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Study of the Tensile and Bending Stiffness Behavior of Antistatic and Antibacterial Knitted Fabrics

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Abstract
The influence of fabric treatments, fabric structure and yarn composition on the strength, elasticity and bending stiffness behavior of developed antistatic knitted fabrics was investigated for daily wear clothing. 1x1 rib knit fabrics showed higher elongation and strength than half-Milano rib knit fabrics, with high elongation in the wale direction of the fabrics. An increase in antistatic polyester content causes an increase in the tensile strength of the fabrics. Fabric treatments were found to be highly influential with respect to the properties of the knitted fabrics developed. Dyed and softened fabrics showed lower stiffness, while the antibacterial finished group showed increased bending stiffness.

Keywords
cotton and polyester, antistatic, strength, elongation, bending stiffness.

1. Introduction

Recently, knitted fabrics have been increasingly used in the manufacture of sportswear, leisurewear, wearable e-textiles [1-3] and composites [4]. A tendency of usage of functional finishes, e.g., antistatic, antibacterial, and others, is also evident [5]. Knit fabrics have a looped structure that provides excellent elasticity, soft handle, and wear comfort [5-7]. Half-Milano rib knitted structures feature good handle property [7]. Fundamental properties determining the wear comfort of knitted fabrics are strength, elongation, bending stiffness, and others, which usually depend on the knitted fabric structure [8-12]. Today, mechanical properties are also necessary for 3D garment virtualization, which is majorly important for the individualization of fashion products [13]. Thus, investigations of mechanical properties are always relevant for newly developed textiles. Research work [14] showed that air vortex yarn knit fabric features better tactile handles, which depended on high extensibility and low bending rigidity compared to fabrics knitted with ring and Siro spun yarns. Weft knitted constructions have a fully elastic property, especially those in the course direction. The tensile behavior along the course direction of rib knitted fabrics is composed of two regions, namely the 'de-curling region' and 'tensile region' [15]. The elasticity of knitted structures depends on yarn bending stiffness and loop interlocking, with a tendency of occupation of a minimal energy position, influencing fabric suitability for different purposes [15]. Furthermore, rib fabrics tend to shrink along the width and are dimensionally stable [15]. Tension tests of 100 % cotton and cotton/Lycra-mixed knitted fabrics showed that their strength and elongation depend on the structure of the knit, the direction of the sample and the fiber content [16]. The tensile strength and percentage of elongation at break of 100 % cotton 1×1 rib knit fabrics were higher than those of cotton/Lycra blended fabrics. In addition, 1×1 rib knitted fabrics demonstrated higher elongation in their width [16]. The tensile strength and elongation at break of 100 % cotton and cotton/Lycra blended 1×1 rib knit fabrics were inversely proportional [16]. The elongation of polyester plain jersey knitted fabrics was higher than that of fabrics made from cotton, viscose, and paper yarns [9]. The tensile, bending and shear properties of 1×1 rib, half-cardigan rib, half-Milano rib, interlock, single-pique, and cross-miss interlock knit fabrics increased, thereby increasing their density [7]. Half-Milano rib knitted fabrics with tuck and miss stitches have better dimensional stability than knitted fabrics with only knit stitches [7]. The literature reviewed shows that mechanical properties were thoroughly investigated for knitted fabrics manufactured from classical fibers; but this research aims to investigate the mechanical properties of antistatic cotton / antistatic polyester knitted fabrics having carbon black in their structure and treated with antibacterial finishing. However, these textiles were studied mainly for their functional properties, such as electrical and antibacterial [17-20], with strong focus on their mechanical behavior.

The purpose of this study was to investigate the influence of dyeing, softening and treatment with antibacterial finish, knit type, and fabric direction on the tension and bending stiffness characteristics of newly developed functional cotton/antistatic polyester blend knitted fabrics for sportswear.

2. Materials and Methods

2.1. Characteristics of Investigated Materials

The knit fabrics investigated were manufactured using a fully automatic flat knitting machine M-100, produced by MATSUYA (Japan, 2016), with a

14E gauge and other constant machine settings. Blended cotton/antistatic polyester Z-twisted yarns having four different fiber compositions were purchased from Haining TAIERXIN New Materials Co. LTD for fabric knitting. The antistatic properties of the antistatic yarns were ensured by adding carbon black in the structure of the polyester fibers. This technology gives the properties of semiconductors for both the front and back technical sides of knitted fabrics. Due to these properties, they quickly and uniformly eliminate the static electricity of clothing being in contact with both the human body and the outside world. Thus, there is no charge accumulation in the garments. This advantage leads to the avoidance of handling problems during knitted fabric processing, the disruption of sensitive electronic devices, the ignition of flammable vapors and dusts in the environment, annoying electrical shocks, and the clinging tendency during consumer use [20]. In addition, the presence of antistatic fibers in materials allows them to be used not only in the special applications discussed earlier but also in the production of casual wear. Clothing made from such materials will stay cleaner longer and will be washed less frequently because they will not accumulate dust or other dirt in its structure. The antibacterial finish also allows less washing of products. This is especially important for knitted fabrics with a high content of cotton fibers, which absorb moisture well but evaporate it slowly. All this will ensure a more sustainable use of textiles.

Fundamental rib knit structures, namely: 1×1 rib (MR) and half-Milano rib (MM), were chosen due to their higher width elasticity and higher dimensional stability than those of single jersey fabrics [15]. 1×1 rib knitted fabrics, due to their high elasticity in the crosswise direction, are suitable for a complete garment or its elements such as neck and sleeve bands, waistbands, etc. In addition, 1×1 rib knit trims may be used with other knit structures or even with woven fabrics in garments. Half-Milano rib knit fabrics feature an unbalanced structure. Therefore, they are better for making sweaters.

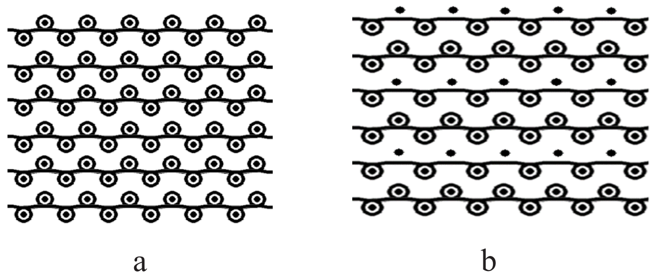

Fig. 1. Fabric structures (a) 1x1 rib (b) half-Milano

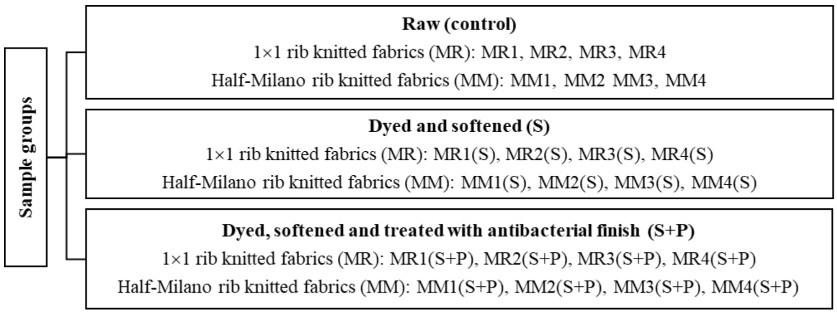

Fig. 2. Sample groups of the knitted fabrics investigated

Strength, elasticity and bending stiffness characteristics were analyzed for three sample groups of the fabrics investigated (Figure 2).

Raw (control) knitted fabrics were dyed by applying reactive dye with the use of a THIES MINISOFT machine (Germany, model 1995). The temperature of water used for preparation of the dyeing solution was 20 °C. The dyeing solution comprised of the following chemicals: wrinkle prevention agent - W BREVIOL® PAM-N (1 g/l), produced by Pulcra Chemicals GmbH (Germany), SARABID TS 300 (1 g/l), produced by CHT R. Beitlich GmbH (Germany), anionic dispersing agent MEROPAN DPE (0.5-1 g/l), produced by CHT R. Beitlich GmbH (Germany), and salt (60-100 g/l). Later, reactive BEZAKTIV dye, produced by CHT R. Beitlich GmbH (Germany), was added, ensuring the following color ratio: yellow S-3R 150 (0.088 %), red S-3B 150 (0.1 %), and blue S-GLD 150 (0.64 %). Sodium (5 g/l) was also added. The temperature of the dyeing solution was raised from 20 °C up to 60 °C at 1 °C/min. The fabrics were dyed at 60 °C temperature for 10 min. Later, 1.6 g/l of NaOH (20 %) was added. After this, the dyeing lasted for 60 min and the dyeing solution was drained. The first washing was carried out in water of 20 °C temperature for 10 min. The second washing was carried out in water, the temperature of which was raised from 20 °C up to 40 °C at a 2 °C/min speed for 10 min. Then the water used was drained, and neutralization in a solution of both water and acid (1.0-3.0 g/l), the temperature of which was increased from 20 °C up to 60 °C at a 2 °C/min speed, was done for 10 min. Afterwards, the solution was drained. Later, a new water solution was made adding both SECURON 540 (0.5-1.0 g/l) and BREVIOL® PAM-N (1 g/l), produced by Pulcra Chemicals GmbH (Germany). The temperature of the solution was raised from 20 °C up to 95 °C at a 1 °C/min speed, and this treatment of the fabrics lasted for 20 min. The solution temperature was then decreased from 95 °C up to 40 °C at a 1 °C/min speed, and the solution was drained again. The temperature of the next washing was raised from 20 °C up to 70 °C at 1 °C/min speed, and later the washing was done at 70 °C temperature for 15 min. Then the water was cooled from 70 °C up to 40 °C at a 1 °C/min speed and drained. The last washing was carried out at 40 °C temperature, raised from 20 °C at a 1 °C/min speed for 10

Sample Code	Fiber Composition (%)	Yarn Linear Density (tex)	Wale Density (cm^{-1})	Course Density (cm^{-1})	Loop Density (cm^{-2})	Fabric Thickness (mm)	Fabric Area Density (g/m^2)
		1×1 rib fabrics (MR)					
MR1	90 % CO, 10 % PET_A	28.1×3	15.0±0.5	10.6±0.6	159.0	1.95±0.04	597.73±0.09
MR1(S)			16.0±0.0	12.0±0.0	192.0	1.82±0.02	611.50±0.06
MR1(S+P)			16.0±0.0	12.0±0.0	192.0	1.80±0.02	603.60±0.05
MR2	80 % CO, 20 % PET_A	28.1×3	15.0±0.5	11.0±0.0	165.0	1.95±0.05	577.60±0.10
MR2(S)			16.0±0.0	12.0±0.0	192.0	1.78±0.02	607.10±0.06
MR2(S+P)			16.0±0.0	12.0±0.0	192.0	1.80±0.01	608.10±0.06
MR3	70 % CO, 30 % PET_A	18.5×4	14.6±0.5	10.6±0.6	154.8	1.90±0.03	565.73±0.05
MR3(S)			16.0±0.0	12.0±0.0	192.0	1.84±0.01	528.70±0.05
MR3(S+P)			16.0±0.0	12.0±0.0	192.0	1.87±0.02	616.40±0.09
MR4	65 % CO, 35 % PET_A	14.8×3	15.8±0.5	11.6±0.6	183.3	1.89±0.02	511.07±0.12
MR4(S)			16.0±0.0	12.0±0.0	192.0	1.71±0.01	524.90±0.07
MR4(S+P)			16.0±0.0	12.0±0.0	192.0	1.81±0.02	509.60±0.08
		Half-Milano rib fabrics (MM)					
MM1	90 % CO, 10 % PET_A	28.1×3	14.0±0.5	13.8±0.5	193.2	1.96±0.04	587.33±0.09
MM1(S)			16.0±0.0	18.0±0.0	288.0	1.80±0.02	642.40±0.08
MM1(S+P)			16.0±0.0	18.0±0.0	288.0	1.83±0.01	641.20±0.05
MM2	80 % CO, 20 % PET_A	28.1×3	14.2±0.5	13.8±0.5	196.0	1.95±0.05	588.40±0.09
MM2(S)			16.0±0.0	18.0±0.0	288.0	1.77±0.01	659.30±0.05
MM2(S+P)			16.0±0.0	18.0±0.0	288.0	1.79±0.02	658.30±0.05
MM3	70 % CO, 30 % PET_A	18.5×4	13.0±0.5	13.8±0.5	179.4	1.91±0.04	544.67±0.05
MM3(S)			16.0±0.0	18.0±0.0	288.0	1.86±0.01	577.60±0.04
MM3(S+P)			16.0±0.0	18.0±0.0	288.0	1.94±0.02	667.60±0.06
MM4	65 % CO, 35 % PET_A	14.8×3	14.0±0.5	12.2±0.5	170.8	1.91±0.03	498.13±0.07
MM4(S)			16.0±0.0	16.0±0.0	256.0	1.83±0.01	539.30±0.06
MM4(S+P)			16.0±0.0	16.0±0.0	256.0	1.82±0.02	506.70±0.04

Table 1. Characteristics of the knitted fabrics investigated
Notes: 1) CO – cotton; PET_A - antistatic polyester

min. The drying velocity was 15 m/min in the padder, produced by Santex. Treatment and softening of the knitted materials were carried out using a Santex CH-9555 Tobel machine (Switzerland). Hydrophilic softener was applied at a concentration of 20 g/l in the solution (5-6 pH) at a 40-50 °C temperature for 15-30 min. Drying proceeded at the standard temperature. Polygiene VO-600 was applied by the normal pad process at a concentration of 25 g/l and temperature of 30-40 °C for 20-30 minutes. The antibacterial finish Polygiene VO-600 is an active antiviral technology based on silver salt and is resistant to both dry cleaning and washing. Characteristics of the fabric's samples prepared are presented in Table 1.

2) The antistatic performance of the yarns used for fabric knitting was equal to 10^7-10^8 Ω/cm, determined by the yarn manufacturer.

3) Fabric area density, wale and course densities and fabric thickness of the knitted fabrics investigated were determined according to the standards ISO 3801, EN 14971, and ISO 5084, respectively.

From Table 1 the raw fabric thickness of the (control) fabrics developed was equal to 1.89-1.95 mm; the wales and courses were equal to 14.6-15.8 cm^{-1} and 10.6-11.6 cm^{-1} for all 1×1 rib fabrics (Table 1). The thickness of the raw fabrics was equal to 1.91-1.96 mm, wale densities - 13.0-14.2 cm^{-1}, and course densities - 10.6-11.6 cm^{-1}. The differences in the parameters of these fabrics varied in the limits of their measurement errors. Thus, they could be assumed to be constant characteristics of the knitted fabrics investigated.

2.2. Tensile Properties Testing Methodology

Tensile properties of the fabrics were tested to study the strength and elasticity of the developed fabrics affected by the fabric treatment, fabric structure and yarn composition. In this research work conventional polyester was replaced with antistatic polyester to achieve an antistatic property, and the yarn composition showed the effect of changing the fibre percentage on tensile properties. The knit fabrics investigated were tested according to the EN ISO 13934-1 standard using a computerized constant rate extension testing machine H10KT (Tinius Olsen). Five fabric samples of gauge dimensions of 50 mm×100 mm was tested in each sample group for the course and wales directions. The specimens were mounted with 0.5 N pretension at the beginning of the tests. Later, they were extended to the point of rupture at a rate of extension. The measurement error of the measurement of both the force and elongation value measurements varied from 1.40 % up to 14.5 %, and the variation coefficient did not exceed 8 %.

2.3. Bending Stiffness Testing Methodology

Bending stiffness is defined as the ability to resist bending. The method of hanging a pear loop [21] was used to assess the bending stiffness of the knitted fabrics in this research. This method was adopted to check the level of easy handling and interpreting of this method as it is not reported in literature to measure the bending stiffness, like cantilever or KESF-2 methods. It was only proposed by the researchers to measure the bending stiffness of fabrics. According to the method of hanging the pear loop (Figure 3), the ends of the bent fabric specimen were clamped to a stand.

The hung specimen formed a loop under its own weight. Photographs of the fabric samples were taken using a digital camera 5 minutes after the specimen clamping. The height of the specimen height $\hat{h}$ (mm) was measured in the photographs using AutoCAD®2019 software (Figure 3). The number of the specimens of 50´150 mm dimensions tested in each sample group was five for both the fabric's wale and course directions, as well as for both of the fabric's technical sides: face side (F) and back side (B). The error in the measurement of the loop height varied from 1.2 % up to 4.4 %. The variation coefficient varied from 0.7 % up to 2.5 %. The bending stiffness B (g) of the knitted fabrics investigated was calculated according to Equation 1 [21]:

$$B = \frac{wL^3}{b\hat{W}} \tag{1}$$

Where w – weight of the specimen, g/mm^2; L – length of the specimen, mm; b – width of the specimen, mm; $\hat{W}$ – a non-dimensional weight parameter calculated according to Equation 2 [21]:

$$\hat{W} = -8.3330631 \times 10^{8} + 9.50206993 \times 10^{9}\hat{h} - 4.33422998 \times 10^{10}\hat{h}^{2} + 9.88557465 \times 1010 \times \hat{h}^{3} - 1.12744452 \times 10^{11}\hat{h}^{4} + 5.143869 \times 10^{10}\hat{h}^{5}, \tag{2}$$

where $\hat{h} = \frac{h}{L}$.

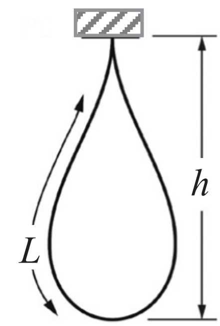

Fig. 3. Principle of bending stiffness testing according to the method of a hanging pear loop [21]

3. Results and Discussion

3.1. Tension Test Results Analysis

According to the EN ISO 13934-1 standard, the maximum force is defined as 'the maximum force recorded when a test specimen is taken to rupture during a tensile test under specified conditions. The determined values of the maximum force of the knitted fabrics investigated are presented in Figure 4.

In Figure 4 the maximum force of both raw and treated 1×1 rib knitted fabrics was significantly higher than that of the half-Milano rib knit fabrics along the wale direction. It could be assumed that the structure of the 1x1 rib knitted fabrics comprised all knit stitches, thereby increasing their elasticity and absorbing the higher tension force to reach its maximum point. The maximum force of the 1×1 rib knitted fabrics in the wale direction was 2.5-3.1 times higher than in the course direction, and that of the half-Milano knit fabrics was 2.0-3.2 times higher, supposedly due to the presence of straight yarns in the fabric structure. The maximum force for both 1×1 rib and half-Milano knit patterns was similar along their course direction. The dyeing, softening and antibacterial finish applied did not have a significant influence on the maximum force of the knitted fabrics investigated for both knit patterns. The maximum force of 65 % cotton/35 % antistatic polyester knitted fabrics in the course direction (Figure 4 (d)) was significantly lower than that of the fabrics with a different fiber content (Figure 4 (a-c)). This could be influenced by the higher amount of carbon black in the structure of the antistatic polyester fiber. The lower maximum forces of half-Milano rib knitted fabrics than those of the 1×1 rib knitted fabrics could be influenced by the existence of miss/float yarns in their structure, more capable of absorbing the lower tension force than knit loop. The flattened (miss stitch) yarn in the fabric structure does not need to absorb the tension force for its straightening. It only needs to resist breakage. The knit stitch absorbs force to straighten itself into a flat yarn first and then it absorbs higher force to resist breakage. The half-Milano rib knitted fabrics consisted of 25 % miss stitches and 75 % knit stitches in their structure, while the 1x1 rib knitted fabrics consisted of 100 % knit stitches, which showed a significant difference in the maximum force of the knitted fabrics investigated.

According to the EN ISO 13934-1 standard, the elongation at maximum force is defined as "elongation of a test

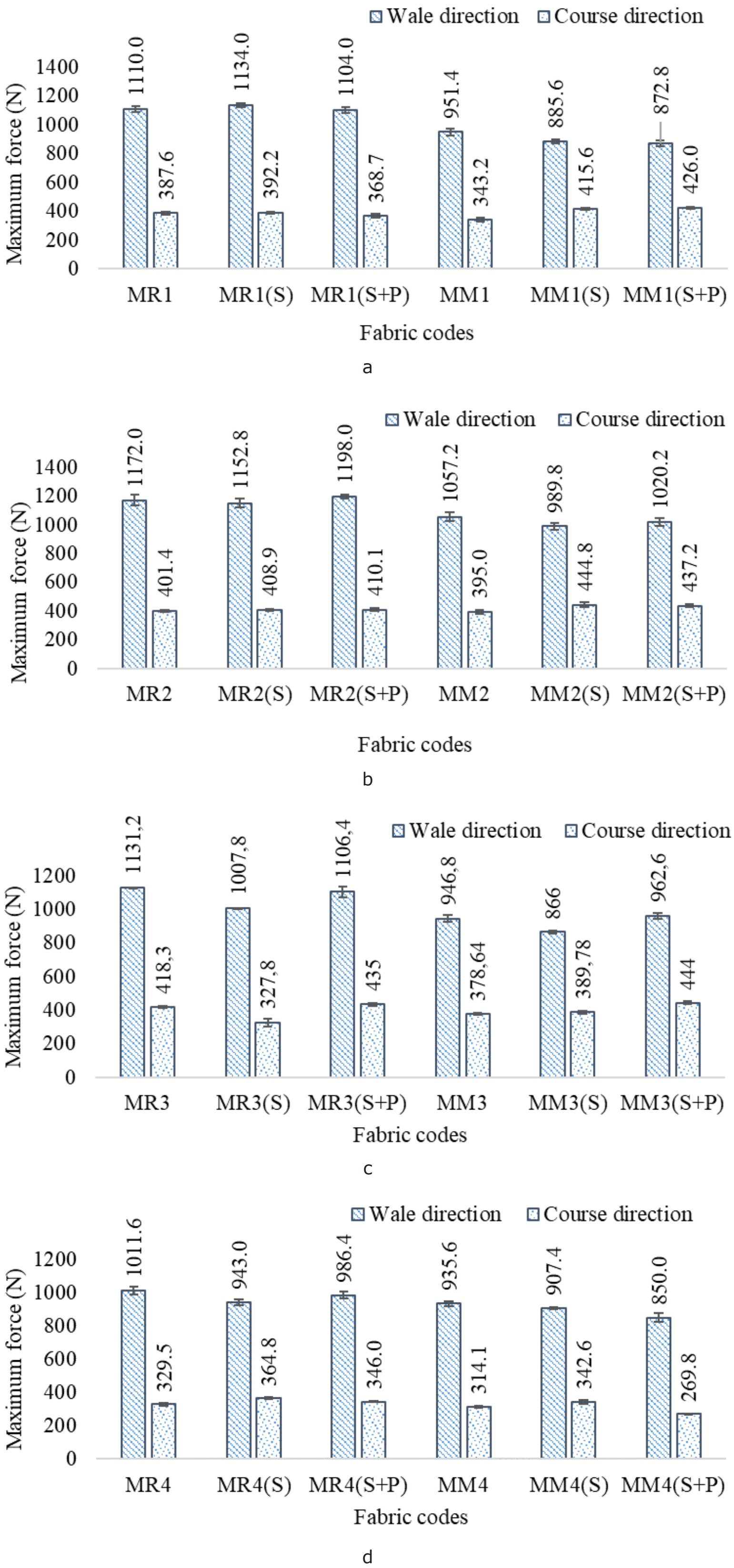

Fig. 4. Maximum force of the knitted fabrics raw samples for both 1×1 rib knitted fabrics (MR1, MR2, MR3, MR4) and for half-Milano rib knitted fabrics (MM1, MM2, MM3, MM4); (S) – softened samples; (S+P) – samples treated with softener and antibacterial finish. Fabrics' fiber content: a - 90 % CO / 10 % PET_A; b - 80 % CO / 20 % PET_A; c -70 % CO / 30 % PET_A; d - 65 % CO / 35 % PET_A

specimen produced by maximum force". The elongation values at the elongation at maximum force of the knitted fabrics investigated are presented in Figure 5.

In Figure 5 the elongation at maximum force was significantly higher along the course direction of both raw and treated 1×1 rib knitted fabrics than that of half-Milano rib knitted fabrics. The elongation at maximum force was approximately 3.3-4.3 times higher for the course specimens of 1×1 rib knitted fabrics than that for the wale specimens, and it was 2.0-2.8 times higher for the half-Milano knitted fabrics, supposedly, due to the straightening of the ribs not requesting high tension forces [15]. A similar trend was also determined previously [16]. Furthermore, it could be observed that the difference in the elongation at maximum force for the course and wale directions was significantly higher for 1×1 rib knitted fabrics than for half-Milano knitted fabrics. However, there was no significant difference in the elongation at maximum force for the fabric specimens of both 1×1 rib and half-Milano knit patterns cut lengthwise along the wales. The finishing processes applied did not have a significant influence on the elongation at maximum force of the knitted fabrics of both knit patterns investigated. The elongation at maximum force of 65 % cotton/35 % antistatic polyester knitted fabrics in the course direction (Figure 5 (d)) was significantly higher than that of the fabrics of different fiber content (Figure 5 (ac)). However, an opposite tendency was observed for the maximum force of the same fabric samples (Figure 4). When summarizing the results obtained, it could be stated that the strength and elongation of the fabrics investigated depend on the knit structure, specimen cut direction, and fiber content. Other researchers [16] also obtained similar results.

3.2. Analysis of Results of Bending Stiffness Tests

A summary of bending stiffness test results of the 1×1 rib and half-Milano rib knitted fabrics investigated is presented in Figure 6. The bending stiffness of

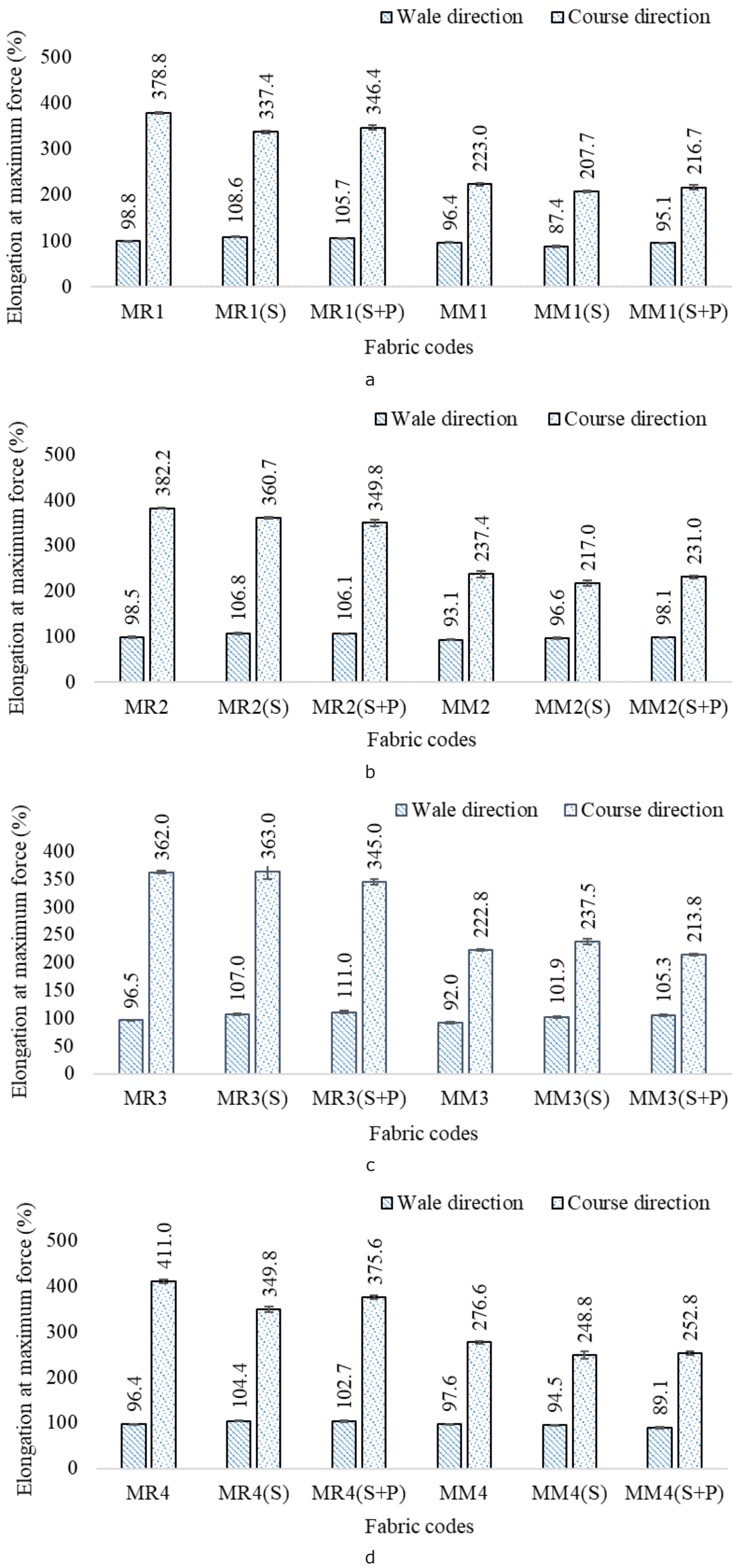

Fig. 5. Elongation at maximum force of the knitted fabrics: raw samples investigated for both 1×1 rib knitted fabrics (MR1, MR2, MR3, MR4) and half-Milano rib knitted fabrics (MM1, MM2, MM3, MM4); (S) – softened samples; (S+P) – samples treated with softener and antibacterial finish. Fabrics' fiber content: a - 90 % CO / 10 % PET_A; b - 80 % CO / 20 % PET_A; c -70 % CO / 30 % PET_A; d - 65 % CO / 35 % PET_A

both 1×1 rib and half-Milano rib knitted fabrics in the wale direction significantly increased after their dyeing and softening (S samples) and after the treatment with antibacterial finish (S+P samples) compared to the raw samples, supposedly due to their density [7] and the fact that after the treatments the fabrics are relaxed and their stitch density increases, which also increases the bending stiffness of the fabrics. Different behavior was determined only for the back side of (B) MM4(S+P) samples and face side of MR4(S+P) samples. The lowest changes in bending stiffness due to the treatment of the knitted fabrics were determined for the MM4 and MR4, which contain the highest amount of antistatic polyester fibers (Table 1). The stiffness of the bending decreased for most of the knitted fabrics in the course direction after their dyeing and softening (S samples) compared to the raw samples, whereas the samples treated with the antibacterial finish (S+P samples) became stiffer than the raw samples and those dyed with softening (S). The highest stiffness was determined for the MR1, MR2, MM1, and MM2 samples, containing the lowest amount of antistatic polyester fibers after their dyeing, softening, and treatment with the antibacterial finish (S+P samples).

The bending stiffness of the 1×1 rib knitted fabrics in the wale direction was not significantly dependent (for MR1(S), MR1(S+P), MR2, MR2 (S), MR2 (S+P) and MR4(S+P)) or absolutely independent (MR3, MR3 (S), MR3 (S+P) and MR4(S) fabrics) on the technical side (Figure 6 (a, c, e, g)). The bending stiffness of the raw MR4 fabric was lower for the back (B) than for the face side (F) (Figure 6 (g)). The bending stiffness of the 1×1 rib knitted fabrics in the course direction was higher for the face side (F) of the raw MR1 samples, lower for the back side (B) of raw MR2, treated MR1(S) and MR1(S+P) samples, and it was independent for the raw MR3, MR4, treated MR2(S), MR3(S), MR4(S), MR2(S+P), MR3(S+P) and MR4(S+P) samples. The bending stiffness of the raw 1×1 rib knitted fabric (MR1) was almost equal along the wale and course directions, but for MR2, MR3, MR4,

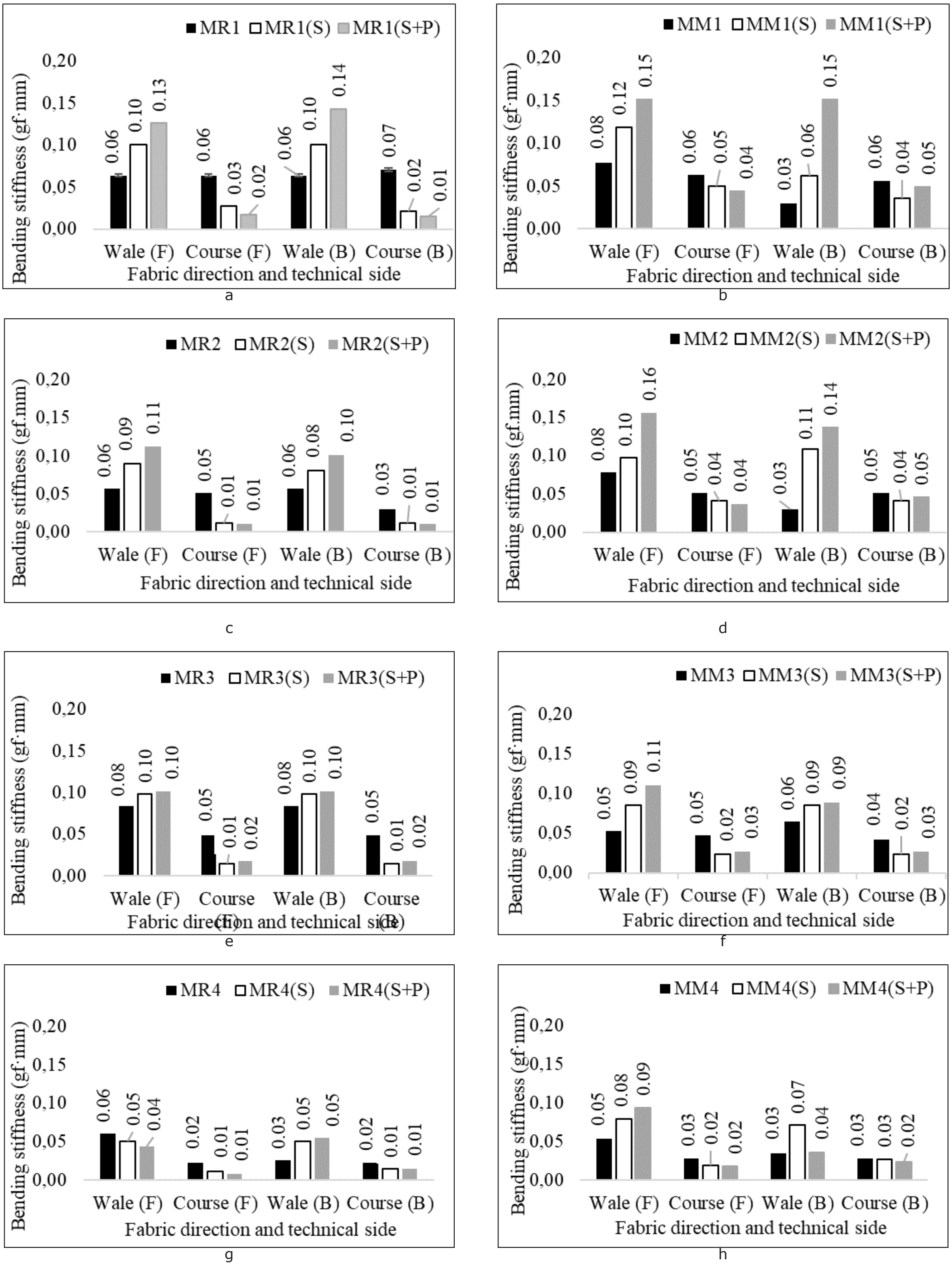

Fig. 6. Results of bend stiffness of the knitted fabrics investigated applying the hanging pear loop method: raw (control) samples for 1×1 rib knitted fabrics (MR1, MR2, MR3, MR4) and for half-Milano rib knitted fabrics (MM1, MM2, MM3, MM4); (S) – softened samples; (S+P) – samples treated with softener and antibacterial finish. Fabrics' fiber content: a - 90 % CO / 10 % PET_A; b - 80 % CO / 20 % PET_A; c -70 % CO / 30 % PET_A; d - 65 % CO / 35 % PET_A.

MR1(S), MR2(S), MR4(S), MR1(S+P), MR2(S+P) and MR4(S+P) fabrics the bending stiffness in the wale direction was higher than in the course direction. Dyeing and softening (S) and treatment with antibacterial finish treatment (S+P) increased the bending stiffness of the MR1 (S), MR2 (S), MR3 (S),MR1(S+P), MR2(S+P) and MR3(S+P) fabrics in the wale direction but decreased it in the course direction . The treatment decreased the bending stiffness of both the MR4 (S) and MR4(S+P) samples compared to the raw MR4 sample, with the exception the back side (B) of the samples in the wale direction.

The bending stiffness of the half-Milano rib knit fabric was lower for the back side (B) of raw (MM1, MM2, MM4) and treated MM1(S), MM4(S) and MM4(S+P) samples than for the face side (F) of the samples in wale direction. However, the bending stiffness was almost independent on the technical side for the MM3, MM2(S), MM3(S), MM1(S+P), MM2(S+P), MM3(S+P) and MM4(S+P) samples in the wale direction and for the raw sample (MM1, MM2), and for the treated sample in course direction. The bending stiffness for the face side (F) of raw samples (MM3), treated MM1 (S), MM4 (S), and MM1 (S+P) in the course direction were higher than for the back side (B). The stiffness of the bending of the half-Milano rib knitted fabrics was higher in the wale direction than in the course direction in raw and treated samples, except for MM2 wale case (B) (Figure 6 (b, d)). Softening and dyeing and antibacterial finish increased the bending stiffness of MM1(S), MM2(S), MM3(S), MM4(S), MR1(S+P), MM2(S+P), MM3(S+P) and MM4(S+P) fabrics in the wale direction but decreased it in the fabric course direction. The bending stiffness of the 1×1 rib knitted fabric samples (Figure 6 (a, c, e, g)) was lower than those of the half-Milano rib knit fabric samples (Figure 6 (b, d, f, h)) for most of the treated fabric samples investigated.

4. Conclusions

Tension and bending stiffness characteristics of cotton/antistatic polyester blended 1×1 rib and half-Milano rib fabrics were studied in this investigation.

Tensile tests of the fabrics investigated showed that the maximum forces of both raw and treated 1×1 rib knitted fabrics was higher than those of the half-Milano rib knitted fabrics along the wale direction. The maximum force of the wale specimens of both 1×1 rib knitted fabrics and half-Milano knitted fabrics was higher than that of the samples in the course direction. This difference was higher for the 1×1 rib knitted fabrics than for the half-Milano rib knit fabrics. The maximum force was similar for both 1×1 rib and half-Milano knit patterns along their course direction . The elongation at maximum force was significantly higher along the course direction of both raw and treated 1×1 rib knitted fabrics than that of the half-Milano rib knitted fabrics, with this difference being greater for the half-Milano rib knitted fabrics. The elongation at maximum force of both 1×1 rib knitted fabrics and half-Milano knitted fabrics was higher for the course specimens than for the wale specimens. This difference was higher for the 1×1 rib knitted fabrics than for the half-Milano knitted fabrics. The difference in elongation at maximum force of both 1×1 rib and half-Milano knitted fabrics lengthwise the wale direction was not significant. The finishing processes applied did not have a significant influence on either the maximum force and elongation at maximum force of knitted fabrics of the two knit patterns investigated. The maximum force of the knitted fabrics having the highest amount of antistatic polyester fibers in the course direction was significantly lower than for the other fabrics investigated, while the elongation at maximum force was significantly higher in this case.

The bending stiffness of the 1×1 rib knitted fabrics was lower than that of the half-Milano rib knitted fabrics for most of the treated fabric samples investigated. The bending stiffness of both 1×1 rib and half-Milano rib knitted fabrics in the wale direction increased significantly after their dyeing and softening as well as after treatment with antibacterial finish compared to the raw samples. The bending stiffness decreased for most of the knitted fabrics investigated in the course direction after their dyeing and softening (S samples) compared to the raw samples. The samples treated with the antibacterial finish (S+P samples) became stiffer than the raw samples and those dyed with softening. The highest stiffness was determined for the MR1, MR2, MM1 and MM2 fabric samples, containing the lowest amount of antistatic polyester fibers after their dyeing, softening, and treatment with the antibacterial finish.

Declaration of Conflicting Interests

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References

1. Islam G. N., Ali A., Collie S. Textile sensors for wearable applications: A comprehensive review. *Cellulose*, 2000; 27(11), 6103-6131. https://doi.org/10.1007/s10570-020-03215-5
2. Kubley A., Chauhan D., Kanakaraj S. N., Shanov V., Xu C., Chen R., Schulz, M. J. Smart textiles and wearable technology innovation with carbon nanotube technology. 2019; In *Nanotube Superfiber Materials* (pp. 263-311). William Andrew Publishing. https://doi.org/10.1016/B978-0-12-812667-7.00012-4
3. Lund A., van der Velden N. M., Persson N. K., Hamedi M. M., Müller C. Electrically conducting fibres for e-textiles: An open playground for conjugated polymers and carbon nanomaterials. *Materials Science and Engineering: R: Reports*, 2018; 126, 1-29. https://doi.org/10.1016/j.mser.2018.03.001
4. Hessami R., Yazdi A. A., Mazidi A. Investigation of tensile and flexural behavior of biaxial and rib 1×1 weft-knitted composite using experimental tests and multi-scale finite element modeling. *Journal of Composite Materials*, 2019; 53(23), 3201-3215. https://doi.org/10.1177/0021998319839855
5. Kothari V. K. Polyester and polyamide fibres–apparel applications. In *Polyesters and polyamides* 2008; (pp. 419-440). Woodhead Publishing. https://doi.org/10.1533/9781845694609.3.419
6. Berenguer J. L., Diaz-García P., Martinez P. M. Determining the loop length during the knitting and dyeing processes. *Textile Research Journal*, 2021; 91(1-2), 188-199. https://doi.org/10.1177/0040517520931898
7. Choi M.S., Ashdow S. P. Effect of changes in knit structure and density on the mechanical and hand properties of weft knitted fabrics for outerwear. *Textile Research Journal*, 2000; 70(12), 1033-1045. https://doi.org/10.1177/004051750007001201
8. Amreeva, G., Kurbak, A. Experimental studies on the dimensional properties of Milano and Milano rib fabrics. *Textile Research Journal*, 2007; 77(3), 151-160. https://doi.org/10.1177/0040517507079410
9. Peterson J., Eckard A., Hjelm J., Morikawa H. Mechanical-Property-Based Comparison of Paper Yarn with Cotton, Viscose, and Polyester Yarns. *Journal of Natural Fibers*, 2021; 18(4), 492-501. https://doi.org/10.1080/15440478.2019.1629372
10. Sayed Z.B, Islam T.,Chawdhury N.H., Amhed M. Effect of knitted structures and yarn count on the properties of weft knitted fabrics. *Journal of Textile Science and Technology*, 2018; 4(2), 67-77. https://doi.org/10.4236/jtst.2018.42004
11. Tausif M., Ahmad F., Hussain U., Basit A., Hussain T. A comparative study of mechanical and comfort properties of bamboo viscose as an eco-friendly alternative to conventional cotton fiber in polyester blended knitted fabrics. *Journal of Cleaner Production*, 2015; 89, 110-115. https://doi.org/10.1016/j.jclepro.2014.11.011
12. Telli A., Özdil N. Effect of recycled PET fibers on the performance properties of knitted fabrics. *Journal of Engineered Fibers and Fabrics*, 2015; 10(2), 155892501501000206. https://doi.org/10.1177/155892501501000206
13. Kim J., Kim Y. J., Shim M., Jun Y., Yun . Prediction and categorization of fabric drapability for 3D garment virtualization. *International Journal of Clothing Science and Technology*, 2020; 32(4), 523-535. https://doi.org/10.1108/IJCST-08-2019-0126
14. Kim H. A., Kim S. J. Hand and wear comfort of knitted fabrics made of hemp/tencel yarns applicable to garment. *Fibers and Polymers*, 2018; 19(7), 1539-1547. https://doi.org/10.1007/s12221-018-8275-z
15. Singhal K., Mishra S., Kumar B. A study of curling in rib-knit constructions. *The Journal of The Textile Institute*, 2021; 112(4), 666-675. https://doi.org/10.1080/00405000.2020.1778224
16. Sitotaw D. B., Adamu B. F. Tensile properties of single jersey and 1×1 rib knitted fabrics made from 100% cotton and cotton/lycra yarns. *Journal of Engineering,* 2017; 1-7. https://doi.org/10.1155/2017/4310782
17. Mao T., Wei Y., Zheng C., Cheng W., Zhang Z., Zhu Y., Zeng Z. Antibacterial cotton fabrics coated by biodegradable cationic silicone softeners. *Journal of Surfactants and Detergents*, 2019; 22(6), 1429-1443. https://doi.org/10.1002/jsde.12316
18. Pinar A., Oleksiewicz I., Wrobel S. Assessment of the electrostatic properties of polyester knitted fabrics containing carbon fibres after enzymatic modification for the improving of hygroscopic properties. *Fibres & Textiles in Eastern Europe*, 2014; 3(105), 84-90.
19. Telipan G., Moasa B., Helerea E., Carpus E., Scarlat R., Enache G. ESD Knitted Fabrics from Conductive Yarns Used as Protective Garment for Electronic Industry. *Textiles for Advanced Applications*, 2017; 371. http://dx.doi.org/10.5772/intechopen.69843
20. Zhang X. Antistatic and conductive textiles. In *Functional Textiles for Improved Performance, Protection and Health* , 2011; (pp. 27-44). Woodhead Publishing. https://doi.org/10.1533/9780857092878.27
21. Plaut R. H. Formulas to determine fabric bending rigidity from simple tests. *Textile Research Journal*, 2015; 85(8), 884-894. https://doi.org/10.1177/0040517514553877
22. EN ISO 13934-1: 2013. Textiles. Tensile properties of fabrics. Part 1: Determination of maximum force and elongation at maximum force using the strip method, 7 p.