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The Effect of Temporary Stiffeners Concentration upon Bending Properties of Fabrics

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Bending rigidity of plain weave cotton fabric in principal directions (warp, weft) and 45º bias was investigated. Textile samples were prepared by finishing them with different concentrations (0 g/l, 5 g/l, 10 g/l, 15 g/l) of polyvinyl acetate based temporary stiffener. Two different experimental methods, a conventional cantilever method and buckling wave method were applied. Sensitivity range of the apparatus to the variation of stiffness was investigated. Linear dependence between bending rigidity and concentration of stiffener, obtained with the cantilever method, was supported with additional samples treated with 2.5 g/l and 7,5 g/l concentrations of stiffener. The influence of stiffener's concentration upon changes of buckling wave's geometry was analysed.

Keywords: bending rigidity, buckling, concentration of stiffener.

INTRODUCTION

There is an increasing focus on automating the textile industry, particularly labour-intensive tasks such as fabric manipulation and assembly. The highly flexible nature of these materials makes automation very challenging [1 – 3]. Buckling behaviour is usually observed in processing and exploiting textile materials. Affected by compressive forces they loose their plain shape and start to buckle, these waves hinder obtaining of a smooth spatial shape [4 – 6].

Treatment of textiles with firming or stiffening agents influences their handle properties, adds consumer appeal to certain types of fabrics, makes processing easier, etc.

Stiffening finishes may be either temporary or durable. The most common finishes for temporary stiffening are starch, modified starch or polyvinyl acetate [7]. Fabrics are impregnated with water dispersion of stiffener, and this is followed by drying process and formation of glassy polymer film adhered to the yarns and fabrics. This way the resiliency component of the system increases thus increasing fabric stiffness. Film morphology is related to the intrinsic film forming properties of material and to the size and size distribution of the particles dispersed in water [8].

The cantilever test method has been used since the 1930's for the measurement of fabric stiffness: Peirce proposed a method [9] based on the measurement of the cantilever length of a textile specimen with one edge fixed on a platform and deformed under its own weight as a cantilever. Bending stiffness makes a big contribution to the formability and handle of fabrics [10]. Fabric buckling is inseparable part of bending behaviour [11, 12]. Buckling phenomenon in textile materials reveals at a very small loads and this is the main factor limiting the use of conventional testing methods for its investigation. Plenty of researchers are looking for new, universal and technically simple testing methods to investigate the deformability properties of textile materials at small loads. In [3] the method was presented to analyse fabric buckling during planar lateral compression. The dynamics of buckling wave change is investigated and the results could be applied for the investigation of fabric bending behaviour, buckling and drape, also.

In this research bending rigidity of the fabric was measured by two different methods: conventional cantilever test method and buckling wave test method, developed in Kaunas University of Technology. The scope of the research was to study the affect of stiffener concentration upon the bending behaviour of textiles discovering sensitivity range of the apparatus.

MATERIALS AND TEST METHODS

100 % cotton fabric woven in plain (area density – 138 g/m^2; warp density – 236 dm^{-1}; weft density – 232 dm^{-1}) was investigated. Four groups of samples treated with 0 g/l, 5 g/l, 10 g/l and 15 g/l concentration of polyvinyl acetate (PVA) stiffener were prepared, respectively. PVA stiffeners were used as a temporary handbuilders for textiles. Bending rigidity properties of each group were investigated in three directions: warp, weft and 45° bias using two different methods: conventional cantilever and buckling wave method.

The dimensions of tested specimens in both experiments were (50×100) mm. Prior to testing the samples were ironed and conditioned for 24 hours, folding or yielding of fabrics was carefully avoided.

Bending stiffness of fabrics was measured on the basis of cantilever test with inclination angle 41.5° [13]. Principle of the test method is shown in Figure 1.

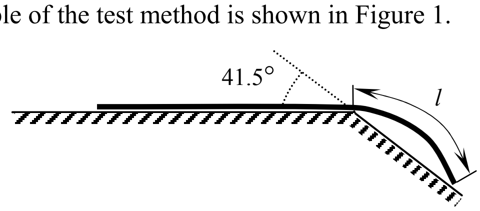

Fig. 1. Principle of cantilever test method

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Out of 10 measurements the average bending length ($c = l/2$ in mm) of the specimen bent under it's own weight, was measured by the constant angle 41.5°. Bending rigidity values $B = 9.81 \cdot 10^{-6} w \cdot c^3$ in μN·m were calculated, where w is area density in g/m^2.

Other group of experiments was performed using construction tester (see Fig. 2), where a specimen was placed on a glass pad, one edge of sample was clamped stationary and the opposite edge moved towards unmovable clamp at the steps of $\Delta L = 5$ mm.

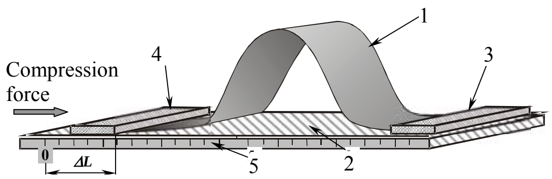

Fig. 2. Buckling wave tester: 1 – test specimen, 2 – glass pad, 3 – stationary clamp, 4 – movable clamp, 5 – ruler

Sample buckled due to compression in plane. The analysis of specimen's surface buckling progress under the increasing in-plane deformation was performed by graphical analysis of captured images (see Fig. 3) on the basis of variation of height H of the buckling wave and the area S under it [3].

When displacement ΔL reaches 30 mm neck formation in a wave is observed (see Fig. 3, c). After formation of neck, when buckling wave starts to lean because of its own weight, height H is measured as length of wave's symmetry line (see Fig. 3, c).

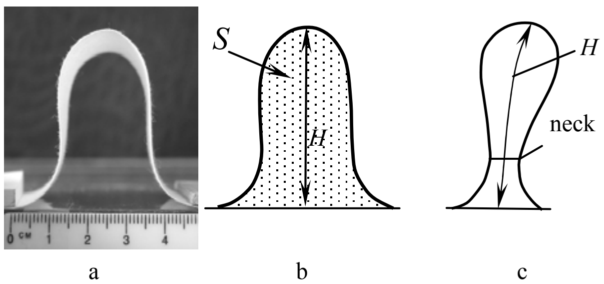

Fig. 3. Captured image of the deformed specimen (a); graphical analysis of buckling wave to obtain parameters H, S (b, c)

In [3] this method was proved as an effective one to determine fabric behavior in three directions of the fabrics relatively different in structure and mechanical properties, during planar lateral compression. In this research the main interest was taken to discover sensitivity range of the apparatus only slightly changing bending properties of the same material by increasing concentration of stiffener.

RESULTS AND DISCUSSION

Bending rigidity values were found using conventional cantilever bending rigidity tester. Figure 4 presents the changes of bending rigidity changing concentration of stiffener (C) from 0 g/l with step 5 to 15 g/l. Fabric exhibited the highest stiffness value in warp direction and the lowest in weft direction.

Linear dependence between bending rigidity (B) and concentration of stiffener (C) is observed. Equation coefficients a and b and determination coefficients R^2 between B, C and $B = aC + b$ for all three directions of tested fabrics are presented in Table 1.

Table 1. Coefficients of dependence between bending rigidity and concentration of stiffener: $B = aC + b$

	a	b	R^2	R^{2*}
Warp	3.40	10.63	0.997	0.992
Bias	2.91	7.48	0.970	0.969
Weft	2.18	4.90	0.995	0.976

Note: * – value of correlation coefficient after introduction of mediate concentrations

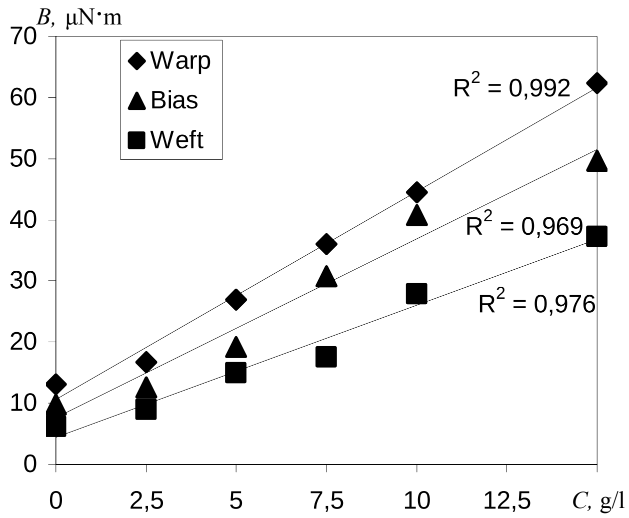

Fig. 4. The effect of stiffener concentration upon bending rigidity values of fabric

The highest coefficient a value in warp direction shows the biggest increase rate of bending rigidity, increasing stiffener concentration.

Additional samples with 2.5 g/l and 7.5 g/l concentrations of stiffener were prepared to check the linear dependency of bending rigidity coefficient. Additional experimental points at 2.5 g/l and 7.5 g/l concentrations were obtained and new determination coefficients R^{2*} were recalculated for each fabric direction leaving a and b values the same. A negligible change of determination coefficients from R to R^{2*} (see Table 1) proves the linearity of bending rigidity and allows to calculate bending rigidity value at any concentration needed with relatively small error.

The dependencies between buckling wave's geometry changes in three directions and concentration changes of stiffener were investigated by buckling wave test method.

Figures 5 and 6 show the changes of buckling wave's height H and area under buckling wave S in the same directions (warp, weft or bias), increasing the displacement ΔL of a movable clamp by 5 mm steps, changing concentrations of PVA stiffener (0, 5, 10, 15 g/l).

The change of buckling wave's height H with the increase of compressive deformation show logarithmic tendency: $H = a\ln(\Delta L) + b$ (Fig. 5).

Area under buckling wave S shows much more complex tendency. It could be described with third order polynomial: $S = a(\Delta L)^3 + b(\Delta L)^2 + c(\Delta L) + d$ (Fig. 6).

It is noticeable that changes of concentration from 0 g/l to 5 g/l and to 10 g/l are well represented by the increase of buckling wave's height H and area S while the increase of concentration from 10 g/l to 15 g/l starts to show negligible changes of H and S. These results show that stiffer specimens tend to form a higher and wider wave.

Observing the behaviour of fabric in three directions at the same concentration of stiffener it was found that with the increase of concentration, the difference in buckling wave's height H changes is obvious at 0 g/l concentration and becomes less tangible with each step of increase of concentration (see Fig. 7, a, b, c, d). At 10 g/l and 15 g/l concentrations all curves start to overlap – the method starts to be incapable to distinguish different directions of fabric by the value of H.

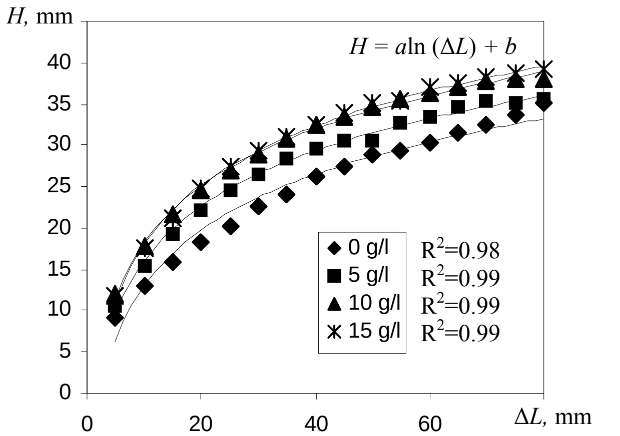

Fig. 5. The dependence of buckling wave's height H on the concentration of PVA stiffener and the displacement ΔL of movable clamp (in weft direction)

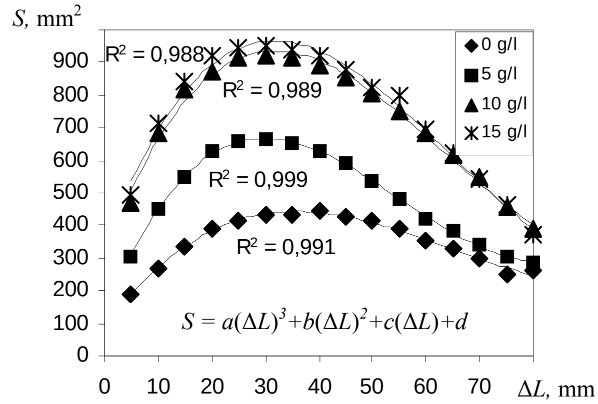

Fig. 6. The variation of the are S under buckling wave in weft direction changing concentration of PVA stiffener

Table 2 presents numerical values of buckling wave's height when displacement $\Delta L = 30$ mm. At this value of ΔL buckling wave reaches the biggest height and highest S value before it starts to lean. As it is seen from Δ (absolute error, calculated as difference of H and S values between different fabric directions in mm) and δ (relative error calculated as ratio of Δ and measured H and S values, in %), good representation of difference between three fabric directions is obtained. Difference of buckling wave's height at 0 g/l concentration varies between 5 % and 11.1 %, while at 5 g/l concentration – 4.9 % and at 10 g/l and 15 g/l concentrations this difference ranges from 0.4 to 2 %.

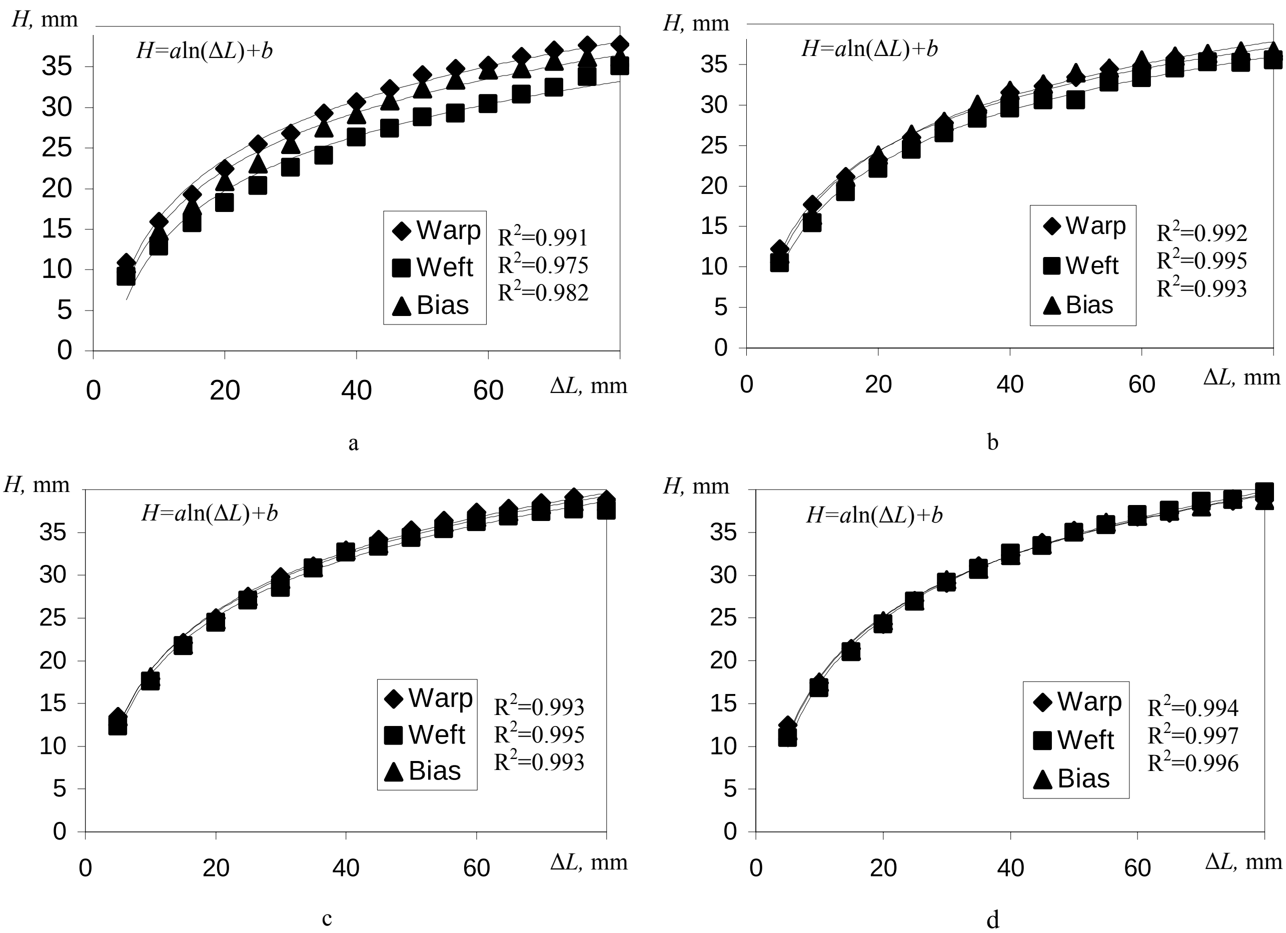

Fig. 7. The dependence of buckling wave's height H in thee fabric directions on the displacement ΔL at different concentrations of stiffener: a – 0 g/l; b – 5 g/l; c – 10 g/l; d – 15 g/l

Table 2. Values of buckling wave's geometry

C, g/l		0			5			10			15		
	ΔL, mm	Warp	Bias	Weft	Warp	Bias	Weft	Warp	Bias	Weft	Warp	Bias	Weft
H, mm	30	26.82	25.47	22.63	27.81	27.93	26.55	29.77	29.47	28.86	29.07	29.43	29.31
		Δ = 1.35 mm		Δ = 2.84 mm	Δ= –0.12 mm		Δ = 1.38 mm	Δ = 0.3 mm		Δ = 0.61 mm	Δ = –0.36 mm		Δ = 0.12 mm
		δ = 5.0 %		δ = 11.1 %	δ = 0.4 %		δ = 4.9 %	δ = 1 %		δ = 2.1 %	δ = 1.2 %		δ = 0.4 %
S, mm^2	30	860.7	644.3	434.7	892.5	840.5	667.0	968.6	955.6	921.2	970.0	958.1	939.2
		Δ = 216.4 mm^2		Δ = 209.6 mm^2	Δ = 52.0 mm^2		Δ = 173.5 mm^2	Δ = 13.0 mm^2		Δ = 34.4 mm^2	Δ = 11.9 mm^2		Δ = 18.9 mm^2
		δ = 25.1 %		δ = 32.5 %	δ = 5.8 %		δ = 20.6 %	δ = 1.3 %		δ = 3.6 %	δ = 1.2 %		δ = 2.0 %

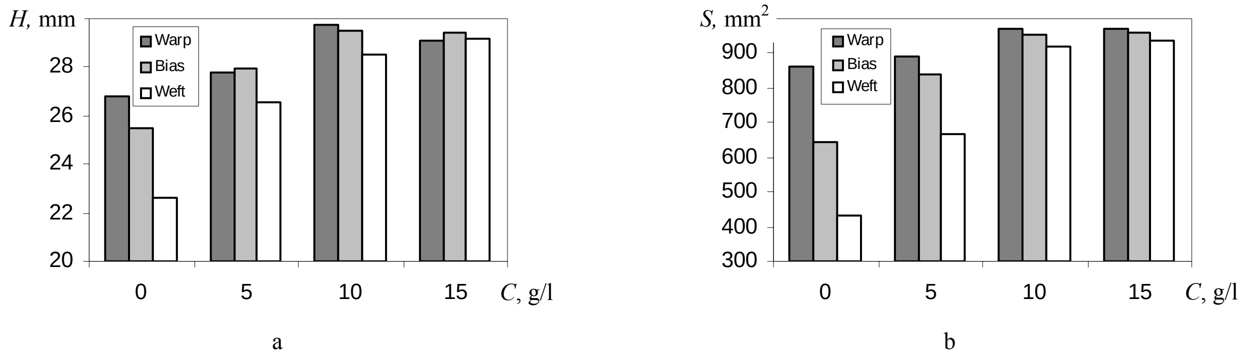

Fig. 8. Values of buckling wave's height H (a) and area under buckling wave S (b) at different concentrations of stiffener at the displacement ΔL = 30 mm

Figure 8, a, shows that at 5 g/l and 15 g/l concentrations descending tendency *warp* > *bias* > *weft* is not supported.

Better results are obtained analyzing changes in area under buckling wave. At all stiffener concentrations descending tendency *warp* > *bias* > *weft* is supported (see Fig. 8, b), i.e. that even if specimens form a wave of a same height, this wave is wider, however this difference diminishes at 10 g/l and 15 g/l concentrations. From Table 2 it is seen that difference of S in warp, bias and weft directions at 0 g/l concentration varies between 25.1 % and 32.5 %, at 5 g/l concentration – between 5.8 % and 20.6 %, at 10 g/l and 15 g/l concentrations differences between warp, bias and weft directions become less tangible and range from 1.2 % to 3.6 %.

It is noticeable that according to buckling wave test method at 10 g/l and 15 g/l concentrations of stiffener a fabric tends to loose the difference between warp, weft and bias directions (i.e. un-isotropic features characteristic to textile fabrics) and starts to act similarly to thin plate.

CONCLUSIONS

Investigation results obtained by conventional cantilever test method showed linear dependence between stiffener concentration and bending rigidity. Linear dependence was proved after introduction of additional mediate concentrations (2.5 g/l and 7.5 g/l). Hence it enables the prediction of fabric's bending behaviour with relatively small error.

Buckling wave test method enables to detect small stiffness variations of the fabric, changing concentration of stiffener by analysing geometry alternations (H, S) of buckling wave.

Changes of concentration from 0 g/l to 5 g/l and to 10 g/l are well represented by increase of buckling wave's height H and area S while increase of concentration from 10 g/l to 15 g/l starts to be negligible (analyzing case of same direction: warp, weft or bias).

Method showed to be effective to distinguish stiffness changes in three fabric directions analyzing area under buckling wave S for the same fabric. At 0 g/l concentration changes reach 25.1 – 32.5 %, at 5 g/l conc. 5.8 – 20.6%, at 10 g/l and 15 g/l concentration differences between warp, bias and weft directions become less tangible and range from 1.2 to 3.6 %. Analysis of buckling wave height didn't support the descending tendency *warp* > *bias* > *weft* in all cases what shows that the height of wave could be very similar, but the shape of wave is different: the stiffer is a fabric, the wider is the wave.

Comparing the data obtained in different test methods the second one shows the loss of sensitivity between 10 g/l and 15 g/l concentrations when fabric behaviour tends to loose the difference between warp, weft and bias directions and it starts to act as a thin plate.

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