Investigating the Performance of Dry Processing on the Properties of Denim Garments

Md. Shamsuzzaman[1], Joy Sarkar[2] and Dip Das[1*]

[1]Department of Textile Engineering, World University of Bangladesh, Dhaka-1230, Bangladesh.
[2]Department of Textile Engineering, Khulna University of Engineering and Technology, Khulna, Bangladesh.

Abstract

This research assessed how well various dry processes work when applied to various denim garment samples. The washing technology instills values, produces/modifies the exceptional final appearance and ensures the customer's complete satisfaction. Dry processes like hand sanding, hand scraping, spraying with P.P. (Potassium Permanganate), destroying, tagging, whiskering, etc., are frequently employed in practice. In this study, we processed various denim garment specimens using P.P. spray, hand sanding and laser engraving/fading (based on their weave construction). Then, under dry processing circumstances, we examined several physicomechanical parameters of the samples and compared the findings among them. Furthermore, we found that the treated samples' characteristics differed noticeably from those of untreated samples and other dry treated samples. Additionally, we have observed that the qualities such as colorfastness to washing, stains, dry rub and wet rub, are enhanced following various dry processes. The qualities of colorfastness to light, tearing strength, tensile strength, GSM, pilling, abrasion, etc., on the other hand, were found to be drastically diminished. Compared to those treated with the other two types of dry processing, like laser fading and P.P. spray, samples treated with hand sanding have a much more severe effect. However, laser fading samples required additional costs over hand sanding and P.P. spray.

Keywords— Denim garments, hand sanding, P.P. spray, laser fading, denim properties.

1. Introduction

Garment washing treatments widely change the mechanical and surface properties of the textile materials specially hand, comfort, tactile, tensile, bending, air permeability, flexibility, compressibility and thermal property [1]. Along with these aspects, appearance, comfort and design of clothing are also changing or modifying that are creating scopes of a vast variety of products in the garment stage [2]. Washing technologies are mainly applied on the face side of the garment according to the requirements of the buyer or appearance [3]. Mainly two types of garment washing processes are available such as (a) dry processes (such as sandblasting, hand sanding, whiskering, tagging, grinding, destroying, potassium permanganate (P.P.) spray and color spraying/sponging); and (b) wet washing (such as regular washing, pigment washing, caustic soda washing, stone washing, enzyme washing and bleach washing) [4-5]. These techniques are used to create faded effects on solid or patterned garments. As a result, the physical and mechanical characteristics of both knit and denim clothing have changed, making them more appealing to consumers. Only wet processing is appropriate for knit clothing since it is susceptible to dry processing [6]. On the other hand, both dry and wet techniques are practical and can be applied to woven clothing, particularly denim, without affecting the fabric of the garment [7].

The growth of denim production has gained prominence for design diversity which expands the global market with newer finishes [7-9]. Since denim is manufactured differently than other fabrics, it becomes stiff and uncomfortable to wear when it is unfinished. Compared with pre-washed and washed denim, mostly washed denims have shown better properties than pre-washed/unwashed denim except in case of edge abrasion, etc. [10]. Applying garment dry processes is therefore essential to make denim clothing more supple, smooth and comfortable [6]. Numerous processes are available in the market for finishing denim garments and updating older technology and procedures [11]. According to previous research, enzyme, bleach, acid and stone washes are the most frequently used chemical washing methods on denim clothing. In contrast, the most significant dry processes are tagging, grinding, destroying, whiskering, permanent wrinkle, P.P. spray, hand scraping and other finishing procedures [1].

Besides washing have several fading effects on denim garments made of 100% cotton, spandex, polyester, acrylic, or blended yarn. A group of researchers examined the impact of several fading processes over 100% cotton and 98% cotton + 2% elastane denim garments and noticed significant difference in the performance in mechanical, functional and comfort properties between cotton and elastane fibers [12].

Further, the application of $KMnO_4$,/H_3PO_4 solutions on denim samples has much significant impact where enhanced properties like brightness can be achieved with the changing of the concentrations of $KMnO_4$, H_3PO_4 and process time [4-5]. Another research has conducted on stretched denim garments with Potassium Permanganate ($KMnO_4$) spray and alternative PP ($KMnO_4$) Spray with varying concentrations. After neutralization, mechanical and physical properties were checked and noticed that potassium permanganate spray exhibited poor performance than the alternative potassium permanganate sprayed sample. Moreover, the increase in the concentration of the chemicals exhibited lower properties [13-14]. The most effective and sustainable denim fading process is considered laser engraving nowadays. Much research has been conducted on the impact of laser fading on the mechanical

and physical properties of denim. Most of the cases laser fading has much better properties than industrial/ conventional washing techniques [15]. Ahmed et al., 2022 reviewed laser fading effects on denim garments which is considered an eco-friendly treatment. They discussed various properties of laser fading, the influence of laser parameters and color fading on the mechanical and physical properties of denim garments [16]. Tarhan et al., 2009 applied sandblasting and laser fading on denim garments and then washed them. Other sample was only washed. At the end of the study, loss of weight, color abrasion, loss of tensile strength and other properties of denim fabrics were measured. Laser-faded samples showed better properties than sand-blasted garments [17]. Joy et al., 2022 developed a fuzzy logic-based model for measuring the warp and weft way tearing strength after the applications of laser fading. However, the model exhibited a similar pattern for tear strength relationship with dot per inch (dpi) and pixel time (pt). The model also suggested that upto 98% of changes in tear strength can be explained satisfactorily [18].

Moreover, blended research like chemically washed and laser-treated denim garments were considered for multiple research cases. The application of laser engraving on denim garments has a significantly greater impact than conventional industrial washing techniques such as whiskered, potassium permanganate (PP) spray, acid washed, etc. [19].

Furthermore, hydrose technique also implementing to fade the denim garment on a widespread scale. Rashid et al., 2020 applied hydrose technique for color fading of denim garments without or minimal loss of physical properties. The samples were treated with hydrose and sodium hydroxide of variable concentrations. And the results revealed that the mechanical properties were reduced by only 5-15% with higher concentrations of hydrose and hydroxide [20].

Among numerous industrial denim washing techniques, manufacturers are trying to improve the sustainability practices. The purpose of this is to demonstrate how current denim goods can be made more consumer and environmentally friendly [8-9].

Numerous washing application procedures are being applied in the modification of denim garments on a widespread scale at present. Therefore, our target was to apply hand sanding, P.P. spray and laser engraving/fading on various (construction-based) denim garments that have not yet been considered for research altogether. Both treated and untreated samples were considered for several mechanical and physical properties and compared the obtained values among each other. Finally, several recommendations were raised based on our findings.

2. Materials and methods

2.1. Materials

Four types of denim garment samples were collected from a textile mill based on different weave constructions, including various EPI, PPI and yarn count, fabrics weight, tensile and tear strength etc. The samples were made of 100% cotton twill weave.The particulars of the samples are presented in Table 1.

Table 1. Samples specifications

Parameters	Sample 1	Sample 2	Sample 3	Sample 4
EPI	79	100	70	95
PPI	60	64	60	66
GSM	455	405	375	347
Tensile Strength (Warp Way), N	843.4	814	1069.9	568.8
Tensile Strength (Weft Way), N	603.1	536.4	673.7	382.5
Tearing Strenght (Warp Way), N	60.6	57.2	62.7	44.7
Tearing Strength (Weft Way), N	48.3	45.1	57.2	30.2
pH	7.8	7.6	7.5	6.8
Construction	79 × 60 / 7 x 7	100 × 64 / 10 x 8	70 × 60 / 8 x 8	95 × 66 / 12 x 10

2.2. Research design

Figure 1 describes the proposed research

methodology for the experiment. Initially, 4 distinct types of samples were considered as test samples. All samples were passed through selected dry processes separately and tested to determine their physicomechanical properties. The obtained test values of treated and untreated samples were compared.

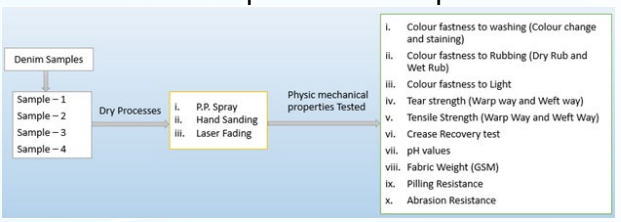

Figure1. Research design

3. Methods

3.1. Methods of sample preparation

3.1.1. Application process of Potassium Permanganate (P.P.) spray

At first, a stock solution was prepared by mixing Potassium permanganate (6 gm/L) and acetic acid (30 ml/L). Then by using a spray gun, the liquid was applied to the denim garments. The indigo-dyed garments turned pink and then grey. Finally, all the samples were normally washed and dried.

3.1.2. The application procedure of hand sanding

In this process, a 220 number emery paper was directly applied by hand to get the faded effects until desired looks were achieved without damaging the denim garments.

3.1.3. The application procedure for laser fading

A CO_2 laser fading machine was used to fade all the samples. DPI was 10 and the pixel time was 0.05 seconds for each sample.

(a) (b) (c) (d)

Figure 2. Samples of dry processes; (a) normal sample, (b) P.P.sprayed sample, (c) hand sanded sample and (d) laser faded sample

3.1.4. Accessories and machinery

The following equipment and chemicals were required while preparing denim samples are shown in Table 2.

Table 2 : Required accessories

Hand Sanding	P.P. Spray	Laser fading
220 number emery paper	Potassium Permanganate	CO_2 laser fading machine
Sanding Pads	Spray Gun	
	Garment Washing Machine	

3.2. Determination of physical and mechanical properties of denim samples

3.2.1. Determination of colorfastness to washing test (BS EN ISO 105 C06)

The samples were tested according to BS EN ISO 105 C06 standard, where multifibre from James Heal was used. The washing liquor ratio (liquor/sample) was 20:1. Sample fabric, white paper and multifibre fabric were attached and cut edges straight. Then it was boiled for 20 minutes at a temperature of 70°C in a dye bath and dried out. The samples were washed separately. To compare the obtained values, a grey scale rated from 1-5 was used [21].

3.2.2. Determination of fabric weight (Grams per Square Meter, GSM)

According to the ASTM D3776 method, the samples' weight was measured. Samples were cut using a GSM cutter, weighed on an electric balance and multiplied by 100 to get the fabric weight in gm [22].

3.2.3. Determination of pH (AATCC 81-2006)

The pH (potentials of hydrogen) value of denim samples was measured by AATCC 81 method. 10 gm of fabric samples were cut into small pieces and boiled for 10 minutes at 250 ml of distilled water. After a short period of cooling the pH was measured for all the samples separately. The pH value ranges from 1-14, where <7 is acidic, >7 is alkaline and 7 is neutral [23].

3.3.4. Determination of rub property

According to AATCC 8 standards, both the dry and wet rub tests were done. Both case results are compared with a grey scale ranging from 1 to 5 [24].

3.3.5. Determination of colorfastness to light/ Xenon arc fading lamp test

According to ISO 105-B02:2013 test method, light fastness properties were measured. A sample fabric was placed in the testing chamber with a standard blue scale reference fabric sample. This wool fabric comprises 8 dark to light blue shades for standard measurement. After a specific time, the color fading of the samples was measured by comparing them with a grey scale rating from 1-8 [25].

3.3.6. Determination of tearing strength of samples

The tear strength was measured as per the ASTM D412 standard test method, followed by the pendulum lever principle. At first, the specimen was cut to 100 ×75 mm from the fabric and further cut according to the template. The cut piece was clamped and fixed on the frame, raising the pendulum from the starting position. The specimen was transferred between the two clamps that tear by slit cut. Finally, the amount of force was recorded from the frame in Newton [26].

3.3.7. Determination of tensile strength of samples

The tensile/breaking strength of the sample was measured by ASTM D5034 – 09(2017) standard test method. At first, the fabric sample was cut according to (60mm x 300mm) and then frayed down to (50mm x 300mm). Then the sample was clamped in the jaws and a CRE 500mm per minute loading was applied until the fabric broke. The breaking strength was measured in Newton [27].

3.3.8. Determination of crease recovery of samples

Fabric wrinkle property was measured by AATCC 128 method where samples were cut to 15 x 28cm in size, folded in half, placed between two glass plates and added to 500gm weight. After 1 min, the load was removed and placed on the machine to recover the crease of the sample. The recovery angle was read from the engraved scale. All the samples were tested and the recovery angle was measured (degree of angle) [28].

3.3.9. Determination of pilling resistance of samples

According to ASTM D4970 standard method fabric, pilling resistance was measured. Specimens were cut and placed on the top of the specimen holder. A Lissajous Figure is used to perform a cycle where tests were carried out for 12000 cycles. Samples were individually compared with the standard greyscale (1-5) to measure the amount of pill formation [29].

3.3.10. Determination of abrasion resistance of samples

The fabric samples' abrasion resistance was measured by ASTM D4966 standard method, also known as the Martindale abrasion test. Sample fabric was mounted on the machine and run for 12000 cycles. Samples were compared with the grey rating scale (1-5) to find the abrasion resistance properties of the fabric [30].

4. Results and Discusson

4.1. The effect of dry processing on color change after washing of denim garments

The color fastness to washing was evaluated to ascertain the extent of color bleed from the samples after washing. A 1 to 5 point greyscale was used to compare the investigated

materials and any additional alterations were noted. According to Figure 3, after using dry procedures, the color fastness of treated samples to washing (color change) was either unchanged or somewhat improved. Examples 1 and 2 displayed a mixed pattern of behavior, but samples 3 and 4 had a strongly established tendency (values range from 4 - 4.5).The use of various dry techniques that alter or destroy the face side of the garment was one of the potential causes of the modifications in each sample case. It can be said that the use of dry processes on denim samples has little to no real effect on their characteristics (Figure 3).

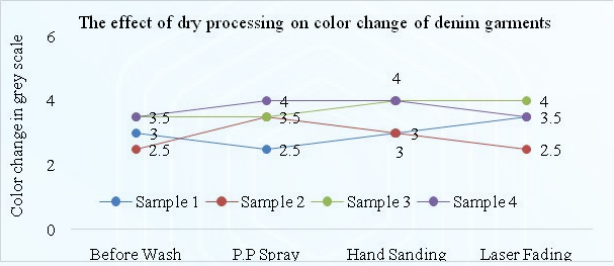

Figure 3. The effect of dry processing on the color change of denim garments

4.2. The effect of dry processing on color staining of denim garments

Color stains left behind after washing were used to gauge the degree of color bleed and discoloration on other clothing. To compare and evaluate the color stain, a 1–5 point grey scale was employed. Dry methods used on the samples showed that color stain properties were either unchanged or slightly modified in every case (Figure 4). While hand-sanded samples remained stable and laser faded samples exhibited lower values (2 – 3.5) on the grey scale, all samples used for P.P. spray showed the most significant developed modifications (values ranging from 2.5 to 4.5). The use of potassium permanganate chemicals, which instantly dimmed the color of the outer surface and eliminated the stain problem, may have been the cause.

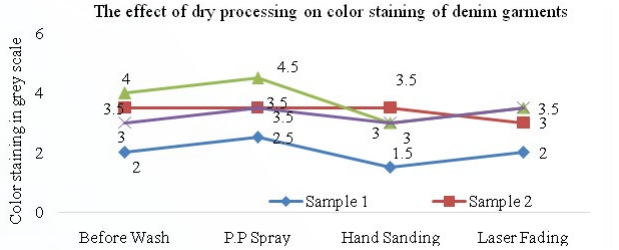

Figure 4. The effect of dry processing on the color stain of denim garments

4.3. The effect of dry processing on colorfastness to rubbing (dry rub) of denim garments

Dry rubbing is used to measure changes in the garment's outer surface look in dry conditions. Additionally, the differences were assessed by contrast with a grey scale (values 1-5). P.P. spray-treated samples displayed improved characteristics (values ranging from 2.5–4.5). However, when all samples were subjected to hand sanding, a reduced dry rub feature was noted for all samples (almost 0.5–1 lower rating recorded than normal samples). Additionally, laser fading had no impact on the dry rub feature because it just minimally damaged the fabric's surface and not the yarn or fibers inside (Figure 5).

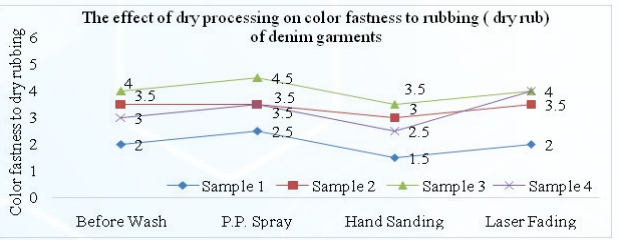

Figure 5.The effect of dry processing on dry rub fastness of denim garments

4.4. The effect of dry processing on color fastness to rubbing (wet rub) of denim garments

Additionally, gray scale comparisons were used to assess the changes (values 1-5). After receiving a P.P. spray treatment, samples had more features and a nearly 0.5–1 increase in their grey scale grade. But when four different types of denim samples were subjected to

dry hand sanding and laser fading processes, significant downward wet rub characteristics were discovered.types of denim samples were subjected to dry hand sanding and laser fading processes, significant downward wet rub characteristics were discovered. Both occurrences had a lowered grey scale grade of roughly 0.5 to 1 (Figure 6).

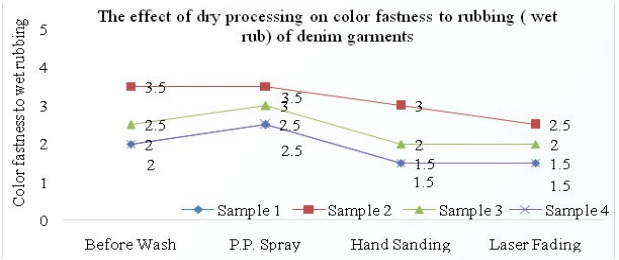

Figure 6. The effect of dry processing on the wet rub fastness of denim garments

4.5. The effect of dry processing on color fastness to light of denim garments

The sensitivity of clothing to stronger sunlight was tested by colorfastness to light. Similar to this, changes observed after testing were evaluated on a scale from 1 to 8 using a grey scale. Figure 7 demonstrates that after receiving P.P. spray treatment, all sample cases showed stable or marginally developed properties. However, when the sample cases were subjected to hand sanding and laser fading, significantly lower values were seen for each example. Reduced rating values of around 0.5 to 1 were seen on the grey scale for both categories of dry operations.

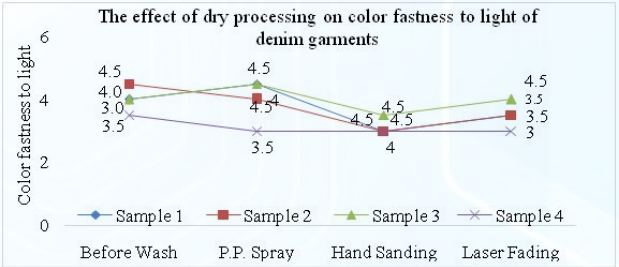

Figure 7. The effect of dry processing on the color fastness to light of denim garments

4.6. The effect of dry processing on tearing strength (warp way) of denim garments

To find out how much power is needed to rip the warp yarn from a fabric, the warp method tearing strength was measured. The data were automatically converted to Newtons by the machine that tested tearing strength. In all sample situations, the warped manner tearing strength was significantly reduced, as shown by the consistent phenomena in Figure 8. The most noteworthy strength loss was from samples that were hand-sanded as compared to samples that weren't handled and it was over 20 N. Contrarily, samples that had undergone laser fading had a lower tear strength of nearly 1-5 N, while samples that had had P.P. spraying displayed a loss of 1-6 N. Reason behind this are the application of dry processes such as P.P. spray consumes the face side of the garment; hand sanding destroys the fiber/yarn portion of the fabric and laser treatment also do the same as P.P. spray.

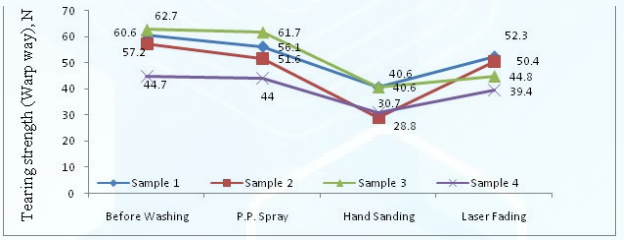

Figure 8.The effect of dry processing on the tearing strength of denim garment

4.7. The effect of dry processing on tearing strength (weft way) of denim garments

Weft way tearing strength was assessed in a manner similar to the warp way tearing strength test in order to determine how much force is necessary to break the weft yarn in the garment. Weft manner tearing strength tended to decrease with the use of dry procedures (Figure 9). Figure 9 illustrates how samples were sanded by hand. Weft method tearing strength was much lower than in normal samples, measuring 17 to 30 N less. Additionally, results for samples that were P.P. sprayed and laser faded were both decreased by 2–6 N and 6–16 N, respectively. The same

result can be obtained using dry techniques such as P.P. spray consumption of the fabric's facing side, hand sanding destruction of the fiber/yarn section and laser treatment.

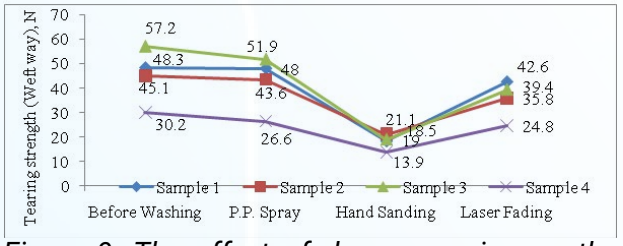

Figure 9. The effect of dry processing on the tearing strength (weft way) of denim garments

4.8. The effect of dry processing on tensile strength (warp way) of denim garments

After using dry procedures, treated samples' tensile strength was significantly lowered and measured in Newtons (Figure 10). The hand-sanded samples, which removed the warp yarn section of the fabric's surface fibers, showed more dramatic effects, with reductions in tension of roughly 150–250 N. Those exposed to laser fading saw a tensile strength loss of around 90–180 N, compared to a loss of 26–85 N for samples treated to P.P. spray. After its application, the cloth surface in both circumstances could become weaker. The face side of the garment is consumed by dry treatments like P.P. spray, while the fiber/yarn portion of the cloth is destroyed by hand sanding and laser treatment. Dry treatments such as P.P. spray consume the face side of the garment; hand sanding destroys the fabric's fiber/yarn portion; and laser treatment does the same.

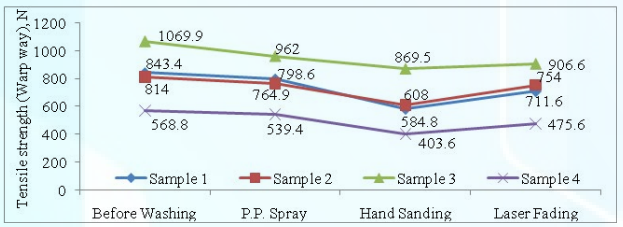

Figure 10. The effect of dry processing on the tensile strength (warp way) of denim garments

4.9. The effect of dry processing on tensile strength (weft way) of denim garments

After using dry procedures, the weft way's tensile strength also greatly fell (Figure 11). The tensile strength decreased by 98 to 175 N in the weft yarn fiber segment of the hand-sanded samples. Laser fading, which causes a reduction in breaking strength of 40 to 90 N, had the second-highest impact. P.P.-sprayed samples consequently displayed a 30 to 50 N reduction. P.P. spray, hand sanding and laser treatment all damage the fabric's face side. Hand sanding eliminates the fiber/yarn portion of the fabric.

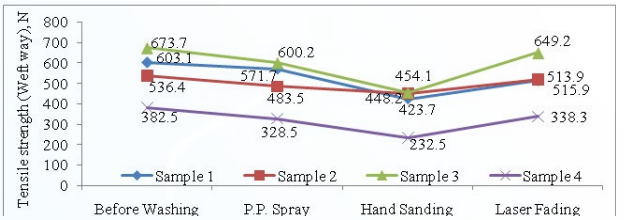

Figure 11. The effect of dry processing on the tensile strength (weft way) of denim garments

4.10. The effect of dry processing on crease recovery of denim garments

The degree of crease recovery of samples was assessed to demonstrate how much crease can be recovered when the garment is put under high tension. Figure 12 illustrates that all samples are crumpled and partially recoverable. The samples that underwent hand sanding and laser fading, whose crease angles of 10 to 20 degrees could not be recovered, displayed the most significant changes. P.P. sprayed samples moreover only showed 6 to 12 degrees of irrecoverable heat.

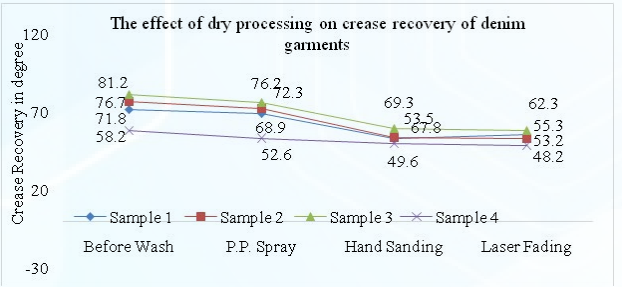

Figure 12. The effect of dry processing on the crease recovery of denim garments

4.11. The effect of dry processing on the pH value of denim garments

The samples' pH was initially found to be moderately acidic (primarily), with values ranging from 6.8 to 7.8. They became neutral following the application of all dry treatments, as indicated in Figure 13. The P.P. samples that had potassium permanganate sprayed on them had the most effects, with all of the samples becoming very alkaline as a result of the treatment. Other dry procedures only had a minor influence.

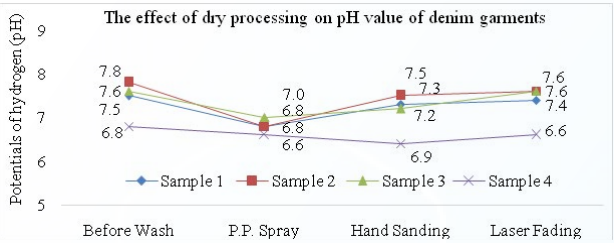

Figure 13. The effect of dry processing on the P[H] value of denim garments

4.12. The effect of dry processing on fabric weight (GSM) of denim garments

The fabric's weight or density was the most important aspect to evaluate. All dry processes led to a decrease in fabric weight (Figure 14), with hand-sanded samples shedding 35 to 40 grams on average. As a result, for the other two types of dry procedures, a lower fabric weight of 15–25 grams was also seen. Emery paper partially destroys the fiber/yarn component of denim samples during dry processing; as a result, these samples have lower densities (GSM) than other treatments.

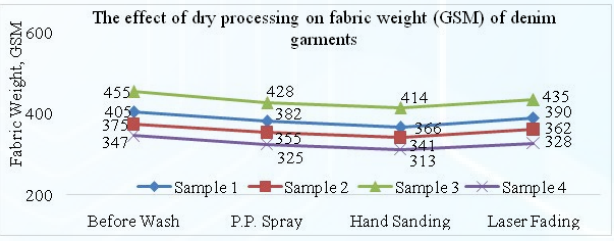

Figure 14. The effect of dry processing on GSM of denim garments

4.13. The effect of dry processing on pilling resistance (after 12000 cycles) of denim garments

The number of pills that could be produced after a specific number of cycles was determined using the pilling resistance test. The findings of 12000 cycles were compared to a 1–5 grey scale. The only samples with a lower grey scale value of 1.5 seemed to be the ones that were hand sanded. There were no other significant changes found. Greyscale values in samples that had been laser faded were reduced by 0.5, while there were no noticeable changes in those that had been P.P. sprayed (Figure 15). Emery paper partially damages the fiber/yarn section of the denim samples during dry treatment, which is why samples treated with this produced the most pills in comparison to other treatments. Even with laser fading, the samples are still in rather decent shape.

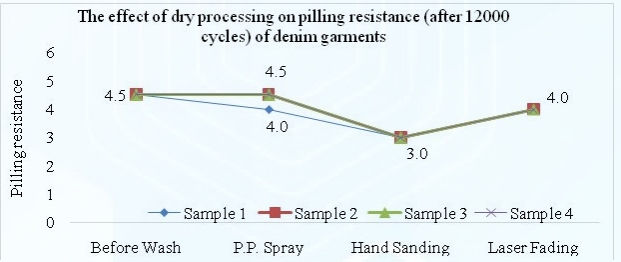

Figure 15. The effect of dry processing on the pilling resistance of denim garments

4.14. The effect of dry processing on abrasion resistance (color change) (after12000 cycles) of denim garments

Following a pre-determined number of abrasion cycles, samples' abrasion resistance provided a quantitative measure of how abrasive they were. A scale of one to five was used to rank the abrasion resistance. The application of P.P. spray on denim samples has improved this quality, as seen in Figure 16, where some samples have ratings that are almost 0.5 on the grey scale and others have ratings that have remained stable or even decreased to 0.5 -1 for hand-sanded and laser-faded samples. Both P.P. sprayed and hand-sanded case surfaces

are significantly roughened by fabric surface degradation. However, samples that had been laser-treated demonstrated good results because dry process applications didn't result in any significant harm.

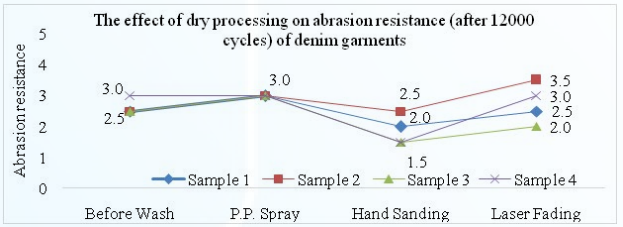

Figure 16. The effect of dry processing on theabrasion resistance of denim garments

4.15. Cost analysis of garment samples after the application of dry processes

Figure 17 shows the sample preparation cost under different dry processes.

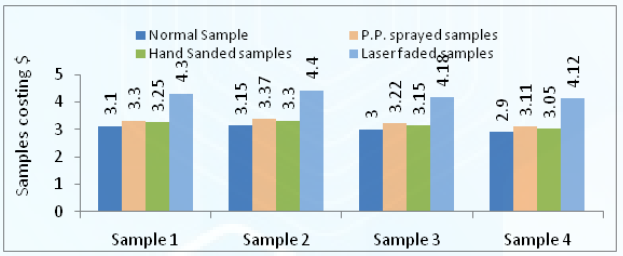

Figure 17. Samples cost analysis after application of several dry processes

The graph demonstrates that, in comparison to untreated samples, sample costs rose following any sort of dry processing. While laser fading cost roughly $1 to $1.20 per sample to fade, the average sample cost climbed from $0.20 to $1.2 per operation. The samples' initial costs were $3.1 for sample 1, $3.15 for sample 2, $3 for sample 3 and $2.9 for sample 4. P.P. spray was priced on average between $0.20 and $0.22, hand sanding between $0.15 and $0.18 and laser fading between $1.20 and $1.25. This research leads to the conclusion that the hand sanding technique is less expensive than the laser fading process, which costs more.

5. Conclusion

Both dry and wet techniques modify the appearance of the outer garment and produce a variety of different products. Denim dry processes primarily have a direct impact on the physical look, softness and comfort of the finished product. Moreover, the surface appearance is influenced by the fading process, time, equipment,and technology. Furthermore, the ultimate cost the consumer would be expected to pay for the clothes is increased by dry treatments.

From the experimental findings, the conclusion may be drawn as follows:

i. Dry processes reduced the properties of the sample for colorfastness to light (0.5–1 on scale), tearing strength (warp way 1-20 N; weft way 2-30 N), tensile strength (warp way 26-250 N; weft way 30-175 N), GSM (15-40 gram), pilling (0.5-1.5 on scale) and abrasion (0.5-1 on scale)

ii. Slightly increased properties were also noted for colorfastness to Washing (0.5-1 on scale), staining (0.5 on scale), dry rub (0.5-1 on scale) and wet rub (0.5-1 on scale).

iii. The hand sanding process significantly degraded the fabric surface more than other dry processes

iv. The process cost for laser fading is considerably higher than the other two types of dry processing

Importantly, this study will help manufacturing workers select and implement the most effective denim fading techniques. Anyone can learn how to use appropriate samples and sampling techniques rapidly, which will surely boost output, productivity and manufacturing profits. Additionally, this can increase the researcher's interest in creating new denim finishing models in comparison to the ones that now exist. Similar to that, it will help stakeholders concentrate on and emphasize potential advances in the future.

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Conflict of interest

All coauthors have declared no conflict of interest of this research.

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