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# Bending Stiffness of Knitted Fabrics – Comparison of Test Methods

**Abstract**
*The bending stiffness of a textile is a feature determining comprehensive indicators such as fabric drapability and handle. Most methods of assessing the bending stiffness of textiles are based on the principle of the determination of the strain and force dependence. The simplest are methods involving the unidirectional straining force, which do not consider the anisotropy of the fabric's physical properties. However, methods that allow the determination of multi-directional stiffness provide a more complete assessment. The aim of this work was to comparatively evaluate three testing methods that utilise different measurement principles. The experimental design included a unidirectional force action (PN-73/P0431), multidirectional force action (ASTM-D 4032-94), and bending stiffness testing by the direct determination of Young's modulus by the method used at Kiev University. The methods analysed were assessed by statistical tests. Knitted fabrics with a net stitch were used as the test materials.*

**Key words:** *test methods, bending stiffness, statistic test.*

## Introduction

The stiffness of some fabrics constitutes the basic feature determining their suitability for a specific use. The bending stiffness of textiles has become a fundamental property in determining the complex parameter of fibre or fabric drapability and handle.

The drapeability of textiles in physical terms is a result of mutual interaction between the bending stiffness and fabric weight [1, 2].

Generally rigidity is defined as the capability of a material to resist strain under the influence of different forces such as compression, uniaxial tension, bending, simple shearing or vibration [3]. For elastic bodies, in most strains, stiffness is characterised by **Young's** modulus (**E**), determined as the modulus of linear strain ability [4]. This is a parameter determining fabric elasticity, which makes the material linear strain dependent on stress occurring in it according to the dependence:

$$\boldsymbol{E} = \sigma/\varepsilon, \text{ N/m}^2 \qquad (1)$$

where: $\varepsilon$ - relative linear strain, $\sigma$ - stress

The stiffness rigidity (**G**) is measured by the product of modulus (**E**) and the moment of inertia (**I**) of the cross-section in relation to the neutral axis passing through the middle of the cross-section according to the following formula:

$$\boldsymbol{G} = \boldsymbol{E} \cdot \boldsymbol{I}, \text{ N} \qquad (2)$$

This dependence constitutes a theoretical basis for the physical determination of the bending rigidity parameter [1].

Isotropic materials are characterised by one Young's modulus, while for anisotropic materials such as textiles, the number of elasticity coefficients is higher than one, which are connected with the main anisotropy directions. Due to the complex fibre structure, the action of external forces results in complicated phenomena of mechanical properties that cannot be included in the classic theory of an elastic or plastic body. Taking into account the components of strain occurring under the influence of force, fibres are defined as anisotropic visco-elastic bodies [5]. The complexity of the fabric strain anisotropy results from the overlapping parameters of the structures of fibres, yarns and fabrics.

There are many test methods known for measuring fabric bending stiffness, but only few of them use Young's modulus as a basis for measuring stiffness [2].

Most methods described and used in textile laboratories are based on the principle of indirect stiffness assessment by determining the dependence of strain and the force that induces this strain. Some methods use tensile testing machines for precise measurement of the dependence of the force and strain of flat textile fabrics [6]. In view of the narrow range of the acting forces and occurring strains, such methods allow one to obtain results with smaller errors.

Dziworska [2] introduced two types of testers for measuring bending stiffness. The first type of testers measure the fabric strain under its own weight (gravitation method), whereas the other testers are based on the measurements of forces, bending moments or energy during bending. The most popular gravimetric methods are those using the determination of the bending length as a measure of the interaction between fabric weight and stiffness [7 - 11]. One of them is Pierce's Heard Loop Test [12]. This principle is used by ASTM [8] and PN [11]. A known example of the "bending length" principle is the Cantilever Test for Stiffness [13, 14].

The determination of fabric stiffness is also included in KES (Kawabata Evaluation System) and Handle-O-Meter Tester [15 - 19].

The simplest and most available methods are based on the unidirectional action of the straining force action [19, 20]. In view of the anisotropy of physical properties of textile fabrics, the method of the unidirectional action of force usually takes into account three basic directions of the fabric (longitudinal, transversal and the bias- 45 (deg) to the sample's axis). This is, however, a simplification that does not include the anisotropy character. The methods that determine multidirectional stiffness give a more complete assessment [21 - 26].

An interesting method has been developed at the Kiev National University of Technologies & Design (Ukraine) for the dynamic determination of elasticity modulus ($E_d$) based on a theory that elasto-plastic bodies subjected to cyclic sinusoidal stresses reach a state of equilibrium after a number of cycles, which is a function of the structure's dynamic properties [27]. A similar method of measuring Young's module for fibre was developed by Polish authors [28].

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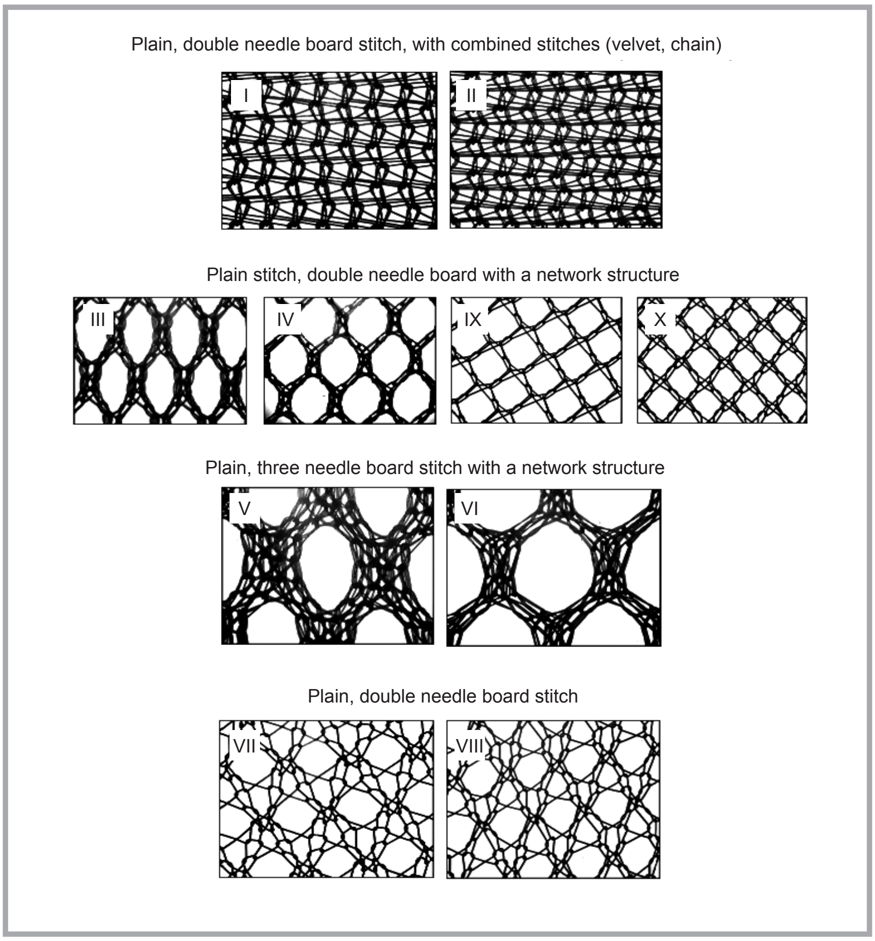
***Table 1.** Characteristics of test materials.*

| Symbol of knitted fabric group | Type of yarn | Type of knitting stitch | Fabric structure, number /cm |  | Weight, g/m$^2$ |
|---|---|---|---|---|---|
|  |  |  | wale | course |  |
| I | Polyester 30 dtex, f 1 | Plain, double needle board stitch with combined stitches (velvet, chain) | 16.3 | 11.8 | 54.0 |
| II |  |  | 20.0 | 12.0 | 65.2 |
| III | Polyester 56 dtex f 24 Double | Plain, double needle board stitch with network structure | 22.1 | 11.2 | 62.6 |
| IV | Polyester 56 dtex f 24 Single |  | 21.8 | 10.9 | 41.9 |
| V | Polyester 56 dtex f 24 Double | Plain, three needle board, stitch with network structure | 16.9 | 11.6 | 67.5 |
| VI | Polyester 56 dtex f 24 Single |  | 18.0 | 12.1 | 49.5 |
| VII | Polyester 30 dtex f 1 | Plain, double needle board stitch with network structure | 19.6 | 10.7 | 22.2 |
| VIII |  |  | 24.6 | 11.8 | 27.2 |
| IX |  | Plain, double needle board stitch, with network structure | 28.2 | 9.5 | 24.7 |
| X |  |  | 29.7 | 11.2 | 28.3 |


Plain, double needle board stitch, with combined stitches (velvet, chain)

Plain stitch, double needle board with a network structure

Plain, three needle board stitch with a network structure

Plain, double needle board stitch

***Figure 1.** Images of knitting stitches.*

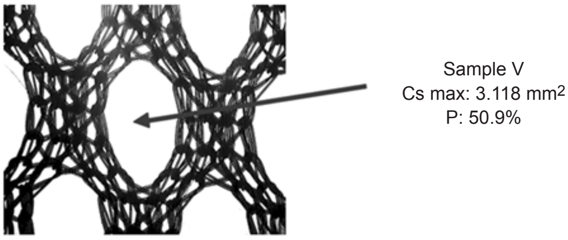

Sample V
Cs max: 3.118 mm$^2$
P: 50.9%

***Figure 2.** Surface of a single void of an exemplary sample.*

The aim of this work was to comparatively evaluate three selected testing methods using different measurement principles to evaluate the bending stiffness of netlike warp knitted fabrics.

The test material consisted of 10 groups of surgical netlike warp knitted fabrics with various variants of yarn and knitting stitches of the same fibre raw material (polyester).

The experimental design includes unidirectional force action (PN-73/P0431) and multidirectional force action (ASTM-D 4032-94) as well as bending stiffness testing by direct determination of Young's modulus by the method used at Kiev University.

Comparison of results and properties of the methods evaluated was carried out by means of statistical tests [29 - 32].

## Experimental details

### Material

Test materials consisted of polyester openwork warp knitted fabrics with different fabric and yarn parameters. Basic fabric parameters and images of knitting stitches are listed in ***Table 1*** and shown in ***Figure 1***.

To better characterise the structure of the net knitted fabrics tested, the following parameters were determined on the basis of microscopic analysis [33]:

*Cs total* - Total surface of voids - the sum of surfaces of all the voids on the sample surface tested *Ss* in mm$^2$

*Cs max.* - Maximal surface of a single void in mm$^2$, ***Figure 2***.

*P* - Porosity - the percentage content of the total void surface in the sample surface

$$P = Cs\ total/Ss, \% \qquad (3)$$

The results of this analysis are listed in ***Table 2***.

### Methods

***Determination of textile fabric stiffness - Polish Standard PN-73/P0463* [11]**

This is a gravitational method based on Pierce's theory. The principle of this method consists in measuring the bending length of a sample, whose both ends are fixed in a clamp. The freely hanging sample forms a heard loop, and the sag length in m is the basis for determination

***Table 2.*** *Structural parameters of the knitted fabrics tested.*

| Symbol of knitted fabric group | Porosity P average value, % | Max clearance surface Cs max., mm$^2$ |
|---|---|---|
| I | 46.6 | 0.14 |
| II | 35.3 | 0.05 |
| III | 55.7 | 1.70 |
| IV | 69.1 | 1.91 |
| V | 50.9 | 4.77 |
| VI | 65.2 | 3.12 |
| VII | 73.9 | 1.04 |
| VIII | 71.0 | 0.89 |
| IX | 74.8 | 1.19 |
| X | 71.2 | 0.86 |

of the bending length. ***Figure 3*** shows the scheme of measurement.

The loop length m allows determination of the bending length *c* on the basis of tabulated values $c = f(m)$

Based on the measurement results, the bending stiffness, ***G***, is determined:

$$\boldsymbol{G} = 10^{-6} \cdot m_F \cdot c^3 \cdot g, \text{ mN·m} \quad \text{(mN·m - milinewton meter)} \qquad (4)$$

where: $m_F$ – fabric weight, g/m$^2$, $c$ – bending length, cm, $g$ – acceleration of gravity, m/s$^2$.

Bending modulus ***q*** is calculated from the formula:

$$\boldsymbol{q} = 1.2 \cdot 10^4 \cdot G/h, \text{ kPa} \qquad (5)$$

where: $h$ –sample thickness, mm.

Measurements are separately performed for the longitudinal and transversal directions and the result is the geometrical average of both measurements.

For each sample and each direction the sample size was n = 10.

All calculations was made in agreement with formula of PN -73/P0463.

### *ASTM D 4032 – 92, Standard test method for measuring fabric stiffness by the circular bend procedure* [22]

This is a method of multidirectional force action to a specified strain. Its principle of measurement consists in determining the maximal force of a mandrel causing a simultaneous multidirectional fabric strain by pushing a sample through the tester table hole. Stiffness measurements according to this method were performed by means of a digital pneumatic. Schema of the Stiffness Tester, shown in ***Figure 4***.

The force **F**, N required to push out a sample along the hole's axis at a length of 57 mm is a result of measurement. An electronic meter with a memory element allows a read-out of 10 measurements with statistics. Stiffness measurements were performed according to the procedure of the above standard for sample size n = 10.

### *Dynamic modulus of elasticity $E_d$ (method UDM-1)* [27]

Tests of bending stiffness based on the determination of Young's modulus were carried out at Kiev National University of Technology & Design. The UDM-1 apparatus operating on the principle of inducing the resonance of the sample's longitudinal vibration and measuring the vibration frequency at the moment of equilibrium allows one to determine the elasticity modulus. A scheme of this apparatus is shown in ***Figure 5***.

The dynamic modulus of elasticity is determined on the basis of the sample vibration and parameters (dimension and weight). The samples were loaded with a given mass MI depending on the type of fabrics tested. Under the influence of this load samples were investigated. Free longitudinal damped oscillations occur in the sample due to the given load. Oscillations depend on the properties of the materials, in particular its elasticity.

To determine the oscillation period, *Tp*, one must determine the oscillation frequency of the sample. This can be achieved by turning the handle of the generator at the frequency which resonance occurs. The numerical value of Tp appears on the frequency meter at the moment of resonance.

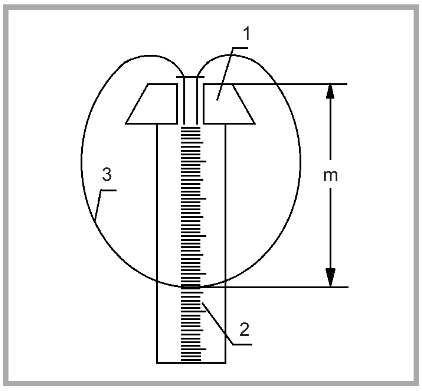


***Figure 3.*** *Scheme of measurement by the loop method; 1) clamps, 2) measuring scale, 3) fabric sample, m) loop length [11].*

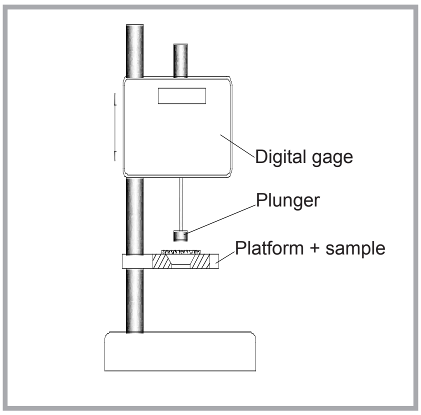


***Figure 4.*** *Digital pneumatic stiffness tester [23].*

The low frequency generator determines the frequency of oscillation at resonance, and the frequency meter gives the numerical value of the period, *Tp*. It is the numerical value of the period that is used for further calculations.

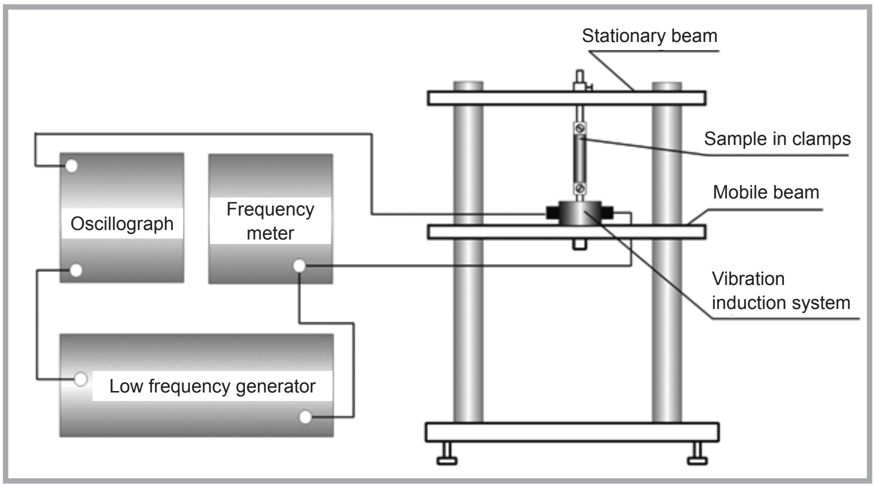


***Figure 5.*** *Operating principle of UDM-1 instrument.*

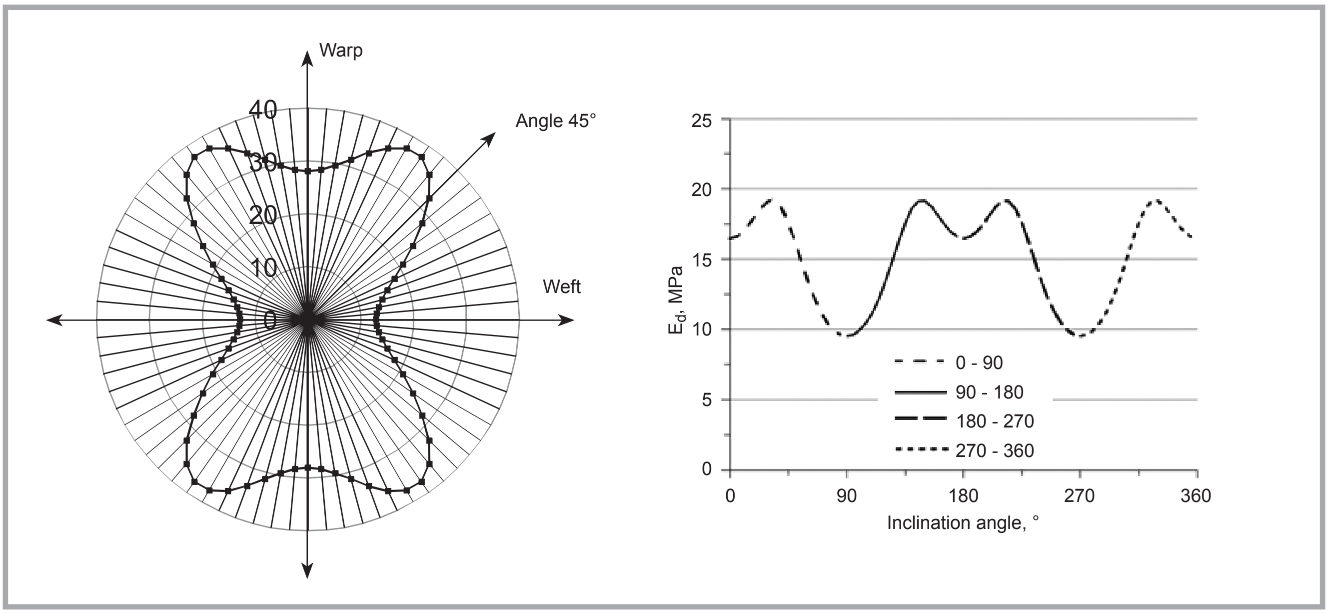


***Figure 6.*** *Diagrams of $E_d$ as a function of the inclination angle of the sample's axis to the direction of vibration (sample VII).*

On the "Oscillograph" one can see the moment when resonance is reached.

The elasticity modulus $E_d$ is calculated from the following formula:

$$E_d = \frac{4\pi^2 l_0 M}{ScTp^2}, \text{ N/m}^2 \qquad (6)$$

where: $l_0$ - operating sample length in m, *Ml* - load weight in kg, *Sc* - surface of sample cross-section in m$^2$, *Tp* - vibration period corresponding to resonance moment in s.

The bending stiffness $R_b$ can be determined using the formula of bending stiffness:

$$R_b = E_d I, \text{ Nm}^2 \qquad (7)$$

The moment of inertia *I* for a rectangular sample cross-section amounts to:

$$I = \frac{bh^3}{12}, \text{ m}^4 \qquad (8)$$

where: *b* - sample width, *h* - sample thickness.

Measurements are carried out on rectangular samples of width = 30 mm and length = 100 mm cut out in longitudinal and transversal directions, and at an angle of 45°. The load mass *MI* = 0.0407 kg. The measurement result is an average value of sample size n = 15.

The calculations were performed in accordance with the methodology set [27].

The program developed for mathematical processing, which is linked to the apparatus, allows one to analyse the elasticity modulus in each direction (multi-directionally), within an angle range of 0 - 360°, using the interpolation method [26].

This processing results in a polar diagram of modulus $E_d$ as a function of the inclination angle (angle between the sample's axis and the direction of vibration). The representation of $E_d = f\,(\text{angle})$ within the range of 0 - 360° in the form of a linear diagram shows that in view of the mirror reflections of curves in successive ¼ ranges of the polar diagram, it is enough to analyse the variability of $E_d$ values or angles at 0 – 90°. $E_d$ assessment takes into account the anisotropic properties of textiles. ***Figure 6*** shows examples of polar and linear diagrams.

In the method described above, the result of stiffness assessment consists of the averaged $E_d$ values for the basic directions (longitudinal, transversal and bias direction - 45 (deg) to the sample's axis) and the polar diagram.

## Statistical analysis

Statistical procedures were carried out with the use of the STATISTICA 8 program [29].

The following tests were performed:

- Descriptive statistics – M - mean, SD - standard deviation, SV – coefficient of variation, shape of distribution normality
- Analysis of variance:
  - one-way ANOVA, a technique used to compare the means of groups (ten groups of knitted fabrics)
  - post hoc statistics in groups, results of multiple comparisons peer-to-peer (45 pairs of groups). Significant difference between pairs at the level α = 0.05 ; tests for distribution normality – RIR Tukey's; without normal distribution – Krusk-Wallis H.
- Spearman's rank correlation

  To check the comparability of results of the methods analysed Spearman's rank correlation coefficients between stiffness results of the methods were calculated.
- Test power analysis. Performing power analysis and sample size estimation is an important aspect of experimental results [29 - 32] The power of a test is determined by three factors: the sample size, α level, and effect size. The levels of effect size determined by Cohen [31, 32] and used for test power calculation are listed in ***Table 3***.

***Table 3****. Levels of effect size.*

| Effect size | Power levels | | |
|---|---|---|---|
| | Small | Medium | Large |
| Normal distribution f-tests ANOVA | 0.10 | 0.25 | 0.40 |
| Without a normal distribution t-test on means | 0.20 | 0.50 | 0.80 |

The test power for the groups analysed was calculated using level α = 0.05; effect sizes at a medium and large level of power; tests for distribution normality – f - Anova test; without normal distribution - t-test on means.

The test power for the sample size of the methods was calculated and the number of measurements required for the acceptable test power level 0.8 – 0.9 was analysed [31, 32].

### *Analysis of the variability of directional bending stiffness based on the diagrams $E_d$*

Using the possibility of presenting the values of elasticity modulus ($E_d$) (UDM-1) in the form of a diagram comprising the whole range of the force direction 0 - 90°, an additional analysis of the modulus as a function of the direction of the force was made.

## Results and discussion

### Statistical analysis

### *Basic descriptive statistic parameters*

The test results of bending stiffness and the basic descriptive statistic parameters are listed in ***Table 4***.

Test of normality distribution show that only method UDM-1 has a normality shape of distribution.

### *Analysis of variance*

*One-way ANOVA*. In the results of the analysis of variance at the level of probability $p < 0.05$, marked effects were significant. It means that the averages of groups differ significantly.

*Post hoc statistics in groups, multiple comparisons peer-to-peer*. Analysis of results of multiple comparison peer-to-peer (45 pairs of groups) tests show that significant differences occur only in 40 - 50% of all the groups tested. Among the methods under comparison, it is the UDM-1 ($R_b$) method that better differentiates the groups tested than the remaining two methods.

The results of multiple comparisons by RIR Tukey's test and Krusk-Wallis H. test are listed in ***Table 5***.

Analysis of these results shows that significant differences occur only in 40 - 50% of all the groups tested. Among the methods under comparison, it is the UDM-1 ($R_b$) that better differentiates

***Table 4.*** *Test results of bending stiffness.*

| Symbol of knitted fabric group | PN<br>G, mNm; n = 20 | | | ASTM<br>F, N; n = 10 | | | UDM-1<br>$R_b$, Nm$^2$, n = 15 | | |
|---|---|---|---|---|---|---|---|---|---|
| | M | SD | CV,% | M | SD | CV,% | M | SD | CV, % |
| I | 8.02 | 0.61 | 7.60 | 1.67 | 0.05 | 3.50 | 2.39 | 1.22 | 51.0 |
| II | 4.81 | 1.50 | 31.2 | 1.73 | 0.05 | 14.3 | 3.00 | 2.55 | 84.9 |
| III | 3.28 | 0.44 | 13.4 | 1.52 | 0.18 | 12.1 | 2.02 | 1.13 | 56.0 |
| IV | 3.77 | 0.50 | 13.3 | 1.52 | 0.22 | 14.8 | 0.91 | 0.65 | 71.1 |
| V | 3.71 | 0.53 | 14.3 | 1.35 | 0.10 | 7.50 | 2.49 | 0.68 | 27.6 |
| VI | 3.08 | 0.37 | 12.0 | 1.40 | 0.31 | 23.4 | 2.16 | 1.23 | 56.9 |
| VII | 2.11 | 0.38 | 18.0 | 0.51 | 0.13 | 26.1 | 0.56 | 0.20 | 37.3 |
| VIII | 2.29 | 0.27 | 11.8 | 0.59 | 0.13 | 22.0 | 0.51 | 0.13 | 26.4 |
| IX | 1.79 | 0.76 | 42.5 | 0.51 | 0.11 | 21.8 | 0.47 | 0.49 | 104 |
| X | 2.08 | 0.25 | 12.0 | 0.58 | 0.13 | 22,0 | 0.56 | 0.57 | 102 |

***Table 5.*** *Results of multiple comparisons (45 pairs of groups). Significant difference between pairs at the level $p = 0.05$.*

| Method | Significant differences in number of pairs | Significant differences of all the groups tested, % |
|---|---|---|
| PN | 18 | 40 |
| ASTM | 18 | 40 |
| UDM-1 | 23 | 50 |

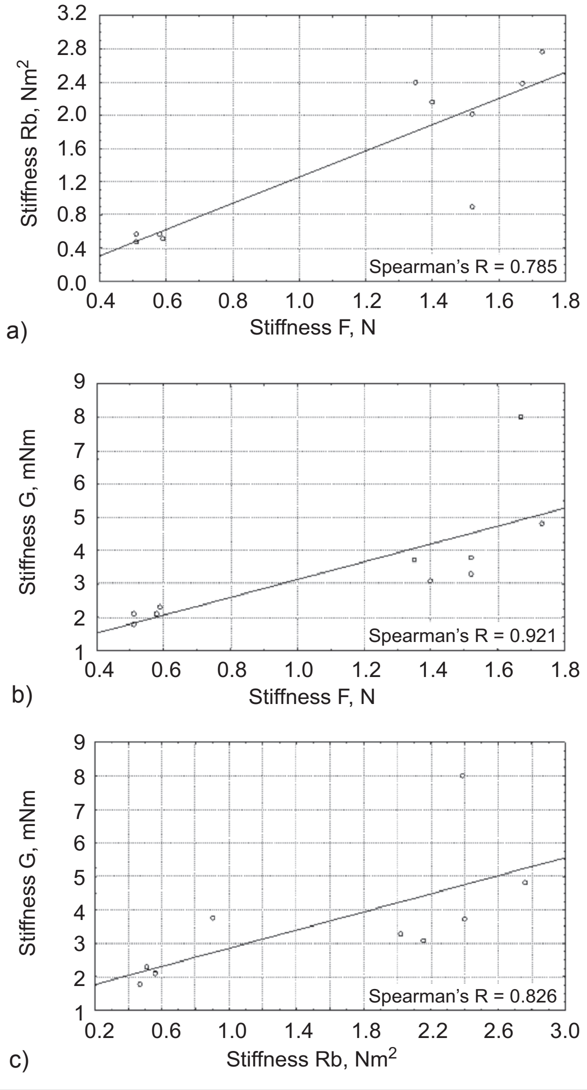


***Figure 7.*** *Results of Sperman's rang correlation between methods compared.*

***Table 6.*** *Results of power test analysis.*

| | Level of power | PN | ASTM | UDM-1 |
|---|---|---|---|---|
| **Sample size, n** | | **20** | **10** | **15** |
| **Effect size** | Medium | t = 0.50 | | f = 0.25 |
| | Large | t = 0.80 | | f = 0.40 |
| **Power calculated** | Medium | 0.15 | 0.09 | 0.45 |
| | Large | 0.31 | 0.17 | 0.98 |
| **Sample size required, n** | Medium | 189 | 189 | 37 |
| | Large | 74 | 74 | 15 |

the groups tested than the remaining two methods.

***Spearman's rank correlation***

Considering the different indicators and value level of the methods under analysis, Spearman's rank correlation was used for their comparison. The results of Spearman's rank correlation coefficients are shown in ***Figure.*** *7*. This graphs

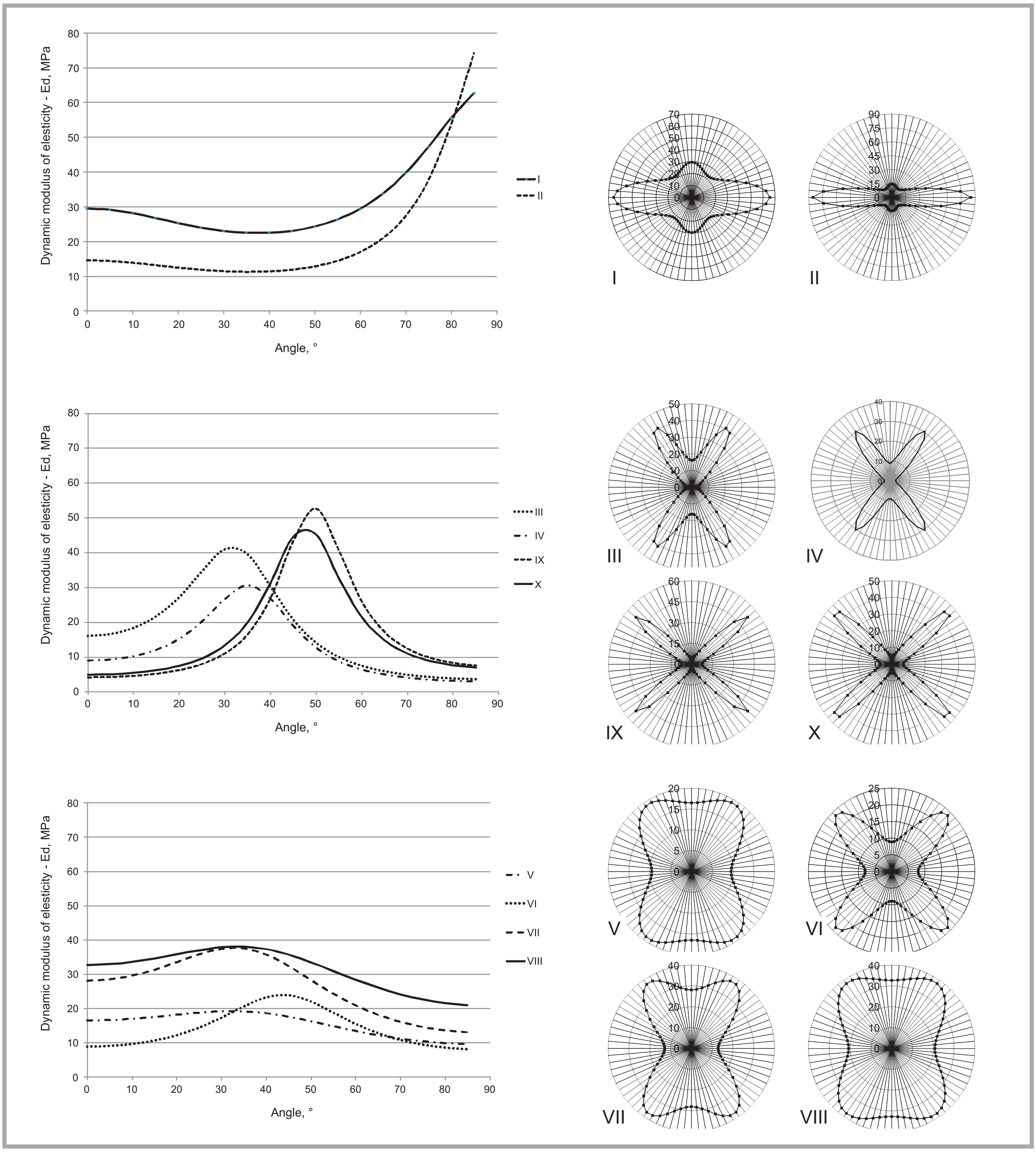


***Figure 8.*** *Image of diagrams for various groups of knitted fabric stitch: a) plain, double needle board stitches (velvet, chain), b) plain stitch, double needle board with a network structure; c) V, VI – plain, three needle board stitch with a network structure; VII, VIII – plain, double needle board stitch.*

show that a high level of correlation coefficients, R > 0.7, between all methods compared means that they give comparable revaluation of the bending stiffness of the fabrics tested. It is suitable to compare estimates of bending stiffness for results $R_b$, $G$ and $F$ but only in a specified range.

***Test power analysis*** Results of the test power calculated at the acceptance level of effect size (STATISTICA 8 program) are presented in ***Table 6.***

This results show that only the UDM-1 method reached a satisfactorily large level of test power - 0.9088 and has a sufficient sample size n = 15. Residual methods did not achieve satisfactory results of power - 0.8 - 0.9 at a large and medium level and could not bring results with a statistically significant difference. On the other hand the required sample size calculated for the standardised methods is difficult to use in practice.

***Analysis of the variability of the directional bending stiffness based on the diagrams $E_d$***

Diagrams of all the samples tested are shown in ***Figure 8***.

The presentation of diagrams $E_d$ as a function of the axis slope of the sample to the direction of force action allows one to isolate some groups corresponding to the stitch of the nets tested and to compare them within these groups. The shape of curves depends on the repeat determining stitch, clearance size, yarn thickness and structure.

Knitting of the first groups I and II, (***Figure 1***, ***Table 2***) with combined stitches (chain, velvet) shows increasing stiffness versus the angle up to the maximal double $E_d$ value for the parallel direction to wales (90°). At the same time, these groups show the greatest anisotropy of stiffness.

In the case of groups with plain net stitches, values of the elasticity modulus are sinusoidally changed, reaching their maximum within the range of 30 - 50°.

Analysing these diagrams, one can assess the character of bending stiffness for the specified fabric stitch on the basis of modulus values. Knitting with combined stitches (I and II) is characterised by the greatest stiffness among the knitting tested, which is shown at about 90°, i.e. in the direction of wales.

Groups with plain two-needle net stitches (III, IV, IX and X), ***Figure 8.b*** reach their maximal stiffness within the range of 30 - 60°.

Groups with plain three-needle and two-needle stitches and with different yarns and numbers of knitted loops (V, VI, VII and VIII), ***Figure 8.c*** constitute nets with the best multi-directionally equalised stiffness due to the smallest differences in the modulus versus the angle.

## Conclusions

The aim of this work was to comparatively evaluate three selected testing methods using different measurement principles and choose the best to evaluate the bending stiffness of net-like warp knitted fabrics. The experimental design included unidirectional force action (PN-73/P0431) and multidirectional force action (ASTM-D 4032-94) as well as bending stiffness testing by direct determination of Young's modulus (E) used for calculations of bending stiffness (method UDM-1). Comparison of results and evaluating properties of the methods was carried out by means of statistical tests with the use of the STATISTICA 8 program.

Results of the analysis of variance show that the one-way ANOVA for the three methods tested confirmed differences between the average values of bending stiffness for all the groups. Results of multiple comparisons peer-to-peer show that significant differences occur only in 40-50% of all the groups tested. Among the methods under comparison, it is the UDM-1 ($R_b$) that better differentiates the groups tested than the remaining two . The high level of Spearman's rank correlation coefficients, R > 0.7, between all methods compared is well suited to compare estimates of bending stiffness for results $R_b$, $G$ and $F$, but only in a specified range. Results of the test power show that only the UDM-1 method reached a satisfactorily large level of test power 0.9088 and has sufficient sample size n = 15. Standardised methods in PN and ASTM did not achieve satisfactory results of power 0.8 - 0.9 at a large and medium level, and the required sample size calculated for them is difficult to use in practice. Analysing the variability of the directional bending stiffness based on the diagrams ($E_d$), one can assess the character of bending stiffness anizotropy for the specified fabric stitch on the basis of modulus values. In a general summary it can be concluded that standardised methods in PN and ASTM, as a comparison, can be used in quality control, applicable in industry. Due to the possibility of analysis diagrams in many directions of force action and the satisfactorily large level of test power, the UDM-1 method is useful for scientific works.

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INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES

LABORATORY OF BIODEGRADATION

The Laboratory of Biodegradation operates within the structure of the Institute of Biopolymers and Chemical Fibres. It is a modern laboratory with a certificate of accreditation according to Standard PN-EN/ISO/IEC-17025: 2005 (a quality system) bestowed by the Polish Accreditation Centre (PCA). The laboratory works at a global level and can cooperate with many institutions that produce, process and investigate polymeric materials. Thanks to its modern equipment, the Laboratory of Biodegradation can maintain cooperation with Polish and foreign research centers as well as manufacturers and be helpful in assessing the biodegradability of polymeric materials and textiles.

The Laboratory of Biodegradation assesses the susceptibility of polymeric and textile materials to biological degradation caused by microorganisms occurring in the natural environment (soil, compost and water medium). The testing of biodegradation is carried out in oxygen using innovative methods like respirometric testing with the continuous reading of the $CO_2$ delivered. The laboratory's modern MICRO-OXYMAX RESPIROMETER is used for carrying out tests in accordance with International Standards.

The methodology of biodegradability testing has been prepared on the basis of the following standards:

- **testing in aqueous medium:** 'Determination of the ultimate aerobic biodegrability of plastic materials and textiles in an aqueous medium. A method of analysing the carbon dioxide evolved' (PN-EN ISO 14 852: 2007, and PN-EN ISO 8192: 2007)
- **testing in compost medium:** 'Determination of the degree of disintergation of plastic materials and textiles under simulated composting conditions in a laboratory-scale test. A method of determining the weight loss' (PN-EN ISO 20 200: 2007, PN-EN ISO 14 045: 2005, and PN-EN ISO 14 806: 2010)
- **testing in soil medium:** 'Determination of the degree of disintergation of plastic materials and textiles under simulated soil conditions in a laboratory-scale test. A method of determining the weight loss" (PN-EN ISO 11 266: 1997, PN-EN ISO 11 721-1: 2002, and PN-EN ISO 11 721-2: 2002).

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The following methods are applied in the assessment of biodegradation: gel chromatography (GPC), infrared spectroscopy (IR), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM).

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