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MATERIAL
SCIENCE

Impact of laser fading on physico-mechanical properties and fibre morphology of multicomponent denim fabrics

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Abstract. Laser fading technology is used to give a unique worn look to a fabric. This finishing technique is environmentally friendly compared to conventional methods because it reduces the use of harmful chemicals and large amounts of water. A carbon dioxide (CO_2) laser with a wavelength of 10.6 μm was used in this study. In bulk production, fixed manufacturing parameters help to reduce production preparation time. Thus, two combinations of laser power and speed of the laser cutter head (14 W and 230 mm/s; 16 W and 350 mm/s) were used to determine how universal the fixed laser parameters are for fading five different types of multicomponent twill and satin weave denim fabrics, which contain cotton, elastane, polyester and viscose. Physico-mechanical properties (tear, tensile properties and abrasion resistance) were tested to evaluate the effect of the selected laser parameters on fabric strength properties. Microscopical analysis was performed to assess the effect of laser fading on the yarn and fibre morphology of denim fabrics.

Keywords: laser fading, sustainable finishing, multicomponent denim fabric, SEM analysis, physico-mechanical properties.

INTRODUCTION

Denim is defined as a 3/1 twill weave cotton fabric made of indigo dyed warp yarns and white filling yarns. Nowadays denim is made of different weave types and the cotton fibre is blended with other fibres to improve fabric properties [1]. The finishing of denim products is an important part of the manufacturing process because it influences the visual appearance and durability of denim fabric. In the 1980s, the denim company Diesel was considered one of the first producers who started to apply the fading effect on garments to make the products attractive to consumers [2].

Many mechanical and chemical finishing techniques are available, such as stone washing, enzyme washing, acid washing, bleaching, sandblasting, mechanical damaging. The growing awareness of today's society about the environmental issues caused by the textile industry makes the industry find new sustainable solutions as well as reduce production time, labour and process costs. Laser fading technology was introduced as a sustainable alternative for the fading of denim garments compared to conventional methods. The laser enables the application of different effects on garment by changing the speed of the laser cutter head, laser power and the size of the focal point. The laser has many advantages over the other processes mentioned. Laser fading technology is eco-friendly because it enables to create various effects on denim garments without using large amounts of water. It is chemical-free, without causing hazards to the workers and has a minimum impact on the environment. Also, it is almost waste-free. In addition, the laser process is precise, easy to control and has high productivity, since it is faster than conventional washing technologies. Laser

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fading is suitable for mass production because it enables the application of the exact same design for bulk production [3,4,5,6].

Lasers are commonly classified into three types: carbon dioxide (CO_2), neodymium (Nd), and neodymium-doped yttrium aluminium garnet (Nd-YAG) lasers. In the denim industry, a CO_2 laser is considered the most suitable laser for garment colour fading because of lower heat generation, which means lower energy waste and lower investment costs compared to the other lasers [3,7].

Unfortunately, different mechanical and chemical finishing processes, including laser fading, reduce fabric durability. During the laser fading process, the material absorbs laser energy, resulting in dye evaporation. This process affects fabric durability, thickness and other properties [3,5].

In previous studies, various laser parameters have been varied to assess the impact of laser irritation on the physico-mechanical properties of denim fabric. All these studies have shown that the durability of denim fabric decreases with the increase in intensity of different laser parameters. Tarhan and Sariişik [8] examined the effect of laser fading, sandblasting and washing on the tensile properties, weight loss and colour changes of 100% cotton denim fabric. After laser treatment at the highest intensity (250 W/cm^2), the fabric lost about 11% of its weight and about 60% of its strength. In their study, the colour loss increased from approximately 10 to 35% when laser intensity was increased from 100 W/cm^2 to 250 W/cm^2.

Sakib et al. [9] reported that the intensity of fabric fading depends on customers' requirements. However, they found that tensile and tear strength of the fabric decreased more in the warp than in the weft direction. This is because in twill weave, the warp yarns of the fabric are more dominant on the right side of the fabric. Kan [10] treated 100% cotton denim fabrics with a CO_2 laser by varying laser pixel and resolution time. Higher resolution and longer pixel time increased laser power. This resulted in removing more dye from the denim surface, but it also damaged the fabric structure. The optimum laser power was found to be 13 W/cm^2. According to Juciene et al. [11], laser speed, energy and beam density have the greatest impact on the tensile properties of denim fabric. They showed that the highest laser energy density ($E = 9.89$ mJ/cm^2) decreased the strength of cotton-elastane denim fabrics by approximately 91% and the lowest density ($E = 6.18$ mJ/cm^2) reduced the fabric strength by about 22%. Studies by Štěpánková et al. [12] showed, after testing dyed and undyed cotton fabrics, that dye appears to protect cotton yarns from infrared laser light. They applied two laser fluencies to cotton fabrics (7.8 mJ/cm^2 and 15.5 mJ/cm^2). The strength decreased more in the warp than in the weft direction. The undyed cotton fabric lost its strength at higher laser fluency by 100% and the dyed cotton fabric by 71% in the warp direction.

Laser fading technology is used for burning the surface of denim fabric. The energy generated by the laser beam, and absorbed as heat, leads to dye removal and a lighter shade on the fabric surface. The laser creates a beam in a very narrow area. Thus, laser fading technology enables material fading in a certain area where the beam impacts the fabric. The final visual appearance of denim fabric depends not only on the intensity of a laser beam, but also on the fibre content, weave type and colour [3]. A Scanning Electron Microscope (SEM) enables us to observe the laser fading effect on fibre morphology. The results of Hung et al. [13] showed that yarn damage in the fabric increased at higher laser processing variables. The intense beam created by the laser caused dehydration of cotton fibres, which led to the creation of pores on the cotton surface, and the fibre surface was peeled off. This resulted in a sponge-like structure and fibre degradation. It was also noted that higher laser irritation affected not only the fibre surface but caused pores to be formed inside the fibre. Due to the thermoplastic nature of polyester fibres, the heat generated by the laser beam melted the polyester fibre so that individual yarns were less apparent. Laser irritation created grain shapes on the fibre ends, which coagulated into tiny polyester grains. Resolidified polyester covered the pores in the fabric and on the cotton fibre surface.

According to the previous research, there are no distinct optimized laser parameters for the surface treatment of denim fabric. It mostly depends on the final appearance desired. However, for bulk production, certain tested parameters help to reduce laser adjustment time, increasing the efficiency of the manufacturing process. In the current study, two kinds of power and speed of the laser cutter head were applied to three different denim fabrics containing different ratios of cotton, elastane, viscose, and polyester. Fibre composition was selected based on the authors' previous research. The fibre content chosen provides durability and comfort for everyday wear. The aim was to determine whether laser parameters can be fixed for bulk production when denim fabrics are processed with different weave constructions and contain different ratios of the same fibres. To achieve the aim of the study, the effect of laser fading on physico-mechanical properties (abrasion resistance, tensile and tear properties) of denim fabrics was analysed.

In addition, the influence of laser fading on fibre morphology was observed by using the SEM to determine how laser power and speed of the laser cutter head affect multicomponent denim fabric. Two fabrics were satin weaves and one fabric was twill weave. Another purpose of this study was to determine how universal the selected fixed laser parameters are for fading multicomponent denim fabrics containing the same fibres but in different ratios.

MATERIALS AND METHODS

Materials

Three indigo dyed denim fabrics were used in this study. The fabrics were woven in the Diraga Home Textiles Ideas & Concepts Private Limited Company, India. The warp yarn was made of 100% cotton. The weft yarn contained different ratios of viscose, elastane and polyester at the core and were covered with cotton fibres. The structural parameters of the used fabrics are given in Table 1.

Methods

Before testing, all the samples were conditioned at a temperature of 20 ± 2 °C and relative humidity of 65 ± 4% in accordance with the standard EN ISO 139:2005/A1:2011 [14]. In addition, the actual number of yarns per unit length was calculated based on EN ISO 1049-2:2000 [15], using Method A indicated in this standard. Five specimens were cut from the warp and five from the weft direction. Two dissecting needles were used to count the number of threads per centimetre. The mean value of each individual test result was quoted.

A CO_2 laser Bodor BLC-1309XU with a wavelength of 10.6 µm was used for fading denim fabrics. The distance of the laser head from the denim fabric was 8 mm. The radius of the laser spot was 0.1 mm. The variable laser parameters were power (W) and speed of the laser cutter head (mm/s). Laser beams with two types of power (14 W and 16 W) and speed (230 mm/s and 350 mm/s) were applied to three denim fabrics.

A Martindale abrasion tester James Heal 1605 was used to test abrasion resistance. The fabrics were tested in accordance with EN ISO 12947-2:2016 [16]. The test specimen diameter was 38 mm and the abradant material diameter was 140 mm. The abrasion test was continued on individual test specimens until all specimens reached the specified end-point/breakdown. According to the standard EN ISO 12947-2:2016, the quoted result is defined as the lowest individual test result of all the test specimens tested. Damaged and broken yarns were examined by using a Dino-Lite Digital Microscope AM4113T and Dino Capture 2.0 computer software.

Tear properties were tested according to EN ISO 13937-2:2000 [17]. Five specimens were cut from the warp and five from the weft direction with the measurements of 50 × 200 mm^2. Tear force was measured on an Instron 5866 tensile testing machine and BlueHill software was used to record the test results. The gauge length of the testing machine was set to 100 mm and pulled apart at a constant test speed of 100 mm/min. A load cell with a maximum capacity of 500 N was used to test the tear resistance of denim fabric.

Tensile properties were evaluated in accordance with the ISO standard 13934-1:2013 [18]. The tensile properties were expressed in terms of force at rupture. To test the tensile properties, five test specimens were cut from the warp and weft directions with the measurements of 50 × 400 mm. The gauge length of the Instron 5866 tensile testing machine was set to 200 mm and the extension rate was 100 mm/min. The pretension was set at 5 N and a load cell with a maximum capacity of 10 000 N was used [18,19].

Table 1. Structural parameters of the denim fabrics

No.	Fabric name	Weave	No. of threads per cm		Mass per unit area g/m^2	Composition %
			Warp	Weft		
1.	KG 4930 Fabric 1	4/1 Satin	55.5	23	318	67.7% CO 20% PES 10.5% CV 1.8% EL
2.	KG 5264 Fabric 2	4/1 Satin	53	18	347	75% CO 19% PES 4.5% CV 1.5% EL
3.	KG 5716 Fabric 3	3/1 Twill	35	22	340	75% CO 13.5% PES 9.5% CV 2% EL

CO – cotton, PES – polyester, CV – viscose, EL – elastane

A SEM TMI-1000 was used to examine the morphology of the yarn and fabric (1000x magnification) before and after the laser fading process. In the SEM analysis, the fibres were attached to the specimen stub by using a double-sided conductive tape 16073 (Ted Pella Inc.), 8 mm W × 20 m L, prior to SEM examination.

The significance of the differences between the means of the different fabrics was evaluated by the Analysis of Variance (ANOVA). The differences amongst means were compared and segregated by Tukey's test (P\0.05).

RESULTS AND DISCUSSION

Laser faded fabrics were first compared with raw denim to understand the impact of laser treatment on the denim fabrics. Then laser treated fabrics were compared with each other and suitable laser parameter combinations were found.

Abrasion resistance

The results of the abrasion resistance test are shown in Fig. 1. It can be seen that the laser fading process decreased abrasion resistance drastically. The abrasion resistance of twill weave raw fabric (Fabric 3) was 67% higher than that of satin weave Fabric 1 and 73% higher than the abrasion resistance of satin weave Fabric 2. The resistance of laser faded twill of Fabric 3 to abrasion decreased by 53% (decreased by 40 000 rubs and the abrasion resistance was 35 000 rubs) compared to the untreated denim fabric. Figure 2 shows the effect of laser fading on fibre morphology. The damage to the warp and weft yarns of Fabric 3 after laser treatment (14 W and 230 mm/s; 16 W and 350mm/s) was analysed by the SEM. It can be observed that in both power and speed combinations, the warp yarns were severely damaged by the laser beam. Pores were formed on cotton fibres. It is consistent with the findings of Kan et al. [20], Hung et al. [13], Montazer et al. [21]. They have stated that higher laser processing variables, such as laser resolution and pixel time or laser power, increased the number of pores, resulting in higher yarn damage. However, Table 2 demonstrates that by using higher power at a higher speed or lower power at a lower speed, the amount of yarn damage is similar. Broken and melted fibre tips can be observed for weft yarns that contain synthetic fibres.

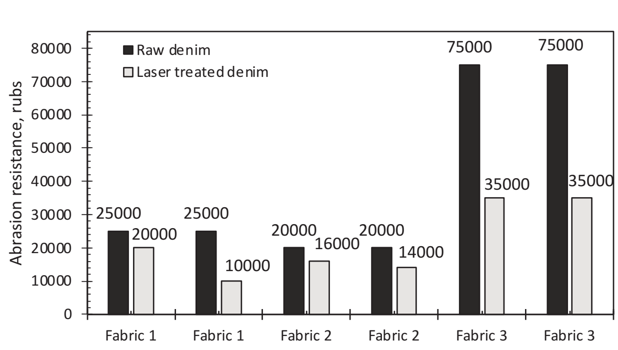


Fig. 1. Comparison of abrasion resistance of raw and laser faded denim fabrics.

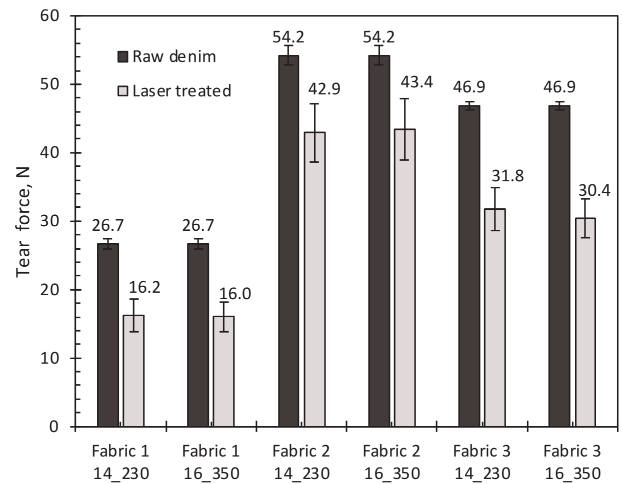
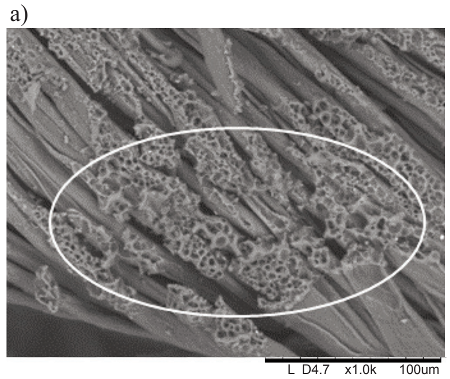
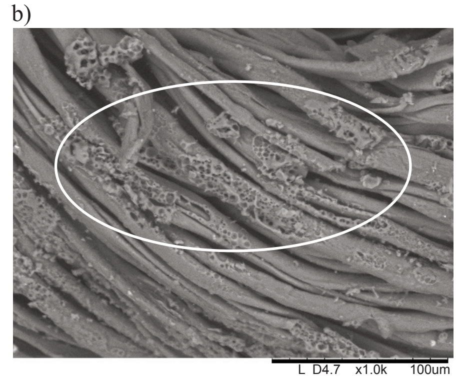
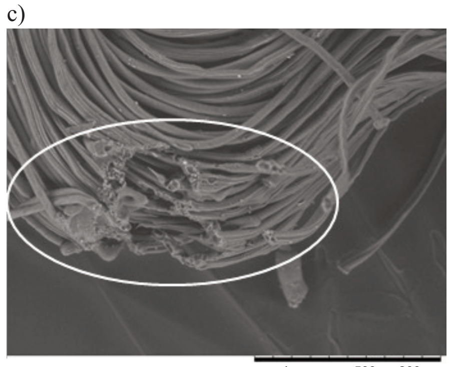
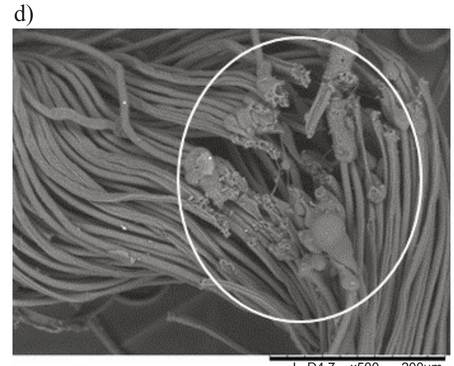
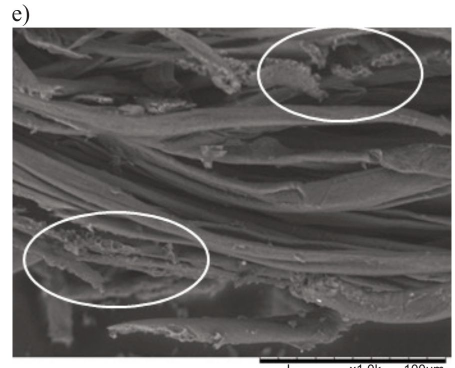


Fig. 2. Comparison of tear properties of raw and laser faded denim fabrics.

The speed of the laser cutter head and the difference in power intensity had a minor effect on fabric durability because for twill weave fabrics faded at different parameters (14 W and 230 mm/s; 16 W and 350 mm/s), the abrasion resistance was the same – 35 000 rubs. The abrasion resistance of laser faded Fabric 2 decreased by 20% (at 14 W and 230 mm/s, the abrasion resistance was 16 000 rubs) and 30% (at 16 W and 350 mm/s, the abrasion resistance was 14 000 rubs) compared to raw denim. The largest difference was observed for Fabric 1. The abrasion resistance decreased by 20% (at 14 W and 230 mm/s, the abrasion resistance was 20 000 rubs) and 60% (at 16 W and 350 mm/s, the abrasion resistance was 10 000 rubs). It can be observed from Fig. 1 that laser fading has intensively damaged cotton fibres in warp yarns. It is because of the weave construction. Warp yarns are more dominant than weft yarns and the laser beam damaged the fabric surface. Twill weave is more tightly woven than satin weave. Arora [22] has found that a higher number of interlacing points and a low number of floats are more durable and resistant to abrasion. In contrast, fabrics woven with longer floats are more prone to abrasion and can cause snagging, which affects negatively the visual appearance of fabric. This might be

Table 2. SEM images of fibre morphology of Fabric 1 and Fabric 3

	Laser fading parameters: 14 W and 230 mm/s	Laser fading parameters: 16 W and 350 mm/s
Fabric 3. Warp yarn (cotton fibres)	a) 	b) 
Fabric 3. Weft yarn (polyester, viscose, elastane)	c) 	d) 
Fabric 1. Warp yarn (cotton fibres)		e) 

the reason why twill fabrics have shown higher test results than satin weave fabrics [22,23].

According to the standard EN ISO 12947-2:2016 [16], abrasion resistance is defined as the lowest individual test result of all the test specimens tested in a certain group.

Denim fabric is mainly used for the production of jeans. For this reason, minimum requirements were established by the Public Waste Agency of Flanders (OVAM) for trousers – abrasion resistance should be at least 20 000 rubs. However, in the current study, the test results showed that after laser fading at both laser parameter combinations (14 W and 230 mm/s; 16 W and 350 mm/s), Fabric 1 and Fabric 2 made of satin weave are not suitable for garment production because this weave construction does not meet the established minimum requirements. Laser parameters cannot be fixed for satin weave denim. Denim garments should be made of twill weave, as it is more resistant to abrasion [24].

Tear strength

Tear force was recorded in the weft direction where the warp yarns were torn. All the warp yarns of the tested fabrics were made of cotton. In the warp direction where weft yarns were torn, the test results could not be recorded because the specimen broke before the test ended. The reason is that the cotton yarns were much weaker than the yarn used in the opposite direction. A yarn shift occurred and the fabric did not tear along the direction of the force applied.

The tear properties test in the weft direction showed that the tear force of laser faded Fabric 1 decreased compared with untreated denim by 39.3% (14 W and 230 mm/s) and 39.9% (16 W and 350 mm/s). The tear force of Fabric 2 decreased by 20.9% (14 W and 230 mm/s) and 20.1% (16 W and 350 mm/s). The tear force of Fabric 3 decreased by 32.2% (14 W and 230 mm/s) and 35.1% (16 W and 350 mm/s). Fabric 2 showed the highest test results. Weave construction and the number of yarns per centimetre affected the tear properties of fabric. Satin weave has fewer interlacings than twill weave. Loose construction allows yarns' mobility and decreases friction between yarns; as a result, yarns move and group together. This leads to higher tear properties. Fabric 1 was also made of satin weave but showed the lowest tear force values. This is due to the higher number of threads per centimetre. Yarn's linear density is another factor that might have reduced the tear properties of Fabric 1 because it contained a higher ratio of synthetic (polyester and elastane) fibres than the other tested fabrics. The strength of the weft yarn influenced the tear properties of the warp yarn. The same effect was observed by Eryuruk et al. [25], Triki et al. [26], Dhamija and Chopra [27] in their studies.

It was also noticed that although different laser power and speeds of the laser cutter head were applied to the denim fabrics, the test results were the same. Figure 2 showed that the results of the satin weave fabrics laser faded at 14 W and 230 mm/s were the same as treated at 16 W and 350 mm/s. In addition, all fabrics showed a similar trend of the loss of tear properties. The satin weave fabrics lost 11 N of their strength after laser fading compared with raw denim. Fabric 3 lost 15 N (14 W and 230 mm/s) and 17 N (16 W and 350 mm/s). It can be concluded that differences in laser power and speed of the laser cutter head had no statistically significant effect on the tear properties of the fabric. Both laser parameter combinations (14 W and 230 mm/s; 16 W and 350 mm/s) were suitable for testing the fabrics because the fabrics met the minimum OVAM requirements and their tear properties were higher than 15 N.

Tensile properties

Tensile properties were expressed in terms of force at rupture. All the tested raw and laser faded fabrics had a higher value of force at rupture in the warp than in the weft direction (Fig. 3). It is related to weaving of a fabric. During weaving, warp yarns are under higher tension compared to weft yarns. Thus, by increasing the tension of warp yarns, the crimp decreases. As a result, it increases the strength of the warp yarn as well as the crimp of the weft yarn. After laser fading, the high standard deviation of denim fabrics is caused by non-uniform fading applied to a fabric [28–30].

The tensile force at rupture of warp yarns was significantly decreased by laser fading for all fabrics (Fig. 3). However, laser fading did not affect the tensile properties of weft yarns, except for Fabric 3, where the laser fading had a statistically significant effect on the tensile properties of the weft yarns. This can be explained by weave construction. Fabric 1 and Fabric 2 were made of satin weave, Fabric 3 was made of twill weave. In both weave constructions, warp yarns are more dominant on the right side of the fabric and the laser beam burnt more warp than weft yarns. Also, satin weave fabrics tend to have lower tensile properties because of lower interlacing points and longer floats than in twill weave. Similar results were reported by Asaduzzaman et al. [31] and Ozguney et al. [32]. For this reason, twill weave fabric showed higher values of tensile force at rupture than satin weave in the warp direction.

Higher tensile force at rupture was shown for satin weave fabric in the weft direction. The highest value of tensile force of raw denim at rupture was shown by Fabric 1, 800 ± 38 N, but after laser fading, the tensile properties decreased by 19% for both fading combinations: 648 ± 177 N (14 W and 230 mm/s), 646 ± 142 N (16 W and 350 mm/s). Satin weave Fabric 2 had slightly

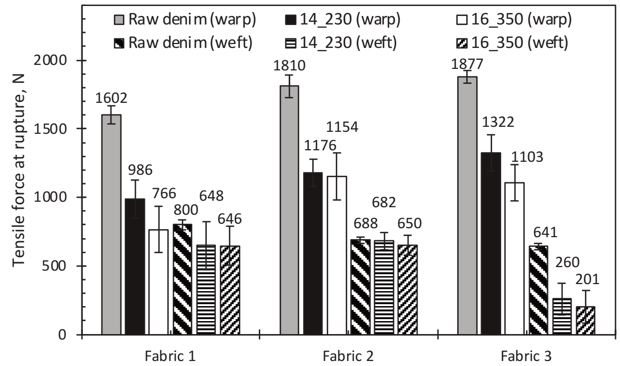


Fig. 3. Comparison of tensile force of raw denim and laser faded fabrics at rupture.

higher tensile force at rupture after laser fading than Fabric 1: 682 ± 62 N (14 W and 230 mm/s), 650 ± 74 N (16 W and 350 mm/s). However, for both fabrics (Fabric 1 and Fabric 2), according to the statistical analysis, the tensile force at rupture was not significantly different. Fabric 3 showed the lowest tensile test results in the weft direction. The tensile force of raw denim at rupture was 641 ± 21 N, which was 6.8% lower than that of Fabric 2 and 19.9% lower than the tensile properties of Fabric 1 in the weft direction. Moreover, all the raw fabrics had statistically different results in the weft direction. Unlike Fabric 1 and Fabric 2, the tensile properties of Fabric 3 decreased remarkably after laser fading. Laser fading at 14 W and 230 mm/s showed a 59.4% decrease and laser fading at 16 W and 350 mm/s showed a 68.6% decrease in the tensile properties of the same fabric compared with raw denim fabric. According to the literature, during the laser fading process, a fabric absorbs thermal energy. It increases the internal volume of the fibre, resulting in expansion and swelling of the fibre and a sponge-like structure forms. In the current study, the SEM analyses revealed pores on the fibre surface. Degradation of the weft yarn was clearly visible after laser fading (Table 2). The weft yarns were broken and melted, grain shapes were formed on the fibre ends. According to the OVAM minimum requirements, the maximum force for clothing should be 250 N. Unfortunately, laser fading of Fabric 3 at the power of 16 W and the speed of 350 mm/s was 201 N, which was below the minimum. This might be because the other fabrics contained a higher ratio of polyester. The laser parameters of 14 W and 230 mm/s were suitable for use for all tested fabrics, but the power of 16 W and the speed of 350 mm/s should be tested before garment production. The reason is that the type of fabric construction and the fibre ratio in the fabric may decrease tensile force at rupture in a different way.

CONCLUSIONS

Resulting from the physico-mechanical testing, it can be concluded that laser fading affected warp yarns more than weft yarns because warp yarns are more dominant on the right side of fabric. Twill weave Fabric 3 of raw denim showed 67% higher abrasion than Fabric 1 and 73% higher than that of Fabric 2. Laser fading decreased the abrasion resistance of Fabric 3 by 53%. Also, laser fading at the parameters of 14 W and 230 mm/s, and 16 W and 350 mm/s decreased the tear properties of Fabric 1 the most (41%). The SEM analyses showed that the laser beam degraded yarns in denim fabric. It generated pores on the cellulosic fibre surface and melted synthetic fibres. The abrasion test showed that twill weave fabric has high abrasion resistance and is suitable for garment production; after laser fading, the tensile properties of Fabric 3 decreased drastically. To increase the tensile properties, the polyester ratio of Fabric 3 could be increased, as in the other tested fabrics. However, further research is needed to find out how much the polyester ratio could be increased. The tear properties of all tested fabrics met the minimum requirements. It can be concluded that the laser parameters of 14 W and 230 mm/s, 16 W and 350 mm/s are more suitable for twill weave fabrics, as generally the test results of twill fabrics showed higher durability than these of satin weave fabrics. Furthermore, the construction type and minor changes in the fibre ratio of fabric can have a major influence on durability properties. For this reason, it is recommended that laser parameters should be tested before garment production.

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Laserkulutuse mõju teksakangaste füüsikalis-mehaanilistele omadustele ja mitmekomponentsete teksakangaste kiumorfoloogia

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Teksatoodetele esteetilise välimuse andmiseks kangaid viimistletakse, mis sageli on küllaltki keskkonda koormav protsess. Seevastu laserkulutust käsitletakse säästva alternatiivina teksakangast valmistatud rõivaste viimistlemiseks. Selleks pole tarvis ei vett ega kemikaale. Laserkulutuse protsess on täpne ja kergesti kontrollitav, sobilik masstootmise jaoks, vähendades aja ja tööjõu kulusid.

Uuringu eesmärk on leida, kui universaalsed on neljakomponentse kiulise koostisega (puuvill, polüester, viskoos ja elastaan) teksakanga jaoks välja töötatud laserviimistluse meetodid. Uuriti teksakangaste füüsikalis-mehaanilisi omadusi enne ja pärast kulutamist ning analüüsiti kiu morfoloogiat lasertöötluse järel. Töös kasutati kaht laserkulutuse parameetrite komplekti, mis valiti varasemate autorite poolt läbiviidud uuringutest – laseri võimsus ja lõikepea kiirus (võimsus 14 W koos laserlõikepea kiirusega 230 mm/s ja 16 W koos kiirusega 350 mm/s).

Selles töös kasutati kolme teksakangast, mille kõigi lõimelõngad olid valmistatud 100% puuvillast ja koelõngad sisaldasid nii polüestrit, viskoosi kui ka elastaani. (Kangas 1 ja Kangas 2 olid atlass-sidusega, Kangas 3 toimse sidusega). Skaneeriva elektronmikroskoobi (SEM) analüüs näitas, et peale laserkulutust puuvilla kiud kahjustusid oluliselt ning kiudude pinnale tekkisid erineva suurusega poorid, sünteetilised kiud sulasid ning nende otsa tekkisid väikesed kerad. Ka füüsikalis-mehaaniliste testide tulemusel selgus, et hõõrdekindlus laserkulutatud kangastel vähenes oluliselt. Toimse sidusega toorkangal (Kangas 3) oli testituist kõrgeim hõõrdekindlus (75000 hõõret), mis peale laserkulutust vähenes 53%. See juhtus nii parameetrite 14 W, 230 mm/s kui ka 16 W, 350 mm/s kasutamisel. Koesuunas laserkulutatud kangaste rebimistugevus vähenes mõlemal atlass-sidusega kangal üsna sarnaselt: 11 N (Kangas 1 ja Kangas 2) ning Kangas 3 puhul vastavalt 15 N (14 W, 230 mm/s) ja 17 N (16 W, 350 mm/s). Kangas 2 oli vastupidavam tänu oma konstruktsioonile, sest lõdvema sidusega kootud tekstiili puhul on lõngadel võimalik jõu rakendamise ajal liikuda ja grupeeruda, mille tulemuseks on suurem rebimistugevus. Tõmbetugevuse vähenemine rohkem lõime kui koe suunas oli tingitud samuti kanga sidusest, sest lõimelõngad on kanga paremal poolel domineerivad.

Katsetulemuste ja SEM analüüsi põhjal võib väita, et toimse sidusega teksakanga tugevusomadused olid kõrgemad kui atlass-sidusega variandil. Uurimustöös jõuti järeldusele, et siduse ja kiulise koostise suhe mõjutab kanga tugevusomadusi, mistõttu tuleks laseri parameetreid enne tootmist katsetada testkangal.