Pre-post Bleaching Behaviors of Cotton Knits Using Reductive and Oxidative bleaches

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Abstract
Cotton fiber contains natural impurities on its' surface. To remove those impurities, cotton is treated with several types of bleaching agents based on industrial practice. The study investigated pre-post behaviors of single jersey knit after the bleaching treatments. Two types of bleaching chemicals were used to perform the study: such as (a) reductive, and (b) oxidative bleaching agents. The specimens were subjected to weight loss, absorption, color measurement, and bursting strength tests at the pre-post stages of the bleaching. Results from the statistical analysis revealed that the bleaching treatments significantly impacted on the behaviors of cotton knits. The findings also disclosed that hydrogen peroxide bleaching in the alkaline medium had the superior bleaching performance in cotton fabrics.

Keywords - *Bleaching, Color Measurement, Dye Absorption, Bursting Strength*

I. INTRODUCTION

Bleaching is a dyeing pretreatment that removes the natural coloring materials from raw cotton fabrics [1]. This natural coloration occurs due to the presence of organic compounds on the fiber surface, such as oil, wax, and fat [2]. The bleaching process dismisses natural colors by damaging the chemical bonds between cellulose and unwanted organic compounds [3]. Not only cotton but also other naturally occurred fibers are off-white in the shade due to the presence of the cuticle layer [2]. The extent of this off-whiteness or yellowness depends on the origin of raw materials: such as country of origin, cultivation time, and weather [4]. The bleaching process, therefore, eradicates natural colors.

Whiteness is a vital issue for dye houses since the dyeing recipe is prepared considering the level of whiteness in the bleached specimen [5]. However, dark shades such as navy or black colors are not affected by this off-whiteness. On the contrary, light shades, such as yellow, ballerina, turquoise, and so on, are sensible to this off-whiteness [6]. Thus, fabrics should be bleached properly before dyeing in a light color. Besides that, whiteness consistency increases the reproducibility of the same shade [7].

The modern bleach was first synthesized by 18th-century scientists Carl Wilhelm Scheele and Claude Berthollet [8]. They reported that chlorine compound can be used for cotton bleaching. There are two types of bleaches: such as (a) reductive, and (b) oxidative [9]. In the reductive bleaching process, cotton is reduced to a colorless substrate with the help of nascent hydrogen [H]. Zinc dust (Zn) [10], thiourea dioxide ($CH_4N_2O_2S$) [11], and sodium dithionite ($Na_2S_2O_4$) [12] are mostly used reductive bleaching agents. On the other hand, oxidative bleaching process produces either nascent oxygen [O] or chlorine (Cl_2) to promote the bleaching. Oxidative bleaching agents are divided into two categories; (b1) chlorine-based bleaching agents, such as sodium hypochlorite and calcium hypochlorite, and (b2) peroxide-based bleaching agent: such as hydrogen peroxide [13].

Even though there are lots of bleaching processes available in the current market, manufacturers are still looking for an economical way with enhanced bleaching performance. Very few studies compared among the bleaches. Bahtiyari & Benli (2019) compared between ozone-based bleaching process with the conventional hydrogen peroxide bleaching. The results were nearly similar, yet the conventional process yielded a better result than the ozone-based bleaching. The ozone-based bleach can be used as an alternative to conventional bleaching in terms of chemical/water/energy saving [14]. Nazir, Arooj, & Kashif (2017) compared the bleaching efficiency of ozone using methanol, isopropanol, oxalic acid, and sodium borohydride [15]. Fišerová et al. (2018) compared among hydrogen peroxide and sodium dithionite bleaching of deinked pulp. The brightness was 5.7% (max) to 4.4% (min) ISO for peroxide bleaching, while it was 4.0% (max) to 3.8% (min) for sodium dithionite bleaching [16].

Many studies reported that cotton goes through significant changes due to the bleaching process [15, 17-19]. It improves the water absorbency and dyeability of the fabrics [15]. The cotton tends to lose its' weight and bursting strength after bleaching treatment [17]. On the other hand, the K/S and whiteness index values increase significantly [18-19].

The reported study compared the influence of oxidative and reductive bleaching agents on single jersey knit. Five different bleaching chemicals were selected for the study: such as (three oxidative bleaches) hydrogen peroxide, sodium hypochlorite and calcium hypochlorite, and (two reductive bleaches) thiourea dioxide and sodium dithionite. Several chemical and physical experiments were carried out to assess the bleaching performance. Chemical testing includes water absorbency and uniformity in dye absorption tests. Physical testing includes weight loss, bursting strength, whiteness index, and CIELAB assessments.

II. LITERATURE REVIEW

Oxidative Bleaching Agents

Bleaching with Hydrogen Peroxide (H_2O_2) [20]

Hydrogen peroxide is a chemical compound that has an oxygen-oxygen single bond. Normally, it is stored in dark bottles as a form of liquid to prevent the decomposition due to the presence of UV light. Hydrogen peroxide decomposes in an alkaline medium and produces nascent oxygen [O] for the bleaching process.

$$H_2O_2 \rightarrow H^+ + HO^{2-}$$
$$HO^{2-} \rightarrow HO^- + [O]$$

Bleaching with Sodium Hypochlorite (NaOCl) [21-22]

Sodium hypochlorite is a salt of hypochlorous acid that easily dissolves in water and produces chlorine in acidic medium. The chlorine is responsible for the bleaching of cotton. In an acidic medium, sodium hypochlorite reacts as follows.

$$NaOCl + H_2O \rightarrow NaOH + HOCl$$
$$HOCl + HCl \rightarrow H_2O + Cl_2$$
$$HOCl \rightarrow HCl + [O]$$

Bleaching with Calcium Hypochlorite [23]

Calcium hypochlorite is another salt of hypochlorous acid. It is manufactured as chlorine powder or bleaching powder (Ca(OCl)Cl). It can produce a higher amount of chlorine than sodium hypochlorite. Bleaching powder decomposes in the aqueous solution that creates calcium chlorite, calcium hypochlorite.

$$2Ca(OCl)Cl + H_2O \rightarrow CaCl_2 + Ca(OCl)_2 + H_2O$$

Then, calcium hypochlorite produces calcium carbonate and hypochlorous acid by CO_2 of air. $CaCO_3$ deposits on the fabric surface that causes harshness. On the other hand, hypochlorous acid follows the same reaction for bleaching as it did for sodium hypochlorite.

$$Ca(OCl)_2 + H_2O + CO_2 \rightarrow CaCO_3 + 2HOCl$$

Reductive Bleaching Agents

Bleaching with Sodium Dithionite [16]

Sodium dithionite is a powerful reductive bleaching agent that is available in the form of crystalline powder. Textile industries widely use it for bleaching and color stripping processes. The reaction of sodium dithionite in an alkaline bath as following. The nascent [H] is responsible for bleaching activity.

$$Na_2S_2O_4 + H_2O \rightarrow NaHSO_3 + [H]$$

Bleaching with Thiourea Dioxide [$(NH)(NH_2)CSO_2H$] [24]

Thiourea dioxide is an organic sulfur compound that is used by some textile dyeing industries. It acts as a robust reductive bleaching agent at P^H 7.1. During the bleaching process, the P^H is maintained by Ammonia. Thiourea Dioxide produces sulfonate ion, which is highly reactive as a bleaching agent.

Thiourea Dioxide → [Sulfonate ion] (P^H 7.1)
Causes for the bleaching action

III. MATERIALS

The cotton knit was obtained from one of the leading garment product manufacturers in Bangladesh. Table I listed the details regarding fabric type [25], yarn size [26], GSM [27], and fabric composition [28]. Table II listed all the chemicals required to bleach the fabric. Point to be noted that four different concentrations of bleaches were employed to form the bleaching recipes; 2 g/l, 3 g/l, 4g/l, and 5 g/l.

TABLE I
Fabric specification

Type	Yarn Count	Composition	GSM
Single Jersey	30/S	100% BCI Cotton	280

TABLE II
Chemical Lists

Type	Chemical Name	Bleaching medium
Oxidative	Hydrogen peroxide	Alkaline
	Sodium hypochlorite	Acidic
	Calcium hypochlorite	Acidic
Reductive	Sodium dithionite	Alkaline
	thiourea dioxide	Alkaline

TABLE III
Bleaching Recipes and Conditions

Chemical Name (a)	Concentration				Main Auxiliary (b)	Conc.
Hydrogen peroxide	2 g/l	3 g/l	4 g/l	5 g/l	Caustic Soda	3 g/l
Sodium hypochlorite	2 g/l	3 g/l	4 g/l	5 g/l	Hydrochloric Acid	0.5 g/l
Calcium hypochlorite	2 g/l	3 g/l	4 g/l	5 g/l	Acetic Acid	1 g/l
Sodium dithionite	2 g/l	3 g/l	4 g/l	5 g/l	Caustic Soda	1.5 g/l
thiourea dioxide	2 g/l	3 g/l	4 g/l	5 g/l	Caustic Soda	1.5 g/l
Common Auxiliaries (c)	**Conc.**	**Bleaching Condition (d)**			**Parameter**	
Wetting agent	1 g/l	Temperature			80^0C	
Sequestering agent	1 g/l	M:L			1:15	
Anti-foaming agent	1 g/l	Time			60 in	

IV. METHODS

The study was conducted in nine different steps. Such as (a) recipe formulation, (b) bleaching, (c) weight loss calculation, (d) absorbency test, (e) spot test, (f) CIELAB, (g) whiteness index, (h) bursting strength, and (i) statistical analysis.

Recipe Formulation

A typical bleaching recipe includes (a) concentration of principal bleaching agent, (b) amount of primary auxiliary (which is used for controlling pH), (c) common auxiliaries (those are used in all the bleaching process), and finally (d) bleaching condition. Table 3 listed a total of four concentrations for each bleaching agent. The number of total bleaching recipes is (bleaching agents x concentrations), or (5 x 4), or 20.

Bleaching

The bleaching process starts with solution preparation. At first, the bleaching solution was prepared considering the weight of the specimens. Then the temperature was raised to 60^0C and the fabric specimens were loaded in cylindrical vessels of a Rota dyeing machine. The temperature was again raised to 80^0C. The machine run-time was set to 60 min. After 60 min, the bleached specimens were recovered and then washed with distilled water. Finally, the specimens were run into a dryer and kept in the environmental chamber for 24 hours to condition them.

Weight Loss (%) Calculation

The weight loss calculation was done based on the fabric GSM before and after the bleaching process. If the initial GSM is W_0 and after bleach GSM is W_1, then the weight loss (%) will be as follows:

$$\text{Weight loss (\%)} = [\ (W_0 - W_1)/ W_0 \ \times 100\ ]\ \%$$

Water absorbency test (AATCC 79-2018) [29]

In this test, a water droplet is fallen on the fabric surface using a pipette. Then the water is absorbed by the textile after a certain time. The water absorption time is recorded using a stopwatch. The standard water absorption time for a perfectly bleached specimen can vary from 0.5 sec to 1 sec (max).

Spot test [29]

This test requires a 1% (Congo red) direct dye solution for the experiment. Again, a droplet from the dye solution is fallen upon the textile substrate using a pipette, and the shape of absorption area is observed. If the shape of absorption area is almost circular, then it is called good bleaching.

For the spot test, a Likert scale was followed to grade the dye absorbency rating. The highest rating is 5, which indicates excellent uniformity in dye absorption. On the other hand, the lowest rating is 1, which means non-uniformity in dye absorption.

CIELAB [30]

CIELAB is a color measurement system of the textile substrate that is widely used by textile dyeing industries to quantify the color. The international commission on illumination introduced the CIELAB system in 1931. According to this system, all the colors are expressed numerically using three color coordinates; L*, a*, and b*. The higher value of L* indicates shade lightness, while the lower value of L* indicates shade darkness. Similarly, the higher value of a* and b* represents shade reddishness and yellowishness consecutively, and the lower value of a* and b* represents shade greenness and bluishness sequentially.

Whiteness index [31]

It is a whiteness measurement technique that compares specimens' whiteness with a standard white surface. The two most popular whiteness index scales are CIE whiteness index and Ganz-Griesser whiteness index. The current study used the CIE whiteness index.

Bursting Strength [32]

Bursting strength is a property of textile materials that withstands perpendicular force against the fabric plane. In this test, a 5"x5" specimen is placed over the expansive diaphragm and then clipped by a circular clamping ring. The air pressure is applied to the diaphragm, which causes the expansion of diaphragm and finally rupture the fabric.

Statistical analysis

The study identified five different bleaching agents with four different concentrations. A general factorial design was approached for statistical analysis using a 95% confidence level, for instance (no. of bleaching agent x concentrations x no. of experiments), or (5 x 4 x 7). Finally, each type of reading was taken five times for statistical significance.

V. RESULT AND DISCUSSION

After carrying out stepwise procedures based on methodology, the results were recorded in SPSS v25. The mean and standard deviation is attached to the appendix for each experiment. The following section discussed the findings that were obtained from the analysis.

Weight Loss (%)

Two-way analysis of variance revealed that the weight loss (%) of bleached specimens varied significantly for all of the five different bleaching agents with four different concentrations. According to the analysis, the weight loss (%) differed significantly at F-test $_{(80, 12)}$= 4.066 and $p \leq 0.000$. Figure 2 represents that weight loss percentage was the highest for hydrogen peroxide bleaching, while it was the lowest for calcium hypochlorite bleaching. It was mentioned earlier that calcium hypochlorite bleaching produces $CaCO_3$, which deposits on the fabric surface during bleaching. So, the lowest weight loss percentage of calcium hypochlorite might be influenced by this $CaCO_3$ depositions. Figure 1 also discloses another inference. The weight loss percentage increases with the concentrations of bleaching agents.

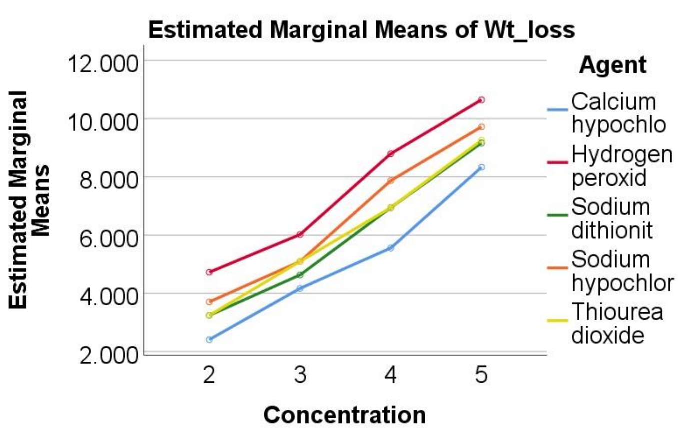


Fig 1: Effect of different bleaching agents on fabric weight loss.

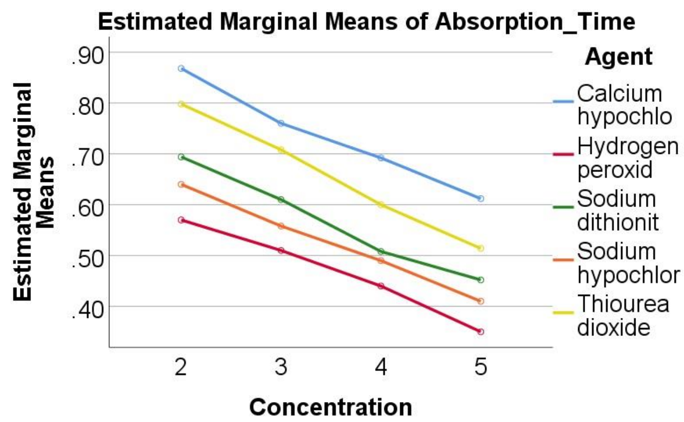


Fig 2: Effect of different bleaching agents on water absorption time.

Water absorbency test

The unbleached specimens took more than 6 min to absorb one water droplet. However, the absorbency of cotton increased significantly after the bleaching process was done. The specimens took less than 1 sec to absorb the water that indicates each bleaching agent worked perfectly. Again, the results from water absorbency tests were statistically analyzed to see which bleaching agent took the least amount of time to absorb the water.

According to the two-way analysis of variance, the water absorption time (sec) of bleached specimens varied significantly [at F-test $_{(80,\ 12)}$= 12.688 and p $\leq$ 0.000] for all of the five different bleaching agents with four different concentrations. Figure 2 revealed that the water absorption time (sec) was the highest for calcium hypochlorite bleaching, while it was the lowest for hydrogen peroxide bleaching. The analysis from figure 3 also revealed that the water absorption time decreased with the concentrations of bleaching agents in bleach baths.

Spot test

The spot test from pre-bleaching experiments exposed that the uniformity in color absorption was worst for unbleached cotton. However, consistency was improved from moderate to outstanding after conducting the bleaching treatments.

Two-way analysis of variance revealed that the uniformity in dye absorption differed significantly [F-test $_{(80,\ 12)}$= 8.267 and p $\leq$ 0.000] for all of the five different bleaching agents with four different concentrations. Figure 3 disclosed that the dye absorption uniformity was the highest for hydrogen peroxide bleaching, while it was the lowest for calcium hypochlorite bleaching. The analysis from figure 3 also revealed that the dye absorption uniformity increased with the concentrations of bleaching agents in bleach baths.

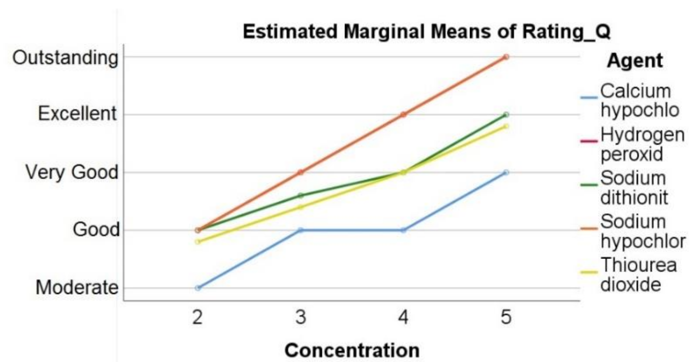


Fig 3: Effect of different bleaching treatments on the uniformity of dye absorption.

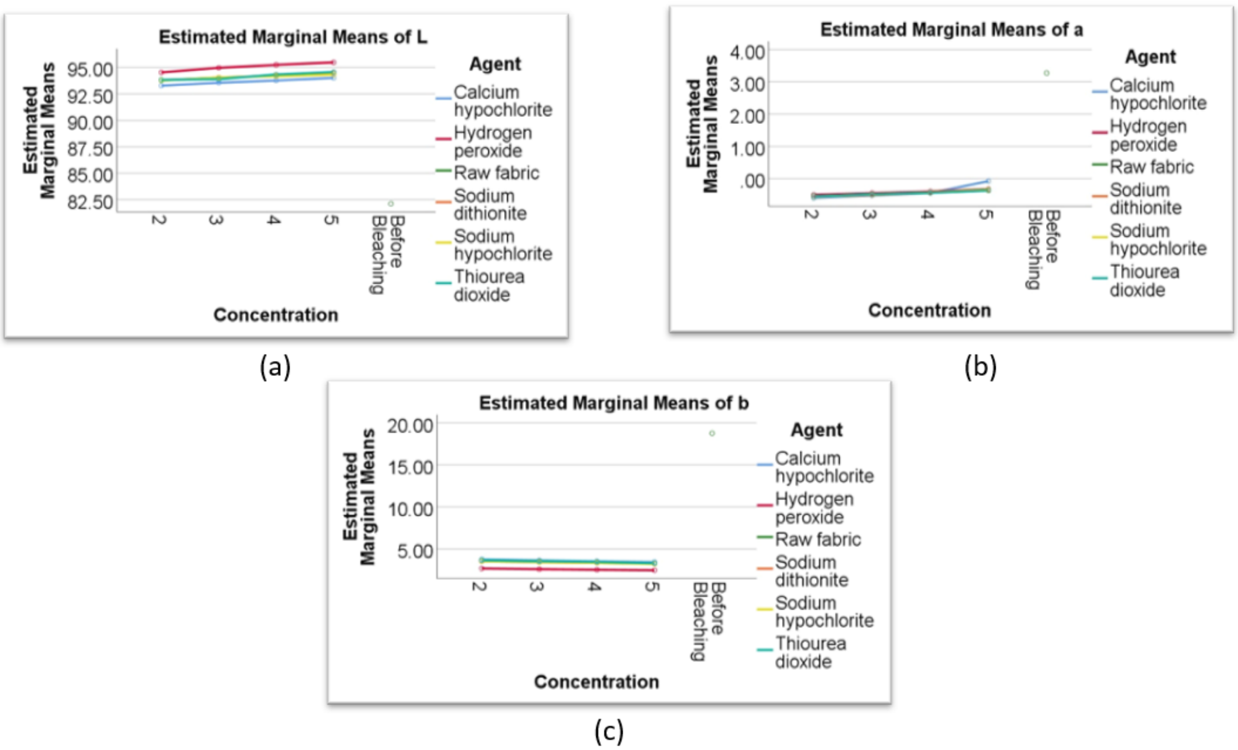


Fig 4: CIELAB color measurement.

CIELAB color measurement

The CIE L* a* b* values of unbleached and bleached specimens were obtained using spectrophotometer. The statistical analysis revealed that the CIE L* a* b* varied significantly among bleached and unbleached specimens. According to the analysis, the value of L* differed significantly [F-test $_{(84, 12)}$= 3.560 and $p \leq 0.000$], where the raw fabric had the lowest mean L* value (μ = 82.12). It indicated that the unbleached specimens had the darkest appearance (for mean values, please see the Appendix). Figure 4(a) shows that cotton bleached with hydrogen peroxide had the highest values of L*. On the contrary the specimens bleached with calcium hypochlorite had the lowest values of L* among all bleached specimens. Therefore, the hydrogen peroxide bleaching agent acts better than other bleaches to improve whiteness of the specimens.

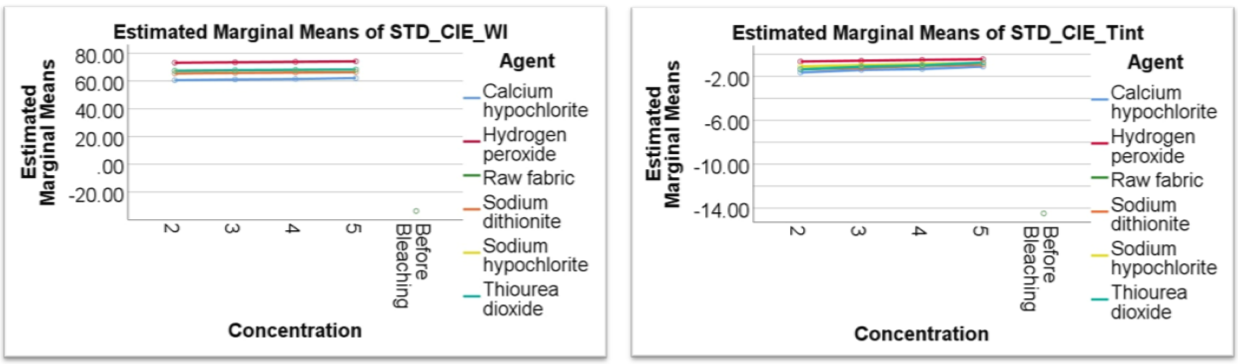
Similarly, the statistical analysis also disclosed that the value of a* and b* varied significantly among bleached and unbleached specimens. According to the analysis, the value of a* differed significantly at F-test $_{(84, 12)}$= 2.699 and $p \leq 0.004$ and the value of b* differed significantly at F-test $_{(84, 12)}$= 30.317 and $p \leq 0.000$, where the raw fabric had the highest mean a* and b* values (μ_a = 3.27 & μ_b = 18.76). It indicated that the unbleached specimens had the reddish and yellowish appearance. Figure 4(b) and 4(c) shows that cotton bleached with hydrogen peroxide had the lowest values of a* and b*, On the contrary the specimens bleached with calcium hypochlorite had the highest values of a* and b* among all bleached specimens. Therefore, the hydrogen peroxide bleaching agent acts better than other bleaches to reduce reddishness and yellowishness of the specimens.

Whiteness index

The CIE whiteness index has two different scales to express whiteness numerically: such as (a) STD CIE WI and (b) STD CIE Tints. The 'WI' scale expresses the degree of whiteness, while the 'Tint' expresses the presence of tints.

Two-way analysis of variance of raw specimens and bleached specimens disclosed that the CIE WI and CIE Tint values varied significantly for all the five different bleaching agents with four different concentrations. According to the analysis, the value of CIE WI differed significantly [F-test $_{(84, 12)}$= 277.924 and $p \leq 0.000$], where the raw fabric had the lowest mean of CIE WI value (μ = -33.67) (for mean values, please see the Appendix). It represented that the unbleached specimens had the darkest appearance. Figure 5(a) shows that cotton bleached with hydrogen peroxide had the highest values of CIE WI. On the other hand, the specimens bleached with calcium hypochlorite had the lowest values of CIE WI among all bleached specimens.

Similarly, the value of CIE Tint differed significantly [F-test $_{(84,\ 12)}$ = 161.109 and $p \leq 0.000$], where the raw fabric had the lowest mean of CIE Tint value (μ = -14.49). It represented that the unbleached specimens had more tints than the bleached one (for mean values, please see appendix). Figure 5(b) shows that cotton bleached with hydrogen peroxide had the highest values of CIE Tint, contrarily the specimens bleached with calcium hypochlorite had the lowest values of CIE Tint among the all bleached specimens. Therefore, the hydrogen peroxide bleaching agent acts better than other bleaches to improve the whiteness of the specimens.



(a) (b)

Fig 5: Effect of different bleaching treatments on STD CIE WI and STD CIE Tint values.

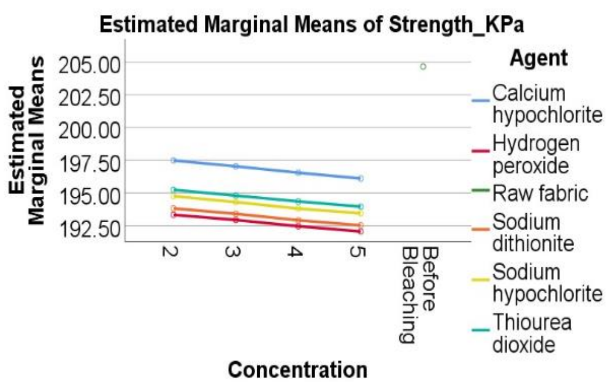


Fig 6: Effect of different bleaching treatments on fabric bursting strength.

Bursting strength

The statistical analysis found a significant difference in bursting strengths between raw specimens and bleached specimens. According to the analysis, the value of bursting strength differed significantly at F-test $_{(84,\ 12)}$ = 3.021 and $p \leq 0.001$, where the raw fabric had the highest mean of bursting strength (μ = 204.65 KPa) [see appendix]. It represented that the unbleached specimens had the highest bursting strength (figure 6). Figure 6 also shows that cotton bleached with hydrogen peroxide had the lowest values of bursting strength. On the other hand, the specimens bleached with calcium hypochlorite had the highest values of bursting strength from all bleached specimens. Therefore, the hydrogen peroxide bleaching agent damages fiber strength than other bleaches.

VI. LIMITATIONS

The study focused only on water-based bleaching treatments using five different bleaches for single jersey knit. Hence, the study must be repeated using different bleaches and different types of fabric constructions. Also, the microscopic analysis was not conducted to see the fiber damages after bleaching processes since SEM was not available for this project. So, the application of microscopic structure analysis to see the fiber damages in this research will improve the research dimension. However, the purpose of this study was to mimic the workflow of the textile dyeing industry before and after bleaching processes. Even though the industries assess the bursting strength to understand fiber damage and strength loss, they do not conduct any microscopic analysis. Finally, some other tests, like shrinkage test, wicking test [33], and moisture transfer [33] test could be done in this study. But these tests are meaningful just before the garment production stage since fabric goes through several chemical finishes after bleaching and dyeing treatments that impact on the shrinkage, wicking, and moisture transfer tests.

VII. CONCLUSION

In this study, the authors analyzed the effect of different bleaching agents on cotton fabric properties. Five different bleaching agents were used, and their after-effects were analyzed. Bleaching with hydrogen peroxide provided the best results in most cases, while bleaching with calcium hypochlorite offered unsatisfactory results in most cases. The findings also revealed that bleaching performance increased proportionally with the concentration of bleaching agents. However, the concentration impacted adversely on the weight loss and bursting strength tests. At present, most of the textile industries of Bangladesh use hydrogen peroxide for bleaching. Some of the textile industries started to use TUD (Thiourea Dioxide) in recent times. TUD is cheap, but it has a terrible effect on the human body. If a person inhales TUD during respiration, it may cause cancer.

VIII. APPENDIX

Weight Loss (%)			
Agent	**Conc.**	**Mean**	**SD**
Hydrogen Peroxide	2 g/l	4.722	0.207
Hydrogen Peroxide	3 g/l	6.019	0.327
Hydrogen Peroxide	4 g/l	8.796	0.000
Hydrogen Peroxide	5 g/l	10.648	0.327
Sodium Hypochlorite	2 g/l	3.704	0.327
Sodium Hypochlorite	3 g/l	5.093	0.327
Sodium Hypochlorite	4 g/l	7.870	0.327
Sodium Hypochlorite	5 g/l	9.722	0.327
Calcium Hypochlorite	2 g/l	2.407	0.387
Calcium Hypochlorite	3 g/l	4.167	0.327
Calcium Hypochlorite	4 g/l	5.556	0.463
Calcium Hypochlorite	5 g/l	8.333	0.000
Sodium Dithionite	2 g/l	3.241	0.000
Sodium Dithionite	3 g/l	4.630	0.327
Sodium Dithionite	4 g/l	6.944	0.000
Sodium Dithionite	5 g/l	9.167	0.207
Thiourea Dioxide	2 g/l	3.241	0.327
Thiourea Dioxide	3 g/l	5.093	0.000
Thiourea Dioxide	4 g/l	6.944	0.327
Thiourea Dioxide	5 g/l	9.259	0.327

Water Absorbency			
Agent	**Conc.**	**Mean**	**SD**
Hydrogen Peroxide	2 g/l	0.570	0.010
Hydrogen Peroxide	3 g/l	0.510	0.010
Hydrogen Peroxide	4 g/l	0.440	0.010
Hydrogen Peroxide	5 g/l	0.350	0.010
Sodium Hypochlorite	2 g/l	0.640	0.000
Sodium Hypochlorite	3 g/l	0.560	0.010

Sodium Hypochlorite	4 g/l	0.490	0.010
Sodium Hypochlorite	5 g/l	0.410	0.010
Calcium Hypochlorite	2 g/l	0.870	0.020
Calcium Hypochlorite	3 g/l	0.760	0.010
Calcium Hypochlorite	4 g/l	0.690	0.000
Calcium Hypochlorite	5 g/l	0.610	0.010
Sodium Dithionite	2 g/l	0.690	0.010
Sodium Dithionite	3 g/l	0.610	0.010
Sodium Dithionite	4 g/l	0.510	0.010
Sodium Dithionite	5 g/l	0.450	0.000
Thiourea Dioxide	2 g/l	0.800	0.000
Thiourea Dioxide	3 g/l	0.710	0.010
Thiourea Dioxide	4 g/l	0.600	0.010
Thiourea Dioxide	5 g/l	0.510	0.010

Spot Test

Agent	**Conc.**	**Mean**	**SD**
Hydrogen Peroxide	2 g/l	Good	0.000
Hydrogen Peroxide	3 g/l	Very Good	0.000
Hydrogen Peroxide	4 g/l	Excellent	0.000
Hydrogen Peroxide	5 g/l	Outstanding	0.000
Sodium Hypochlorite	2 g/l	Good	0.000
Sodium Hypochlorite	3 g/l	Very Good	0.000
Sodium Hypochlorite	4 g/l	Excellent	0.000
Sodium Hypochlorite	5 g/l	Outstanding	0.000
Calcium Hypochlorite	2 g/l	Moderate	0.000
Calcium Hypochlorite	3 g/l	Good	0.000
Calcium Hypochlorite	4 g/l	Good	0.000
Calcium Hypochlorite	5 g/l	Very Good	0.000
Sodium Dithionite	2 g/l	Good	0.000
Sodium Dithionite	3 g/l	Very Good to Good	0.548
Sodium Dithionite	4 g/l	Very Good	0.000
Sodium Dithionite	5 g/l	Excellent	0.000
Thiourea Dioxide	2 g/l	Good to Moderate	0.447
Thiourea Dioxide	3 g/l	Good to Very Good	0.548
Thiourea Dioxide	4 g/l	Very Good	0.000
Thiourea Dioxide	5 g/l	Excellent to Very Good	0.447

CIELAB

Agent	**Conc.**	**L^*_{Mean}**	**L^*_{SD}**	**a^*_{Mean}**	**a^*_{SD}**	**b^*_{Mean}**	**b^*_{SD}**
Raw Fabric	**NA**	**82.120**	**0.023**	**3.270**	**0.023**	**18.76**	**0.017**
Hydrogen Peroxide	2 g/l	94.520	0.030	-0.500	0.022	2.670	0.012
Hydrogen Peroxide	3 g/l	94.960	0.020	-0.450	0.008	2.590	0.009
Hydrogen Peroxide	4 g/l	95.240	0.019	-0.400	0.009	2.510	0.005

Hydrogen Peroxide	5 g/l	95.470	0.023	-0.330	0.008	2.460	0.005
Sodium Hypochlorite	2 g/l	93.750	0.019	-0.560	0.005	3.530	0.008
Sodium Hypochlorite	3 g/l	94.040	0.016	-0.490	0.005	3.420	0.010
Sodium Hypochlorite	4 g/l	94.160	0.013	-0.440	0.009	3.330	0.008
Sodium Hypochlorite	5 g/l	94.320	0.018	-0.350	0.015	3.210	0.011
Calcium Hypochlorite	2 g/l	93.280	0.015	-0.600	0.011	3.750	0.011
Calcium Hypochlorite	3 g/l	93.550	0.015	-0.530	0.011	3.630	0.011
Calcium Hypochlorite	4 g/l	93.760	0.023	-0.450	0.008	3.520	0.007
Calcium Hypochlorite	5 g/l	94.010	0.018	-0.080	0.438	3.430	0.007
Sodium Dithionite	2 g/l	93.780	0.021	-0.560	0.008	3.520	0.000
Sodium Dithionite	3 g/l	94.030	0.017	-0.510	0.013	3.410	0.013
Sodium Dithionite	4 g/l	94.220	0.018	-0.440	0.008	3.330	0.009
Sodium Dithionite	5 g/l	94.490	0.026	-0.360	0.012	3.250	0.008
Thiourea Dioxide	2 g/l	93.820	0.015	-0.550	0.015	3.650	0.009
Thiourea Dioxide	3 g/l	93.890	0.453	-0.480	0.005	3.540	0.005
Thiourea Dioxide	4 g/l	94.330	0.017	-0.440	0.009	3.450	0.011
Thiourea Dioxide	5 g/l	94.560	0.009	-0.370	0.011	3.300	0.017

Whiteness Index

Agent	**Conc.**	**WI_{Mean}**	**WI_{SD}**	**$Tint_{Mean}$**	**$Tint_{SD}$**
Raw Fabric	**NA**	**-33.670**	**0.000**	**-14.490**	**0.010**
Hydrogen Peroxide	2 g/l	73.140	0.020	-0.660	0.010
Hydrogen Peroxide	3 g/l	73.480	0.010	-0.580	0.010
Hydrogen Peroxide	4 g/l	73.790	0.010	-0.500	0.010
Hydrogen Peroxide	5 g/l	74.110	0.020	-0.440	0.010
Sodium Hypochlorite	2 g/l	67.450	0.010	-1.100	0.020
Sodium Hypochlorite	3 g/l	67.730	0.010	-0.980	0.020
Sodium Hypochlorite	4 g/l	67.960	0.020	-0.880	0.010
Sodium Hypochlorite	5 g/l	68.230	0.010	-0.790	0.010
Calcium Hypochlorite	2 g/l	60.550	0.030	-1.650	0.020
Calcium Hypochlorite	3 g/l	61.090	0.030	-1.420	0.010
Calcium Hypochlorite	4 g/l	61.450	0.010	-1.340	0.000
Calcium Hypochlorite	5 g/l	62.100	0.020	-1.110	0.010
Sodium Dithionite	2 g/l	65.450	0.020	-1.370	0.020
Sodium Dithionite	3 g/l	65.800	0.010	-1.240	0.020
Sodium Dithionite	4 g/l	66.100	0.020	-1.070	0.010
Sodium Dithionite	5 g/l	66.390	0.020	-0.920	0.000
Thiourea Dioxide	2 g/l	67.350	0.010	-1.360	0.010
Thiourea Dioxide	3 g/l	67.780	0.020	-1.130	0.010
Thiourea Dioxide	4 g/l	68.050	0.010	-1.010	0.020
Thiourea Dioxide	5 g/l	68.320	0.030	-0.760	0.010

Bursting Strength (Kpa)

Agent	**Conc.**	**Mean**	**SD**

Raw Fabric	**NA**	**204.65**	**0.04**
Hydrogen Peroxide	2 g/l	193.300	0.040
Hydrogen Peroxide	3 g/l	192.900	0.020
Hydrogen Peroxide	4 g/l	192.500	0.030
Hydrogen Peroxide	5 g/l	192.100	0.030
Sodium Hypochlorite	2 g/l	194.800	0.040
Sodium Hypochlorite	3 g/l	194.300	0.020
Sodium Hypochlorite	4 g/l	193.800	0.040
Sodium Hypochlorite	5 g/l	193.400	0.020
Calcium Hypochlorite	2 g/l	197.500	0.020
Calcium Hypochlorite	3 g/l	197.000	0.030
Calcium Hypochlorite	4 g/l	196.500	0.030
Calcium Hypochlorite	5 g/l	196.100	0.020
Sodium Dithionite	2 g/l	193.800	0.030
Sodium Dithionite	3 g/l	193.400	0.030
Sodium Dithionite	4 g/l	192.900	0.010
Sodium Dithionite	5 g/l	192.500	0.030
Thiourea Dioxide	2 g/l	195.200	0.030
Thiourea Dioxide	3 g/l	194.800	0.010
Thiourea Dioxide	4 g/l	194.400	0.020
Thiourea Dioxide	5 g/l	194.000	0.030

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