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Impact of Weft Yarn Density and Core-yarn Fibre Composition on Tensile Properties, Abrasion Resistance and Air Permeability of Denim Fabrics

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Characteristics and serviceability of denim fabrics have undergone major changes. Nowadays denim is commonly used for casual wear. Durability and comfort are important parameters for consumers when choosing a denim garment. Therefore, in this study, abrasion resistance, tear and tensile properties of core–spun yarns and air permeability of denim fabrics with different weft yarns per centimetre and fibre content were analysed. The test results showed that weft yarns per centimetre influences fabric air permeability negatively but abrasion resistance increases. Higher weft yarns per centimetre influences fabric air permeability negatively but abrasion resistance increases. Polyester, elastane, modal, viscose and Lycra T400 were used in the core of weft yarn to analyse the impact of those fibres on the durability and comfort properties. Elastane is used to add stretchability to the fabric, which provides comfort to the wearer. The higher the elastomeric fibre content in the fabric, the greater is its elasticity; however, the tensile properties of the woven fabric decrease. The tear strength of the fabric was increased by the presence of the polyester fibre in the core.

Keywords: denim fabric, specific stress, air permeability, abrasion resistance.

1. INTRODUCTION

Denim fabric has been known as a strong and rigid material. Today the characteristics of the fabric have been improved to provide good performance, durability, comfort and fashion properties for garments. The number of yarns per centimetre and the core–yarn ratio plays an important role in determining physical and performance properties of the fabric. Yarn number per centimetre (weft yarn density) influences fabric strength and air permeability significantly; core–spun yarns are used in the weft yarn to combine strength and stretchability of the fabric [1 – 3].

Core–spun yarn is defined as a sheath–core yarn where sheath yarn is twisted around the core filament. Natural or synthetic fibres can be used as the sheath material, but the core material preferably contains elastomeric filament. For denim, cotton fibre is commonly used as sheath and elastane filament is used in the core of weft yarn. The purpose of the two–layered structure is to improve the properties of the fabric, where the sheath layer provides strength and durability and the core part gives stretch and comfort. This fibre combination provides high elasticity, flexibility and makes denim goods comfortable to wear. There is no one certain definition for comfort. But it has been identified as a combination of physiological, physical and psychological properties that satisfy the requirements of the consumers. Elastic denim garment has a figure shaping function, which provides ease of movement without restricting body movements. 1 – 5 % of elastane provides sufficient stretchability to denim fabric. But on the other hand, elastane affects air permeability which is considered as comfort parameter in this study [4 – 8].

In several studies, the impact of weft yarn count per centimetre on the fabric properties has been tested. For example, the impact of dual-core weft yarns number per centimetre, elastane ratio per unit area on the denim fabrics, also, tensile and tear strength, colour properties and cost per unit were determined. It was concluded that higher elastane content and ratio decreased elasticity value of the fabric because of the increased density that makes the fabric more rigid. Increments in the weft yarns per centimetre were found to decrease the fabric tear strength in the warp and weft direction. But in the weft direction, the decrease was higher [1]. In another study, cotton, polyester/cotton blend and polyester fabrics made in plain and twill weave were tested. The effect of fabric weave, yarn number per centimetre and linear density on the tear resistance was observed. Test results showed that fabrics with plain and twill weave have increased tear strength with the increase of weft yarn count per centimetre and higher linear density. Twill weave fabrics produced with higher number of yarns per/cm showed better resistance to tear than plain weave fabrics because of the higher yarn mobility inside of the fabric structure [9]. In the study by Ute, dimensional and mechanical properties of 3/1 twill weave fabrics produced with double-core and core-spun weft yarns were tested. With the increase of the yarns number per centimetre, the tear strength decreased in the warp and weft direction. Higher weft yarn number per centimetre increased the tensile strength in the weft direction but decreased in the warp direction. In this study, it was observed that tensile strength was higher for the fabrics produced with core-spun yarns compared with double-core spun [10].

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In addition, elastane ratio in the weft yarn affects the tensile and tear strength of a fabric significantly. Unfortunately, using elastic fibre in denim fabrics can reduce the lifespan of garments. Polyester or its derivates are added to improve fabric performance properties [6, 11]. Many previous studies have focused on the evaluation of physical properties of cotton and elastane blended denim fabrics. Sarıoğlu and Babaarslan compared 100% cotton and core–spun yarn filament fineness and yarn count on tensile and tear strength [6]. Özdil compared tensile, tear and bagging properties of denim fabrics containing different percentage of elastane. Higher elastane content was found to increase bending rigidity and elastic bagging, but to decrease permanent bagging properties [12]. Bagging is defined as a three-dimensional residual deformation in used garments, which deteriorates in the appearance of the garment. Deformation can be observed on the elbow or on knee area of the garment [13]. In another study, five woven fabrics containing different rates of elastane yarns were prepared. Tear and tensile properties as well as air permeability, fabric growth and permanent stretch of plain weave fabrics were tested [14]. Fabric growth is defined as the difference between the original length of a specimen and its length after the application of a specified tension for a prescribed time and the subsequent removal of the tension. [15]. According to their test results the core yarn ratio is an important parameter that affects tensile and tear strength. Finer yarns increased the core ratio and it led to better tensile strength. At higher elastane ratio, the tensile strength and tear resistance decreased [14].

Core–spun yarn has been developed to eliminate the durability problems caused by elastane filament. Two-layered structure core provides the mechanical properties of the yarn, for example, yarn strength, the sheath improves the aesthetic appearance, and other physical properties like feel and comfort [16]. In addition to elastane in the core of denim fabric, there are several other elastomeric fibres that are suitable for use as core material. In 2002, INVISTA introduced a new elastomultiester fibre Lycra T400. Lycra T400 is the combination of two polyesters to improve the fabric durability and comfort properties. It contains 40% 3-GT type polyester and 60% 2-GT type polyester. 2-GT type is also known as PET (polyethylene terephthalate) and 3-GT type or PTT is poly(trimethylene terephthalate). This bi-component-filament yarn has very good dimensional stability, high stretch and recovery properties but low growth. On averagely, 10 – 25 % of Lycra T400 is needed for jeans to provide high stretch properties [17 – 21]. Polybutylene terephthalate (PBT) is used in denim fabrics because it has better stretch and recovery properties than polyester (PET). PBT is more expensive but even a small amount can contribute enough to elasticity [22, 23].

To improve synthetic fibres and find alternatives to cotton, the use of regenerated fibres is becoming increasingly popular in the manufacturing of the denim fabric. Regenerated fibres are cellulose-based man-made fibres that are mainly produced from wood pulp. These cellulosic fibres are used in the production of denim because of comfort and breathability; also those fibres provide high tensile strength and soft feel. However, studies of synthetic fibres like Lycra T400, or some regenerated fibres like modal, viscose together with elastane or polyester in the core have been reported only in the few research papers [24 – 26]. Yarn and fabric properties have been analysed on the basis of soft-core filaments such as Dorlastan, Lycra and spandex. Also, some new approaches have emerged where polybutylene terephthalate (PBT) or Lycra T400 is used as core filament [27]. The ring spinning system was used to find optimum spinning parameters for Lycra T400 blended with cotton core-spun yarns [28]. Some research papers have analysed the effect of regenerated fibres in a fabric. Air permeability, water vapour transmission, thermal insulation, total absorbency, wickability properties of polyester-viscose, polyester-cotton ring and MJS (Murata Jet Spinning) yarn fabrics were compared. Ring spun fabrics had lower absorbency, air permeability and water vapour transmission properties than MJS yarn fabrics but higher wickability [29]. Basit, Latif, Baig and Rehman blended viscose with cotton, Tencel, modal and bamboo. Mechanical and comfort properties were compared on the basis of air permeability, moisture management, tensile and tear strength. According to their test results, viscose/Tencel and viscose/modal blended yarns showed higher mechanical and comfort properties than viscose/cotton and viscose/bamboo blend [26]. Air permeability is considered an important comfort parameter for a wearer, which is influenced by the thickness, weight and structure of the fabric. Fibre content and the inter-yarn pores (texture, size, shape) between individual yarns have a significant effect on air permeability [30, 31].

There were very few findings based on comparing physical and comfort properties of core–spun yarn containing different elastomeric and regenerated fibres in the core. According to the above-mentioned studies, weft yarn number per centimetre and core components have a substantial influence on the fabric strength and performance characteristics. For this reason, the current study is divided into two parts, five denim fabrics were produced with the same fabric parameters but different number of weft yarns per centimetre and four fabrics contained synthetic and regenerated yarns in the core to demonstrate the influence of weft yarn between the properties of different types of materials. The aim of the study is to evaluate the effect of the fibre composition on tensile properties, abrasion resistance and air permeability of fabrics containing multifilament yarn by the use of new approaches [8]. The focus is on how to achieve durable but elastic fabric that is comfortable to wear. Based on previous studies fabric abrasion resistance, tensile and tear strength indicate denim fabric durability properties the most and air permeability is considered as comfort parameter. For this reason, those parameters were investigated on the basis of fibre composition and weft yarn number per centimetre.

2. MATERIALS AND METHODS

2.1 Materials

Nine woven denim fabrics were prepared by the Turkish company Kipaş Holding A.Ş. All the tested fabrics were made of 3/1 Z twill weave and warp yarns were made of cotton. Five fabrics CE16, CE17, CE18, CE19, CE20 have different weft yarn count per centimetre and fabrics CMPE, CPVE, CPE, CT400E contained multifilament ring core−spun yarns in the weft direction (Table 1).

Table 1. Fabrics parameters

No	Warp yarn, Ne (composition)	Weft yarn (composition)	Reed	Reed width, cm	Mechanical weft yarn number per/cm	Fabric composition, %	Abbreviation [8]
1.	13.5/1 Ne (CO)	18/1 Ne 50/50 + 78dtex (CO [1]/CMD [2]/PES [3]/EL [4])	75/4	210	18	CO/CMD/PES/EL 70/14/14/2	CMPE
2.	13.5/1 Ne (CO)	18/1 Ne 67/33 + 78dtex (CO/PES/CV [5]/EL)	75/4	210	18	CO/PES/CV/EL 69/19/10/2	CPVE
3.	13.5/1 Ne (CO)	18/1 Ne+ 55dtex + 78dtex (CO/PBT [6]/EL)	75/4	210	18	CO/PBT/EL 94/4/2	CPE
4.	13.5/1 Ne (CO)	18/1 Ne+ 55dtex + 78dtex (CO/T400 [7]/EL)	75/4	210	18	CO/T400/EL 94/4/2	CT400E
5.	13.5/1 Ne (CO)	18/1 Ne + 78 dtex (CO/EL)	75/4	210	16	CO/EL 98/2	CE16
6.	13.5/1 Ne (CO)	18/1 Ne + 78 dtex (CO/EL)	75/4	210	17	CO/EL 98/2	CE17
7.	13.5/1 Ne (CO)	18/1 Ne + 78 dtex (CO/EL)	75/4	210	18	CO/EL 98/2	CE18
8.	13.5/1 Ne (CO)	18/1 Ne + 78 dtex (CO/EL)	75/4	210	19	CO/EL 98/2	CE19
9.	13.5/1 Ne (CO)	18/1 Ne + 78 dtex (CO/EL)	75/4	210	20	CO/EL 98/2	CE20
[1] CO-Cotton; [2] CMD-Modal; [3] PES-Polyester; [4] EL-Elastane; [5] CV-Viscose; [6] PBT-Polybutylene terephthalate; [7] T400-Lycra T400®; [8] Abbreviation used in this article to describe the fibre.							

Fabrics CE16-CE20 weft yarn contained elastane at the core. Fabric CMPE contained elastane, polyester and modal at the core. Fabric CPVE contained elastane, polyester and viscose. Fabric CPE weft yarn core part consisted of elastane and polybutylene terephthalate. Fabric CT400E contained elastane, polyester and Lycra T400®. Fibres were chosen from different origin. All the tested fabrics core yarns were covered with cotton. To evaluate how fibre composition affects fabric strength and comfort properties elastane was used to give the stretch properties, while polyester and polybutylene terephthalate provide strength to the fabric. Lycra T400® is developed to improve both fabric strength and elasticity. Regenerated fibres viscose and modal are considered as more sustainable than other used fibres. Viscose and modal provide enough strength and comfort to the fabric, which make these regenerated fibres suitable to use in denim fabric. Table 1 gives an overview of the tested fabrics parameters.

2.1 Methods

Fabrics performance and durability properties were measured by the methods covered by the ISO standards. Table 2 gives an overview of the standards used in this study. Before testing, all specimens were conditioned in a standard atmosphere at 20 °C and 65 % relative humidity for 24 hours in accordance with the EN ISO 139:2005/A1:2011 [32].

Abrasion resistance was tested in accordance with the ISO standard EN ISO 12947-2:2016. Martindale abrasion tester James Heal 1605 was used to test the abrasion resistance. Three test specimens were cut from each fabric. The diameter of the test specimen and the holder foam were 38 mm. The original Martindale polyurethane foam was used as foam material. Diameters of the abradant and the wool felt underlay were 140 mm. Martindale abrasion cloth SM25 was used as abradant material and woven felt was used as felt material. Then the number of rubs was set. The test continued until two yarns were broken [33]. Dino-Lite Digital Microscope AM4113T was used to examine damaged and broken yarns.

Tensile strength was tested according to the ISO standard ISO 13934-1:2013, using Instron 5866 testing machine. Specific stress was used to evaluate the tensile properties of the tested fabrics; it is a ratio between the maximum load and the mass per unit area, also known as tenacity [34]. The following Eq. 1 was used to calculate the specific stress (P_0):

$$P_0 = (P_t \cdot 100)/(B \cdot GS), \quad (1)$$

where P_0 is the specific stress (N·m/g); P_t is the average load at break/ max load (N); B is the mass per unit area (g/m^2); GS is the sample width (mm) [35].

Five specimens were cut in the warp and five in the weft direction. The length of each specimen was 400 mm and the width was 50 mm. The gauge length of the tensile testing machine was set at 200 mm and the test specimen was mounted between two jaws. The extension rate was 100 mm/min. Pretension was set at 5 N; load cell was 10 000 N. Movable clamps extended the test specimen to the point of rupture. Maximum load (N), were recorded [36]. Tearing was tested according to the ISO standard EN ISO 13937-2:2000. Instron 5866 testing machine was also used to test the tearing performances of the fabrics. Five specimens were cut in the warp and five in the weft direction. The length of each specimen was 200 mm and width 50 mm. A longitudinal slit was cut 100 mm. The end of tear was marked 25 mm from the uncut end of the stripe. The gauge length of the testing machine was set at 100 mm. Then the test specimen was clamped in the jaws. The moving clamp was put in motion at 100 mm/min. The tear was continued to the point marked near the end of the strip. Tear force was recorded in Newtons (N). Tear trace was recorded using BlueHill software [37]. Air permeability was tested in accordance with the EN ISO 9237:2000. Air permeability is a measure to indicate the air flow through the fabric in one square metre per second. FX 3340 MinAir was used to test air permeability of the fabrics. Test surface area was 20 cm^2 and pressure drop 100 Pa. The measurements were taken at ten locations on the same surface of each specimen [38]. Air permeability of the tested fabrics was recorded on the face side to the back side and on the back to the face side of each fabric. The number of yarns per unit length was tested in compliance with the EN 1049-2:2000. Method A was used to calculate yarns number per centimetre, which is the most used laborious method and suitable for all fabrics. Five specimens were cut from the warp and five from the weft direction of the fabric; minimum measuring distance was 5 cm. Two dissecting needles and a heavy steel ruler were used to count the number of warp and weft yarns per centimetre. Each sample width was 5 cm. The means of individual results in the warp and weft direction were quoted [39]. Mass per unit area was tested according to the ISO standard EN 12127:2000. Five test specimens of 100 cm^2 were cut out from each fabric. Because scissors were used for cutting, three measurements were taken of the warp and three of the weft direction. Results were rounded to the nearest 1 mm. Each of the individual specimen was weighed and the value was recorded to the nearest 1 mg. Mass per unit area M was calculated in grams per square metre using the following Eq. 2 [40]:

$$M = (m \cdot 1000)/A, \qquad (2)$$

where m is the mass of a test specimen conditioned (g); A is the area of the same test specimen (cm^2); M is the mean mass per unit area (g/m^2) [40]. The standard test methods used in this study are listed in Table 2.

Table 2. Standard test methods used

No	Fabric property	Standard test methods
1.	Abrasion resistance	EN ISO 12947-2:2016 Textiles – determination of the abrasion resistance of fabrics by the Martindale method – Part 2: Determination of specimen breakdown
2.	Tensile strength	ISO 13934-1:2013 Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method
3.	Tear strength	EN ISO 13937-2:2000 Textiles – Tear properties of fabrics – Part 2: Determination of tear force of trouser-shaped test specimens (Single tear method)
4.	Air permeability	EVS EN ISO 9237:2000 Textiles – Determination of permeability of fabrics to air
5.	Number of threads per unit length	EN 1049-2:2000 Textiles – Woven Fabrics – Construction – Methods of analysis – Part 2: Determination of number of threads per unit length
6.	Mass per unit area	EN 12127:2000 Textiles – Fabrics – Determination of mass per unit area using small samples

3. RESULTS AND DISCUSSION

Fabric mass per unit area and the number of yarns per centimetre in the denim influences air permeability, tensile strength, also, resistance to abrasion. For this reason, tested fabrics mass per unit area, mechanical and actual number of yarns per/cm were measured and presented in Table 3.

Table 3. Fabrics mass per unit area and the number of yarns per centimetre

No	Fabric	Mechanical weft yarn number, per/cm	Actual number of weft yarns, per/cm	Mass per unit area, g/m^2	Mass per unit area, st.dev.*, g/m^2
1.	CMPE	18	22	323	3
2.	CPVE	18	22	330	3
3.	CPE	18	22	323	4
4.	CT400E	18	22	323	2
5.	CE16	16	19	296	5
6.	CE17	17	20	301	3
7.	CE18	18	22	309	2
8.	CE19	19	23	317	4
9.	CE20	20	24	320	4

*st.dev. − standard deviation

3.1. The effect of weft yarn number per centimetre on air permeability and abrasion resistance

Mechanical weft yarn number was compared to the actual number of weft yarns per centimetre. It can be seen in Table 3 and in Fig. 1 and Fig. 2 that actual yarn number was 3 − 4 yarns more than mechanical yarn number per centimetre. Air permeability measurements showed that for all tested fabrics, there was no significant difference between the air permeability whether it was measured from the face side or from the back side of the fabric. So, in this study, the air permeability was measured as follows: air flow was from the back side to the face side of the fabric. These values were lower than the values measured from the opposite direction and usually fabric back side is against the human body. Fabrics CE16–CE20 were all prepared with the same parameters but with different weft yarn densities per centimetre.

According to the test results, higher number of yarns per/cm decreases air permeability. The air permeability of fabric CE20 (27.4 ± 1.2 $l/(m^2 \cdot s)$) was one and a half times lower compared with fabric CE16 (41.7 ± 1.2 $l/(m^2 \cdot s)$). Fabric weight, and yarns number per/cm were the main structural properties that affected abrasion resistance significantly. Higher mass per unit area of fabric with tight structure were more resistant to abrasion. Tight fabric construction decreased air permeability, because pores between yarns become smaller and the air flow through the fabric is restricted [41, 42]. As it can be seen in Fig. 2, abrasion resistance of fabrics CE18 and CE19 was 35 000 rubs, for fabric CE20, it grew exponentially; but it decreased air permeability. Thus, to find the balance between abrasion resistance, which shows strength of the fabric and air permeability, which indicates fabric comfort properties, the optimum thread number per centimetre should be 18. Because fewer yarns per centimetre showed lower strength properties but higher thread numbers per centimetre decreased air permeability remarkably.

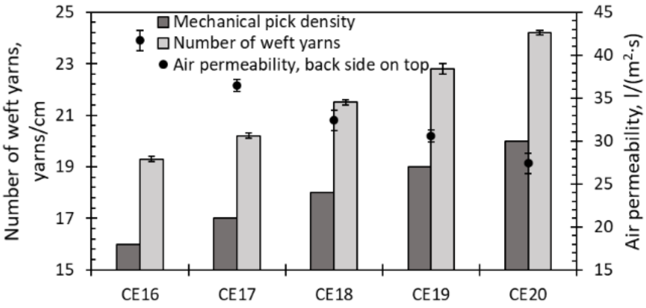


Fig. 1. The effect of weft yarn number per centimetre on air permeability of fabrics CE16–CE20 with different number of weft yarns per centimetre

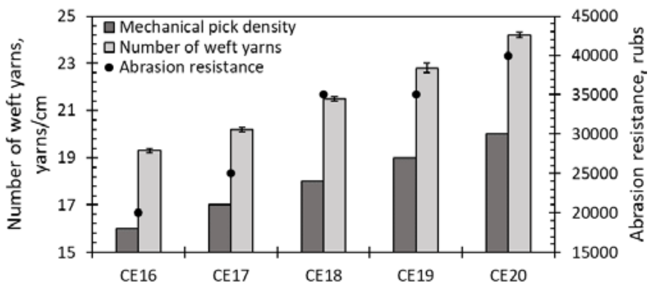


Fig. 2. The effect of weft yarn number per centimetre on abrasion resistance of fabrics CE16–CE20 with different number of weft yarns per centimetre

3.2. The effect of core-yarn on air permeability and abrasion resistance

The test results showed that fabrics CMPE and CE20 had the highest abrasion resistance value, 40 000 rubs (Fig. 2, Fig. 4, Fig. 5), although those fabrics had different number of weft yarns per centimetre, fabric CMPE had mechanical weft yarn number of 18 and fabric CE20 had 20. As can be seen in Fig. 5, the analysis by Dino-Lite microscope revealed that surface warp yarns of fabric CMPE were more damaged than those of fabric CE20. Based on the comparison of those two fabrics, it can be concluded that fabric CE20 provided the highest test results of abrasion resistance. Fabric CE16 showed the lowest abrasion resistance value, 20 000 rubs, which is half less than fabrics CMPE and CE20. (Fig. 2, Fig. 6) It is because fabric CE16 had the lowest number of yarns per centimetre. Fig. 6 shows that many yarns were totally broken and 16 threads per centimetre lacked sufficient fabric strength properties.

In addition, there are other parameters that affect abrasion resistance. Fabric CMPE contained modal, polyester and elastane in the core. Polyester has high abrasion resistance; cotton is considered to have medium resistance to abrasion. The abrasion properties increased by the presence of polyester fibre in the core of cotton covered weft yarn. Usually, polyester is longer fibre than natural staple cotton fibre, which leads to a better abrasion resistance. Longer fibres were more stable, short fibres can be liberated from the fabric more easily. Fabric CPVE showed 10 000 rubs lower test results than fabric CMPE. CPVE abrasion resistance was 30 000 and CMPE was 40 000. Thus, viscose had lower abrasion retention than modal. Fabrics CMPE, CPVE, CPE, CT400E contained various yarns in the core. According to the literature number of yarns per centimetre have a great influence on fabric air permeability. Yarns with higher porosity have better air permeability. It is known that viscose has serrated cross-section but modal has more circular cross–section, this leads to a better air permeability. The test showed different results. Fabric CMPE (30.3 ± 1.3 l/(m^2·s)), which contained modal had lower air permeability than fabric CPVE (34.7 ± 0.8 l/(m^2·s)), that contained viscose. It might be because of the presence of cotton fibre that influenced the air permeability [41 – 44].

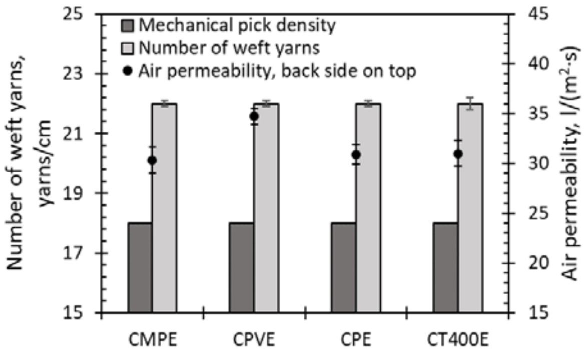


Fig. 3. The effect of weft yarn number per centimetre on air permeability of fabrics CMPE, CPVE, CPE, CT400E with different weft yarn fibre composition.

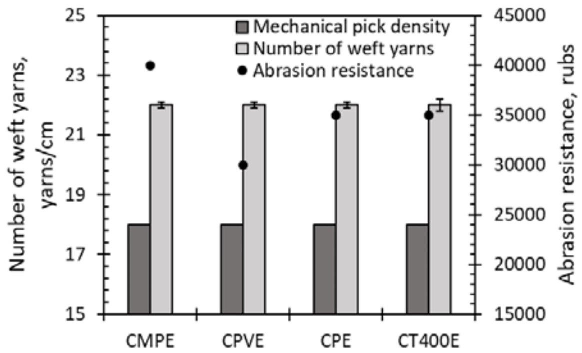
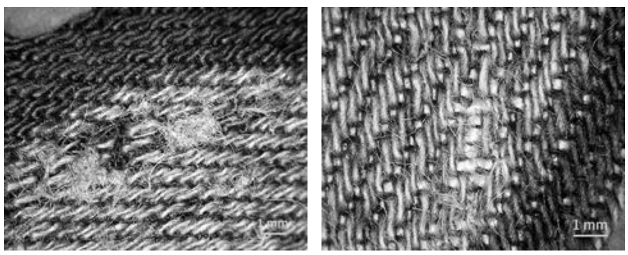


Fig. 4. The effect of weft yarn number per centimetre on abrasion resistance of fabrics CMPE, CPVE, CPE, CT400E with different weft yarn fibre composition



a b

Fig. 5. The highest abrasion resistance of fabrics, specimen's abrasion resistance was 40 000 rubs: a – CMPE; b – CE20

According to the test results higher amount of natural fibre in the yarn led to better air permeability. Fabrics CE16-CE20 contained 2 % of elastane in the core of weft yarns and air permeability was better than with fabrics CMPE, CPVE, CPE, CT400E (Fig. 3, Fig. 4), which additionally contained synthetic or regenerated fibres. This result is similar to the results from the studies of Kadoğlu, Dimitrovski, Marmaralı, Çelik, Bayraktar, Üte, Ertekin, Demšar, Kostanjek, where higher elastane tension exhibited lower air permeability; 100 % cotton showed better air permeability properties than cotton blended with elastane or with PBT [22].

Air permeability test results showed clearly that by increasing the fabrics CE16-CE20 weft yarns per centimetre the air permeability decreases significantly. Fabrics CMPE, CPVE, CPE, CT400E actual weft yarn number per/cm were almost the same. But air permeability test showed different results. Air permeability of the fabrics that contained regenerated fibres were about 10 % better than fabrics CPE and CT400E. Thus, air permeability was more affected by the weft yarn diametre than yarn number per centimetre [29].

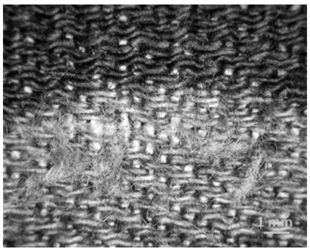


Fig. 6. CE16 showed the lowest abrasion resistance, 20 000 rubs

3.3. Specific stress and air permeability

All the warp yarns of the fabrics showed higher specific stress value than in the weft direction (Fig. 7 and Fig. 8). Fabrics CMPE, CPVE, CPE, CT400E specific stress in the weft direction was about half of the same fabric warp yarns specific stress. And fabrics CE16-CE20 specific stress in the warp direction was 2/3 better than the same fabric weft yarns specific stress. It is because of the elastane yarn in the weft. Elastane provides better stretch properties for denim fabrics but it reduces the tensile properties of the fabric [12, 14].

Differences in the results of the specific stress at the maximum load test were not remarkable (Fig. 7). By increasing the weft yarn count per centimetre, the specific stress values were not influenced significantly. Fabrics CE16-CE20 weft yarn specific stress at max load varied between 19.3 to 22 N·m/g. Higher weft yarn count per centimetre decreases air permeability. Fabric CE16 weft yarn air permeability was about 1/3 better than fabric CE20. Thus, fabrics with tight constructions do not provide as good comfort properties as those with fewer yarns per centimetre. It was expected that higher number of weft yarns increases the specific stress. But specific stress values were similar, it is because warp yarn number was constant, the effect would be greater if the densities in both directions had increased [45].

Regarding the evaluation of the performance and comfort parameters for customers, the air permeability of fabric CE16 showed the highest air permeability result (41.7 ± 1.2 l/(m^2·s)), moderate specific stress value (20.9 N·m/g), but resistance to abrasion was the lowest (20 000 rubs). It was in contrast with the test results of fabric CE20, which showed the highest abrasion resistance (40 000 rubs), as well as a moderate specific stress value (21.5 N·m/g), but the lowest air permeability (27.4 ± 1.2 l/(m^2·s)). Thus, fabrics with 16 and 20 threads per centimetre do not provide sufficient quality to satisfy high strength and comfort characteristics of a fabric.

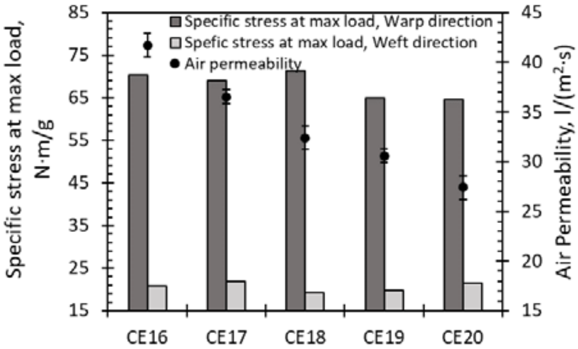


Fig. 7. The effect of specific stress of fabrics CE16-CE20 at maximum load and air permeability

Comparing fabrics CMPE, CPVE, CPE, CT400E specific stress values, fabric CT400E had almost 5% better specific stress properties than the other tested three fabrics in the warp direction (Fig. 8). It might be because it contained Lycra T400 fibre in the weft yarn. This multi–component yarn was made of two kinds of polyesters. In this study, CT400E contained 4 % of Lycra T400. According to the test results, lower percentage of T400 filament also provided good tensile properties. But in the weft direction, fabrics CMPE and CPVE showed higher specific stress values, 32.8 and 39.3 N·m/g accordingly. The tensile properties of the yarn were increased by the presence of the polyester filament at the core, which was the main load carrier when we compared it with cotton yarn [46]. Fabric CMPE contained 14 % of polyester and fabric CPVE contained 19 %. Fabrics containing higher percentage of polyester also showed higher tensile strength, because polyester filament is strong and dimensionally stable fibre. It is used in the core of denim fabrics to add strength and durability. In addition, polyester provides good elasticity [47].

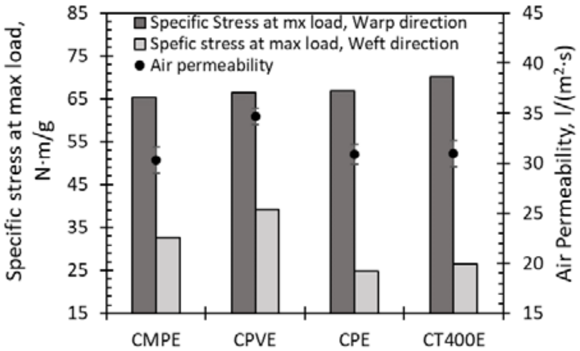


Fig. 8. The effect of specific stress of fabrics CMPE, CPVE, CPE, CT400E at maximum load and air permeability

Viscose and modal are both regenerated cellulose fibres but they have different crystallinity. Usually, viscose crystallinity is lower than modal fibre [48]. Thus, modal provided higher strength than viscose fibre [49].

As can be seen in Fig. 8 fabric CPVE had also the highest air permeability (34.7 ± 0.8 l/(m^2·s)), the other three fabrics showed similar air permeability test results, between

30.3 – 31.0 l/(m^2·s). All the tested four fabrics were produced with the same weave and the same yarn count. Thus, the air permeability differences were caused by the blend ratio, different fibre diameter and pore size. Tested fabrics CMPE, CPVE, CPE, CT400E showed lower air permeability than the other five fabrics because of the differences in the yarn cross section. It influenced inter-yarn spaces and the porosity of the denim fabric. Polyester blended with viscose provided better air permeability properties than polyester/cotton blends [50].

3.4. Tear strength

Tear strength of fabrics CMPE, CPVE, CPE, CT400E was recorded in the warp and weft direction (Fig. 9). Tear strength of fabrics CE16-CE20 failed in the weft direction because of the yarn shift (Fig. 10). The failure occurred by tearing across one leg of the specimen. It might be because the tearing direction of the tested fabrics was much stronger than the other direction [51, 52].

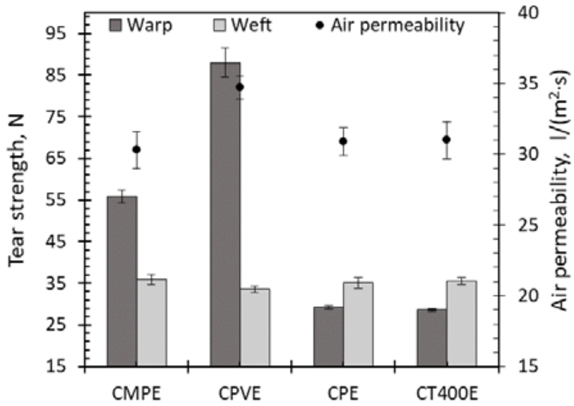


Fig. 9. Average tear strength and air permeability of fabrics CMPE, CPVE, CPE, CT400E in the warp and weft direction

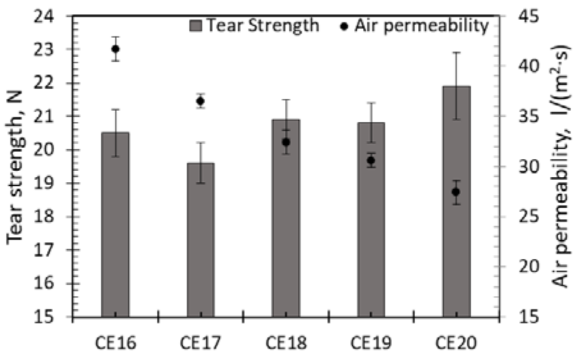


Fig. 10. Average tear strength and air permeability of fabrics CE16-CE20 in the warp direction

Fabrics CMPE, CPVE, CPE, CT400E had similar test results in the weft direction because warp yarns were made of cotton. But there were significantly different results in the warp direction. Tear strength of fabrics CMPE (55.8 ± 1.6 N) and CPVE (88.0 ± 3.5 N) was higher in the warp direction. In the weft direction fabrics CPE (35.1 ± 1.3 N) and CT400E (35.5 ± 0.8 N) showed similar test results as fabric CMPE (36.0 ± 1.2 N). Fabric CPVE had the lowest tear strength in the weft direction (33.6 ± 0.8 N). As mentioned before, polyester influences yarn's tensile strength, as well as tear strength positively. This is consistent with Pramanik and Patil findings. They investigated the energy to break cotton/polyester core spun yarn made of ring and air-jet systems. Polyester filament clearly increased single ring-core yarn strength. The strength was in proportion to the increase in the filament ratio in the core. Single ring core-spun yarn strength increased 15 % to 43 % as compared to 100 % of cotton yarn. Thus, higher filament percentages needed more energy to break the yarn [46].

According to previous research, it was expected that Lycra T400 shows higher tearing properties than the other tested fabrics. Test results might be influenced by the amount of Lycra T400 in the weft or yarns number per unit area. According to Kurtulmuş, Güner, Akkaya and Kayaoğlu, who analysed two fabrics containing Lycra T400, fabric that had lower number of warp yarns per/cm showed the highest tear strength [53]. There might be other reasons; fabric CT400E contained only 4 % of Lycra T400, which is quite an optimal value. To improve comfort and strength properties, the percentage should be higher than the elastane percentage in the fabric [54]. PBT fibre has lower tensile properties than PET fibre; for this reason, fabrics CMPE and CPVE showed higher tearing performance [23]. Both fabrics contained polyester filament, which probably affected the fabric durability properties positively and modal, viscose, which had better air permeability properties than cotton [23].

4. CONCLUSIONS

Abrasion resistance, tear strength and tensile properties are important parameters for characterizing the lifespan of a fabric. Air permeability has high influence on the fabric comfort properties. In current study, elastic fibre was added to provide more stretchy and comfortable wear. Nine denim fabrics with different fibre content and weft yarn densities were produced to evaluate durability and comfort properties.

Fabrics CMPE, CPVE, CPE, CT400E contained various filaments in the core of weft yarn and fabrics CE16–CE20 were produced with the same parameters containing elastane in the core, but with different number of weft yarns per centimetre.

Test results showed that fabrics CMPE, CPVE, CPE, CT400E specific stress in warp direction was about 50 % higher than the same fabrics specific stress in weft direction. And fabrics CE16-CE20 specific stress in weft direction was only 1/3 of the same fabric specific stress value in the warp direction. Using polyester or regenerated fibres (modal, viscose) in the core resulted in better tensile and tear strength. Fabric CMPE tear strength was 55.8 ± 1.6 N, which was two times higher and fabric CPVE tear strength was 88.0 ± 3.5 N, it was three times higher than fabrics CE16-CE20 tear strength.

Tear strength of five fabrics (CE16-CE20) failed in the weft direction because of the direction the force applied was so much stronger than in the other direction. Fabrics CMPE, CPVE, CPE, CT400E tear strength was between 33.6 – 36.0 N in the weft direction. Fabric CMPE showed the highest tear strength value.

Fabric, weight and structure affected air permeability as well. Inter-yarn pores had a substantial influence on air permeability. Fabric CE16 with lower number of yarns per centimetre showed better air permeability (41.7 ± 1.2 l/(m^2·s)) but quite low abrasion resistance (20 000 rubs). Fabric CE20, which had the highest number of yarns per centimetre showed the lowest air permeability (27.4 ± 1.2 l/(m^2·s)) and highest abrasion resistance (40 000 rubs). The aim of this paper was to find the optimum fibre content for denim fabric to provide durability and comfort at the same time. Although all the tested fabrics had some disadvantages it can be concluded that fabric CPVE showed higher specific stress values, also very good resistance to tear and satisfying air permeability than other tested fabrics.

Thus, to satisfy customer needs, prolong the lifespan of denim fabric and depict the shape of body, denim fabric weft yarn core part should contain polyester fibres; which provide strength. Moreover, elastane in the core gives good elasticity and viscose provides both good durability and comfort to the fabric. Those three fibres in the weft yarn should be covered with cotton.

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