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Introduction of Potassium Permanganate spray with Laser Treatment to Achieve Improved Fading and Mechanical Properties of Denim Fabric

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ABSTRACT

Nowadays, faded denim garments have become one of the exoteric fashion trends among the young generation. As a result, denim washing turns into a crucial issue in the washing plant to meet the consumer demand. In this research, denim cotton fabrics were washed with laser followed by potassium permanganate (pp) spray, also with similar alternative processes like laser, whiskering, enzyme and stone wash etc. This study provides a set of experimental results, discussion, and comparison among the different denim washed processes. Among them, laser with pp spray faded fabric shown better mechanical properties such as tensile strength, elongation properties, tear strength etc. than only laser, whiskering, enzyme and stone faded samples. Moreover, Color Measurement Committee (CMC) and reflectance data presented also better values for laser with pp spray faded fabrics and it has shown lower Color Strength (K/S) value than other similar alternative processes. Yellowness index and whiteness index values are almost similar at all of the washed processes. Dimensional stability and weight loss% of the laser+PP faded samples are lower than the similar alternatives. Surface of the differently treated samples were examined by microscope and got less protruding fibers in case of laser and laser+PP compare to others. Even though, the laser+PP fading process could be reduced processing time, lesser consumption of energy and water, as well as it provides improved product quality and potential process integration.

Keywords: Denim fabric, denim wash, laser treatment, potassium permanganate (pp), mechanical properties

1. Introduction

Denim jeans are created into a part of the fashion range, its success is due to its ability to change with every social and cultural revolution. Denim garment manufacturers are interested in finishing cloth that consumers want to purchase. Consumer's demand for jeans with worn look began a revolution in denim processing (Khedher, Dhouib, Msahli, & Sakli, 2011). The warp yarns of the denim are mostly dyed with indigo dye and sized (Grieve, Biermann, & Schaub, 2006; Rashid, Hossain, Islam, & Nakib-Ul-Hasan, 2013), thus, it is a very firm texture and hard. It is also strong, stiff and hard wearing woven fabric (Paul, 2015). The denims are normally dyed with indigo, vat and sulpher dyes, among them indigo share is about 67%. Indigo colors are utilized for fashion dyeing in denim, fibers dyed with indigo are excluded in fiber-transfer examinations, remains surface dyeing (C.-w. Kan & Wong, 2010; Saikhao, Setthayanond, Karpkird, Bechtold, & Suwanruji, 2018). Denim garment (Jeans) washing is known as one of the broadly utilized finishing treatment that has tremendous usage in textile sectors due to creating extraordinary appearance and making stylish and wear comfortable garments in the present condition (C.-w. Kan, Lam, & Siu, 2015; C. Kan, 2015; Ondogan, Pamuk, Ondogan, & Ozguney, 2005). Without finishing treatments, denim garment is uncomfortable to wear, because of its weaving and dyeing impacts.

Washing is one of the most significant finishing treatments applied on apparels that have remarkable use to create special outlooks and improving the fashion. Different washing techniques (C. Kan, 2015; Tarhan & Sarıışık, 2009) can be applied for denim fabrics finishing. It is possible to make customized denim garments applying different physical processes such as whiskering, sand blasting, brushing, embroidering; and chemical processes such as pre-washing, rinsing, stone washing, sand washing, snow washing, stone washing with enzymes, enzyme, potassium permanganate spray, bleaching (Choudhury, 2017). But some processes like the sand blasting was obsolete due to the unhygienic the worker and quality of the product (Kalaoglu & Paul, 2015). The use of an enzyme process in textile industry is one of the most rapidly growing fields in industrial enzymology because of their non-toxic and eco-friendly characteristics (Buschle-Diller, Yang, & Yamamoto, 2016; Dhurai, 2007; C. W. Kan, Yuen, Jiang, Tung, & Cheng, 2007). In the textile industry enzymes are applied mainly to get fluffiness free a cleaner fabric surface (Uddin, 2015), which could be reduced tendency to pill formation. Furthermore, the use of enzymes in the textiles results in reduced process time, water and energy savings, improved product quality and potential process integration (Choudhury, 2017; Shah, 2013). Many investigators have investigated bio-bleaches (cellulase enzymes) which are environmental friendly (Mojsov, 2014) and successful at improving flexibility and soft hand feel, but their attack is not only limited to the fabric surfaces, causing unacceptable weight and strength loss to the fibers (Linko, 1977). In addition, required color shade cannot be achieved, if enzymes are used. In the case of stone wash there are difficulties of removing residual pumice from processed cloth items and difficult to reduce the damage to the equipment by over loading of tumbling stones (Hoque, Hossain, Imtiaz, Das, & Rashid†, 2018). Pumice stones and particulate material can also clog machine drainage passages, drainages and sewer line at the machine line. Moreover, Bleaching is one of the essential chemical processing steps prior to dyeing textiles which removes natural and adherent colorants in cotton and has the largest effect on whiteness of cotton gray fabric (Buschle-Diller et al., 2016; Prabaharan, Nayar, & Rao, 2016). Bleaching treatment improves the appearance and enhancing aesthetic properties of cotton fabrics. The most well-known industrial bleaching agent for cotton is hydrogen peroxide which removes natural and adhere color of cotton and increased whiteness

(Tang, Ji, & Sun, 2016). But hydrogen peroxide is less effective in denim washing, because it is applied under boiling conditions and increased fiber damage as well as high temperature bleaching promotes to higher energy consumption. Sodium chlorite and hypochlorite have been widely used to bleach cotton in textile industry (Prabaharan et al., 2016), but it has harmful effects on the environment due to chlorine liberation during bleaching. The strength of the fabric is decreased during increasing of washing, temperature and concentration of bleaching agent. Fading process including several washing steps is applied after desizing. Although conventional technologies are very beneficial in point of mass customization, production of discolored jeans using those technologies involves large quantities of water most of which being highly contaminated by chemical products used in the process (C. Kan, 2015). Apart from the associated environmental problems, conventional methods such as enzyme & stone and bleaching also have problems of relatively low reproducibility and it is difficult to apply design processes to different fabrics (Tarhan & Sarıışık, 2009). The time consuming and non-standard procedures of conventional methods are a significant barrier to mass production and causes increased production costs. An alternative technology, which might eliminate several drawbacks of conventional wet methods, are the whiskering and sand blasting. But it has some limitations such as more time consuming and hazardous for working environment. Recently, the dry process of using a CO2 laser has shown that it is possible to create reproducible patterns and eliminate drawback of conventional chemical and dry washing methods (Dalbaşı & İlleez, 2019; Juciene, Urbelis, Juchneviciene, Saceviciene, & Dobilaite, 2018; Venkatraman & Liauw, 2019). Laser is able to transfer graphics of a desired variety, size and intensity on textile surfaces, including knitted and woven fabrics, with less water consumption, process flexibility, precision and reproducibility of design (ÖZGÜNEY, ÖZÇELİK, & ÖZKAYA, 2009). It would be possible to transfer certain designs onto the surface of textile material by changing the dye molecules structure in the fabric and creating alterations in its color quality by directing the laser to the material at reduced intensity. But it could not produce white effect similar as whiskering or other conventional relevant processes as well as deteriorate fibers of the fabrics.

In this study, an alternative technology such as laser with pp spray, which might eliminate several drawbacks of convention dry and wet methods as well as optimized the mechanical properties and fading performance. However, no study seems to have reported the physical performance of laser with pp spray treated washing on cotton denim fabrics. The effect of laser with pp spray treatment on cotton denim fabrics like as physical performance, dimensional stability, color fading and economic feasibility were evaluated.

2. Materials and methods

2.1 Materials

The investigation has been carried out with indigo dyed 100% cotton denim long pant was obtained from Standard Group of Industries, Konabari, Gazipur, Bangladesh. The fabric weight was 372 gm/m2 while the fabric density was 54 ends/inch and 54 picks/inch. The denim fabric was conditioned under standard atmosphere of 20 ± 2^oc and relative humidity 65 ± 2% before laser with PP spray treatment and other alternatives.

2.2 Methods

The laser technology utilizes a beam of light, to produce a non-contact mark on the denim fabric. When ready denim lay down under the laser beam, the laser burns away the indigo dye to produce a worn look. In this case the samples were treated by laser according to the parameters of 100μs with 34 resolutions (dpi). Then the laser treated samples were treated with pp according to the laser faded area and neutralized by sodium metabisulfite for 10 minutes. After that the samples were rinsed one time for 3 minutes and excess water was removed by hydro extractor and finally dryed with tumble dryer at 100ºC for 30 minutes. Other samples were prepared according to the standard methods.

2.3 Characterizing the treated denim fabric

At first, all treated washed denim fabrics were conditioned in 65% RH and at 20ºC for 24 hours before testing according to ASTM D1776. Then tensile strength and elongation at break of the treated fabric were determined according to ASTM D5034 (Grab test) with a horizontal strength tester. Tear strength of the treated fabrics were measured according to EN ISO 13937-2. The color of the fabrics was measured by using a datacolor spectrophotometer. The parameters of D65 daylight with a 10º standard observer were used during color measurement. Reflectance curves and K/S and CIE L*a*b* values were obtained. Dimensional changes/ shrinkage (%) was calculated from the difference in fabric length before and after washed denim fabric according to AATCC test method 96. Weight loss (%) in fabric/ GSM was calculated from the difference in fabric weight before and after washed denim fabric according to ASTM D3776. Surface of the fabric was studied using a microscope.

3. Results and discussion

3.1 Mechanical properties of washed denim fabrics

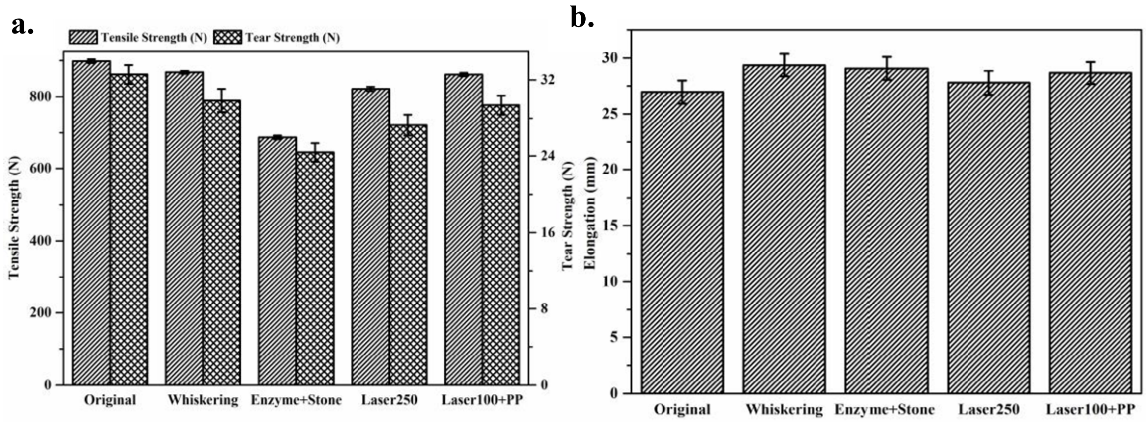


Figure 1. (a) Tensile and Tear Strength (b) Elongation properties of washed samples

The data of differently washed for cotton denim fabric is shown in Figure 1 (a). In terms of fabric tensile strength after washing, its tensile strength tends to be weaker after washing compare with the original. According to the Figure 1 (a), the fabric tensile strength tends to be weaker after whiskering, enzyme and stone, laser, and laser with pp washing respectively. However, the tensile strength of treated fabric becomes more or less similar for whiskering and laser100 with pp washing but more rapidly decreases in enzyme and stone washing. The possible explanation could be the fabric after enzyme and stone washing, the fibers degradation becomes severe, as because the enzyme damages the cellulose, on the 1, 4 β- glucosidal linkages of the cellulose molecules (C. W. Kan et al., 2007; Linko, 1977) and the stone renders higher level of abrasion between the yarns as yarns could not share the loading and withstand tensile force applied. As the enzyme and stone washing could withstand tensile force approximately 687 (N), which was decreased by 23.53 %. However, after whiskering, and laser100 with pp could withstand tensile force 867.20 (N) and 860.90 (N) respectively approximately which was decreased by 3.47% and 4.17% compared to the original. The whiskering and laser100 with pp processes exhibited less abrasion compared to the enzyme and stone process. The laser250 fading process also decreased the sample strength which was 8.60 %. The probable reason might be light fiber interaction during laser fading and intensity of light. The tear strength of laser250 and laser100 with pp fading fabric are less than that of original fabric but more of whiskering and enormous decrease in enzyme & stone washing. Tear strength of enzyme and stone; laser250 and laser100 with pp fading fabric are decreased by 25.14%, 16.24%, and 9.82% respectively compared to original fabrics.

Elongation at break for different washed in cotton denim fabric is shown on Figure 1 (b). According to the Figure 1 (b), the percentage of elongation at break is increased from original to whiskering; enzyme and stone; laser250 and laser100 with pp fading; which are 8.98%, 7.87%, 3.08%, and 6.35% respectively. From the wiskering and enzyme & stone washing, the percentages have been highly changed than other similar alternative. It has higher elongation to break of the washed sample because of it was fully relaxed and processed more yarn crimp percentage. Another cause of higher elongation to break of the washed sample may be removed sizing ingredient from the original denim fabric.

3.2 Fading properties of washed denim fabrics

Results of differently faded garments samples in comparison with original sample in respect of CMC value, K/S value, Yellowness, Whiteness and Reflectance value through spectrophotometer are presented in Table 1 and Figure 2 respectively. The parameters are assessed by D65 illuminates and 10^{0} angles.

Table 1. CMC value of washed denim fabrics

Comparison to Original	Light source	ΔE	ΔL*	Δa*	Δb*	Δc*	ΔH*	CMC
Whiskering	D65 10°	4.52	-0.21	-0.97	-4.41	4.37	-1.11	5.40
Enzyme+Stone		5.55	2.93	-0.92	-4.62	4.58	-1.12	6.08
Laser250		8.62	8.36	-1.62	-1.34	1.40	-1.56	7.16
laser100+PP		9.99	8.32	-1.15	-5.41	5.39	-1.23	9.30

The CMC value of raw sample to whiskering, enzyme and stone, laser250, and laser100 with pp fading were 5.40; 6.08; 7.16; and 9.30 respectively. However, the value of CMC are increased, the shade deviation of raw to different processes are increased. As a result, the shade deviation of laser100 with pp is comparatively more than other processes. The allowable explanation could be the fabric after laser100 with pp washing treatment become more effective because during the laser100 with pp treatment, the blue indigo dye would be released from the fiber by photo degradation and oxidation of dye by potassium permanganate. On the other hand enzyme & stone washing process was less effective due to redeposit on the surface of the fabric leading to back staining (C.-w. Kan & Wong, 2010). Other processes are almost similar except wiskering process. It can be seen clearly from Table 1, the value of ΔL* are approximately similar except whiskering and enzyme+stone washed fabric which indicate the fabric whiteness. Due to this reason, the value of ΔL* of whiskering and enzyme+stone were 0.21 and 2.93 which indicate the fabric was less faded. However, it is interesting to note that the laser fading and other similar alternative color fading approximately similar CMC values. This finding can support the argument to use laser treatment as an alternative to conventional treatment to create color fading effect on textile fabric.

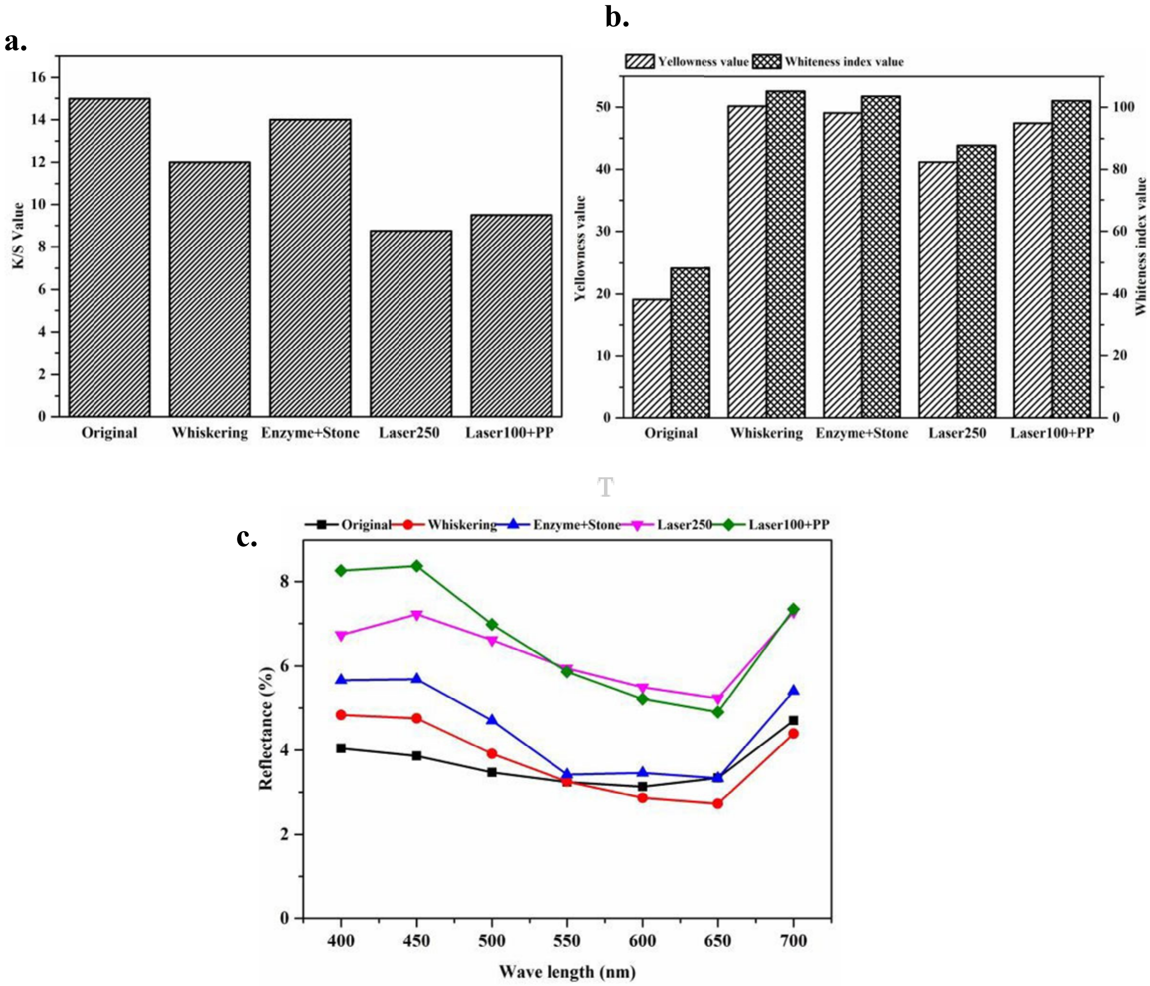


Figure 2. (a) K/S value (b) Yellowness and Whiteness value and (c) Reflectance value of differently washed sample

The K/S value is related to the concentration of the colorant in the fabric. The K/S values of the different washed samples can be seen from Figure 2 (a). From the results, it is noted that the differently treated fabrics have lower K/S values except whiskering and enzyme & stone process than untreated fabric. Normally, the higher K/S value will be the higher color yield and it can conclude that a paler shade is obtained after different treatment. The laser250 and laser100 with pp treated fabrics have a paler shade than the untreated fabric. The reason is that during the laser treatment, the laser beam from CO2 laser (λ: 10600nm) would burn the dyes in the fabric surface leading to a color fading effect (ÖZGÜNEY et al., 2009) and pp also enhanced removing residual burn dye molecules. However, in the case of enzymatic color-fading treatment, the enzyme in the aqueous medium can penetrate effectively into the interior part of fabric. The enzymatic hydrolysis induced by the enzyme in the fabric would be occurred (Dhurai, 2007; C. W. Kan et al., 2007). More fibers on fabric surface are hydrolyzed by enzyme, and the weaken fibers are further removed by abrasion of fabric and mechanical agitation i.e. stone wash. As a result, bluish shade is produced during enzyme treatment.

The yellowness index of different washed samples is given in Figure 2 (b). The yellowness index value of whiskering (-50.18); enzyme and stone (-49.09); laser250 (-41.16); and laser100 with pp fading (-47.45) samples are increased compared to original sample (-19.09). But laser250 wash sample was comparatively less yellowness index than other similar alternative fading treatment due to the less thermal oxidation occurred. Here negative (-) sign indicates more greenish of the samples. During the laser treatment, thermal oxidation effect may occur in the fabric surface leading to certain degree of yellowness (C. W. Kan, Yuen, & Tsoi, 2011). The thermal induced yellow color together with the original blue color in the fabric surface would result in increased greenish effect.

The whiteness index of different washed samples is given in Figure 2 (b). The whiteness index value of whiskering (105.32); enzyme and stone (103.66); laser250 (87.83); and laser 100 with pp fading (102.07) samples are increased compared to original sample (48.32). Whiskering fading and enzyme & stone treatment samples are approximately similar value bluish white tone and laser250 treatments samples were yellowish white tone due to the deposited carbon particles during color fading. Laser100 with pp washed sample were more bluish white tone due to the chemical reaction with the fabric.

Considering experimental results in Figure 2 (c) show that results are comparatively different among the differently treated samples. Since the laser fading and whiskering treatment are physically a surface etching process, the surface protruding fiber in the fabric surface would be removed together with the dye leading to a smooth surface and laser with pp spray treatment was also physical and chemical etching process. As a result, the reflectance value of laser with pp spray treatment process is increased compare to original. During the enzyme treatment, hydrolysis of cellulose would occur, and the blue dye would be released from the fiber and redeposit on the surface of the fabric leading to back staining (C.-w. Kan & Wong, 2010). As a result, the reflectance value of enzyme treatment process remains constant compare to original.

3.3 Change of fabric specification after differently washed samples

Results of differently faded denim samples in comparison with original one in respect of physical properties are shown in Table 2.

Table 2. Physical properties of washed denim fabric

Sample Description	Dimensional stability/ Shrinkage (%)	Weight of fabric (GSM)	EPI & PPI (ends/ inch)	Weight Loss (%)
Original	0	372	54×54	0
Whiskering	L=1.90 W=5.26	375	54×55	2.87
Enzyme+Stone	L=3.57 W=4.21	374	55×57	6.97
Laser250	L=00 W=2.10	373	54×54	2.69
Laser100+PP	L=2.38 W=2.10	373	54×55	4.50

During weaving fabrics were subjected to considerable tensions, particularly warp direction. In subsequent finishing process such as calendaring this stretch was increased and temporarily set in the fabric. The fabric is then in a state of dimensional instable. When the denim fabric was thoroughly wetted in different process, it tended to revert its more stable dimensions which results in the contraction of yarns. This effect is usually greater in warp direction than in the weft direction. This is known as relaxation shrinkage (Nayak et al., 2016). From the data Table 2, EPI (ends per inch) remained constant but PPI changed for differently wet washed sample due to the relaxation shrinkage. Relaxation shrinkage could be minimized by laser fading process. As a result, EPI and PPI remain constant in the denim fabrics during laser fading process was performed.

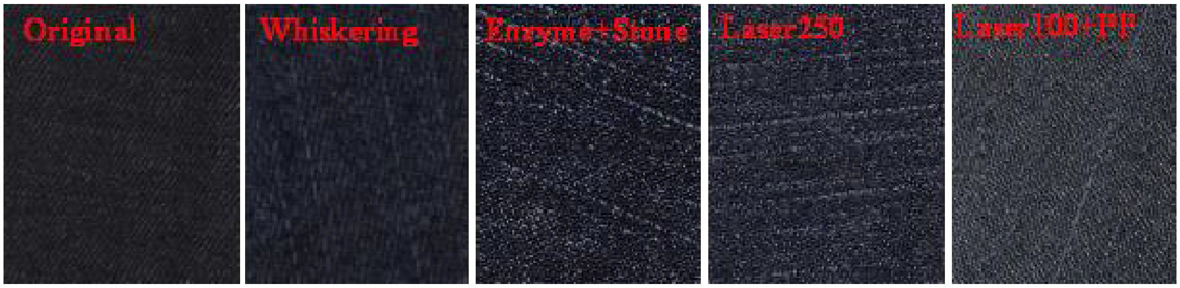
When the denim fabric was thoroughly wetted in different process such as enzyme & stone, desizing etc., it tended to revert its more stable dimensions which results in the contraction of yarns. As a result, the weights of the treated fabric were increased 0.81 % of whiskering, 0.54 % of enzyme and stone wash process. But laser with pp faded fabric and laser250 were almost unchanged and it was 0.27% due to the thermal degradation of cotton fiber.

The percentages changes in the dimensions of different denim fabric samples are shown Table 2. However, the widthwise direction shows a higher extent of shrinkage, which may be due to the yarn in the widthwise direction having been subjected to a higher tension during fabric production process. As a result, during the washing process, severe relaxation shrinkage may have occurred. Denim fabric samples treated with a higher laser power experience less shrinkage because fibers in the yarn no longer adhere closely to one another.

Table 2 also shows that percentages of weight changes after different treatments. In enzyme & stone color fading shows more weight loss (6.97%) than other due to the action of enzyme and mechanical agitation will abrade fiber surface and cotton fiber would be released resulting in weight reduction. When cellulose is heated, it undergoes a series of interrelated physical and chemical changes, such as loss of weight. The weight loss of laser treatment samples were 2.69% due to thermal degradation of cotton. The weight loss of laser with pp treatment was increased (4.50%) due to thermal degradation and chemically oxidation of cotton fibers.

In this experiment, the visual appearance and microscopic view of washed samples, it is observed that the original sample is less bright than the other.

a.



b.

Figure 3. (a) Visual appearance and (b) Microscopic view of differently washed samples

The microscopic photographs of the differently washed denim fabrics are given in Figure 3 (b). As it can be seen from the photographs, there is really small difference in protruding fibers of the differently faded sample compared to the original fabrics due to the mechanically and chemically abrade the fabrics. Laser100+PP sample was whiter than others due to the photo- degradation as well as chemical degradation reaction with cotton fabrics. Besides that, whiskering treated samples were contained more hairy fiber due to physical abrasion of the fabric.

3.5 Comparison of different parameters among differently fading process

The comparison result of denim fabric under different washing methods and analyze the impacts after washing is discussed in Table 3.

Table 3: Comparison of Different Parameters of Differently Washed Process

Process Parameters	Whiskering	Enzyme+ Stone	Laser250	Laser100+PP
Amount of Water (L)	3600	9390	1200	2400
Electricity Consumed (KWh)	18.02	43.5	12.41	16.702
Cost of ETP ($)	3.15	8.19	Nil	2.10
Time Required (hours)	20.76	1.75	1	1.16
Total Cost ($)	62.92	66.59	4.10	14.47

[Considering 120 kg of garments, 1USD=84.54Taka]

The water requirement for laser fading process is less than the other washed processes in Table 3 shows the comparison. In enzyme and stone process, the fabric was treated with desizing agent to remove sizing ingredients and washing with different chemicals and lastly rinsed 2-3 times to remove chemicals. As a result, huge water is required compare to laser process which is around 92.75%. Besides, the more water used, the more wastewater is generated for treatment in water treatment plant. Laser with pp spray process was required moderate level of water which contained less amount of chemicals.

The electricity requirement for laser fading process is also less compare to the common washed processes. In enzyme and stone washed process, the electricity is required 43.5 KWh whereas, the laser fading process required 12.41 KWh which is 71.47% less than the enzyme and stone washed processes. In case of laser with pp process, the amount of electricity required 16.702 KWh which is 61.60 % less than the enzyme and stone washed processes but 25.70 % more than laser fading process.

The more water used, the more wastewater is generated for ETP treatment. As a result, the cost for ETP is so much high of enzyme & stone and whiskering than laser and laser with pp fading system. In laser fading only rinsed water are drain out which is not required to ETP treatment and laser with pp fading only neutralized water should be done ETP treatment.

The time requirement of laser fading system is less than the wishkering and enzyme & stone washing processes. The whiskering and enzyme & stone washing processes take place about 20.76 hours and 1.75 hours for completion whereas the laser fading process will not take 1 hour for completion 120 kg of garments and 1.16 hours was required for laser with pp fading process. For 120 kg fabric washing laser fading process will save 19.76 hours compare to whiskering and 0.75 hour compare to enzyme and stone washed process. It will also reduce the production cost of the whole process and adding the economic benefit. In terms of percentage the time saving will be 95.18 % and 42.86 % which is shown in the table 3.

From the above table 3 shows that total cost of enzyme & stone and whiskering washed $69.59 and $62.92 respectively for 120 kg denim garments washed which is almost similar. Whereas, laser fading and laser with pp fading system required $4.10 and $14.47 for the similar amount of fabric treatments.

4. Conclusion

Though the dry and wet wash are using nowadays, it has great bad effect on environment. So, this study was attempted to find out the usability of laser with pp spray fading over other similar conventional alternative washed methods. The prospect of laser with pp spray fading over other similar alternative washed methods can be assumed from the following decision:

During the washing, the starch surface fibers and some dyestuff were removed by the abrading laser, whiskering, stone, enzyme etc. The tensile strength of these samples became weaker. Keeping relation to this concept, denim cotton fabric of 372 gsm was washed common process like whiskering, enzyme & stone, laser and proposed laser with pp spray fading process in the research work. The result shows lower tensile strength of the enzyme & stone washed fabric. Laser with pp spray fabrics show better tensile strength (860.97 N) than laser treated fabrics (821.10 N) and other similar alternative processes. Elongation properties of whiskering and enzyme & stone got higher value than laser treated samples. But laser with pp spray fading sample also shows greater elongation properties than only laser treated samples. Laser with pp spray faded sample got better tear strength than other similar alternative processes except whiskering process. The result shows color difference between original to laser with pp spray i.e. CMC value is higher (9.30) than other similar alternative which indicates more fading of the samples. K/S value of laser with pp faded fabric was lower (9.5) than enzyme & stone (14), whiskering (12) and only laser (10.25) faded samples which indicate less dye molecules present in the laser with pp spray faded areas. That is strongly support the more fading of the laser with pp spray samples. Yellowness index value and whiteness index value of laser with pp faded sample was almost similar to other similar alternative. The result of reflectance value shows more in case of laser with pp spray than other similar alternative. EPI and PPI changes and weight of differently washed samples were almost similar. Dimensional stability of laser with pp spray and only laser were less than conventional whiskering and enzyme & stone washed samples. Weight loss% of laser with pp spray was moderate level than other alternative processes.

Considering the cost, only laser fading process is more effective than other similar alternative washing processes. But laser with pp spray process shows moderate level of cost but other physical and mechanical properties were acceptation level. As the laser with pp spray fading washing machine is highly costly at initial condition but it has required less water, electricity, time and produced small amount of effluents. However, it can produce similar effect on denim garments at least cost and shorter time. So the results of this study conclude that laser with pp spray fading washing process is more sustainable and suitable process compare to the common conventional processes.

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