OPTICAL MESUREMENT OF TEXTILE BENDING CARACTERISTICS

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Abstract

The optical bending test equipment developed at the Budapest University of Technology and Economics has an advantage opposite to traditional ones namely the measuring process works without mechanical contact. There are three laser lines projected onto the bended material that are stored on photo taken by camera. The aim of the measurement is to determine the bending stiffness and other bending properties of the textile material from the deflection curves by image processing and mathematical methods. The measured parameters can be used in 3D simulation of the textiles tested.

Introduction

Simulating the drapability behaviour of textiles basically needs the knowledge of their bending properties. The bending behaviour of textiles is mainly characterized by the bending length measured by Cantilever Test developed by Peirce [1]. Other characteristic is the bending stiffness measured by the special bending tester instrument of KES-F system [2].

We present a measurement method working in a new optical way – similar to our formerly developed system for measuring fabric drape [3] – which make possible to determine the bending characteristic of textiles with application of image processing.

During the measurement the fabric sample is griped on its two ends and three laser lights are projected onto sample deflecting freely between the two grips. The curves of laser curves on the bended sample are recorded by a camera and the shape of them is determined by image processing making possible to create a virtual surface of the bent sample. The bending characteristics and the data such as the bending stiffness needed to simulate drape behaviour are determined by mathematical methods from the determined shape.

In this paper the instrument developed for measuring bending characteristics, and the way of measurement and evaluation are presented.

Measuring Instrument

The test table of the equipment consists of several element pairs of same dimensions of upper and lower sections. Upper sections can be turned up separately and the lowers can be turned down separately as well. During measurement a 100 mm by 600 mm sized specimen is laid on the turned down lower elements strainlessly that is fixed by turning down the upper elements. There is an unslipping coat on fixing elements. Thanks for the construction the bending effect can be measured with different length. In case of measuring the upper fixed parts of suitable number are turned up and the lowers opposite them are turned down. Specimen will deflect down because of the gravity. There is a bijection between the mechanical parameters and the shape of specimen. There are three laser projectors above the table and a camera. The camera takes the image of the projected laser lines (Figure 1.).

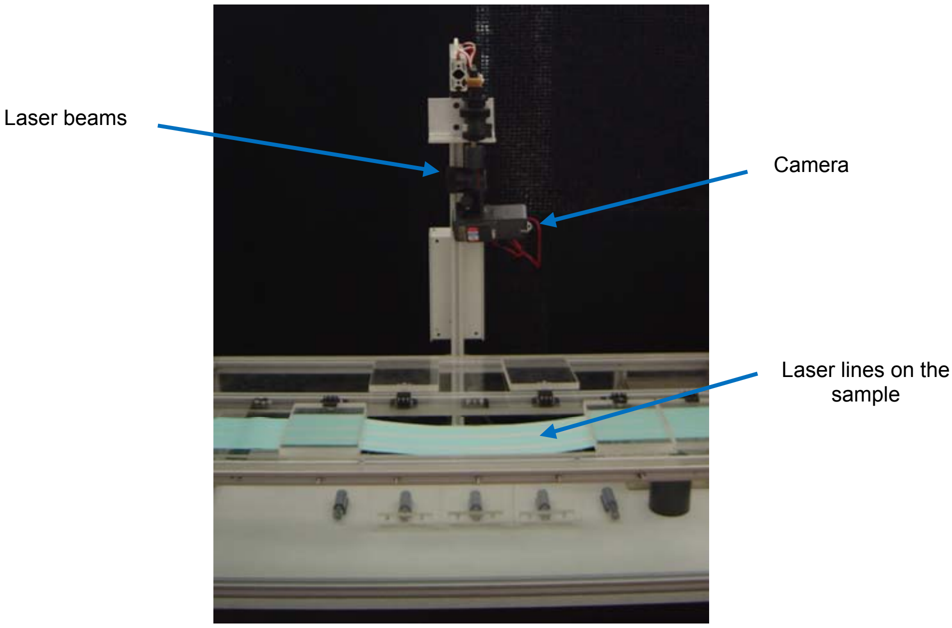

Figure 1. Instrument for measuring bending properties of textiles

Calibration and Picture Processing

In order to develop suitable measuring methods and achieve necessary accuracy, we had to calibrate the cross-sections on the photo as well as to analyze errors.

Light-beams forms planar curves in three positions. Points of curve are determined by processing of pictures. For 3D scanning the plane to plane perspective transformation is a bijection. Perspective transformation by homogenous coordinates is a linear transformation [4] that projects quadrangle to quadrangle. The matrix of transformation (1) has eight independent coordinates.

$$\underline{\underline{P}} = \begin{bmatrix} p_0 & p_1 & p_2 \\ p_3 & p_4 & p_5 \\ p_6 & p_7 & 1 \end{bmatrix} \qquad (1)$$

Corners of a rectangular calibration element are appropriate to define of matrix coordinates (Figure 2).

Corners of calibration equipment are $\left(t_x^i, t_y^i\right)$, and corners of its picture are $\left(v_x^i, v_y^i\right)$ (i=0, 1, 2, 3) and the transformation is shown in Equation (2).

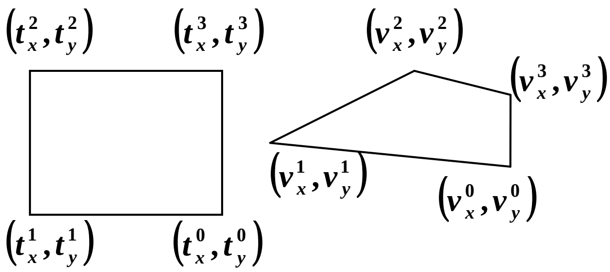

Figure 2. Planar perspective projection

$$\begin{bmatrix} v_x^i \\ v_y^i \\ 1 \end{bmatrix} = \begin{bmatrix} p_0 & p_1 & p_2 \\ p_3 & p_4 & p_5 \\ p_6 & p_7 & 1 \end{bmatrix} \cdot \begin{bmatrix} t_x^i \\ t_y^i \\ 1 \end{bmatrix} \tag{2}$$

There are eight unknown coordinates and eight equations represented by formulas (3) in every plane [5].

$$v_x^i = \frac{p_0 \cdot t_x^i + p_1 \cdot t_y^i + p_2}{p_6 \cdot t_x^i + p_7 \cdot t_y^i + 1}$$
$$v_y^i = \frac{p_3 \cdot t_x^i + p_4 \cdot t_y^i + p_5}{p_6 \cdot t_x^i + p_7 \cdot t_y^i + 1} \qquad i = 0, 1, 2, 3 \tag{3}$$

Determination of corner coordinates can be defined from calibration photo (Figure 3).

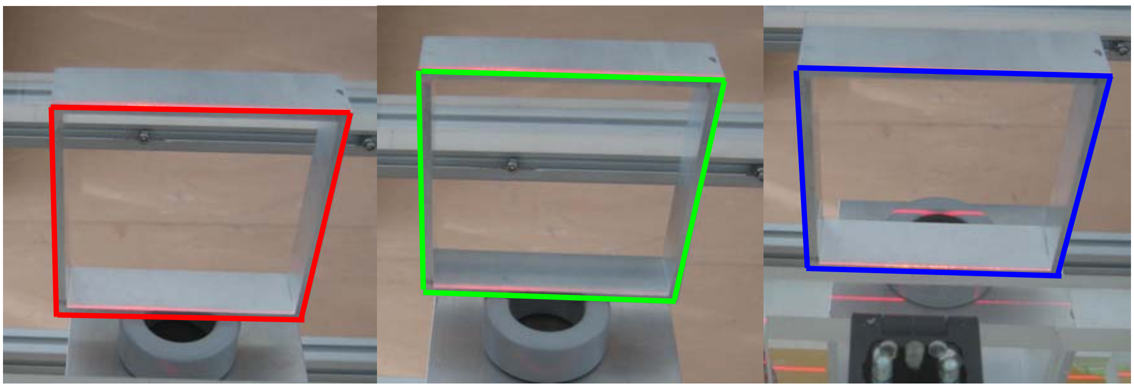

Figure 3. Calibrating rectangles

We are able to process different curves of the beams from the picture (Figure 4). Upon the filtered points and calibrating rectangles 3D coordinates of the surface points are defined. The surface curves of the specimen are defined by polynomial regression (Figure 5) [6].

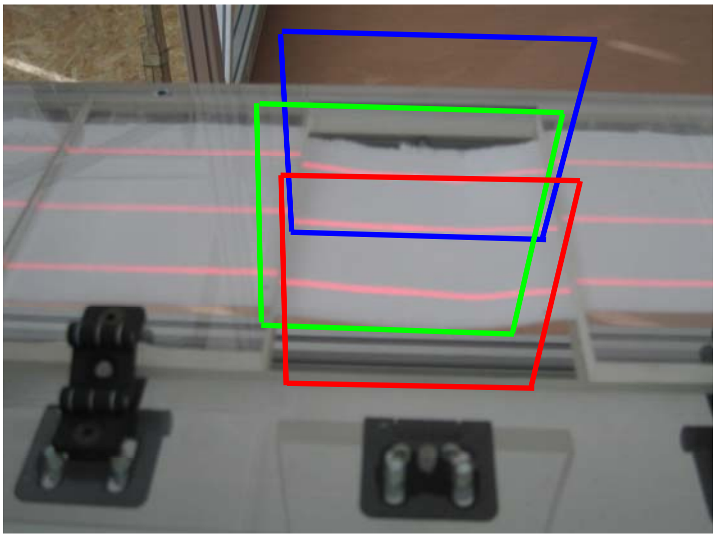

Figure 4. Measuring Process

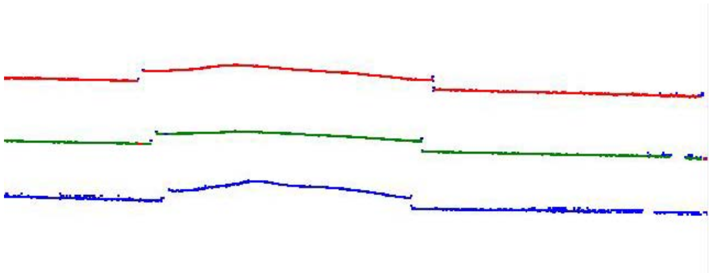

Figure 5. Processed curves

Estimation of the bending parameters

The strip-like specimen cut out of fabrics, fibrous mats, or flexible fiber reinforced composites is laid on a horizontal plate and gripped at both ends with a span length L_o. After removing the supporting plate from between the grips the specimen stretches under its weight and takes up a curved shape that is represented by the middle line in Figure 6. This middle line can be determined as a y(x) function from the image of the laser beams projected on the specimen using suitable image processing methods developed. Before loading the initial geometrical parameters of the specimen of rectangle cross section are the cross section area ($A_o=b_oh_o$), the inertial moment ($I_o=h_o^3b_o/12$), and the linear density ($q_o=\rho A_o$) where b_o and h_o are the width and the thickness respectively, and ρ is the volume density.

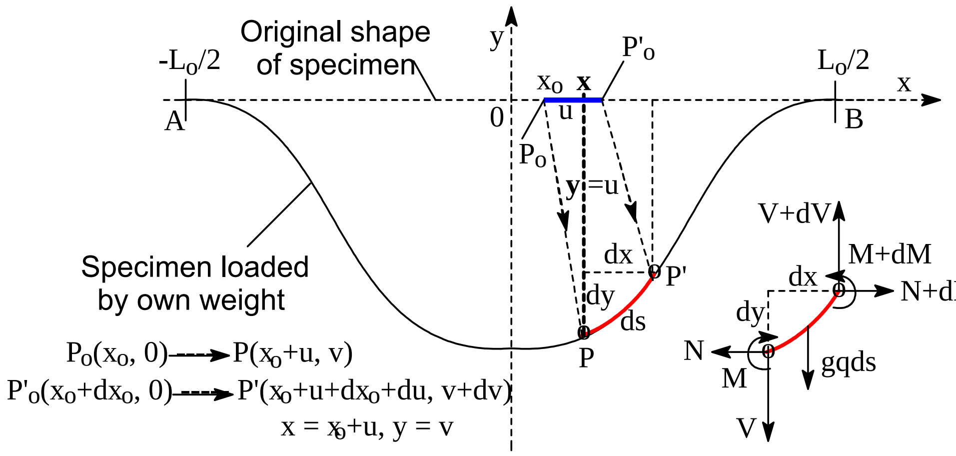

Figure 6. Shape of a fabric specimen and the displacement and deformation of a small segment as an effect of forces and bending moments

Supposing that the material of the specimen is linear elastic with finite tensile (A_oE) and bending (I_oE') stiffnesses – E and E' are the tensile and bending modulus respectively – the equilibriums of the forces and moments acted on a segment of length ds provide the following equations (Figure 6):

$$N = N_o = constant; \quad \frac{dV}{dx} = gq\sqrt{1+y'^2}; \quad \frac{dM}{dx} = Ny' - V \tag{4}$$

where q is the local linear density of the loaded specimen, y' and y" are derivatives, g is the gravitational acceleration. The relationship between the bending moment and the local curvature (κ) is well known from the classical bending theory [7-10]:

$$M = IE'\kappa; \quad \kappa = \frac{y''}{\left(1+y'^2\right)^{3/2}} \tag{5}$$

where I is the inertial moment of the cross section of the loaded specimen. For wide specimens, if $b_o > 6h_o$, E' is to be calculated with the Young modulus (E) and the Poisson factor (ν) as follows [8]:

$$E' = \begin{cases} E, & b_o \le 6h_o \\ \dfrac{E}{1-\nu^2}, & b_o > 6h_o \end{cases} \tag{6}$$

The crosswise contraction is taken into account with assuming volume permanence during deformation hence the cross section (A), the linear density (q), and the inertial moment (I) of the loaded specimen are as follows:

$$A = \frac{A_o}{1+\varepsilon}, \quad q = \frac{q_o}{1+\varepsilon}, \quad I = \frac{I_o}{(1+\varepsilon)^2} \tag{7}$$

Combining all the equations obtained above the following differential equation can be derived:

$$I_o E' \frac{d^2}{dx^2}\left[\frac{\kappa(x)}{(1+\varepsilon(x))^2}\right] = N_o y'' - g q_o \frac{\sqrt{1+y'^2}}{1+\varepsilon(x)} \tag{8}$$

In equation (8) the unknown parameters are E' and N_o. They can be determined in the knowledge of the deflection curve, y(x), and the local strain ε(x). To the latter the Hooke's law can be applied:

$$F(x) = AE\varepsilon(x) = A_o E \frac{\varepsilon(x)}{1+\varepsilon(x)} \tag{9}$$

where F(x) is the tangent projection of the resultant force (Figure 7) for which we obtain utilizing equation tgα=y' as well:

$$F(x) = \sqrt{N^2 + V^2}\, cos(\beta - \alpha) = N_o \frac{1 + \frac{V(x)}{N_o}}{\sqrt{1+y'^2}} \tag{10}$$

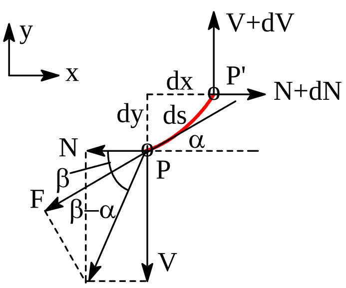

Figure 7. Tensile force (F) as the projection of the resultant in tangential direction

By combining equations (4), (9), and (10) the local strain, ε(x), can be expressed by the derivatives of y(x).

Using some simplifications described below the creation and use of another differential equation for ε(x) can be avoided besides retaining the effects of bending and stretching.

(1) Neglecting displacement u(x) ($u \equiv 0 \Rightarrow x = x_o \Rightarrow 1+\varepsilon = \sqrt{1+y'^2}$) leads to the following differential equation:

$$I_o E' \frac{d^2}{dx^2}\left[\frac{\kappa(x)}{1+y'^2}\right] = N_o y'' - g q_o \tag{11}$$

(2) Considering the mean strain ($\bar{\varepsilon}$) instead of the local one (ε) in equation (8):

$$\bar{\varepsilon} = \frac{s(L_o/2) - L_o/2}{L_o/2} = \frac{2}{L_o}\int_o^{L_o/2}\sqrt{1+y'^2}\,dx - 1 \qquad (12)$$

where s(x) is the arc-length of the loaded specimen.

(3) Neglecting the crosswise contraction (ε<<1) strongly simplifies equation (8):

$$I_o E' \frac{d^2\kappa(x)}{dx^2} = N_o y'' - g\bar{q}\sqrt{1+y'^2} \qquad (13)$$

where $\bar{q}$ is the mean linear density of the loaded specimen:

$$\bar{q} = q_o \frac{s(L_o/2)}{L_o/2} = \frac{2q_o}{L_o}\int_o^{L_o/2}\sqrt{1+y'^2}\,dx \qquad (14)$$

Substituting the measured deflection function, y(x), into any of the simplified differential equations and considering that at the maximum deflection (x=0, y'(0)=0) and e.g. at the inflection point ($x=x_I$, $y''(x_I)=0$) provides two algebraic equations from which the sought parameters can be determined.

Summary

A contactless optical measuring method was developed for determining the bending properties among them the bending stiffness of textiles such as woven or knitted fabrics, fleeces, and mats. The shape of specimen deformed under its own weight is scanned by laser beams and recorded by a camera. Using suitable calibration the surface can be described by polynomial regressions that can be treated as the solution of a differential equation derived for the bent sample. After substituting the measured solution into the differential equation linear algebraic equations can be obtained from which the bending parameters can be estimated.
In a following paper we intend to report about the results obtained by applying this measuring and evaluating method.

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