min	kN/dm *min	%/min	%/min	kN/dm *min	kN/dm *min	%/min	%/min
1:1	0,410	0,410	0,249	0,300	0,410	0,410	0,247	0,299
	0,410	0,410	0,245	0,298				
2:1	0,420	0,201	0,289	0,137	0,420	0,201	0,287	0,136
	0,420	0,201	0,285	0,135				
1:2	0,196	0,410	0,074	0,321	0,196	0,410	0,073	0,319
	0,196	0,410	0,071	0,316				
1:0	0,420	0,000	0,284	-0,113	0,420	0,000	0,283	-0,110
	0,420	0,000	0,281	-0,107				
0:1	0,000	0,410	-0,125	0,333	0,000	0,410	-0,124	0,330
	0,000	0,410	-0,122	0,327				

Table 5.2: Elastic moduli in dependency of stress ratio combination

		warp to weft stress ratio combination						
		1:1 2:1	1:1 1:2	1:1 1:0	1:1 0:1	2:1 1:0	1:2 0:1	all combi- nations
E_{1111}	kN/m	1337	1263	1529	1142	1480	1017	1363
E_{1122}	kN/m	175	234	256	267	144	227	271
E_{2222}	kN/m	1303	1255	1037	1283	809	1270	1187
ν_{12}		0,13	0,19	0,17	0,23	0,10	0,22	0,20
ν_{21}		0,13	0,19	0,25	0,21	0,18	0,18	0,23
classical evaluation E_{1111} * resp. E_{2222} * $(1-E_{1122}^2/(E_{1111} * E_{2222}))$ respectively $\varepsilon_{11} = \sigma_{11}/E_1 - \nu_{12} * \sigma_{22}/E_2$; $\varepsilon_{22} = \sigma_{22}/E_2 - \nu_{21} * \sigma_{11}/E_1$ mit $E_1 * \nu_{12} = E_2 * \nu_{21}$								
E_1	kN/m	1313	1219	1466	1086	1454	976	
E_2	kN/m	1280	1212	994	1221	795	1219	
evaluation from single sloping graph								
		1:1	*2:1*	*1:2*	*1:0*	*0:1*		
E_1	*kN/m*	*1660*	*1463*	*2703*	*1487*	*0*		
E_2	*kN/m*	*1371*	*1478*	*1287*	*0*	*1242*		

Young's modulus determination is valid only for the calculated loads.

The results of the biaxial test above should not be used for compensation.

Remark:

All test results are only referring to the above-mentioned samples. A publication in extracts is only allowed in accordance with DEKRA (Automobil GmbH) Laboratory for Technical Textiles and Films.

Stuttgart, 14.02.2019

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