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Performance Optimization of Super White Washed Stretch Denim Fabric by Deviating Washing Process Time and Machine RPM

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Abstract: Over the last few decades, a lot of innovations and development works had already made denim “classic” in the fashion cycle. The modern consumers of today’s world are not only devoting themselves on clothing comfort but also emphasizing on economic and environmental sustainability. As a result, there has been increasing interests in terms of using environment friendly, non-toxic and biodegradable wet process such as super white wash. Though it enlarged higher consumer aspects and market opportunities in the denim washing technology, no research work had done yet regarding to super white wash. It can easily be applied to solid fabrics and finished garments. This research work was intended to analyze the physical and chemical changes of denim fabric while incorporating into super white wash at variable process parameters such as washing process time and machine rpm. Though its prime objective is to improve the whitening effect of textiles and apparels, it also can improve color strength (K/S), color fastness properties (color fastness to washing, color fastness to light, color fastness to perspiration), pilling resistance and fabric handle. In this article, it was demonstrated that all the fabric samples achieved gradual deterioration of tensile strength, tear strength and dimensional stability with the increase of washing process time and machine rpm up to a certain stage. Furthermore, the fabric samples showed better results regarding whitening index (WI), color strength (K/S), pilling resistance, fabric handle and color fastness properties with the gradual rise of washing process time and machine rpm. There were some notable changes in fabric GSM at the following washing conditions.

Keywords: Super White Wash, Stretch Denim, Washing Time, Machine RPM, Whitening Index (WI), Color Strength (K/S)

1. Introduction

Denim, one of the ancient clothing items in today’s fashion industry, upholding its dignity and public acceptance even today within people around the world; beyond age, gender, climatic conditions and social status [1-3]. A lot of innovations and development works in the last few decades had already made denim “classic” in the fashion cycle till now [4]. The consumer expectations from denim fabric had changed over the years with technological advancements [5-8]. Nowadays, the modern consumers are not only devoted on infant designs and new appearances [9]; but also want to belong clothing comfort, user-friendly performance and consumer sustainability [10]. To meet the compatibility with rapidly changing and strategic market conditions at growing customers’ demands; apparel technologists are now trying to introduce different infant variants of denim garments through physical and chemical modification of fabric’s morphology [11-15]. For instances, there has been increasing eagerness at environment friendly, nontoxic, fully biodegradable products from modern textile dyeing, apparel washing and finishing operations [16-20]. Wet processes like enzyme wash, super white washing treatment can replace a number of mechanical and chemical operations, whose were basically imposed to improve both the comfortability and quality characteristics of fabrics [20-23]. Besides, super white wash is one of the garments wet processes; that is generally performed by using a strong oxidizing agent such as Hydrogen Peroxide (H_2O_2) [24-26]. In addition, H_2O_2 had played its role by breaking down chemical bond that builds up chromophore (color building group) and vanished away the ability of chromophore to absorb light [27-30]. It is a popular washing technique that was mainly introduced to denim fabric, with a view to increasing the whitening index and color strength (K/S) of the garments by deviating washing process time and machine rpm [30-34]. Thus, it also improved color fastness properties and hand feel rating of garments according to buyer proposed washing standards [35-36]. Beyond some very good advantages, there are few narrow drawbacks such that, this technical wet process sometimes damages celluloses very roughly [37], causes strength loss, pin holing at the side seam and pocket areas. Thus, it also causes corrosion to metallic machine parts of garments washing machines [38]. Apart from those, it has ecofriendly influences over modern fashion industry, as it doesn't cooperate with any aggressive and hazardous chemicals [39]. In a comparison to other wet processes, it encourages reduced consumption of utilities i.e. water, chemicals and power supply [40]. In this research work, the denim fabrics of same construction were washed at different ways by deviating process variables i.e. washing time and machine rpm. After that, the following samples are being tested at the laboratory for evaluating whitening index, color strength (K/S) value, colorfastness properties (color fastness to washing, color fastness to light, color fastness to perspiration), tensile properties (tensile strength, tear strength, abrasion resistance, pilling strength, hand feel).

2. Materials and Methods

2.1. Necessary Materials

2.1.1. Fabric

For conducting the following research work, off- white 3/1 "Z" twill fabric of cotton-spandex blend was used, where composition of cotton included 97.80% and spandex of 2.2%. The GSM of unwashed fabric was 345 grams per square meter and maximum fabric width was 52″.

Figure 1. *3/1 "Z" Twill Fabric.*

2.1.2. Necessary Chemicals

1) DENIMCOL Wash-.RGN (Desizing Agent)
2) Caustic Soda (NaOH)
3) Hydrogen Peroxide, (H_2O_2)
4) Soda Ash (Na_2CO_3)
5) Biode (Detergent & Wetting Agent)
6) B-Tex (OBA)
7) Acetic Acid (CH_3COOH)
8) DENIMCOL-N (Enzyme)

2.1.3. Necessary Apparatus

For performing super white washing process and necessary lab tests, there were in need of garments washing machine, hydro extractor, garments dryer, datacolor spectrophotometer 650, tensile and tear strength tester, GSM cutter, pH meter, electrical balance, laundering machine, tumble dryer etc.

2.2. Methodology

2.2.1. Working Flow Diagram of Super White Wash

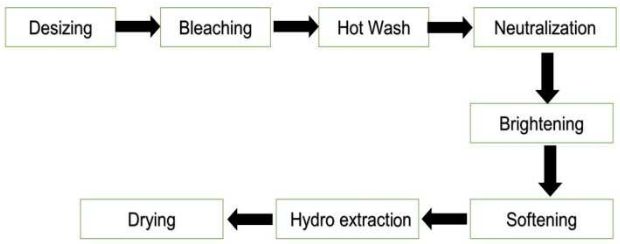

Figure 2. *Operational flow diagram of super white wash.*

2.2.2. Determination of Tensile Strength

This tensile strength test was conducted according to ISO 13934. This method specifies about the determination of the maximum force of textile fabrics known as the grab test. For experimentation, test specimen gripped in its center part by jaws of specified dimensions, extended at constant rate until it ruptures. Then the maximum force was recorded.

Testing Method: ISO 13934-2 (grab test)

Testing Condition: Temperature (20 ± 2)°C, Relative humidity (65 ± 2)%

Sample size: 200 mm × 100 mm

Apparatus: Titan–Universal Strength Tester, air compressor, computer

2.2.3. Determination of Tear Strength

The determination of tear strength of different fabric samples treated with various washing processes were measured according to ISO 13937-1 [41]. Tear strength is the resistance of the fabric against tearing or force required to propagate the tear once it is initiated. The tear strength is required in high performance applications and in conventional textiles like bulletproof jackets, tents, aesthetic apparel. This is also important in the industrial textiles where heavy duty work is performed. The average reading was recorded as tear strength in Pounds per Inch.

Sample Conditioning: Conditioning specimen at least 4 hours as per ISO 139.

Testing Condition: Temperature (20 ± 2)°C and Relative humidity (65 ± 4)%

Specimen size: As per template

Apparatus: Tearing tester, different capacity load, conditioning rack, calibrated ruler

2.2.4. Determination of Pilling Resistance

The determination of pilling resistance of different fabric samples treated with super white washing process measured according to ISO 12945-2 [42]. Pilling test is carried out to determine the resistance to pilling and change in appearance of apparel fabrics. Generally, pills are formed during wear and washing by entanglement of loose fibers which obtrude from the fabric surface.

Testing Method: ISO 12945-2

Testing Condition: Temperature (20 ± 2)°C and Relative humidity (65 ± 4)%

Specimen size: 125 mm × 125 mm

Apparatus: GSM cutter, electronic balance, scissor, Martindale abrasion and pilling tester

2.2.5. Determination of Dimensional Stability

The dimensional stability of the sample was measured according to ISO 23231 [43] which postulates about an accelerated procedure for the understanding of dimensional changes of fabrics. This standard signifies a procedure which implies an apparatus with programmable settings simulate numerous domestic and industrial laundering actions and wet processing operations in fabric manufacturing. In this research, this standard method was used for the determination of dimensional change. After washing, drying, conditioning and measuring the specimen, the change in dimension was calculated.

Dimensional Change (%) = {(Dimension after wash – Original dimension) × 100} / Original dimension

Sample Conditioning: Conditioning specimen at least 4 hours as per ISO 139 prior to preparing and measuring.

Testing Condition: Temperature (20±2)°C and Relative humidity (65 ± 4)%

Specimen size: As per template

2.2.6. Measurement of Color Fastness Properties

The following color fastness tests were done for this research work [44]:

1) Color fastness to wash (Method: ISO 105 C10)
2) Color fastness to light (Method: ISO 105 B02)
3) Color fastness to perspiration (Method: ISO 105 E04)

2.2.7. Datacolor Spectrophotometer 650: [45-47]

1) Test Standard: ISO 170340
2) Testing Condition: Temperature (20±2)°C and Relative humidity (65 ± 4)%
3) Specimen Size: As per template

3. Results and Discussions

3.1. Effect of Washing Time and Machine RPM Variation on Whitening Index (WI) and Color Strength (K/S) of Super White Washed Denim

The following tables reveal that there was reduced whitening index and color strength, at the initial samples of washing process time and machine rpm. In case of washing time variation, minimum whitening index and color strength was depicted respectively 69.21 and 3.4 at 35 min. After a gradual increase of process time, it was moved up at 79.65 & 4.5 at 80 minute. For machine rpm variation, minimum whitening index and color strength was depicted respectively 70.21 and 3.1 at 16 rpm. After a gradual rise of machine rpm, it was moved up at 78.43 & 4.7 at 25 rpm. Due to the increase of washing time and machine rpm, the fabric structure had opened out. And, it caused a very significant amount of OBA (Optical Brightening Agent) uptake%. As a result, there had been notable amount of diffusions of OBA at the beneath of fabric. Hence, it leads to the rise of whitening index and color strength of super white washed denim.

Table 1. *Effect of washing time variation on whitening index (WI) and color strength (K/S) for super white washed stretch denim fabric.*

SL. No.	Time Variation (minute)	Parameter Name	
		Whitening Index	K/S Value
1	35	69.21	3.4
2	50	75.87	3.7
3	65	77.38	4.3
4	80	79.65	4.5

Table 2. *Effect of machine rpm variation on whitening index (WI) and color strength (K/S) for super white washed stretch denim fabric.*

SL. No.	Machine RPM Variation	Parameter Name	
		Whitening Index	K/S Value
1	16	70.21	3.1
2	19	73.76	3.6
3	22	75.94	4.1
4	25	78.43	4.7

3.2. Effect of Washing Time and Machine RPM Variation on Tensile Strength of Super White Washed Denim

The following diagrams reveal that there was a gradual falling of tensile strength in both the warp and weft direction with the increase of washing process time and machine rpm up to a certain stage. In terms of washing time variation, maximum tensile strength value of warp and weft was depicted respectively 207 & 160 lbs. at 35 min. After a gradual increase of process time, it was settling down in 190 and 151 lbs. at 80 min. For machine rpm variation, maximum tensile strength value of warp and weft was depicted respectively 204 & 164 lbs. at 16 rpm of washing machine. After a gradual increase of process machine rpm, it was settling down in 184 & 154 at 25 rpm of washing machine. From the above mentioned details, it can be assumed that the gradual increase of washing process time and machine rpm had established more frictional force among the garments, washing machine surface and chemical contaminated water. Hence, it leads to continuous drop of tensile strength up to a certain level. This is because, the –OH groups of polymer structure and many other strong covalent bonds in fiber had broken down with the following circumstances.

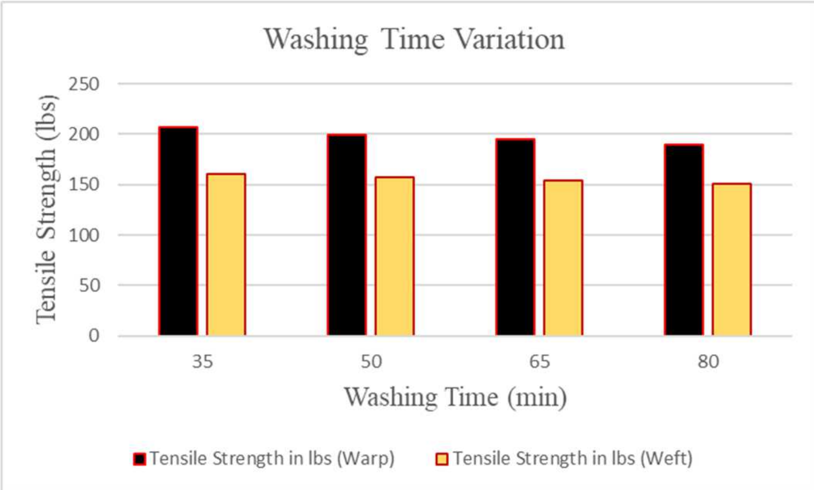

Figure 3. *Effect of washing time variation on tensile strength of super white washed stretch denim fabric.*

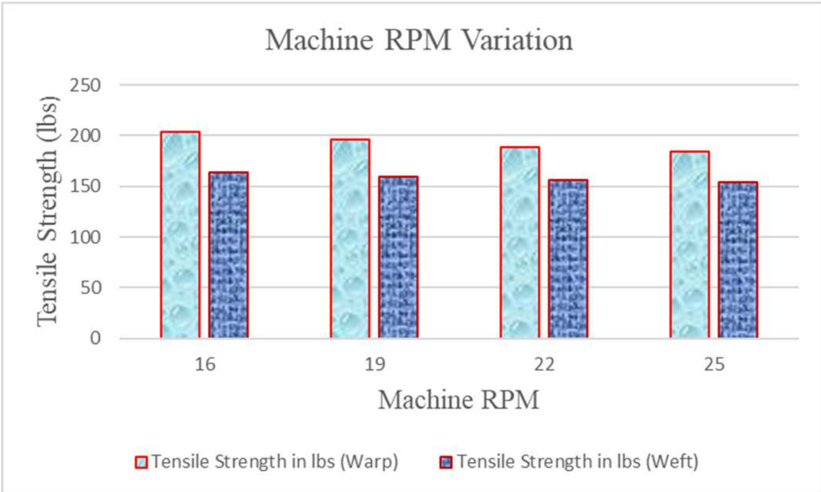

Figure 4. *Effect of machine rpm variation on tensile strength of super white washed stretch denim fabric.*

3.3. Effect of Washing Time and Machine RPM Variation on Tear Strength of Super White Washed Denim

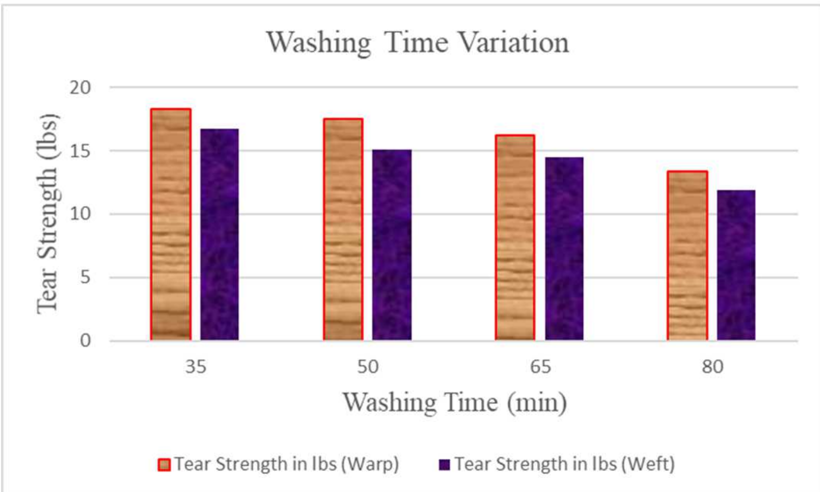

Figure 5. *Effect of washing time variation on tear strength of super white washed stretch denim fabric.*

The following diagrams reveal that there was a gradual falling of tear strength in both the warp and weft direction with the increase of washing process time and machine rpm up to a certain stage. In case of washing time variation, maximum tear strength value of warp & weft was depicted respectively 18.3 & 16.7 lbs. at 35 min. After a gradual increase of process time, it was settling down in 13.4 & 11.9 lbs. at 80 min. For machine rpm variation, maximum tear strength value of warp & weft is depicted respectively 17 & 15 lbs. at 16 rpm of washing machine. After a gradual rise of washing machine rpm, it was settling down in 13.4 & 11 lbs. at 25 rpm of washing machine.

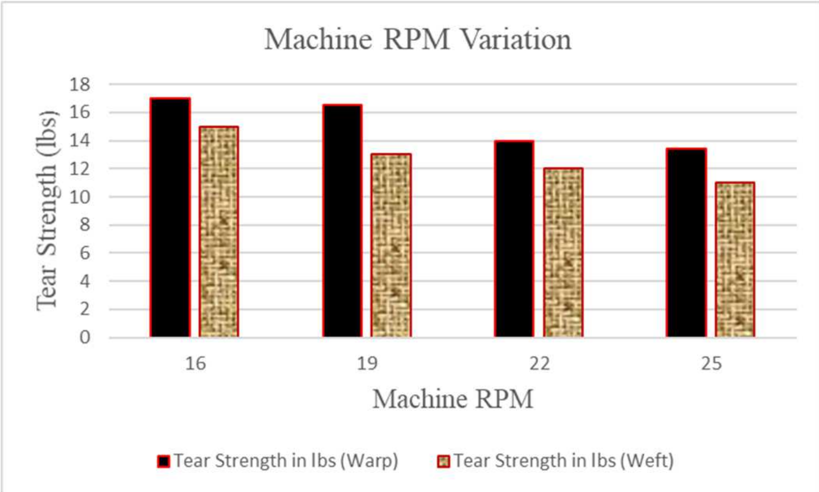

Figure 6. *Effect of machine rpm variation on tear strength of super white washed stretch denim fabric.*

From the above mentioned details, it can be assumed that gradual enhance of washing time and machine rpm had established more abrasion and discontinuity between fiber & fiber matrix surface, thus leads to continuous drop of tear strength up to a certain level

3.4. Effect of Washing Time and Machine RPM Variation on Dimensional Stability of Super White Washed Denim

Table 3. *Effect of washing time variation on dimensional stability for super white washed stretch denim fabric.*

SL. No.	Time Variation (min)	Shrinkage%	
		Warp	Weft
1	35	-2.1	-3.8
2	50	-2.4	-3.9
3	65	-2.9	-4.5
4	80	-3.1	-5.3

Table 4. *Effect of machine rpm variation on dimensional stability for super white washed stretch denim fabric.*

SL. No.	Machine RPM Variation	Shrinkage%	
		Warp	Weft
1	16	-1.3	-3.2
2	19	-2.7	-3.5
3	22	-3.5	-4.1
4	25	-4.8	-5.2

The following tables reveal that there was a gradual increase of negative shrinkage% in both the warp and weft direction with the increase of process time and machine rpm. For washing time variation, minimum shrinkage% in case of warp and weft were depicted respectively -2.1% and -3.8% at 35 minute. After a frequent increase of process time, it was moving up -3.1% and -5.3% respectively at 80 min. In terms of machine rpm variation, minimum negative shrinkage% of warp and weft were depicted respectively -1.3% and -3.2% at 16 rpm of washing machine. After a gradual rise of machine rpm, it was moving up at -4.8% and -5.2% at 25 rpm. Besides, it can easily be evaluated that weft shrinkage% for all the eight samples had quite large value than those of warp shrinkage%. This is because, the fabric blend contained 97.80% cotton and 2.20% spandex, which allowed the fabric to absorb more moisture both in hot air and cold water medium. And, it is to be noted that cotton fiber has higher tendency to shrink, when it comes in contact to water; whereas spandex fiber shrinks more where there is hot water or air contamination both in the garments washing and drying machine.

3.5. Effect of Washing Time and Machine RPM Variation on Pilling Resistance & Hand Feel Rating of Super White Washed Denim

The following diagrams reveal that there was a gradual improvement of both the pilling resistance and hand feel ratings with the continuous enhancement of washing process time and machine rpm up to a certain stage. In case of washing time variation, minimum pilling resistance and hand feel rating were depicted respectively 2.0 and 2.5 at 35 min process time. After a gradual rise of process time, it was moving up within 3-4 and 4 respectively at 80 min process time. For machine rpm deviation, minimum pilling resistance and hand feel rating was depicted respectively 2.0 and 2.5 at machine rpm of 16. After a gradual rise of machine rpm, it was ranged 3.0 and 4 respectively at machine rpm of 25. From the above mentioned details, it can be assumed that pilling not only creates unsightly and fuzzing appearance but also drops the hand feel rating and serviceability of textiles.

Figure 7. *Variation of washing time on pilling resistance and hand feel rating of super white washed stretch denim fabric.*

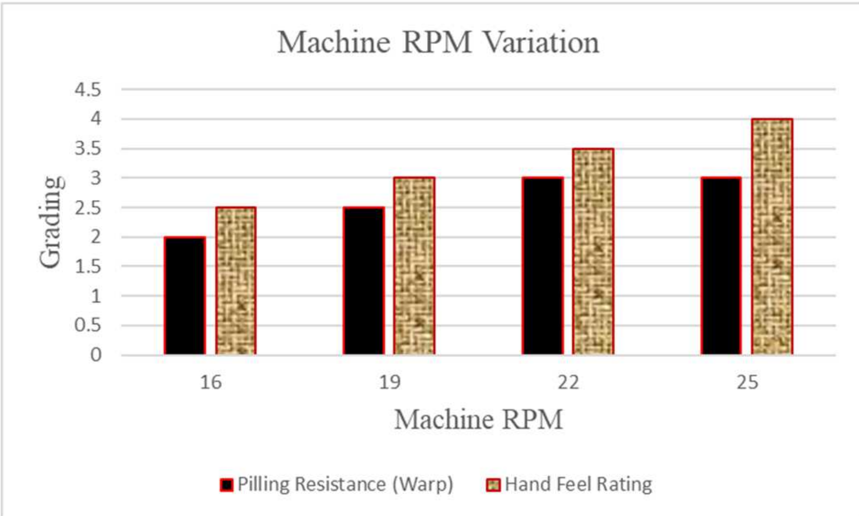

Figure 8. *Variation of machine rpm on pilling resistance and hand feel rating of super white washed stretch denim fabric.*

3.6. Effect of Washing Time and Machine RPM Variation on Changes of GSM for Super White Washed Denim

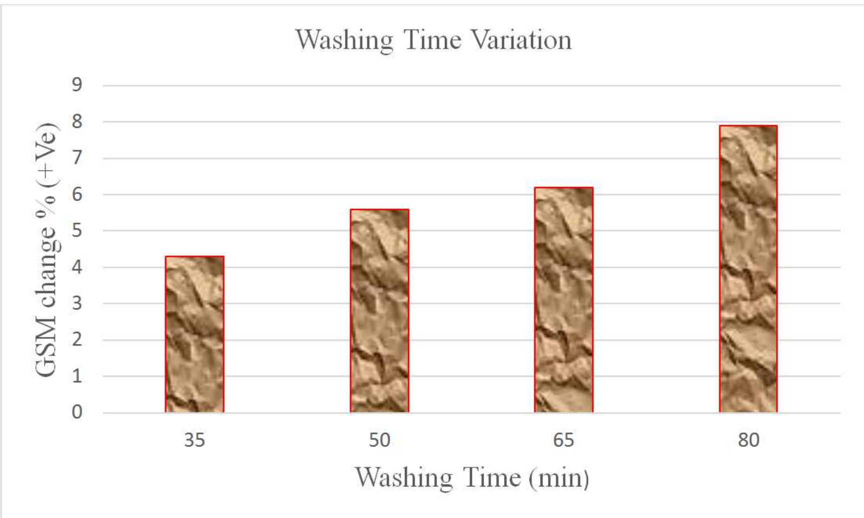

Figure 9. *Variation of washing time on GSM Change% of super white washed stretch denim fabric.*

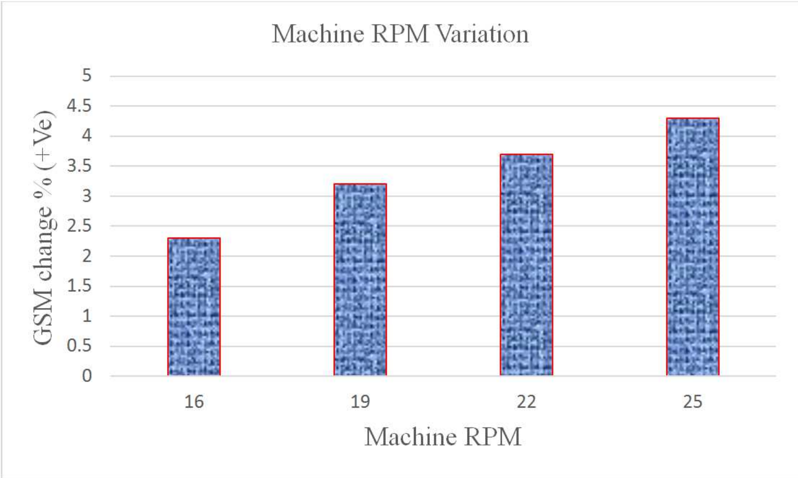

Figure 10. *Variation of machine rpm on GSM change% of super white washed stretch denim fabric.*

The following diagrams reveal that there was a gradual increase of GSM with respect to gradual enhance of process time and machine rpm. In case of washing time variation, maximum change of GSM% was depicted 4.3% at 35 min. After a frequent enhance of process time, it was moving up 7.9% at 80 min. For machine rpm variation, minimum change of GSM% was depicted 2.3% at machine rpm of 16. After a gradual increase of process temperature, it was moving up 4.3% at machine rpm of 25. During washing and drying of super white washed denim, the cotton-spandex fabric composition had shown a tendency to shrink in both the warp and weft direction, which leads to the rise of GSM%. And, EPI & PPI of denim garments had increased after washing; as a result, it can also be clearly mentioned that the enhancement of EPI and PPI also played a key role onto the enhancement of GSM%.

3.7. Effect of Washing Time and Machine RPM Variation on Color Fastness to Washing for Super White Washed Denim

Table 5. *Effect of washing time variation on color fastness to washing for super white washed stretch denim fabric.*

Sl. No.	Time Variation (min)	Grade (Change in Color)	Grade (Color Staining on Multi Fiber)					
			Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
1	35	3-4	3	4	3-4	4	3-4	3-4
2	50	4	4	4	3-4	3-4	3-4	3
3	65	4	4	4-5	4	4-5	4	4-5
4	80	4-5	4-5	4-5	4-5	4	4-5	4-5

Table 6. *Effect of machine rpm variation on color fastness to washing for super white washed stretch denim fabric.*

Sl. No.	Machine RPM Variation	Grade (Change in Color)	Grade (Color Staining on Multi Fiber)					
			Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
1	16	3	3-4	3	3	3	3-4	3-4
2	19	3-4	3-4	4	3-4	4	4	3-4
3	22	4	4	4	4	4	3-4	4
4	25	4-5	4-5	4-5	4-5	4-5	4	3-4

The above presented tables reveal the effect of washing process time and machine rpm on color fastness to washing properties of super white washed stretch denim fabric. It was investigated that at the initial washing time (35 minutes) and machine rpm (16 rpm), the samples demonstrated fair grading in case of color change and color staining. With the gradual rise of washing time and machine rpm, grading for both the color change and color staining moved towards moderate to good for all the samples.

3.8. Effect of Washing Time and Machine RPM Variation on Color Fastness to Perspiration for Super White Washed Denim

Table 7. *Effect of washing time variation on color fastness to perspiration (acidic) for super white washed stretch denim fabric.*

Sl. No.	Time Variation (min)	Grade (Change in Color)	Grade (Color Staining on Multi Fiber)					
			Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
1	35	3-4	3-4	3-4	3	3	3-4	3-4
2	50	4	3-4	3-4	3	3-4	3-4	3
3	65	4	4	4	4	3-4	4-5	4-5
4	80	4-5	4-5	4-5	4	4	4-5	4-5

Table 8. *Effect of washing time variation on color fastness to perspiration (alkaline) for super white washed stretch denim fabric.*

Sl. No.	Time Variation (min)	Grade (Change in Color)	Grade (Color Staining on Multi Fiber)					
			Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
1	35	3-4	3-4	3-4	3	3	3-4	3
2	50	3-4	3-4	3-4	3-4	3	3-4	3-4
3	65	4	4	4	4	4	4	4
4	80	4	4	4	4-5	4-5	4-5	4-5

Table 9. *Effect of machine rpm variation on color fastness to perspiration (acidic) for super white washed stretch denim fabric.*

Sl. No.	Machine RPM Variation	Grade (Change in Color)	Grade (Color Staining on Multi Fiber)					
			Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
1	16	3	3	3-4	3	3	3-4	3
2	19	3-4	3	3-4	3	3-4	3-4	3-4
3	22	4	4	4	3-4	4	4	4
4	25	4	4-5	4	4	4	4	4

Table 10. *Effect of machine rpm variation on color fastness to perspiration (alkaline) for super white washed stretch denim fabric.*

Sl. No.	Machine RPM Variation	Grade (Change in Color)	Grade (Color Staining on Multi Fiber)					
			Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
1	16	3	3-4	3-4	3-4	3	3-4	3-4
2	19	3-4	3-4	3-4	3-4	3	3-4	3-4
3	22	3-4	4	4	4	3-4	4	4
4	25	4	4-5	4-5	4-5	3-4	4	4-5

The above mentioned tables reveal the effect of super white washing process time and machine rpm on color fastness to perspiration properties in both the acidic and alkaline medium. It was found that, in the very beginning of the increase of both the washing time and machine rpm, the super white washed sample experienced moderate rating in case of color change and color staining for acidic and alkaline medium. After the frequent rise of washing process time and machine rpm, all the samples had experienced steady improvement in terms of color change and color staining for both the acidic and alkaline medium.

3.9. Effect of Washing Time and Machine RPM Variation on Color Fastness to Light for Super White Washed Denim

Table 11. *Effect of washing time variation on color fastness to light for super white washed stretch denim fabric.*

Sl. No.	Time Variation (min)	Fastness Rating according to Blue Wool Standard Grading
1	35	3
2	50	3-4
3	65	3-4
4	80	4

Table 12. *Effect of machine rpm variation on color fastness to light for super white washed stretch denim fabric.*

Sl. No.	Machine RPM Variation	Fastness Rating according to Blue Wool Standard Grading
1	16	3-4
2	19	3-4
3	22	4
4	25	4

The following tables reveal the effect of super white washing process time and machine rpm on color fastness to light property. It was found that, in the very beginning of both the washing time and machine rpm enhancement, the super white washed samples had experienced moderate rating in blue wool standard grading, which indicates the samples had very low resistance against UV light. After the gradual rise of washing process time and machine rpm, the following samples had experienced moderate to good grading.

4. Conclusions

The prime aspect of this research paper is to evaluate, how washing process time and machine rpm affect the collective functions of stretch denim fabric. It was found that there was a gradual falling of tensile and tear strength in both the warp and weft direction, with the rise of washing process time and machine rpm. Furthermore, the negative weft shrinkage% for all the samples are higher than those of negative warp shrinkage%, as the fabric blend was composed of cotton-spandex. Hence, it also leads to the rise of GSM change%. Beyond those narrow drawbacks, there were some improvement of color strength (K/S), whitening index (WI), pilling resistance and fabric handle on stretch denim under following washing and testing conditions. In addition, it was demonstrated that there was not significant amount of change in color fastness properties of denim fabric, while deviating washing time and machine rpm. Indeed, those analytical and experimental estimations may provide very few technical recommendations for the manufactures and washing technologists about the appropriate selection of washing process time and machine rpm, while undergoing super white washing process.

Compliance with Ethics Requirements

This article does not contain any studies with human or animal subjects performed by any of the authors.

Conflict of Interest

The authors have declared no conflict of interest.

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