# Analytical and Experimental Determination of Elastic Properties for Synthetic Leather

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*Composite materials based on synthetic leathers from Polyvinyl Chloride and Polyurethane with knitted fabric support are increasingly used in many sectors of industry. Two synthetic leathers have been analysed both through experimental and analytical methods in order to evaluate their elastic properties. The analytical evaluation of material elasticity was conducted based on a micromechanical approach, taking into account the Krenchel's coefficient for Polyester fibre orientation and based on the analytical models of Leaf and Glaskin and Chamis. Experimental data was gathered using microscopic analysis and the mechanical impulse excitation test method. Results showed a good correlation with that from the experimental study. Thus, it was confirmed that the Leaf and Glaskin model and the Chamis model have a good accuracy in prediction of fibres orientation and respectively elastic properties of synthetic leather based on plain jersey.*

*Keywords: synthetic leather, plain weft knitted fabric, mechanical properties, micromechanical models, mechanical impulse excitation.*

In the last decade many researchers have analyzed materials from synthetic leather with knitted fabric support. Different knitted structures in various geometric patterns and constants of elasticity were studied. In order to calculate the mechanical properties one must know the knitting structure, the length of the loops of plain, the parameters of the knitted yarn, and the knitted fabric parameters.

The most popular models for calculating geometric length of a yarn loop knit were examined by Alenka Pavko-Cuden et al. [1]; these models are: Pierce, Dalidovici, Vekassy and Morooka & Matsumoto. They studied the loop length of the knitting fabric using parameters of the structure such as: loop width (A), loop height (B), loop length (l), yarn thickness (d) and fabric thickness (t). Fabric thickness (t) is one of the most important knitted fabric parameters, influencing insulation properties, UV radiation protection, material consumption and air permeability. The loop length (l) is influenced by yarn input tension, yarn structure, yarn linear density, knitted fabric take-down tension, knitting velocity, machine gauge, etc. [2,3]. H.R. Karimi et al. [4] have analyzed theoretical load-extension behaviour of plain weft-knitted fabric, based on the Castigliano's teorem. This theorem was used as the principal method and provided a theoretical relationship between the initial fabric modulus and the fabric geometry. An analysis of the initial load-extension behaviour of plain-woven fabric is also presented by Leaf and Kandil [5]. In this study they showed that the material elasticity is dependent on the fabric specification such as CPC (course per centimetre), WPC (wale per centimetre), and stitch length. Yarn properties such as compression, extension and bending rigidity were taken into account in addition to fabric characteristics and tightness factor. Dusserre et al. [6] analyzed knitted composite materials with inlaid yarns by micromechanical models. These models have been studied starting from some theories developed by Chamis [7], rule of mixtures [8-11], and Uemura model [12]. To predict the elastic behaviour of weft-knitted composites, Ruan & Chou [13] have proposed a mixed iso-strain and iso-stress model. The iso-strain model was used in assembling sub-volumes of the curved yarns in the course and respectively wale direction; they are assembled in series using the iso-stress model. This model was applied on the plain-stitch fabric.

In this paper two leather substitutes materials with a knitted plain jersey on the back side were analyzed. The focus was on the elastic properties of the composite material in longitudinal and transverse direction, of the knitted structure of plain jersey, and of the sheet of the PVC and PU. Synthetic leather from these materials is used in many industrial fields [14], thus, it is important to know their tensile behaviour both in longitudinal and transversal direction, and to adopt different improved solutions using the obtained values of the elasticity modulus.

## Experimental part

### *Materials and methods*

The composite synthetic leathers

First material tested was a material used in the manufacture of sheets tents and upholstery cars. It was synthetic leather composed of polyester woven into a polyurethane matrix. The samples had the following characteristics: fibber content: 11.328 % Polyester fiber (knitten fabric); flexibile PU 88.671 % (polyurethane matrix). The second material is synthetic leather used especially for upholstery, beds, chairs, etc. Its composition is: fibber Polyester 13.75% (knitted fabric); flexibile P.V.C 81.25% (polymer matrix) and 5% organic constituents.

The knitted material, which is on the back of the composite fabric, is made on flat knitting machines and it is obtained by successive looping of one or more threads in the transverse direction, resulting in a plain jersey or single jersey [15].

Besides the two different matrices of the analyzed materials, another difference is that in the plain knitted fabric from PVC appears an additional yarn knitted with 1:3 ratio (one eye contains an additional yarn and the

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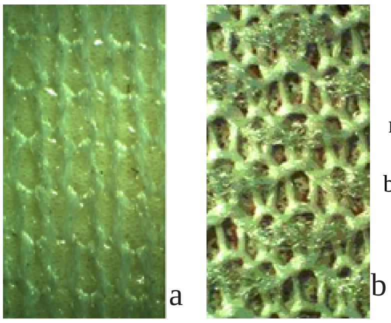

Fig. 1. The analyzed synthetic leather materials: a) plain knitted fabric with PU; b) plain knitted fabric with PVC

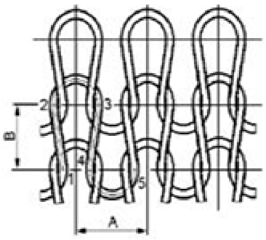

Fig. 2. The plain knitted fabric [15]

following three do not have this additional wire) ( fig. 1.a and b).

### Geometric characterization of the plain jerseys

Microscopic analysis of the two plain jerseys from the backside of the composite materials was used to determine the structural and the geometrical parameters.

In figure 2, the structural parameters are described where A is the distance between the symmetry axes of two neighbouring loops, in mm, and B is the loop height in mm.

For the analytical model three geometric parameters are needed, the fibre yarn diameter, d (cm), the fabric loops per unit length in course direction, called wale number, W (loop/cm), and the fabric loops per unit length in the wale direction, called course number, C (loops/cm), which are described in the figure 3 and figure 4. The relationship between the structure parameters and geometric parameters of the plain jersey is: C = A and W=2B.

For the first material, with polyurethane (PU), the microscopic analysis showed the following values for the geometrical parameters: C = A = 0.675 loops/mm, W = 0.842 loops/cm, B = 0.421 loops/cm and d = 0.18 mm; for the second material, with polyvinyl chloride (PVC), the parameters were: C = A = 0.83 loops/cm, W =1.76 loop/cm, B = 0.88 loops/cm and d = 0.20 mm.

### Analytical evaluation of elastic properties

Ramakrishna et al. [9], proposed a model to study the analytical evaluation of elastic properties of composite materials based on the models of Leaf and Glaskin and Chamis. The same algorithm was used in this paper to obtain the analytical elastic properties of the two chosen materials.

Knowing $V_{fy}$ (volume fraction of the yarn) the unidirectional elastic properties of the materials: the laminate constants in the elastic plane (tensile modulus in the fibre directions $E_{11}$ and in the transverse direction $E_{22}$, Poisson's Ratio $\nu_{12}$ and in plane Shear Modulus $G_{12}$) and the angle between the segment K and the load direction $\psi_{k}$, can be calculated.

$E_{11}$, $E_{22}$, $\nu_{12}$ and $G_{12}$ are calculated from the elastic properties of the fibre and matrix (tensile modulus, respectively $G_f$ and $G_m$), using a homogenizations model of a unidirectional laminate. Ramakrishna et al. introduced the Krenchel'coeficient in the calculation of Young's modulus of the Chamis model, and obtained:

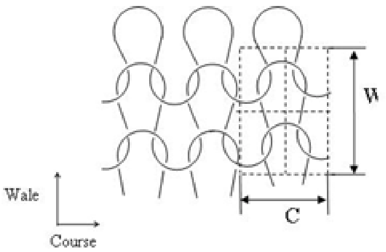

Fig. 3. Structural representation of the plain jersey for sample 1 with PU

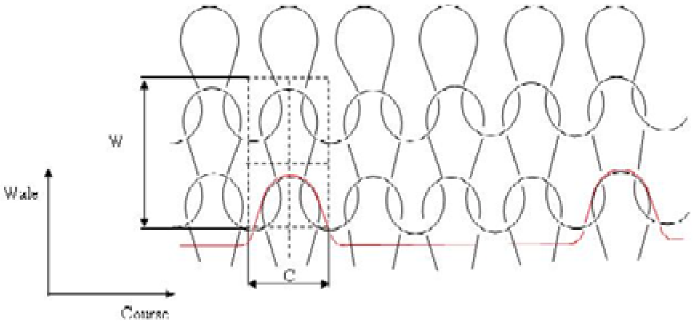

Fig. 4. Structural representation of the plain jersey (with one additional yarn in relation 1:3) for sample 2 with PVC

$$E_{11} = \eta \cdot Vf_y E_f + (1 - Vf_y)E_m \tag{1}$$

$$\nu_{12} = Vf_y \nu_f + (1 - Vf_y)\nu_m \tag{2}$$

$$E_{22} = \frac{E_m}{1 - Vf_y\left(1 - \frac{E_m}{E_f}\right)} \tag{3}$$

$$G_{12} = \frac{G_m}{1 - Vf_y\left(1 - \frac{G_m}{G_f}\right)} \tag{4}$$

For the plain jerseys the Krenchel factor depends on L which is the total length of the fibres yarn in the RVE (Representative Volume Element, fig.5 and 6), and $\alpha_i$ is the angle of a considered yarn segment $L_i$:

$$\eta = \frac{1}{L}\int_0^L \cos^4(\alpha)dL \approx \frac{1}{L}\sum_{i=1}^{M} L_i \cos^4(\alpha_i) \tag{5}$$

Leaf and Glaskin determined the coordinates for the first and second yarn of the RVE section along the x, y, z axes based on the W (loop/cm), C (loop/cm) and d (cm) (fig.6 and 7).

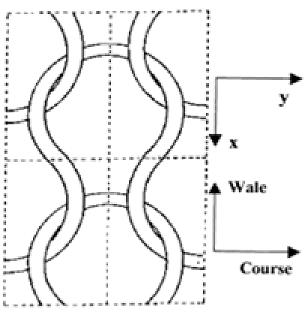

Fig. 5. Schematic diagram of (a) unit cell divided in four RVE [ 9]

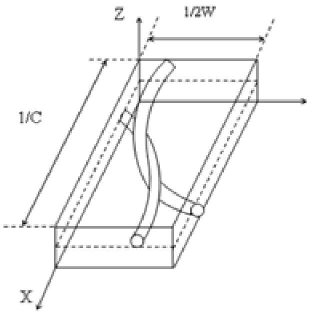

Fig. 6. The RVE of plain weft-knitted fabric with 2 yarns (sample 1 with PU)

The coordinates of the first yarn are:

$$\begin{cases} x = ad(1 - \cos\theta) + x_0 \\ y = ad\sin\theta \end{cases} \quad 0 \leq \theta \leq \varphi \tag{6}$$

$$a = \frac{1}{4Wd \sin \varphi} \qquad (7)$$

$$\varphi = \pi + \sin^{-1}\left( \frac{C^2 d}{\left[ C^2 + W^2 \left(1 - C^2 d^2\right)^2 \right]^{1/2}} \right) - \tan^{-1}\left( \frac{C}{W\left(1 - C^2 d^2\right)} \right) \qquad (8)$$

$$\psi = \sin^{-1}\left( \frac{2a}{2a - 1} \sin \varphi \right) \qquad (9)$$

$$x_0 = \frac{1}{C} - ad\left(1 - \cos \varphi\right) \qquad (10)$$

For the second test material in RVE section we have 3 yarns, two yarns woven together and the third is anchored over the two, (fig. 7).

The coordinates of the second yarn are:

$$\begin{cases} x_1^{2nd} = 2ad - \dfrac{1}{2W \tan(\psi)} + x_0 \\ y_1^{2nd} = \dfrac{1}{2W} \end{cases} \qquad (11)$$

$$\begin{cases} x_n^{2nd} = x_1^{2nd} - x_n^{1st} + x_0 \\ y_n^{2nd} = y_1^{2nd} - y_n^{1st} \end{cases} \qquad (12)$$

$$n \geq 2,\ 3, \ldots$$

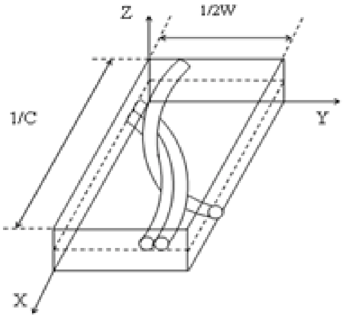

Fig. 7. The RVE of plain weft knitted fabric with 3 yarns (sample 2 with PVC)

Experimental evaluation of elastic properties using mechanical impulse excitation

The tests on the chosen materials were performed according to ASTM E 1876-01- Standard Test Method for Dynamic Young's modulus, Shear modulus and Poisson's ratio by Impulse Excitation of Vibration [16, 17]. The sample dimensions were: 6 mm in diameter, and thickness: t = 0.96 mm (first material with PU), and t = 0.84 mm (second material with PVC). Four samples were tested for each material.

**Table 1**
RESULTS OF ELASTIC PROPERTIES FOR THE ANALYZED MATERIALS

| | Young's modulus $E_{11}$(MPa) | | Young's modulus $E_{22}$(MPa) | Shear modulus G(MPa) | | Poisson's Ratio ν | |
|---|---|---|---|---|---|---|---|
| **Samples** | Analytical | Experimental | Analytical | Analytical | Experimental | Analytical | Experimental |
| Synthetic leather with PU | 63.16 | 69.77 | 2.293 | 24.67 | 29.43 | 0.204 | 0.185 |
| Synthetic leather with PVC | 37.76 | 38.73 | 3.96 | 14.98 | 16.98 | 0.162 | 0.141 |

## Results and discussions

Based on RVE cell size the ö angle was determined: φ = 158.283° for the first material with PU, and φ =145.264° for the second material with PVC. The angle φ was then divided into eight equal angles, resulting in eight equal linear segments on each curved knitted yarn.

Thus, applying Leaf and Glaskin's model the beginning and end coordinates of each segment were set and the length of each segment and their orientation were calculated. For the first material with PU the Krenchel's coefficient is $\eta$ = 0.298, and $L_{RVE}$ = 2.111, $V_f$ = 0.10 m³; $V_m$ = 0.9 m³; for the second material tested with PVC $\eta$ = 0.271, $L_{RVE}$ = 3.442, = 0.11m³, and 0.88 m³ [18, 19].

The analytical results are in good agreement with the experimental one validating the applicability of Leaf and Glaskin's model for obtaining the elastic properties of plain jersey (table 1).

The Young's modulus ($E_{11}$) of synthetic leather with PU in the 1 direction is higher than the Young's modulus of the synthetic leather with PVC both for experimental and analytical determination. In return in direction 2 the Young's modulus ($E_{22}$) of PU material is less than the PVC material. Shear modulus G in longitudinal direction is higher for the PU synthetic leather because it is a more rigid material compared to that with PVC. Poisson'ratio of the material with PU is the higher than PVC because this material is stiffer and harder than PVC which is soft and flexible.

Analytical prediction of the mechanical properties of synthetic leather is very important for the better evaluation of these materials in industry applications.

## Conclusions

This paper presents an analysis of the mechanical behaviour of two synthetic leather materials commonly used in the textile industry. The analysis includes an experimental study in which the mechanical properties were determined for these two composite materials and a theoretical study of the Young's modulus, Shear modulus and Poisson's ratio of the chosen materials based on micromechanical models.

Results show that the chosen analytical models, Leaf and Glaskin together with Chamis, to evaluate material behaviour showed very similar results with the experimental values. These micromechanical models have proven to be very useful for understanding and analyzing the elastic properties of synthetic leather. Studying these models side by side with different experimental programs provides new information about their behaviour and helps researchers to obtain new structure design of the plain jersey that gives the overall material better mechanical characteristics.

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