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OPTICAL METHOD FOR MEASURING THE FLEXIBILITY OF COATED FABRICS

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Abstract:

The Sylvie 3D Bending Tester is a new equipment that has been developed to analyze the flexural behavior of fabric. The device records the bell-shaped deformation of the fabric sample using an optical method, from which the bending properties are calculated. This new method allows determining the flexural properties of fabric stiffer than home and apparel fabric, for example composite reinforcement fabrics, coated fabrics, etc. Present work aims to determine the bending properties of three types of PVC coated woven polyester fabrics with the new optical method. These results are compared with those determined with Flexometer.

Keywords:
composite, flexibility, Sylvie 3D Bending Tester, optical test,

1 INTRODUCTION

Composite is a structural material that planned to be anisotropic as a result of using high strength reinforcements in the main directions of load. Depending on the manufacturing process and application of the composite product different types of reinforcements could be applied. As the known orientation of fibers results in a more predictable deformation, this makes woven fabric the most common reinforcement type of all [1].

Besides the conventional rigid composite products the importance of flexible composite materials are significant. These flexible composite sheets, usually made of PVC coated polyester or PTFE coated fiberglass, are often used in architecture to create lightweight tensile membrane structures and tents for permanent or temporary covers [2]. They are also used in the automotive industry, for example as side curtains of trucks. Conveyor belts used by the food industry are another typical application of these coated fabrics.

Methods to determine the flexibility of fabrics exist; however, they cannot provide a complete solution for fabrics that are stiffer than home and apparel fabrics, such as composite reinforcements, coated fabrics, etc.

The most notable equipment for determining the mechanical properties of apparel fabric is the Kawabata Evaluation System (KES). It was originally developed to standardize the hand evaluation in the 1970's. KES consists of four instruments measuring the deformations caused by tensile, shear, bending, and compression stresses. It also performs a test to measure surface properties. The bending test is carried out by KES-FB2 providing the bending moment according to curvature, bending stiffness and bending hysteresis. However, the small measurement ranges of KES provide no or limited solution for determining the mechanical properties of technical fabrics [3].

The standardized device to determine bending stiffness is the Flexometer (Figure 1). It is based on the Cantilever Test developed by F.T. Pierce [3], [5]. Although, for thicker and stiffer reinforcing materials this method also has its limits [6].

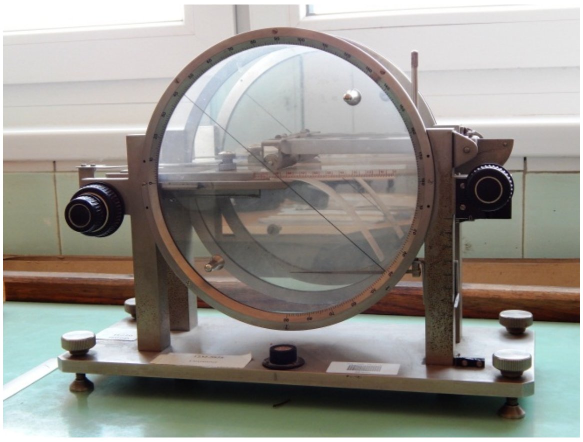


Figure 1: Flexometer

The Hearth Loop Test, also developed by F.T. Pierce, is used to determine the bending stiffness of fabric prone to friction or twisting.

Two departments of the Budapest University of Technology and Economics, the Department of Polymer Engineering and the Department of Mechatronics, Optics and Mechanical Engineering Informatics have developed a special measuring instrument, the Sylvie 3D Bending Tester (*Figure 2*), for analyzing the flexural behavior of fabric.

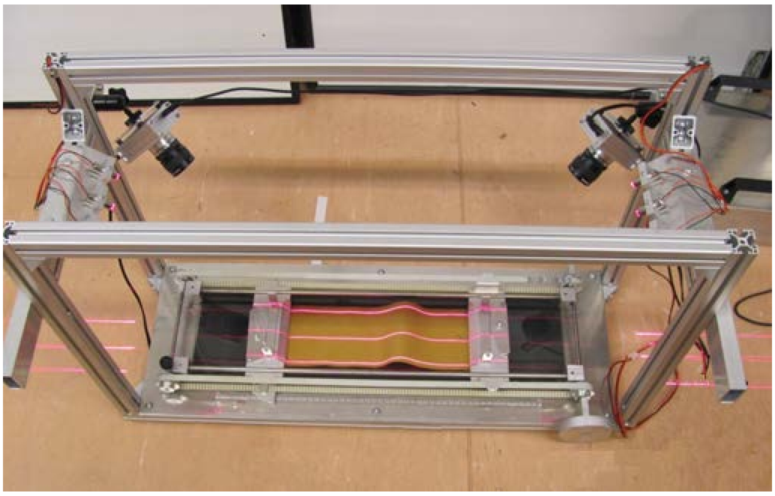


Figure 2: Sylvie 3D Bending Tester [8]

The device uses an optical method to record the deformed shape of the fabric, from which the bending properties are calculated. This new method allows determining the flexural properties of stiffer fabric.

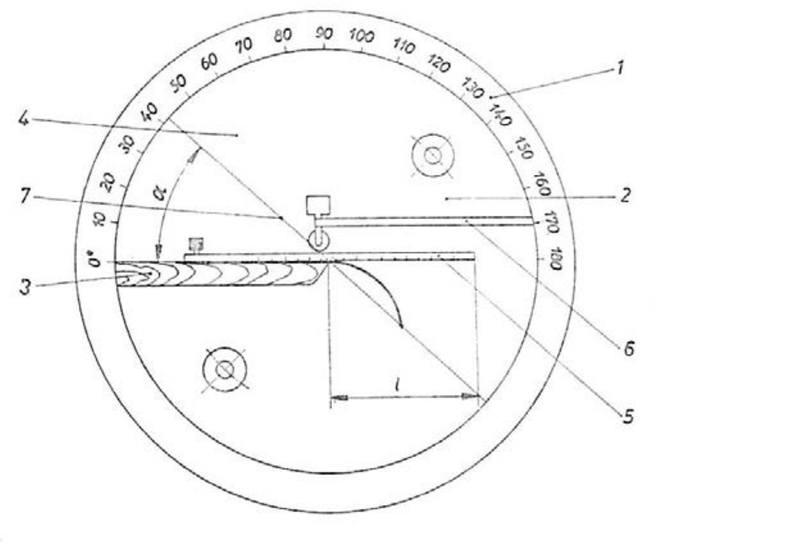
Sylvie 3D Bending Tester is still under development. In this paper the structure and measuring method of the device is presented. Three types of coated fabrics have been analyzed to test the new measuring method.

2 EXPERIMENTAL

The flexural properties of the coated fabrics have been analyzed with Flexometer and Sylvie 3D Bending Tester.

2.1 Flexometer

The Flexometer is shown in Figure 3.



1-protractor ring,
2-rotatable transparent plate with a diameter line,
3-leveled surface,
4-mirror,
5-gauge,
6-load to fix the sample,
7-diameter line

Figure 3: Flexometer

The overhanging length of the sample is measured when it hits the diameter line indicating the 43° angle. Standard samples with 100 mm x 20 mm geometry were used. The bending length is calculated as

$$C[m] = \frac{l}{2} \qquad (1)$$

where l [m] is the overhanging length of the sample.

The flexural modulus is calculated as

$$E[\mathrm{Pa}] = \frac{12 \cdot F_B}{v^3} \tag{2}$$

where F_b[Nm] is the bending stiffness and v[m] the thickness of the sample [9].
The bending stiffness is

$$F_B = G \cdot C^3$$

where $G\left[\frac{\mathrm{N}}{\mathrm{m}^2}\right]$ is the weight per unit area of the sample.

2.2 Sylvie 3D Bending Tester

The Sylvie 3D Bending Tester is shown in Figure 4. The samples are gripped laid flat parallel to the laser beams. Then, the gripping length is shortened to create an bell-shaped crease in the sample. By using three line lasers and a camera on each side this deformed shape of the fabric is recorded. The lasers and cameras must be located on the sides as a higher crease could create a blind spot. The photographs are taken in a dark room to enhance the contrast of the laser beams projected on the sample. The sample geometry is 500 mm x 100 mm. The coordinates of the curve is calculated using image processing.

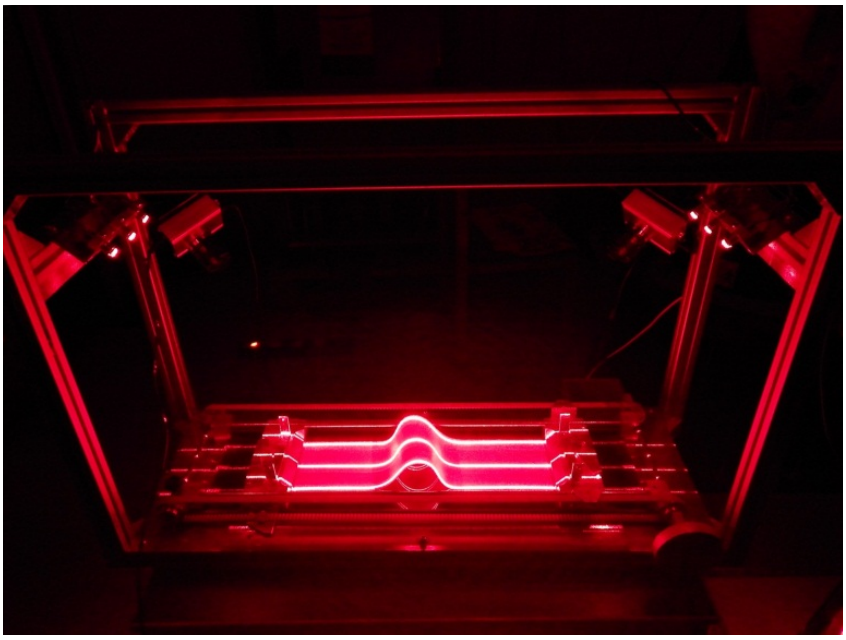


Figure 4: Sylvie 3D Bending Tester during measuring

The images are processed using plane to plane linear perspective transformation with homogeneous coordinates (Figure 5) [10],[11].

The image processing requires calibration, when the corners of the calibration tool (100 mm x 100 mm square) are selected on the photos taken by the cameras. The coordinates of the corners of the calibration tool define the transformation matrix.

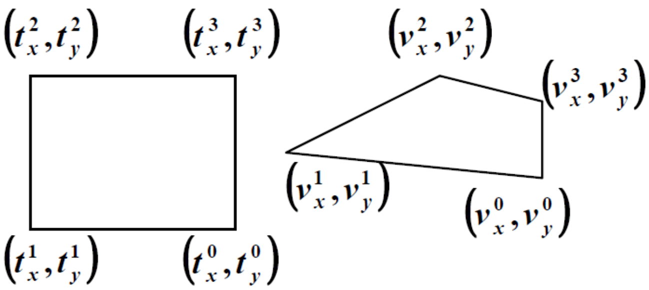


Figure 5: Plane to plane linear perspective transformation

The matrix equation of the transformation is the following:

$$\begin{bmatrix} v_x^i \\ v_y^i \\ 1 \end{bmatrix} = \begin{bmatrix} p_0 & p_1 & p_2 \\ p_3 & p_4 & p_5 \\ p_6 & p_7 & 1 \end{bmatrix} \cdot \begin{bmatrix} t_x^i \\ t_y^i \\ 1 \end{bmatrix} \qquad (3)$$

where t_x^i and t_y^i are homogeneous coordinates of the corners of the calibration tool, v_x^i and v_y^i are homogeneous coordinates of the corners of the calibration tool on the pictures, p_j the elements of the transformation matrix, i=0,1,2,3, and j=0,…7.

The eight unknowns of the transformation matrix are calculated with the eight equations defined by Equation (3).

The points of the curves are filtered to clear errors that came from, for example glares of the laser beams.

An eight degree polynomial fits the shape of the deformation [7]. The curve is fitted on the filtered points (Figure 6).

The equation of the eight degree polynomial is the following:

$$y = a_8 \cdot x^8 + a_7 \cdot x^7 + a_6 \cdot x^6 + a_5 \cdot x^5 + a_4 \cdot x^4 + a_3 \cdot x^3 + a_2 \cdot x^2 + a_1 \cdot x + a_0. \qquad (4)$$

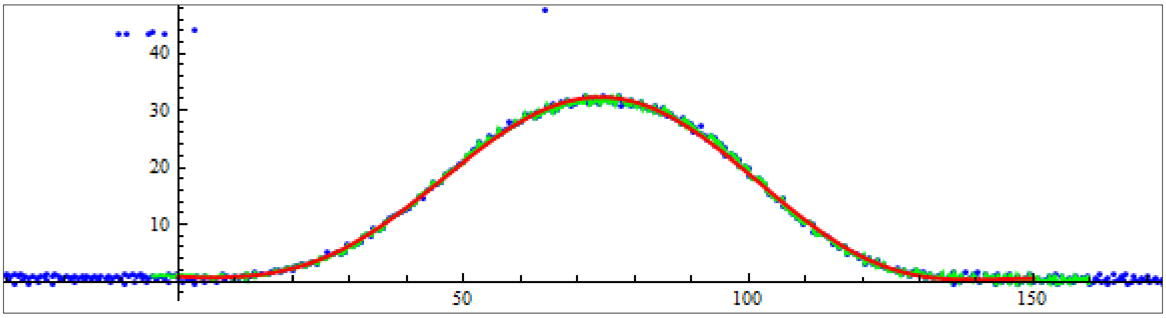


Figure 6: Curve fitting
blue – measured points, green – filtered points, red – curve fitted on filtered points

The mechanical model of the deformed sample in equilibrium is shown in Figure 7.

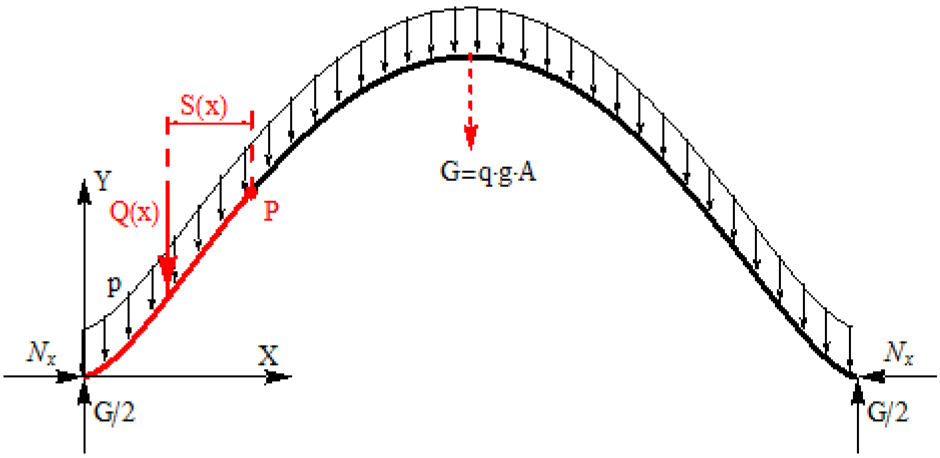


Figure 7: The mechanical model of the deformed sample in equilibrium

The bending moment on an arbitrary point (e.g. point P on Figure 7) is

$$M_h(x) = N_x \cdot y(x) - \frac{G}{2} \cdot x + Q(x) \cdot S(x) \quad (5)$$

where $N_x[N]$ the horizontal forces, G [N] the weight of the sample, $Q(x) \cdot S(x)$ the moment of the distributed load representing the weight of the sample.
In expression (5),

$$S(x) = x - \frac{\int_0^x x \cdot \sqrt{1 + y'^2(u)du}}{\int_0^x \sqrt{1 + y'^2(u)du}} \quad (6)$$

and the resultant of the distributed load is

$$Q(x) = p \int_0^x \sqrt{1 + y'^2(u)du}. \quad (7)$$

The weight of the sample is

$$G\,[N] = q \cdot g \cdot A \tag{8}$$

where $q\left[\frac{kg}{m^2}\right]$ the mass per unit area, $g\left[\frac{m}{s^2}\right]$ the gravitational acceleration, and $A\,[\mathrm{m}^2]$ area of the sample.

The distributed load is

$$p\left[\frac{N}{m}\right] = q \cdot g \cdot b \tag{9}$$

where b [m] is the width of the sample.

The differential equation of the elastic curve is

$$y''(x) = -\frac{M_h(x) \cdot (1 + y'^2)^{\frac{3}{2}}}{I_z \cdot E} \tag{10}$$

where $I_z[m^4]$ is the area moment of inertia and $E[Pa]$ the Young's modulus.

The bending stiffness is

$$D[Nm] = I_z \cdot E \tag{11}$$

After substituting equation (5) into equation (10) and rearrangement , the differential equation used for the evaluation is

$$f(x) = Dy''(x) + \left(N_x y(x) - \frac{1}{2} qgAx + qgb \int_0^x \sqrt{1 + y'^2(u)}du \left[x - \frac{\int_0^x x \cdot \sqrt{1+y'^2(u)}du}{\int_0^x \sqrt{1+y'^2(u)}du} \right] \right) (1 + y'^2)^{\frac{3}{2}} = 0. \tag{12}$$

Equation (12) is evaluated on two arbitrary points to get the two unknowns, that is, D and N_x.

2.3 Analyzed materials

Three types of PVC coated PES woven fabrics with different mass per unit area densities have been analyzed (Figure 8). They are the product of SIOEN Industries.

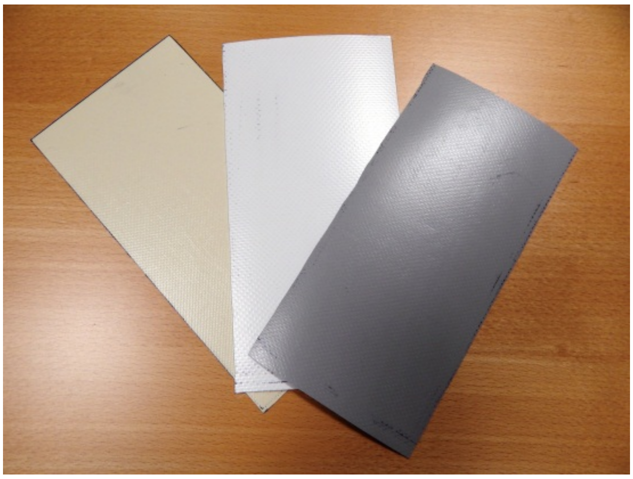


Figure 8: The analyzed PVC coated PES woven fabrics

The properties of the analyzed PVC coated woven fabrics are shown in Table 1.

Table 1:Properties of the analyzed woven fabrics

	B6000 (WHITE)	**B7119 (GRAY)**	**C2357 (BEIGE)**	**UNIT**
Linear mass density of fibers	1100	1100	280	dtex
Fibers	PES continuous	PES continuous	PES continuous	-
Coating	PVC	PVC	PVC	-
Mass per unit area	900	630	350	g/m^2
Mass per unit area – base fabric	260	160	85	g/m^2
Mass per unit area – coating	640	470	265	g/m^2
Weave	plain	plain	plain	–
Average thickness	0,65	0,47	0,31	mm

3 RESULTS

In Table 2 the flexural modulus results measured with Flexometer and Sylvie 3D Bending Tester are compared.

Table 2: Comparison of flexural modulus measured with Flexometer and Sylvie 3D Bending Tester

		FLEXOMETER	SYLVIE 3D BENDING TESTER
DIRECTION	SAMPLE	FLEXURAL MODULUS [Pa]	
WARP	GRAY	$7{,}90 \cdot 10^7$	$3{,}05 \cdot 10^7$
	WHITE	$8{,}33 \cdot 10^7$	$7{,}01 \cdot 10^7$
	BEIGE	$5{,}28 \cdot 10^7$	$4{,}01 \cdot 10^7$
WEFT	GRAY	$5.98 \cdot 10^7$	$5{,}65 \cdot 10^7$
	WHITE	$4{,}97 \cdot 10^7$	$4{,}82 \cdot 10^7$
	BEIGE	$5{,}60 \cdot 10^7$	$2{,}77 \cdot 10^7$
TRANSVERSE	GRAY	$2{,}78 \cdot 10^7$	$3{,}16 \cdot 10^7$
	WHITE	$4{,}03 \cdot 10^7$	$4{,}28 \cdot 10^7$
	BEIGE	$3{,}23 \cdot 10^7$	$3{,}23 \cdot 10^7$

4 CONCLUSIONS

Analyzing the flexural properties of fabrics is an important field, but the current measuring methods are only suitable for apparel and home fabric. The Sylvie 3D Bending Tester can provide a solution for stiffer fabric, such as coated fabrics. The flexural properties are calculated by recording the bell-shaped deformation of the sample and using its mechanical model. Three types of PVC coated PES fabrics have been analyzed with Flexometer and Sylvie 3D Bending Tester. The main purpose of analysis was to test the new measuring and evaluation method. The comparison of flexural modulus results proves that the new method is capable of producing results within the same order of magnitude as a standardized measuring device.

Further directions of improvement will involve the image processing, material model (e.g. non-linear model), and mechanical model.

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