Evaluation of Surface, low stress tensile and shear properties of Denims Made from Cotton, Polyester and Spandex Using KES- FB

Biruk Fentahun Adamu

Ethiopian Institute of Textile and Fashion Technology, Bahir Dar University, Bahir Dar, Ethiopia

*Author for correspondence: Email: Birukfentahun2009@gmail.com

Abstract: Denim fabrics are used in different applications. In the early times denims were manufactured from 100% cotton yarn in which the warp yarn is dyed and floated in 3/1 twill, but now a day's different types of yarns are used as weft. In this study four different denim fabric samples of 3/1 Z twill with warp (6.5Ne) density of 60 yarns per inch and weft yarn (12Ne cotton, 14Ne cotton/70 denier spandex, 400 denier polyester/50 denier spandex and 450 denier polyester) density of 40 yarns per inch, were used for investigating the surface and low stress tensile, shear properties of denim fabrics. Kawabata evaluation system for fabrics (KES-FB) was used to measure surface and mechanical properties of fabrics. The result revealed that denims made from cotton has higher shear and surface properties than denims made from polyester yarn whereas denims made from cotton has lower strength properties than denim made from polyester. Adding spandex in both fabrics (denims made from cotton and denims made from cotton and polyester) improves handling properties like smoothness and recoverability properties.

Keywords: Denim fabric, cotton and cotton/spandex, polyester/spandex and polyester, shear and tensile properties, surface property

1. INTRODUCTION

Originally denim was a 100% cotton serge material with twill design known for its use in blue jeans. However, now denims are from a variety of yarns, including blends that give the same wonderful look as that of 100% cotton denim but having some additional superior features. To meet essential customer demand, the fabric designers and manufacturers are obliged to produce different types of denim at present (Paul, 2015). Polyester/viscose suiting fabrics were studied that showed as polyester content increases, air permeability, extensibility, bending rigidity and moisture vapor of the fabric decreased while the tensile strength and thermal insulation increased (Rajkishore et al., 2009). Kawamura et al., (Kawamura et al., 2016) investigated the relationship between physical and low stress mechanical properties to fabric hand of woolen fabric to determine subjective evaluation and objective measurement by calculations and found thickness and weight properties were highly related with stiffness, softness, smoothness. Guruprasada, et al. (Guruprasada, et al., 2018) studied the low-stress mechanical properties and fabric hand of cotton and polylactic acid fibre blended knitted fabrics and found the addition of polylactic acid fibers to cotton enhances the smoothness and softness of the blended fabrics. Bedez (Bedez, 2019) investigated the effect of double-core and core-spun weft yarns and weft density on the mechanical properties of denim fabrics. The result revealed that fabrics with elastase-cored yarns showed low tensile and tear strength. Elastic yarns are most widely used in denim fabrics to improve comfort during body movements. Singha, K. (Singha, 2012) showed that elastomeric behavior of spandex/cotton properties is due to the soft and hard segmental attachment inside the spandex fiber. The ratio of the soft and the hard segment is very important to determine the elastomeric or mechanical properties (elongation, relaxation) of the spandex fiber blended with natural material like cotton fiber (spandex/cotton blend). Kumar et al. (Kumar et al., 2016) studied that the amount of lycra content on fabrics has a significant influence on physical and elastic properties of denim fabrics, where air permeability and tensile strength decreased with lycra content. Other researchers also investigated the effects of spandex drawing ratio and weave structure on the physical properties of cotton/spandex woven fabrics (Almetwally, 2014). Cotton woven fabrics containing spandex show higher contraction, crease recovery, and flexural rigidity with increasing spandex drawing ratio, whereas air permeability and breaking elongation of fabric properties decreased with the increasing drawing ratio. Özdil, N. (Ozdil, 2008) studied stretch and bagging properties of denim fabrics containing different rates of elastane**.** The outcomes of the tests explicitly revealed that as the elastane content increases, the stretching and the maximum stretching percentages and stiffness values increase, whereas the tensile, tearing strength and permanent stretching percentage decreases.

Investigated the positive correlation of fabric low stress properties (shear rigidity, bending rigidity, shear hysteresis, bending hysteresis, and tensile linearity) with its GSM, thickness, and tightness factor properties and negatively correlated with fabric linear stitch modulus, areal stitch modulus, volume stitch modulus, and porosity (Varadaraju and Srinivasan, 2015).

Fabric shearing behavior determines fabric's performance properties while subjected to a wide variety of complex deformations in use. Shear property permits the fabric to go through complex deformations and to conform to the shape of the body which will affect draping, flexibility and handle of woven fabric (Jurgita, 2005).

Many researchers have been trying to develop a system for measuring the low stress mechanical properties of textiles. The Kawabata Evaluation System (KES) is the first system for testing fabric mechanical and handle properties. Tensile, bending, shearing, compression and surface properties can be measured and from these measurements, properties such as stiffness, softness, extensibility, flexibility, smoothness and roughness can be inferred (Saville, 1999). Low stress mechanical properties can be measured objectively using KES-FB, which includes four kinds of machines: KES-FB1 for tensile and shear tester; KES-FB2 for pure bending tester; KES-FB3 for automatic compression tester; and KES-FB4 for automatic surface tester (Kawabata, 2009). The Kawabata evaluation system for fabrics (KES-FB) is very important to provide suitable information for quality control, product development and product specification (Hawood et al., 1990).

Denim fabric'slow stress mechanical properties are affected by its constituents such as the fiber and yarn characteristics. In this paper the surface and low stress tensile, shear properties of denim fabric samples made from different fibers types and different weft yarns (cotton, polyester, spandex, and bled yarns) were investigated using KWABATA instruments.

Mostly the researchers investigated the effect of spandex on physical and mechanical properties of denims. The investigation of denim fabric (made from cotton, polyester and spandex) Surface property, low stress tensile and shear properties did not study by KWABATA instruments. Therefore, this paper studies the evaluation of surface, low stress tensile and shear properties of denim fabrics made from cotton, polyester and spandex using KES.

2. MATERIALS AND METHODS

2.1 Materials

In this study, four different denim fabric samples of 3/1 Z twill with warp density of 60 yarns per inch and weft density of 40 yarns per inch are used. The weft yarns were made from different fibers. Table1 shows the detailed specifications of denim fabrics with their coding. The fabrics are manufactured with loom specifications and settings as shown below:

Loom specifications and settings

- ✓ Loom type: Toyota air jet loom
- ✓ Weft insertion type: air jet
- ✓ Loom speed: 750 rpm
- ✓ Warp tension: 380kgf
- ✓ Reed width: 190 cm
- ✓ Shed formation: Tappet
- ✓ Beam length: 195 cm
- ✓ Weft stop motion: electronic 2-hole weft slide sensor.
- ✓ Warp detection: electric dropper pin type with 6 rows
- ✓ Let-off: electronic let-off system ensuring uniform warp beam tension.
- ✓ Take up system: electronically
- ✓ Weave type: 3/1 right hand twill
- ✓ Number of sized warp ends- 4416
- ✓ Fabric width-177cm
- ✓ On loom Ends/inch- 60, Picks/inch-40

Table 1. Specifications of denim fabrics

Fabric code	Dyed warp yarn	Weft yarn	Spandex % in weft	Yarn count: Warp *weft	On loom EPIXPPI	Weave type	Fabric width(cm)
F1	Cotton	Cotton	-	6.5 S*10S	60X40	3/1 Z twill	176
F2	Cotton	Cotton/spandex	5.4	6.5 S*14+70D	60X40	3/1 Z twill	176
F3	Cotton	Polyester/spandex	12.5	6.5 S*150+40D	60X40	3/1 Z twill	176
F4	Cotton	Polyester	-	6.5 S * 450D	60X40	3/1 Z twill	176

S means cotton yarn count system which is Ne and D means denier yarn count system Fabric (F1) is made from 100% cotton dyed warp and 100% cotton weft yarns of fabric structure 3/1 twill, fabric (F2) is made from 100% cotton dyed warp and cotton/spandex weft yarns, fabric (F3) is made from 100% cotton dyed warp and polyester/spandex weft yarns, fabric (F4) is made from 100% cotton dyed warp and polyester weft yarns.

2.2 Methods

The methods followed are generally fabric manufacturing, characterizing the low stress fabric properties and analyzing the test results. The denim fabrics were manufactured based on the specifications given in Table 1 on the same loom based on the specifications listed. Basically, the samples are different in their weft yarn type only but the warp yarn is the same for all fabrics samples which is 100% cotton with detail specifications in Table 1. The weft yarns are 100% cotton weft, 95.6% cotton/5.4 spandex (% based on the yarn count), 12.5% spandex/77.5% polyester and 100% polyester. Therefore, all the tests are done in the weft directions taking the consideration that warp yarns are the same.

Handle properties of fabrics were evaluated by measuring the low stress mechanical properties (tensile, shear, surface roughness and surface friction) on Kawabata evaluation system (KES-FB). Five fabric samples were prepared with dimensions of 20cm x 20cm from each type of denim fabric for KES-FB test. Before the fabric objective measurement, all samples were conditioned at 65% relative humidity and 20°C, following textiles' conditioning standard ASTM D1776 (ASTMD1776, 2002).

The tensile and shear properties were studied on KES-FB1 (tensile and shear tester) following KBES 01- determination of tensile and shear test of fabrics. The tensile properties were measured by plotting the force extension curve between zero and a maximum force of 500gf/cm and the recovery curve at the speed of 0.2 mm/sec. Shear properties were measured by shearing a fabric sample parallel to its long axis, keeping a constant tension of 10gf/cm on the clamp with the shearing angle of 8 degrees and shearing weight of 200 gram (Parachuru, 2002).

The surface roughness and surface friction were measured on KES-FB4 (surface tester) at a tension of 400 gram following KBES 04_Determination of surface test (Smoothness Test) of fabrics. KES-FB4 surface tester uses two different electronic sensors that record the geometric roughness of the fabric surface and the coefficient of surface friction, respectively, as the fabric moves forward and backward underneath the two sensors. Both sensors directly contact the fabric surface at two different places and the contact pressure is standard for all measurements. The fabric also carries a preset tension on it as it moves underneath the sensors. Roughness and friction coefficients are computed for a three-centimeter length of fabric; the computation includes both forward and backward movements in both the warp and filling directions. The parameters obtained from the surface test are: MIU - coefficient of surface friction, MMD - mean deviation of coefficient of friction, and SMD - index of surface roughness (mean deviation of surf ace peaks representing thick and thin places, µm) (Parachuru, 2002). All data results were analyzed graphically using Excel.

3. RESULTS AND DISCUSSIONS

3.1 Surface Properties

The surface property of the samples is presented in Table 2. In Table 2, MIU equals the mean value of frictional coefficient (µ) in 20mm distance; MMD is the fluctuation of mean frictional coefficient which means how much it fluctuates (degree of fluctuation) from MIU (mean Frictional Coefficient) and SMD (Surface Roughness) mean deviation of surface roughness. MIU is associated with the slipperiness (of a surface or object, difficult to hold firmly or stand on because it is smooth) and non-slipperiness of the yarn/fabric which we sense when we touch the surface of the fabric. The larger the value of MIU is, the less slippery the yarn/fabric. MMD is correlated with the smoothness and roughness that we feel when we rub through the surface of the fabric and the larger the MMD value is, the rougher the fabric. SMD indicates the surface physical roughness, where, the larger the SMD value is, the less even the fabric.

Table 2. **Surface Properties**

Fabric code	**Fabric surface properties**	**Weft direction**					
		1	2	3	4	5	Average
F1	MIU	0.167	0.325	0.229	0.255	0.22	0.2392
	MMD	0.017	0.024	0.0228	0.026	0.02	0.0217
	SMD(µm)	1.665	2.35	2.29	2.545	2	2.17
F2	MIU	0.183	0.214	0.187	0.214	0.2	0.1996
	MMD	0.018	0.021	0.0187	0.022	0.02	0.01998
	SMD(µm)	1.83	2.145	1.87	2.145	2	1.998
F3	MIU	0.19	0.152	0.154	0.162	0.163	0.1642
	MMD	0.019	0.015	0.0154	0.016	0.016	0.01642
	SMD(µm)	1.9	1.52	1.54	1.162	1.63	1.5504
F4	MIU	0.337	0.201	0.199	0.299	0.252	0.2576
	MMD	0.034	0.020	0.0199	0.03	0.025	0.02576
	SMD(µm)	3.337	2.01	1.99	2.99	2.52	2.5694

From Figure 1, it is observed that the average MIU value is higher (MIU=0.252) for fabric made from cotton as warp and polyester as weft (F4) and the lowest value (MIU=0.163) is found to be for fabric made from cotton as warp and polyester/spandex as weft (F3). This means that fabric type F3 is the softest fabric as compared to other fabrics F1, F2, and F4 and fabric type F4 has the lowest softness, i.e., the highest roughness. This may be due to spandex fibers having better soft segment and cotton fiber has softness than polyester fibers. Therefore, adding spandex will decrease the coefficient of frictional properties.

Roughness is one of the main reasons of tactile perceptions such as prickle, harshness, scratchiness, warmness and coolness. The higher the SMD value is the higher its roughness. As seen in Figure 1, the higher SMD values is found for fabric made from polyester (F4), therefore, fabric made from polyester will feel harsh, scratchy and prickly to the wearer. But it can be used for other applications other than clothing or clothing's which are not in direct contact with human body.

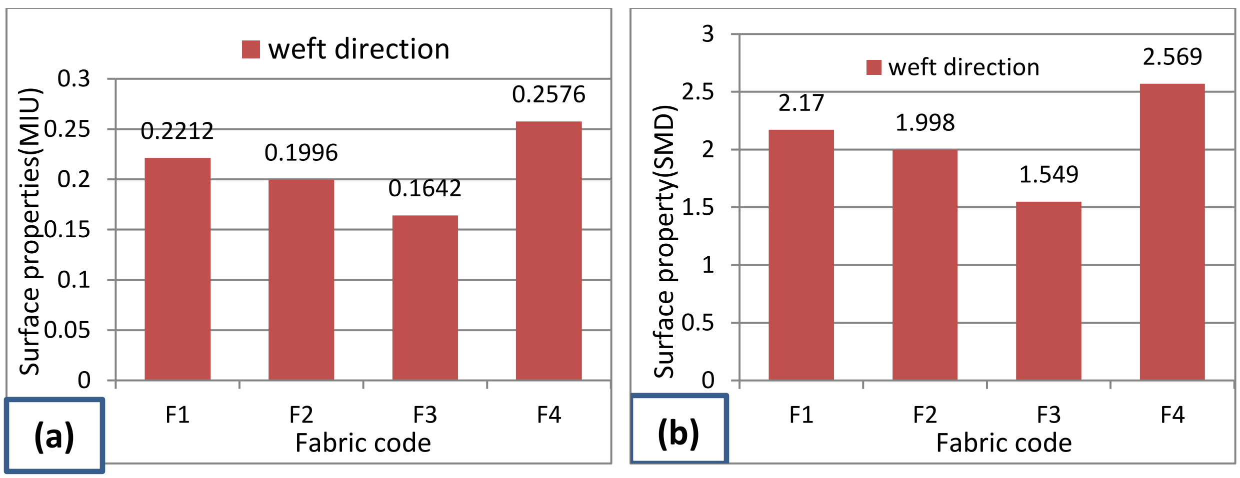


Figure 1. **Effect of yarn type on surface properties**: **a**) **MIU b**) **SMD**

3.2 Tensile Property

The low stress tensile properties are presented in Table 3. These are LT, WT, RT and EMT. WT **(**tensile energy**)** shows the softness that can be obtained in the sensory evaluation**.** The softer the sample is, the easier it becomes to stretch and WT value becomes larger, i**.**e**.** as the WT value becomes larger, it becomes easier to stretch. As we can see from Figure 2(a), the tensile energy in the EMT values relates to the tensile strain values weft directions is high for F3 and F2 and the lowest is at F4, which means the spandex yarn makes the denims to be soft. When we compare the softness of fabrics made from cotton (F1) and cotton/polyester (F4), F1 needs high energy due to high stretchability. Adding spandex in denims will increase the energy used to stretch the fabric since the fabric takes more time due to its high stretch properties.

under strain biaxial extension at low stress extensibility. This value is related to the crimp removal process during tensile loading. The higher the extensibility, the better is the fabric quality from the point of fabric handle that means the higher the EMT value is the greater the wearing comfort. Based on the results of Figure 2b, it is observed that polyester/spandex and cotton/spandex fabrics (F3 and F2) have higher EMT values compared to cotton core spun fabric (F1) and polyester fabric (F4). This is because spandex will give the fabric higher extensibility that will give better fitting comfort. Adding 5.4% spandex to F1 and 12.5% spandex to F4 will increase the WT by 7.456 and 10.434; also increase the EMT value by 5.812 and 8.732 respectively.

Table 3. **Low stress tensile properties**

Fabric code	Tensile properties	Test in the weft direction					Average
F1	LT	0.981	0.973	0.973	0.96	0.97	0.9722
	WT(gf.cm/cm^2)	6.35	6.3	6.3	6.35	6.33	6.326
	RT (%)	51.97	53.17	53.17	52.8	53	52.814
	EMT (%)	2.59	2.59	2.59	2.64	2.6	2.602
F2	LT	0.664	0.69	0.672	0.63	0.66	0.6632
	WT(gf.cm/cm^2)	13.85	13.3	13.65	14.3	13.8	13.782
	RT (%)	45.85	45.49	45.42	45.3	45.5	45.51
	EMT (%)	8.34	7.71	8.13	9.39	8.5	8.414
F3	LT	0.578	0.552	0.578	0.54	0.56	0.5612
	WT(gf.cm/cm^2)	14.9	15	14.47	15.9	15	15.034
	RT (%)	46.31	47	47.47	46.4	46.5	46.73
	EMT (%)	10.32	10.86	10.27	11.8	10.3	10.714
F4	LT	0.917	0.933	0.94	0.95	0.92	0.9314
	WT(gf.cm/cm^2)	4.7	4.5	4.7	4.5	4.6	4.6
	RT(%)	60.64	62.22	60.64	62.2	62	61.544
	EMT(%)	2.05	1.93	2	1.9	2.03	1.982

The linearity of the tensile property (LT) is an indicative of wearing comfort. As the value approaches to 1, it becomes harder. The lower LT value gives higher value of extensibility in the initial strain range, and this gives comfort of wearing. Therefore, fabrics F3 and F2 give better comfort than others. The RT value shows the denim fabric recoverability property. Adding 5.4% spandex to F1 and 12.5% spandex to F4 will decrease the RT value by 7.331 and 14.814 respectively.

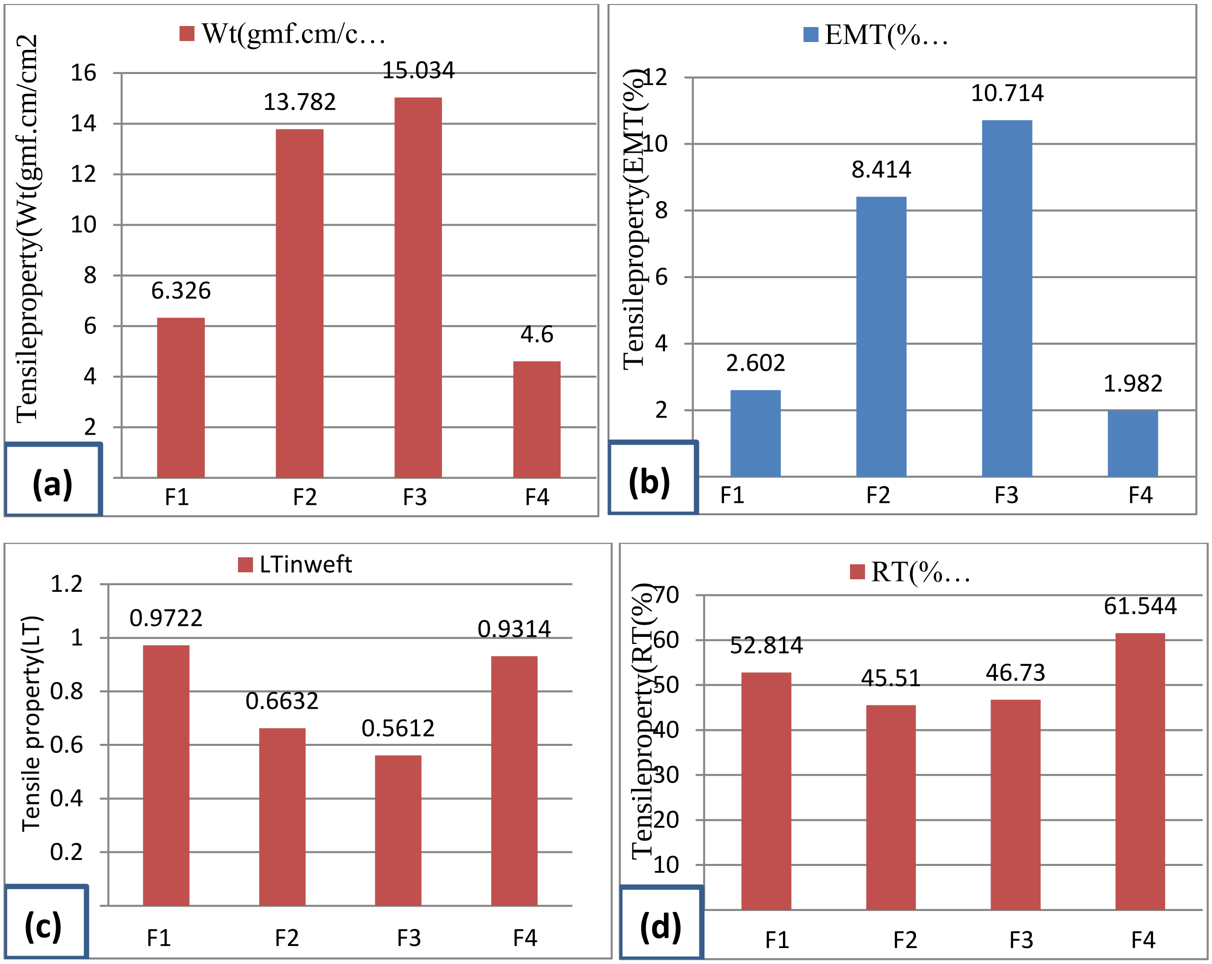


Figure 2. **Effect of yarn type on low stress tensile properties a) WT, b) EMT, c) LT & d) RT**

3.3 Shear Properties

Whenever bending occurs in more than one direction, so that the fabric is subjected to double curvature, shear deformations of the fabric are involved. As revealed by its definition, shear property is highly related to the fabric bending property. The shear property in conjunction with the bending property is thus a good indicator of the ability of a fabric to drape.

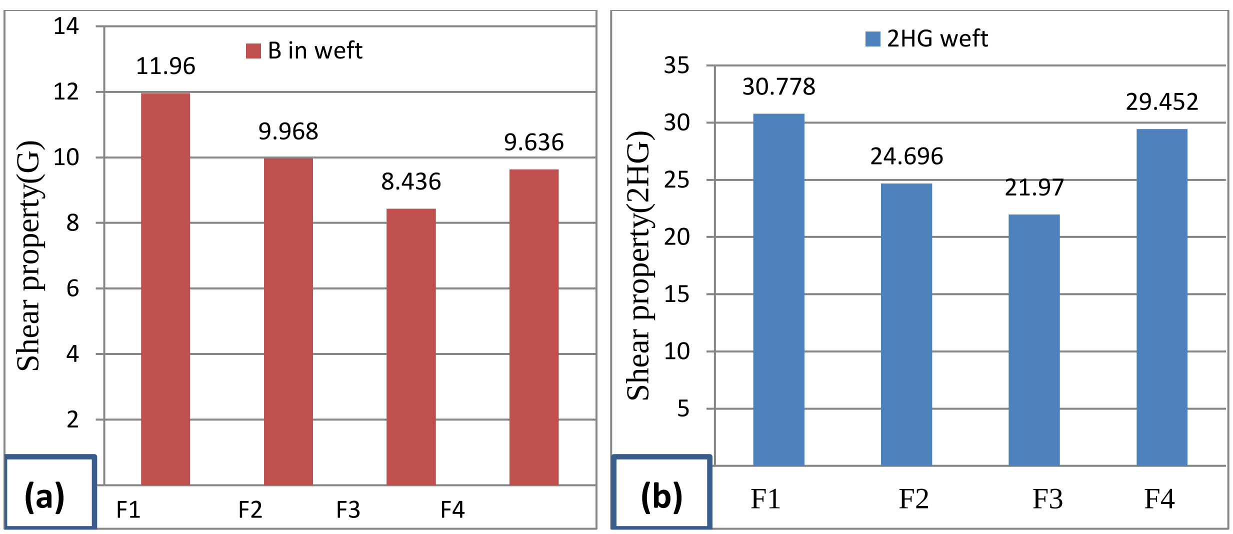
The shearing angle is 8 degrees and shearing weight is 200 g and hysteresis of shear force is at 0.5 degree (2HG) and 5 degrees (2HG5). The shear rigidity of a fabric depends on the surface characteristics of both fiber and yarn. From the point of handle, the lower the shear rigidity (G), easily deformed the sample. Also the higher 2HG value is, the lesser its resilience (recoverability) of sample, and the lower the 2HG value becomes, the better resilience (recoverability) the sample shows. The low stress shear properties of denims is presented in Table 4.

Table 4**.** Denim fabric shear properties (G is shearing rigidity, 2HG is shearing hysteresis

at shear angle of 0.5 and 2HG5 is shearing hysteresis at shear angle of 5).

Table 4. Denim fabric shear properties

Fabric code	Shear properties	Calculated Results(G1=0.5) (2HG5 = 5.0) in the weft direction					
		1	2	3	4	5	Average
F1	G	12.02	11.75	11.86	12.17	12	11.96
	2HG	30.05	31.18	29.56	32.1	31	30.778
	2HG5	38	37.98	38.58	38.63	38	38.238
F2	G	9.93	9.9	9.81	10.28	9.92	9.968
	2HG	25.45	24.5	24.93	24	24.6	24.696
	2HG5	31.53	30.9	30.73	31.23	30.8	31.038
F3	G	8.4	8.11	8.57	8.5	8.6	8.436
	2HG	22.6	21.7	21.55	22	22	21.97
	2HG5	27.3	26.28	26.38	27	27.9	26.972
F4	G	9.36	9.71	9.94	9.47	9.7	9.636
	2HG	29.05	29.33	29.5	29.93	29.45	29.452
	2HG5	34.33	35.03	35.95	35.63	35.45	35.278



(a) (b)

Figure 3. Effect of yarn type on low stress shear properties: **a**) **shearing rigidity, b**) **shearing hysteresis at shear angle of 0.5**

From Figure 3, the higher shear rigidity is found for cotton fabric (F1), which means this fabric cannot be easily deformed as compared to fabric made from cotton and polyester (F4).

4. CONCLUSION

Denim made from cotton has higher shear and surface properties than denims made from polyester yarn as weft. Adding spandex in both fabrics (denims made from cotton and denims made from cotton and polyester as weft) decreases the strength properties of denim fabrics and it improves denims handling properties like smoothness and recoverability properties. By adding 5.4% of spandex in cotton (F2) and 12.5% spandex in polyester (F3), the coefficient of friction was decreased by 0.0216 and 0.093 and the SMD decreased by 0.172 and 1.02 respectively. And also adding 5.4% spandex to F1 and 12.5% spandex to F4 will increase WT by 7.456 and 10.434, as well as increase the EMT value by 5.812 and 8.732 respectively. Adding 5.4% spandex to F1 and 12.5% spandex to F4 will decrease the RT value by 7.331 and 14.814 respectively. And under wear denims should preferably be made of 100% cotton because it is great for sensitive skin and is so much softer, than polyester. Adding some percent of spandex is recommended especially for women wear, to bring some fitness comfort.

Reference

Almetwally, A.A. and M.M. Mourad, *Effects of spandex drawing ratio and weave structure on the physical properties of cotton/spandex woven fabrics.* The Journal of The Textile Institute, 2014. **105**(3): p. 235-245.

ASTMD1776, *Standard practice for conditioning and testing textiles*. 2002.

Bedez Ute, T., *Analysis of mechanical and dimensional properties of the denim fabrics produced with double-core and core-spun weft yarns with different weft densities.* The Journal of The Textile Institute, 2019. **110**(2): p. 179-185.

Jurgita Domskienė and E. Strazdienė, *Investigation of Fabric Shear Behaviour* FIBRES & TEXTILES in Eastern Europe, 2005. **13**.

Kawamura, A., et al., *Relationship between the physical properties and hand of jean fabric.* Autex Research Journal, 2016. **16**(3): p. 138-145.

Kawabata, S., *The standardization and analysis of hand evaluation*. Journal of textile institute, ed. WorkBo. Vol. 80. 2009, Osaka: Textile Machinery Society of Japan.

Kumar S, et al., *Designing and Development of Denim Fabrics: Part 1 - Study the Effect of Fabric Parameters on the Fabric Characteristics for Women's Wear.* Journal of Textile Science & Engineering, 2016. **6**.

Özdil, N., *Stretch and Bagging Properties of Denim Fabrics Containing Different Rates of Elastane.* 6FIBRES & TEXTILES in Eastern Europe, 2008. **16**.

Parachuru, R., *The Kawabata Evaluation System and Its Applications to Product/Process Enhancement*, in *2002 Beltwide cotton conferences*. 2002: Atlanta.

Paul, R., *Denim manufacture, finishing and applications*. Denim and Jeans: An overview, ed. R. Paul. Vol. 164. 2015: wood head publishing Serios in Textiles.

R J Hawood , P J Weedall , and C. Cam, *The use of the Kawabata Evaluation System for product development and quality control* JSDC, 1990. **106**.

R Guruprasada, et al., *Low-stress mechanical properties and fabric hand of cotton and polylactic acid fibre blended knitted fabrics* Indian Journal of Fibre & Textile Research, 2018. **43**.

Rajkishore Nayak, et al., *Comfort properties of suiting fabrics.* Indian Journal of Fibre and Textile Research, 2009. **34**.

Saville, B., *Physical testing of textiles*. 1999: Elsevier.

Singha, K., *Analysis of Spandex/Cotton Elastomeric Properties: Spinning and Applications.* International Journal of Composite Materials, 2012. **2**.

Varadaraju, R. and J. Srinivasan, *Prediction of Certain Low Stress Mechanical Properties of Knitted Fabrics from Their Structural Parameters.* Journal of Engineered Fibers and Fabrics, 2015. **10**(2): p. 155892501501000202.