Comparative Analysis of Fabrics' Bending Behavior Testing Methods

Laura Naujokaitytė, Ph.D. Stud.
Assoc. prof. **Eugenija Strazdienė**, Ph.D.
Ludmila Fridrichová, Ph.D.*
Kaunas University of Technology, Faculty of Design and Technologies
Kaunas, Lithuania
*Technical University of Liberec, Faculty of Textile Engineering
Liberec, Czech Republic
e-mail: laura.naujokaityte@stud.ktu.lt

UDK 677.017.4
Received June 2, 2006
Original scientific paper

There is a variety of methods and standards for measuring bending properties of fabrics. Some of them are based on fabric deformation under its own weight, the others are based on measurements of force, moment or energy producing bending deformation. In this study the comparison of the bending results obtained on two widely accepted methods (KES-FB and FAST) and one novel instrument (TH 7) is presented, using fabrics with different finishing treatment and fabrics differing in weave type. Linear dependencies are obtained between the bending rigidity and stiffener concentration in FAST, KES-FB and TH 7 experiments as well as between bending hysteresis values and stiffener concentration in KES-FB and TH 7 experiments. Good correlations were defined comparing parameters obtained by three different methods, such as bending rigidity, bending hysteresis and coercive couple.

Key words: *bending properties, bending rigidity, bending hysteresis, stiffener concentration, weave type*

1. Introduction

Bending stiffness of fabrics is an important mechanical property that influences its handle and formability [1]. A thorough understanding of fabrics bending behavior is important for the textile research and industrial applications, i.e. for automation of handling and manipulation process of textile garment pieces [2,3].

Bending properties are determined by the bending resistance of threads lying in the direction of bending, some – usually unspecified – interaction between the threads and frictional restraint; weave type of the fabric and finishing treatments applied are affecting these parameters [4,5].

There is a variety of methods or standards to measure woven fabric's bending rigidity that could be divided into two groups: first – based on deformation measurement under its own weight, second – when deformation is applied measuring the force, moments or energy producing the bending deformation. These instruments are generally designed to produce the moment-curvature relationship of fabrics [5-7]. The most widely accepted method belonging to the first group is cantilever method first introduced by **Peirce** in 1930's and based on the formula which describes the pure bending theory of an elastic beam bending within the limit of linear strain. Most of today's methods for the static measurement of bending rigidity are based on this Peirce's theory [8]. FAST (Fabric Assurance by Simple Testing) bending tester [9] is the most popular commercial tester of this group, but FAST measures only the resistance of fabrics to bending deformation and not the recovery of fabric from deformation [10]. The most widely used pure bending tester belonging to the second group is KES-FB (Kawabata Evaluation System) bending tester [11]. KES-FB apparatus is undoubtedly a standard tool for a thorough evaluation of textile fabrics deformability. It is unique by its possibility to characterize fabric behavior under low loads and reliability of the results, typically difficult to work with on standard mechanical testing machines [12]. In this case fabric sample is subjected to a monotonically increasing curvature and the corresponding moment acting on fabric is recorded. This technique enables the measurement of the actual nonlinear bending behavior. Increasing the curvature, the slope of the moment-curvature relation exhibits a large value at an early stage of the bending process and later changes into a less sloped straight line. This proves that a greater moment to overcome the friction between the yarns is needed to bend the unit curvature at an early stage [13]. Bending rigidity and bending hysteresis – the parameters characterizing fabrics bending behavior – are measured by KES-FB bending tester. Bending rigidity represents the resistance of fabric against flexion and bending hysteresis can be considered as a measure of fabrics ability to recover.

However the KES-FB equipment is comparatively expensive and the measurements performed by it are time consuming. These are the limiting factors to use it. As an alternative much cheaper instrument TH 7, developed in Czech Republic (standard: ČSN 80 0858) is chosen to investigate bending properties of fabrics. The measurements by TH 7 are based on recording the forces required to bend a sample to a certain angles.

The objective of this study was to compare the results obtained by three different bending testers: widely accepted FAST and KES-FB bending testers with novel instrument TH 7, analyzing fabrics of various weaves whose bending properties were changed applying different finishing treatments i.e. stiffening and softening.

2. Materials and test methods

Three sets of fabrics were chosen for the investigation. First group is obtained from plain weave fabric treated with different concentrations of PVA (polyvinyl acetate) stiffener. Second group consist of 5 fabrics differing in weave type and yarn count, third set consists of the same fabrics as in second group that are treated with commercial chemical softener according to manufacturers specifications. Properties of the investigated materials are presented in Tab.1.

Tab.1 Characteristics of investigated cotton fabrics

Fabric	Weave type	Count (dm^{-1})		Area density (g/m^2)	Treatment	Thicknes (mm)
		Warp	Weft			
Co_0	Plain			137.8	-	0.43
Co_5	Plain	236	232	138.1	5 g/dm^3 PVA	0.43
Co_10	Plain			138.5	10 g/dm^3 PVA	0.43
Co_15	Plain			142.0	15 g/dm^3 PVA	0.43
F_P 1	Plain	344	236	120		0.32
F_P 2	Plain	344	285	125		0.34
F_P 3	Plain	344	344	140	-	0.34
F_C 3	Combined	344	344	140		0.41
F_S 6	Satin 6	344	344	150		0.44
TF_P 1	Plain	344	236	125		0.32
TF_P 2	Plain	344	285	135		0.34
TF_P 3	Plain	344	344	150	Softener	0.34
TF_C 3	Combined	344	344	150		0.41
TF_S 6	Satin 6	344	344	150		0.44

The cantilever bending test was performed according to a FAST standard method where the overhang length of fabric stripe reaching plane inclined at 41.5° was measured.

Bending hysteresis was investigated using two different bending testers. The moment-curvature relationships were obtained by KES-FB bending measurements, that are perhaps the most widely cited in lit-

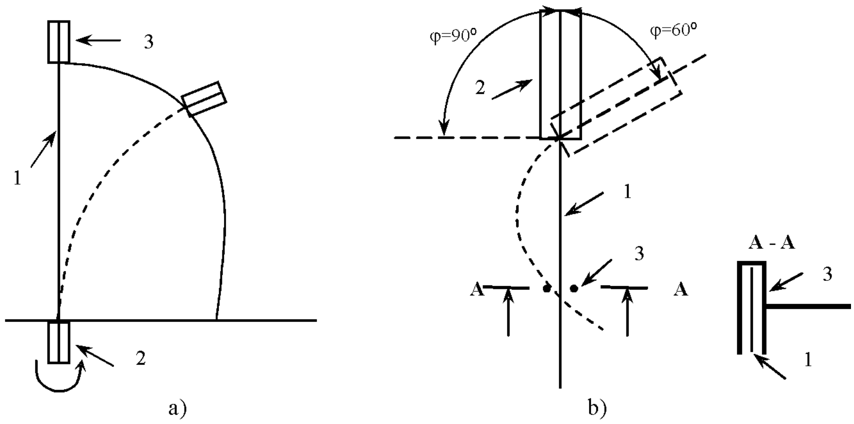

Fig.1 Working principle of: a) KES-FB, b) TH 7

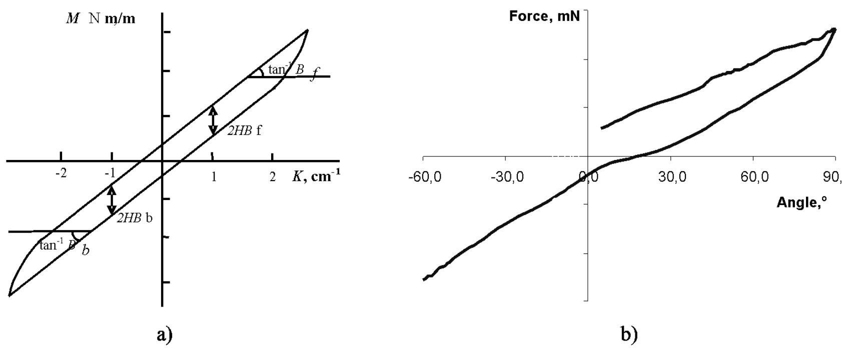

Fig.2 Bending hysteresis obtained by: a) KES-FB tester, b) TH 7 apparatus

erature. Force-angle relationships were obtained by novel Czech instrument TH 7.

In KES-FB bending test the specimen (1) is mounted into two clamps (Fig.1a): a fixed one (2) and a movable clamp (3) that follows a prescribed orbit turning it's head at an angle so that the uniform curvature is maintained on the sample through a bending cycle and the bending hysteresis curve (variation of couple with curvature) is plotted (Fig.2a) [11]. A fabric sample is bent through a range of curvatures between -2.5×10^2 m^{-1} and 2.5×10^2 m^{-1}, bending test is conducted at rate of curvature equal to 0.5×10^2 m^{-1}/s, the test sample is mounted vertically to prevent the effect of gravity influencing the experiment.

The operating principle of the instrument TH 7 is presented in a Fig.1b [14]. The specimen (1) is attached to an upper clamp (2), which can turn by 90° in one direction and by 60° in the other direction. Specimen is hanging freely between the two sides of a U shaped lower clamp (3). The lower clamp is a clamp-sensor that measures the force required to bend a specimen until a certain angle. This way the force-angle curve is obtained (Fig.2b).

Bending rigidity coefficient *B* in mN·m was calculated from a FAST method.

Standard parameters obtained by KES-FB method were *B* – bending rigidity per unit width in Nm^2/m, that is calculated as the mean bending stiffness of two slopes and *2HB* - bending hysteresis value in Nm/m, that is obtained by reading the hysteresis width at curvature ±1. In addition to standard parameters the couple required to restore zero curvature OF, denoted the 'coercive couple' is found from the hysteresis graph (Fig.3) [15,16].

From the force-angle dependence obtained by an instrument TH 7 two parameters were measured: maximum value of force, that could be taken as a bending rigidity evaluation of fabric and hysteresis value *S* in mN° that is taken as an area of hysteresis curve calculated between the angles of 20 and 90° according to a formula [5]:

$$S = \left(\sum_{i=1}^{n} (x_i - x_{i-1}) \cdot \frac{y_i + y_{i-1}}{2} \right)$$

In FAST method the samples of 150×50 mm were tested in warp and weft directions. In KES-FB test method standard samples of 200×200 mm were tested (actual size used for testing: 200×10 mm) in principle fabric directions. Square samples of dimensions 50×50 mm were used in TH 7 apparatus to perform bending test. The same specimen was investigated in both warp and weft directions.

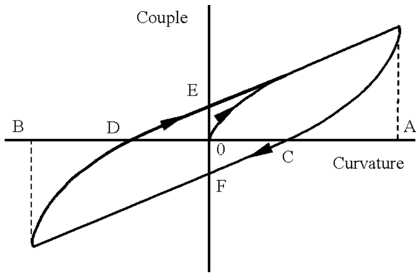

Fig.3 Typical bending hysteresis curve

3. Results and discussion

3.1. Results obtained by FAST method

Bending rigidity values were found for all tested fabrics using FAST bending rigidity tester based on cantilever bending principle. They are presented in Tab.2.

Fig.4 represents the changes of bending rigidity coefficient chan-

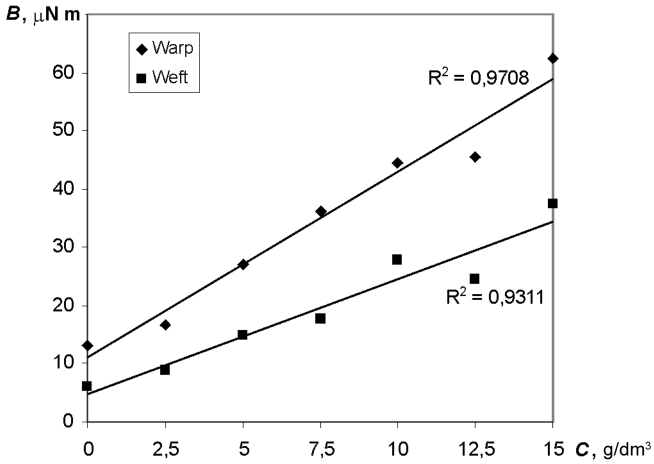

Fig.4 The effect of stiffener concentration upon the bending rigidity

Tab.2 Bending rigidity values obtained according to FAST method

Bending rigidity *B*, (µN·m)	Fabric Code													
	Co_0	Co_5	Co_10	Co_15	F_P1	F_P2	F_P3	F_C3	F_S6	TF_P1	TF_P2	TF_P3	TF_C3	TF_S6
Warp direction	13.12	26.99	44.46	62.37	31.78	21.93	24.49	35.25	26.62	15.41	16.20	25.49	11.99	8.06
Weft direction	6.19	15.01	27.89	37.30	11.14	11.15	18.40	22.77	15.94	6.57	11.81	17.04	10.09	6.61

Tab.3 KES-FB bending hysteresis parameters for fabrics treated with PVA stiffener

Fabric	Coercive couple M_c 10^{-2} (Nm/m)		Initial bending rigidity B_0 10^{-4} (Nm^2/m)		Final bending rigidity B 10^{-4} (Nm^2/m)		Bending hysteresis $2HB$ 10^{-2} (Nm/m)	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Co_0	-0.126	-0.100	0.75	0.34	0.088	0.061	0.129	0.089
Co_5	-0.149	-0.135	1.18	0.52	0.150	0.113	0.215	0.144
Co_10	-0.196	-0.148	1.40	1.06	0.229	0.199	0.302	0.237
Co_15	-0.242	-0.176	1.66	1.33	0.243	0.225	0.327	0.254

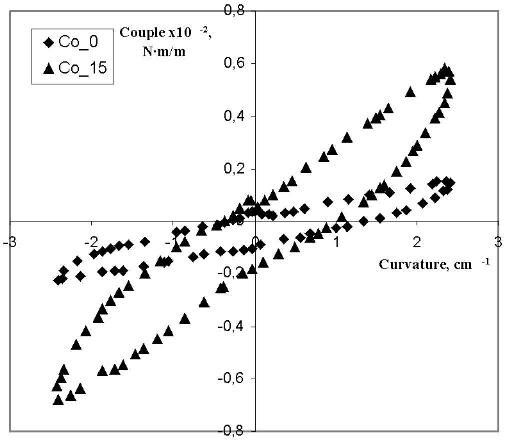

Fig.5 KES-FB bending hysteresis curves for limiting concentrations (in weft direction)

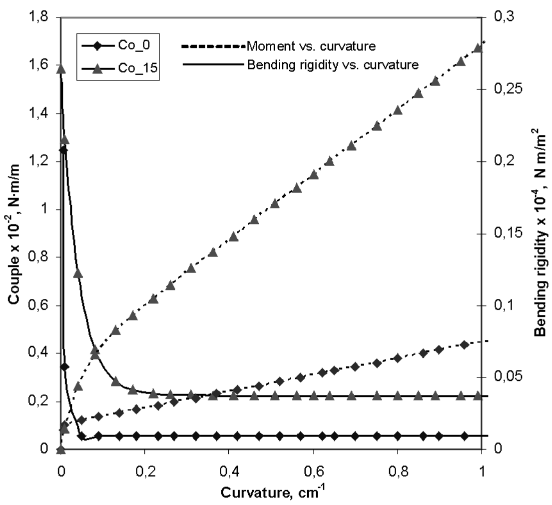

Fig.6 KES-FB bending rigidity dependence upon curvature (in weft direction)

ging concentration of stiffener from 0 to 15 g/dm^3 by the steps of 5 g/dm^3. Linear dependencies between bending rigidity *B* and concentration of stiffener *C* were observed in all tested directions and linear tendency was checked introducing samples treated with additional mediate PVA stiffener concentrations of 2.5, 7.5 and 12.5 g/dm^3.

3.2. Results obtained by KES-FB

In KES-FB experiment bending hysteresis curves for fabrics treated with different concentrations of PVA stiffener were obtained. Coercive couple M_c, bending hysteresis value *2HB* , initial B_0 and final bending rigidity *B* values in warp and weft directions obtained from bending hysteresis curves are presented in Tab.3.

In Fig.5 bending hysteresis curves of limiting concentrations i.e. untreated fabric and treated with 15 g/dm^3 concentration in weft direction are presented. Untreated fabric gives a much narrower and less sloped curve. Increase of concentration gives wider and steeper curve with higher bending rigidity and bending hysteresis values (Tab.3). Nonlinearity of bending rigidity for limiting concentrations is presented in Fig.6; bending rigidity vs. curvature is obtained differentiating the moment-curvature relationship. The initial bending rigidity is from 6 to 8 times higher than final bending rigidity in warp direction and from 4.5 to 5.7 times higher in weft direction. Increasing stiffener concentration percentage increment value of initial and final bending rigidities is very similar. The increase of stiffener concentration results in higher coercive couple value. Coercive couple is almost twice bigger in a case of 15 g/dm^3 concentration in warp direction and a bit less than two times – in weft direction comparing with untreated samples. The mediate concentration gives mediate values of all characteristic hysteresis parameters (Tab.3).

3.3. Results obtained by TH 7 analysing a set of fabrics treated with different concentrations of stiffener

Bending hysteresis curves obtained in TH 7 apparatus for fabrics treated with different concentrations of stiffener are presented in Fig.7.

The same as in bending curves obtained by KES-FB the increase of stiffener concentration gives steeper and wider curves. Relatively high errors are obtained between angle 0 and 40^o going backwards, because of the breadth between two sides of

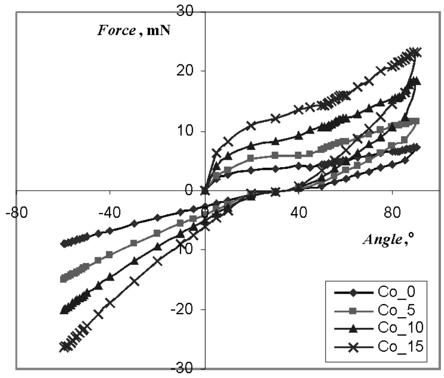

Fig.7 Bending hysteresis curves obtained by TH 7 apparatus increasing stiffener concentration (in weft direction)

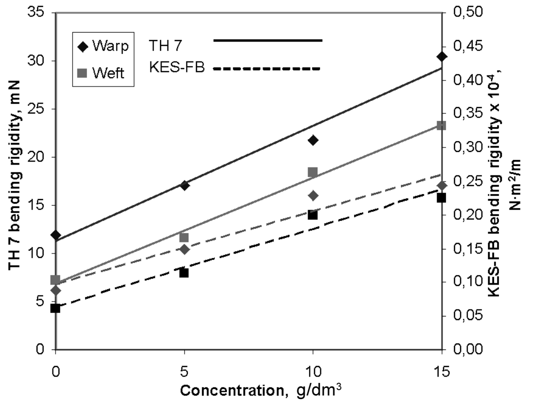

Fig.8 Bending rigidity dependence upon the concentration of stiffener

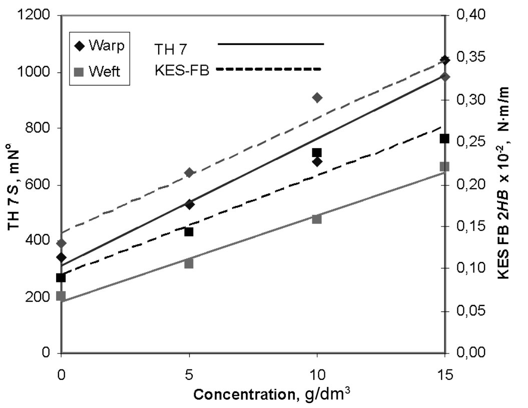

Fig.9 Bending hysteresis dependence upon the concentration of stiffener

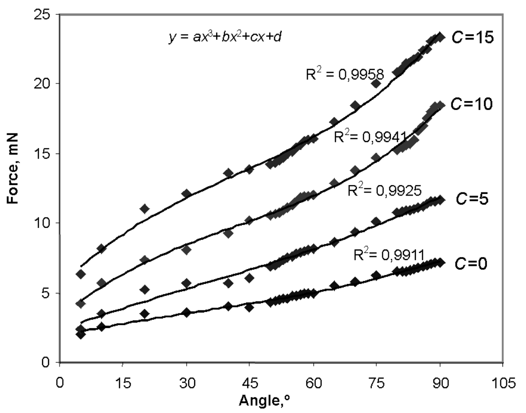

Fig.10 Experimental points and calculated values of hysteresis curve measured on TH 7 machinery

U shaped clamp, when the specimen stops pushing the clamp-sensors side that gives positive value of the force and moves to the side of negative value.

Graphically the changes of bending rigidity and hysteresis values obtained at certain concentrations on TH 7 and KES-FB machinery are presented in Fig.8 and 9.

As it is seen from Fig.8 and 9 both bending rigidity and bending hysteresis values obtained on TH 7 and KES-FB show a linear tendencies increasing stiffener concentration. Good correlation of bending rigidity values obtained for the same fabrics on TH 7 and KES-FB was found (r=0.89). Even better correlations of bending rigidity values were found between measurements on FAST and TH 7 (r=0.98), also between FAST and KES-FB (r=0.92).

The correlation between the coercive couple measured on KES-FB and the force at the zero angle value measured on TH 7 is r=0.96.

Bending hysteresis curves obtained on TH 7 were analyzed dividing them into two parts: first – the curve from the beginning of experiment up to the inclination of upper clamp equal to 90°, second – when upper clamp goes backwards from +90 to -60°.

Using the least square method it was found that the first part of the hysteresis curve could be approximated by third order polynomial equation with high precision (Fig.10).

3.4. Results obtained by TH 7 analysing 2 sets of fabrics differing in weaves and final treatment

Bending properties of two sets of fabrics were investigated on TH 7 apparatus: first set - five fabrics of the same yarn linear densities (three plain weave fabrics differing in weft yarn densities, one - combined weave fabric and one satin 6 weave fabric); second set - the same fabrics with softener treatment. The

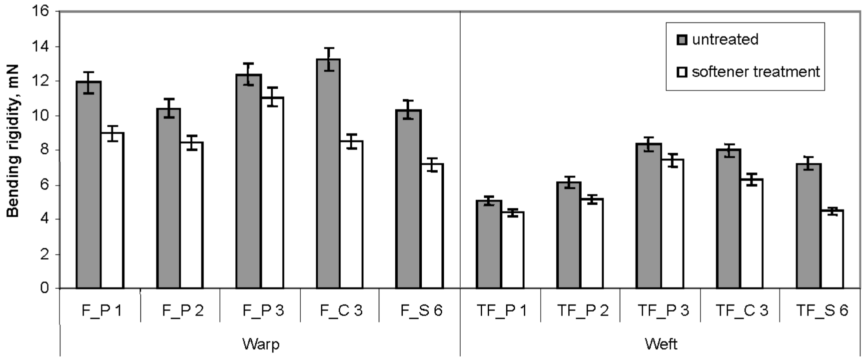

Fig.11 Bending rigidity values of fabrics differing in weave and final treatment

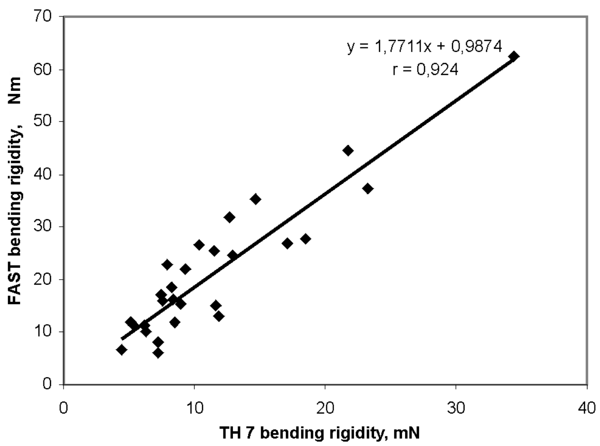

Fig.12 The correlation between the bending rigidity values obtained by different methods based on different measuring principles

Tab.4 TH 7 hysteresis values of two sets of fabrics

Hysteresis value S (mN°)	Fabric Code									
	F_P1	F_P2	F_P3	F_C3	F_S6	TF_P1	TF_P2	TF_P3	TF_C3	TF_S6
Warp direction	238.38	204.68	330.88	280.59	215.3	239.77	262.25	363.31	212.36	163.88
Weft direction	106.31	136.34	200.53	191.89	165.58	112.88	149.46	211.51	168.94	96.64

values of bending rigidity are presented in Fig.11.

Analyzing the results, decrease of the bending rigidity values after treatment of fabrics with 4A in warp direction varies between 11 and 23% for plain weave fabrics and is equal to 35% for combined weave and 30% for satin weave. In weft direction slightly lower drop is observed for plain weave fabrics - 11÷16%. The increase of bending rigidity values in weft direction is explained by fabric composition, i.e. by the increase of weft yarn density.

Hysteresis values of two sets of fabrics differing in weave type and final treatment applied are presented in Tab.4.

Bending hysteresis values in weft direction are from 1.2 to 2.2 times lower than in warp direction. Increase of hysteresis values for plain weave fabrics treated with different finishers in weft direction is due to the increase of yarn density the latter results in higher value of inter fiber friction what means lower bending recovery.

Correlation between bending rigidity values measured in cantilever based FAST method and TH 7 test methods for 3 sets of fabrics differing in treatment and weave types is presented in Fig.12. High correlation coefficient value (r=0.92) is obtained.

4. Conclusions

Increase of stiffener concentration showed a linear increase of bending rigidity values obtained on FAST, KES-FB and TH 7 instruments. In spite of different measuring principles of different apparatus correlations between these values are high.

The initial bending rigidity measured by KES-FB is from 6 to 8 times higher than final bending rigidity in warp direction and from 4.5 to 5.7 times higher in weft direction.

Increase in fabric stiffness gives the increase in bending hysteresis values. Bending hysteresis values measured on KES-FB and TH 7 increases linearly increasing PVA stiffener concentration.

Increase of stiffener concentration increases coercive couple value due to increase of inter fiber friction. High correlation is obtained between the coercive couple measured on KES-FB and force value at zero degrees of upper clamp inclination in TH 7 apparatus.

Increase of hysteresis values for plain weave fabrics treated with different finishers in weft direction is due to the increase of yarn density what results in bigger value of inter fiber friction what means lower bending recovery.

References:

[1] Zhou N., T.K. Ghosh: On-Line Measurement of Fabric Bending Behaviour Part I: Theoretical Study of Static Fabric Loops, Textile Research Journal **67** (1997) 10, 712-719

[2] Clapp T.G., H. Peng: Buckling of Woven Fabrics Part I: Effect of Fabric Weight, Textile Research Journal **60** (1990) 228-234

[3] Clapp T.G. et al: Indirect Measurement of the Moment-Curvature Relationship for Fabrics Textile Research Journal **60** (1990) 525-533

[4] Grosberg P.: The Mechanical Properties of Woven Fabrics Part II: The Bending of woven fabrics, Textile Research Journal **36** (1966) 3, 205-211

[5] Ozcelik G. et al: The Comparison of Two Different bending Rigidity Testers, 4th CEC proceedings 2005 (CD edition)

[6] Zhou N., T.K. Ghosh: On-Line Measurement of Fabric Bending Behaviour Part II: Effect of Fabric Nonlinear behaviour, Textile Research Journal **68** (1998) 7, 533-542

[7] Zhou N., T.K. Ghosh: Communication: On-line Measurement of Fabric-Bending Behavior: Background, Need and Potential Solutions, International Journal of Clothing Science and Technology **10** (1998) 2, 143-156

[8] Szablewski P., W. Kobza: Numerical Analysis of Peirce's Cantilever Test for the Bending Rigidity of Textiles, Fibres and Textiles in Eastern Europe **43** (2003) 11, 54-57

[9] Fabric Assurance by Simple Testing, CSIRO Division of Wool Technology. - Geelong, Australia, 1997

[10] Shishoo R.L.: Importance of Mechanical and Physical Properties of Fabrics in the Clothing Manufacturing Process, International Journal of Clothing Science and Technology **7** (1995) 2/3, 35-42

[11] Manual for Bending Tester KES-FB 2, Katotekko Co. Ltd, Kyoto (1986), Japan

[12] Lomov S.V. et al: Carbon Composites Based on Multiaxial Multiply Stiched Preforms (Part 2); KES-F Characterization of the Deformability of the Preforms at Low Loads (Part A), Composites **34** (2003) 359-370

[13] Kang T.J. et al: Analyzing Fabric Buckling Based on Nonlinear Bending Properties, Textile Research Journal **74** (2004) 2, 172-177

[14] Czhech standard: ČSN 80 0858 Zkouseni Tuhosti A Pruznosti Plošnych Textili 1974

[15] Livsey R.G., J.D. Owen: Cloth Stiffness and Hysteresis in Bending, Journal of the Textile Institute **55** (1964) 10, T516 – T530

Owen J.D.: The Bending Behavior of Plain-Weave Fabrics Woven From Spun Yarns, Journal of the Textile Institute **59** (1968)