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Denim Fabric Surface, Low-stress Tensile and Shear Properties Evaluation based on KES

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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 were formed from one warp of twill with warp (6.5 Ne cotton) and density of 60 yarns per inch and four weft yarns (12 Ne cotton, 14 Ne cotton/70 denier spandex, 400 denier polyester/50 denier spandex and 450 denier polyester) of density of 40 yarns per inch. The four denim fabrics 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. The two fabrics containing spandex in both fabrics (denims made from cotton and denims made from cotton and polyester) showed improved handling properties like smoothness and recoverability properties.

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

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 (Nayak, Punj, Chatterjee, & Behera, 2009). (Kawamura et al., 2016) investigated the rrelationship 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, and smoothness. (Guruprasada, Prasad, Prabu, Raj, & Patil, 2018) studied the low-stress mechanical properties and fabric hand of cotton and polylactic acid fiber blended knitted fabrics and found the addition of polylactic acid fibers to cotton enhances the smoothness and softness of the blended fabrics. (Bedez Ute, 2019) investigated the effect of double-core and core-spun weft yarns and weft density on the mechanical properties of denim fabrics. The results 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, 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, Chatterjee, Padhye, & Nayak, 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. (Almetwally & Mourad, 2014) also investigated the effects of spandex drawing ratio which is determined by the core (spandex) delivery speed and speed of yarn delivery rollers during the spinning process and weave structure on the physical properties of cotton/spandex woven fabrics. 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, 2008) studied stretch and bagging properties of denim fabrics containing different rates of elastases**.** 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.

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 were investigated (Varadaraju & 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 Domskienė & Strazdienė, 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 (R J Hawood , P J Weedall , & Cam, 1990).

Denim fabrics low 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.

MATERIALS AND METHODS

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 speed: 750 rpm
- Warp tension: 380kgf
- Reed width: 190 cm
- Shed formation: Cam
- 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
F1	Cotton	Cotton	-	6.5 S*10 S
F2	Cotton	Cotton/spandex	5.4	6.5 S*14+70 D
F3	Cotton	Polyester/spandex	12.5	6.5 S*150+40 D
F4	Cotton	Polyester	-	6.5 S * 450 D

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.

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 weight), 12.5%spandex/77.5% polyester and 100% polyester.

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.

RESULTS, DISCUSSIONS AND ANALYSIS

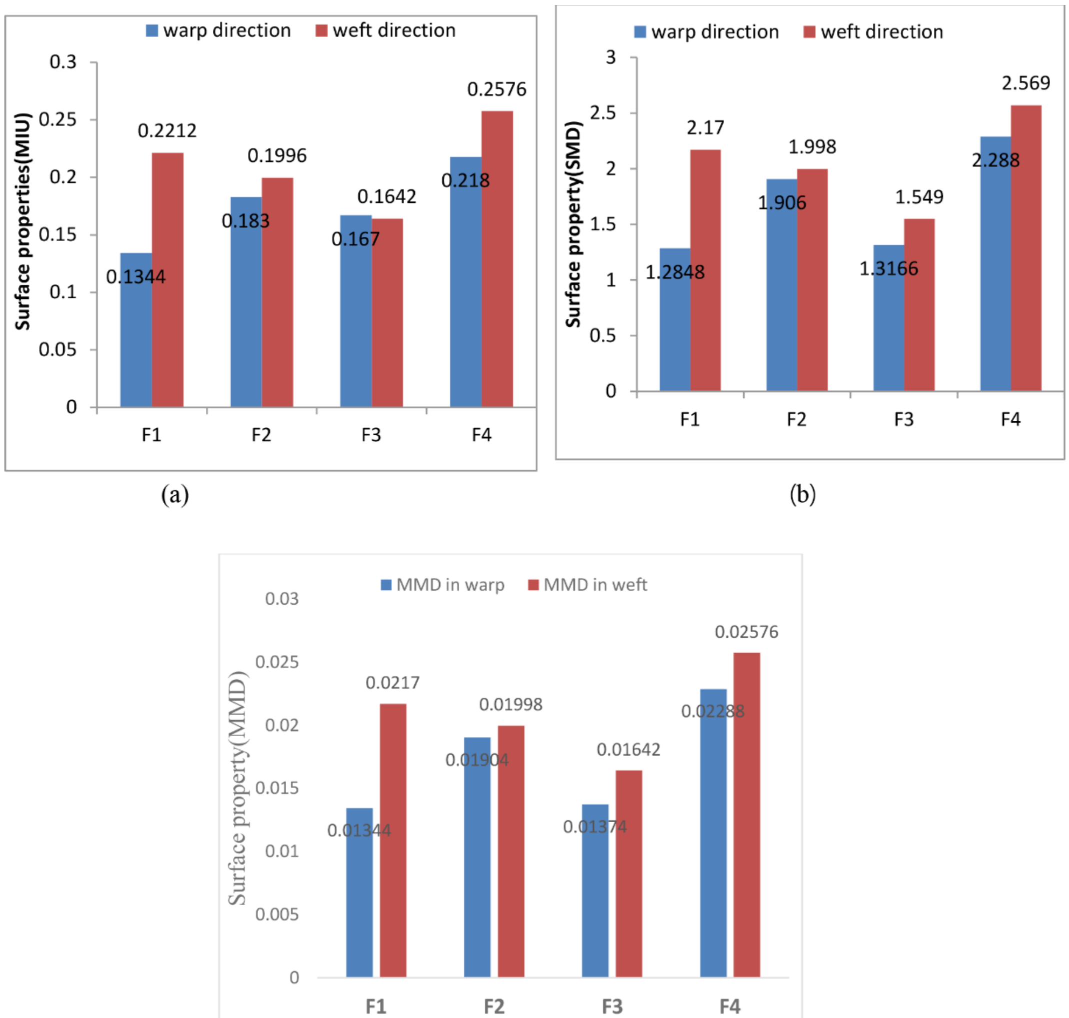
Surface Properties

The surface property of the samples is presented in Figure 1. In Figure 1(a), shows the MIU values of fabrics, that is the mean value of frictional coefficient (µ) in 20 mm distance; Figure 1(b), presents the MMD values which is the fluctuation of mean frictional coefficient that means how much it fluctuates (degree of fluctuation) from MIU (mean Frictional Coefficient) and Figure 1(c), shows the 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 is sensed when the surface of the fabric is touched. The larger the value of MIU is, the less slippery the yarn/fabric. SMD indicates the surface physical roughness, where, the larger the SMD value is, the less even the fabric.

From Figure 1(a), it is observed that the order of MIU values in the weft direction is F4, F1, F2 and F3 with values 0.2576, 0.2212, 0.1996 and 1642 respectively. Whereas, in the warp the order is F4, F2, F3 and F4 with values 0.218, 0.167, 0.183 and 0.1344 respectively. In all the fabrics there is higher MIU values in the weft direction and in weft direction the highest MIU value is 0.2576 for fabric made from cotton as warp and polyester as weft (F4) and the lowest value is 0.1642 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 SMD value is related to fabric roughness which have direct proportional relationship. As seen in Figure 1(b), the higher SMD values is found for fabric made from polyester (F4), and the lowest is for F3 for both warp and weft directions. 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 which are not in direct contact with human body.

Fabrics MMD value is correlated with the smoothness and roughness property that is felt when the surface of the fabric is rubbed and the larger the MMD value is, the rougher the fabric. From Figure1 (c), it can see that the higher MMD value is for F4 in both warp and weft direction whereas, the lowest is for F3 in warp and F1 in the weft direction.



(a) (b)

(c)

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

Tensile Property

The low stress tensile properties are LT, WT, RT and EMT are presented in Figure 2. WT is the tensile energy which 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. As it can be seen from Figure 2(a), the tensile energy in the weft directions is high for F3 and F2 and the lowest is at F4, which means the spandex yarn makes the denims to be softer. 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 increases the energy used to stretch the fabric since the fabric takes more time due to its high stretch properties.

EMT values relates to the tensile values 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 2(b), 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) in the weft direction. 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 increases the WT by 7.456 and 10.434; also increase the EMT value by 5.812 and 8.732 respectively in the weft direction.

The RT value shows the denim fabric recoverability property and it is 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, as seen from Figure 2(c), fabrics F3 and F2 have lower RT values in the weft direction which give extensibility and better comfort than others. Adding 5.4% spandex to F1 and 12.5% spandex to F4 will decrease the RT value by 7.331 and 14.814 respectively.

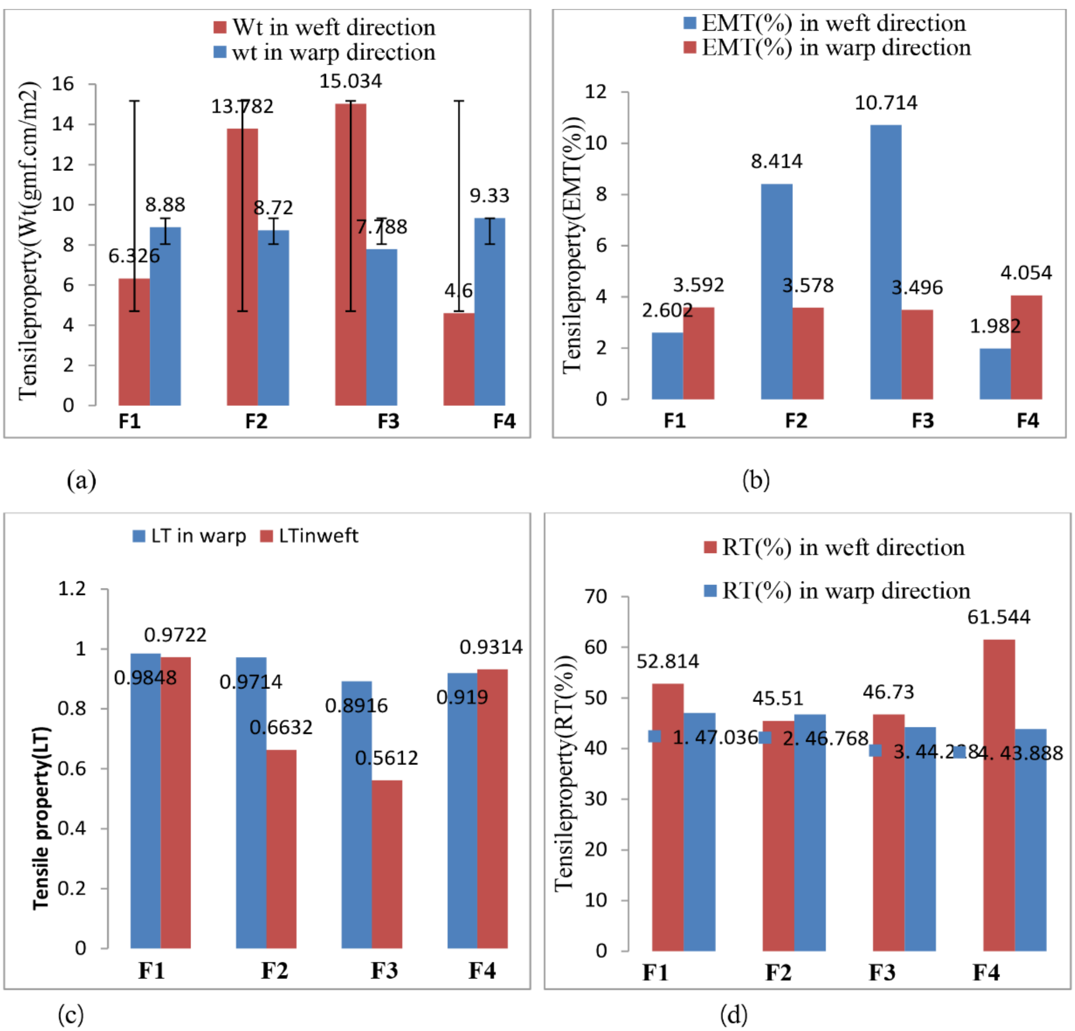


Figure 2. Effect of yarn type on low stress tensile properties: a) WT, b) EMT, c) LT and d) RT

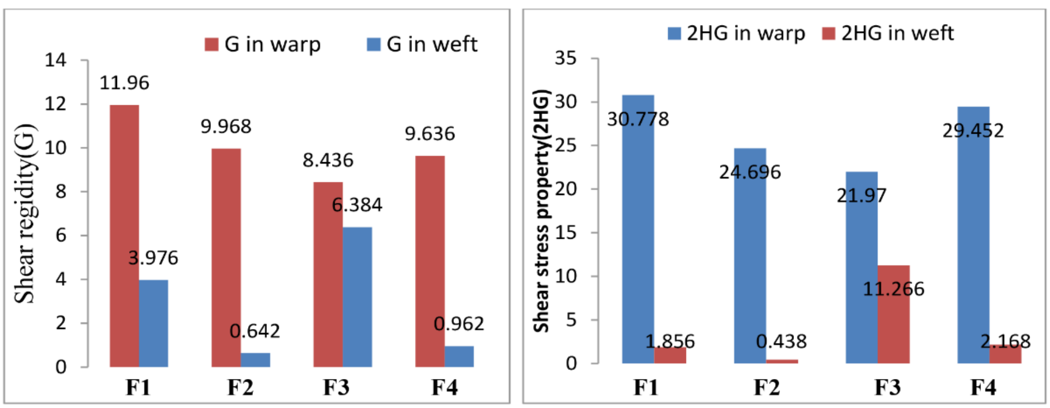
Shear Properties

Whenever bending occurs in more than one direction, so that the fabric is subjected to double curvature, shear deformations of the fabric are involved. 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). 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.

From Figure 3(a), the higher shear rigidity is found for cotton fabric (F1), followed by F2, F4 and F3 in warp direction. Whereas, in the weft direction the higher shear rigidity is found for F3, followed by F1, F4 and F2. The higher G value means the fabric cannot be easily deformed and have no good drape property, as compared to fabric made from cotton and polyester (F4). The shear rigidity is higher in warp direction than in the weft direction.

From Figure 3(b), 2HG is higher in the weft direction for all fabrics and the higher 2HG is for F1, followed by F4, F2 and F3 with values 30.778, 29.452, 24.696 and 21.97 respectively. Whereas, in the weft direction the order of 2HG is F3, F4, F1 and F2 which is the same trend as shear rigidity in the weft. The higher 2HG value is, the lesser its resilience (recoverability) of fabric, and the lower the 2HG value becomes, the better resilience (recoverability). This indicates that G and 2HG values are not directly related to each other in the warp and weft directions.



(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(2HG)

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 low stress tensile 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 in the weft direction. 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 and comfort.

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