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Quality Optimization by Evaluating Physico-Mechanical Properties of Industrial Acid Wash, Cool Dyeing and Dip Dyeing Processes on Knitted Garment

Md. Shohan Parvez, Md. Ishtiaque Rahman, Tarikul Islam, S.M. Razwan Ahmed

Abstract*: Industrial garment washing and garment dyeing are currently taking over fashion trends. At present, these processes are not only confined to woven garments but also applied over knitted garments. Nevertheless, prolonged washing time, use of different chemicals during the washing and dyeing procedure affects the physical and mechanical performance of the garment. This is ultimately affecting the quality of the finished garments and resulting in more fabric wastage during these treatments. In this study, industrial garment finishing processes like Acid wash, Cool Dyeing, Dip Dyeing process were applied on 100% Cotton Slub Single Jersey (160 GSM) knitted T-Shirt. The aim of this study is to determine the effects of industrial Acid washing and cool-dip dyeing on physico-mechanical properties of knitted garments. To evaluate the washing and dyeing effects, changes in fabric weight, changes in dimension, bursting strength, dry and wet rubbing fastness, color fastness to perspiration, pilling and washing tests were performed. Experimental data showed that GSM increased for Acid washed garment but dimension change, color fastness to washing, rubbing, bursting strength and perspiration decreases significantly in comparison with Cool and Dip dyeing.

Keywords*: Acid wash, Cool dyeing, Dip dyeing, Fastness properties, Garment washing, Slub single jersey.

I. INTRODUCTION

Now-a-days, Vintage or color faded textiles are growing immense interest specially among the young consumers because of its commercial acceptance and decent versatile appearances [1], [2]. To achieve these decent fading and color effects various finishing processes are introduced on garments, resulting in a worn-out or vintage look on it [3]. Garment washing and garment dyeing are one of those processes. There are numerous techniques involved in garment washing and dyeing [4]. Moreover, in recent years garment washing and garment dyeing are considered as the most vertical growth sector in Bangladesh [5]. Garment washing is a finishing treatment which is practiced to alter the Outlook, aspect, comfortability, and fashion of the garments [6]. Garment washing and dyeing are performed on a sewn garment, which change, modify or upgrade the color of garments. The application of these treatments, make the garment softer, suppler, smooth and dimensionally stable [7]. Unlike fabric dyeing, garment dyeing is carried out on sewn garment made from grey fabric, to introduce more uniqueness in coloration. Consequently, a new stance and outlook are seen in the garment, which other methods can't exhibit to such extent. Moreover, the presence of residual starch and colorant in the garments is also removed by garment washing [8]. As a result, washed garments induce a feeling of relative comfort similar to a used garment rather than a stiffer one, just after being purchased. Additionally, further shrinkage after worn can also be avoided by garment washing [9]. To keep pace with this faster-growing sector, industries are now introducing newer and improved washing and dyeing techniques to create newer designs and desired outlook on garments [10], [11], [12]. Most of them are applied over woven garments. But currently, buyers are focusing on garment washed and dyed effect also on knitted items [13]. Among different washing processes, acid wash is a finishing treatment performed to create comfort, contrasted aesthetic fading effect throughout a garment. Therefore it adds value to the final garment [14]. Though it was first introduced in the 1980s with Phosphoric acid at present, it's been replaced by Potassium permanganate soaked Pumice stones, sponges, perlite or thermocol balls. In this process, porous substances like, pumice stones are used to deposit the oxidizing agent to fabric surface [15]. Pumice stones are lightweight volcanic rocks that consist of highly perforated surface, which causes wear and tear during washing [16]. These stones are suited mostly for woven garments not for knitted items, as they can cause damage to the knitted structure. Instead of pumice stones, thermocol balls or sponges are used for knitted garments. Thermocol balls are very lightweight and formable material made from polystyrene [17]. Small-sized thermocol balls (0.75-1 cm diameter) are generally used for soaking Potassium permanganate while in acid washing.

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* Correspondence Author

Md. Shohan Parvez*, Department of Textile Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. Email: shohan.parvez@yahoo.com

Md. Ishtiaque Rahman, Department of Textile Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. Email: ishtiaquekuette@gmail.com

Tarikul Islam, Department of Textile Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh. E-mail: matarikul.islam2014@gmail.com

S.M. Razwan Ahmed, Square Denims Limited (Washing Unit), Masterbari, Valuka, Mymensing, Bangladesh. E-mail: ahmedrazwan.87@gmail.com

Potassium permanganate is a strong oxidizing agent, used to produce color fading effect on a sewn garment in acid washing which requires neutralization after the action [18], [19]. Unlike Acid washing, cool dyeing doesn't require hot water for dyeing; preferably it's been done in room temperature or within 24°C to 35°C. Higher temperature is also acceptable but not less than 21°C [20], [21]. Aside from cool dyeing, dip dyeing is done at elevated temperature (70-85°C) and for a certain time, by partially dipping the garment into the dye bath [22]. By this process, a gradient effect of two colors in one garment is generated. Dip dyeing is also known as color and ombre effect [23].

At present, demand for these washing and dyeing effect on knitted garments has been increased at a larger scale. To keep balance with the growing demand, orders for these goods are also increasing continuously. Buyers now want these items to be performed on the same types of fabric and here comes the dilemma. As the fabric construction remains the same but the washing or dyeing procedures varies, it becomes a quite a hardship for the factories to maintain the exact quality required for all the styles from different washed or dyed garments. Even after the completion of the washing or dyeing, there have been happenings of significant differences between the requirements and the actual quality.

Many researchers have investigated the garment washing and dyeing effects on different clothing following various methods but there is a lack of research on the process analysis and optimization of same knitted structured fabric and different effects achievement. Furthermore, many factories are struggling to establish a standard regarding these washes when applied to the same knitted structure. The present investigation is focused on process and quality analysis and as well as the optimization of various washing and dyeing effects on knitted garments. Also, the effects of various process parameters on the same knitted fabric structure were investigated and discussed.

II. MATERIALS

A. *Substrate*

For this work, single jersey scoured and bleached 100% Cotton Slub Single Jersey fabric with 2.85 mm stitch length, 160 GSM and 30 Ne carded yarn was collected from SM Knitwear Ltd, Shirirchala, Bhabanipur Gazipur, Bangladesh.

B. *Garments Washing and Dyeing Source*

Whole experimental work was executed in Square Fashion Ltd (washing unit), Masterbari, Valuka, Mymensing, Bangladesh which is a 100% export-oriented industry in Bangladesh.

C. *Chemicals*

- For Acid Wash: Detergent, Levelling agent, Glauber salt, Soda ash, caustic soda, Dischargeable dyes (e.g. Lava Olive GIF, Lava Stone Grey), Acetic Acid, Potassium Permanganate, Phosphoric acid, Thermocol Ball, Sodium Metabisulphite.
- For Cool Dyeing: Detergent, Pigment Dyes (e.g. Europrint N. Blue, Europrint Blue G, Europrint Black B Con), Catanizer, Binder.
- For Dip Dyeing: Detergent, Soda Ash, Glauber Salt, Hydrogen Peroxide, Acetic Acid, Levelling Agent, Lava Blue GLF, Lava Yellow GLF, Red, Acetic Acid, Fixing agent, Softener.

D. *Washing machine*

Brand Name: Tonello (Front Loading)
Machine Capacity: 15 Kg
RPM (Revolution per minute): 20~25
Origin: Italy

III. METHODS

A. *Acid Wash*

Table- I: Acid washing process (Material: Liquor: 1:20)

Serial No.	Process	Chemicals/ Ingredients	Amount	Temperature *(in °C)*	Time *(in minutes)*	Cycle	Remarks
1	Detergent + Fill		1.5 g/l	50	5	2	
2	Pre-Treatment	Levelling agent	1g/l	Room Temp.	2	1	
		Glauber Salt	70 g/l	Room Temp.	2	1	
		Soda Ash	20 g/l	Room Temp.	2	1	
		Caustic Soda	0.5 g/l	60	2	1	
3	Color Dosing	Lava Olive GIF	3%	60	25	1	20 min dosing
		Lava Stone Grey	0.54%				
4	Drain+Fill						
5	Normal Wash			30	5	1	
6	Neutralization	Acetic Acid	0.3 g/l	50	5	1	50 ltr water req.
7	Drain+Fill						
8	Hot Wash			60	10	1	
9	Fixing Agent (Non-Ionic)		1 g/l	60	10	1	
10	Acid Wash	Potassium Permanganate	15 g/l				
		Phosphoric acid	5 g/l				
		Soaking with Thermocol Ball (0.1% owg)		Room Temp.	5	1	
		Washing Cycle		30	15		
11	Normal Wash			30	5	1	
12	Drain						
13	Neutralization	Sodium Metabisulphite	2 g/l	50	5	1	
14		Acetic Acid	0.5 g/l	50	5		
15	Hydroextraction			Room Temp.	5	1	
16	Softener	Micro finish BP-20	3 g/l	40	10	1	
17	Drying	Tumble Dryer		80	30	1	

At first garment (T-Shirt, RFD) was subjected to detergent wash to remove any residual dirt presence. Thereafter the garment was ready for dyeing. Garment dyeing was done using dischargeable dyes (Brand Name: Lava olive GIF, Glauber Salt, Soda Ash, and Caustic Soda. (Details in Table-I.)

After dyeing, followed by neutralization (using acetic acid) and fixation (Brand Name: Asufix), the garment was ready for acid washing. To perform acid washing, at first potassium permanganate (PP) solution (15 g/l) was prepared using 5% of phosphoric acid. Here, PP solution was added for fading and sometimes phosphoric acid to increase the fading intensity at a faster pace. Thermocol balls (1 cm – 1.5 cm diameter) were used and put into the washing machine (Thermocol balls 0.1% on the weight of garment). Then, PP solution was squirted into the machine and the washing machine ran for 5 min without any garments, so that all the thermocol balls got wetted and soaked with alkaline PP solution completely. Mild rinsing was also followed to avoid any residual mixture in the machine rather getting them to be absorbed by thermocaol ball. Then the garments were loaded into the machine with PP soaked thermocol balls and acid washing process was carried out for 10 min at normal room temperature.

After completing the PP action, garments were unloaded from the washing machine; a normal wash was performed along with detergent 1gm/l (For 5 min, at 30ºC temperature). Followed by neutralization with 2gm/L Sodium meta-bi-sulfite for 5 min at 50ºC. Then hydro extraction was conducted to release the excess water and finally by drying the garments by using a tumble dryer for 10 min at 60 ºC temperature to get the final washed garment.

B. *Cool Dyeing*

To perform cool dyeing, at first, the garment made from RFD fabric was subjected to detergent wash so that the garment could be free from any residual dirt presence. Dyeing was performed at room temperature for 15 minutes using pigment dyes, catanizer, and binder.

After that, hydro extraction was performed to remove any excess water and was subjected to drying afterward. Curing was done for color fixation at 160℃ for 5 minutes. Finally, upon application of softener and drying, cool dyed garment was ready.

Table- II: Cool dyeing process (Material: Liquor: 1:20)

Serial No.	Process	Chemicals/ Ingredients	Amount	Temp. *(in ℃)*	Time *(in minutes)*	Cycle	Remarks
1	Detergent wash		1 g/l	50	5	2	
2	Dyes	Europrint N. Blue Europrint Blue G Europrint Black B Con	9 gm 2.8 gm 1.4 gm	Room Temp.	10	1	Dipping
3	Catanizer		2.5 g/l	Room Temp.	5	1	Dipping
4	Binder		2 g/l	Room Temp.	15	1	
5	Hydroextraction			Room Temp.	5	1	
6	Dryer			60	50	1	
7	Curing			160	5	1	
8	Softener	Micro finish BP-20	3 g/l	40	10	1	
9	Hydroextraction			Room Temp.	5	1	
10	Drying			80	30	1	

C. *Dip Dyeing*

Dip dyeing was implemented on the garments to have a gradient look on it. During Dip dyeing process, further scouring was done over RFD garment to increase the absorbency of the garment, as Dip dyeing is done in an open bath rather than in a closed bath like cool dyeing or acid wash. To perform the dip dyeing, dye bath is prepared using reactive dyes (Brand name: Lava Blue GLF & Lava Yellow GLF), Sallt, Soda ash.

Table- III: Dip dyeing process (Material: Liquor: 1:20)

Serial No.	Process	Chemicals/ Ingredients	Amount	Temp. *(in ℃)*	Time (in minutes)	Cycle	Remarks
1	Scouring	Detergent Soda Ash Hydrogen Peroxide	0.5 g/l 2 g/l 4 g/l	80	15	1	2 Rinse
2	Neutralization	Acetic Acid	0.5 g/l	50	5	1	2 Rinse
3	Hydroextraction					1	
4	Dyeing	Levelling Agent Lava Blue GLF Lava Yellow GLF Red Salt Soda Ash	50 g/l 2% 0.8% 0.2% 5 g/l 15 g/l	50	15	1	Dipping
5	Neutralization	Acetic Acid	0.5 g/l	50	5	1	2 Rinse
6	Fixing Agent	Sarafast	5 g/l	50	5	1	(pH 4.5)
7	Softener	Micro finish BP-20	3 g/l	40	10	1	
8	Hydroextraction					1	
	Drying			80	25	1	

Subjected garment was hanged using hanger and the bottom portion of the garment was dipped to into the bath to a certain position. The dyeing process took almost 15 minutes at 50ºC. After dyeing, dip dyed garment was neutralized using Acetic acid. Soon, fixer and softener were applied to the garment. Finally, after drying Dip dyeing process was finished.

IV. RESULT

A. Effect on GSM & Dimensional Change: In this study, for both non-washed RFD and processed fabrics weights were measured according to ASTM D 3776 method. It was observed that the weight of the fabrics increased with each different process. The increase in fabric weight was comparatively lower in cool dyeing and dips dyeing than Acid washed garment as there were less chemical processes involved.

Process Type	GSM
Non-Wash	161
Acid Wash	180
Cool Dyeing	173
Dip Dyeing	173

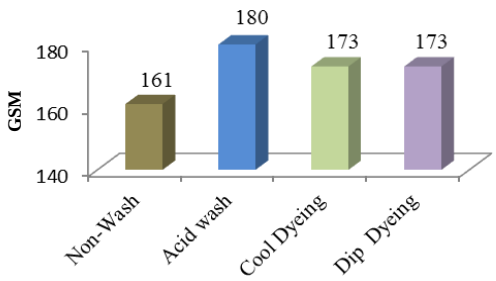

Fig.1. Change in GSM on Non-washed, Acid washed, Cool dyed and Dip dyed Garment

Determination of spirality was evaluated following test method ISO 16322-3, it was found from the spirality test, that acid washed t-shirt was more prone to spirality (2.5%) rather than the rest of the processed garments (1.5%).

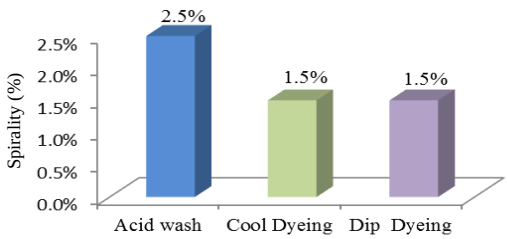

Fig.2. Change in Spirality on Non-washed, Acid washed, Cool dyed and Dip dyed Garments

Evaluation of shrinkage percentage was performed to assess the dimensional changes of fabric or clothing. In this study, the determination of shrinkage percentage was carried out following the test procedure AATCC 135 on different washed T-Shirts. Shrinkage levels for cool dyeing and dip dyeing were satisfactory. Though the shrinkage percentage for acid was within tolerance for acid washed T-Shirt, it was on marginal state.

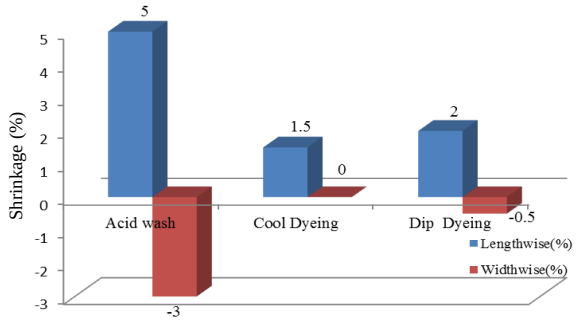

Fig.3. Change in Shrinkage on Non-washed, Acid washed, Cool dyed and Dip dyed

B. Effect on Bursting Test: Bursting strength of the aforementioned samples was measured using an automatic bursting strength tester according to test method ISO 13938-2. In this test, it was found that the tensile strength of the acid washed garment decreased significantly in comparison with cool dyed or dip dyed garments.

Maximum strength loss (15.86%) occurred in case of Acid washed T-Shirt. (-0.71%) for Cool dyed and (1.04%) for dip dyed t-shirt.

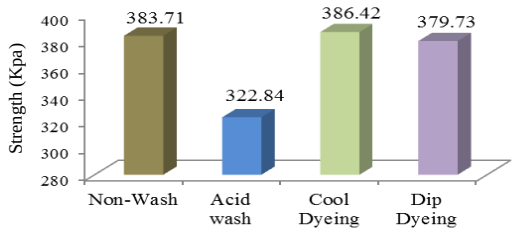

Fig.4. Change in Bursting strength on Non-washed, Acid washed, Cool dyed and Dip dyed Garments

C. Effect on Pilling Test: Pilling test of Single Jersey and Rib fabric was done according to ISO 12945-1 (Pilling Box method). In this test, Acid washed garment showed better performance than Cool Dyed and Dip dyed garment. As the Potassium permanganate literally pilled off of the resultant protruding fibre from fabric surface.

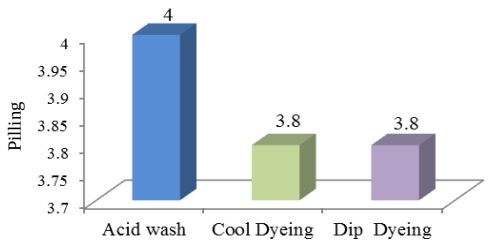

Fig.5. Change in pilling on Non-washed, Acid washed, Cool dyed and Dip dyed Garments

D. Effect on Color Fastness to Washing: Color fastness to washing test was carried out for all these samples following the test procedure ISO 105-C06 method. It was found that the color fastness to washing of acid washed sample was in the worst condition, cool dyed sample and Dip dyed sample seemed comparatively better. Grey scale is used to measure the fastness properties [24].

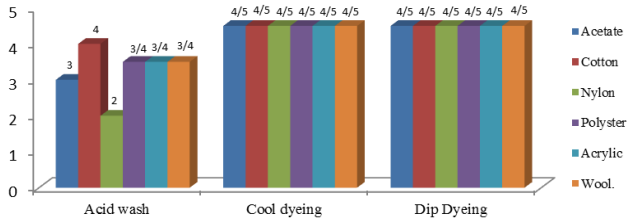

Fig.6. Change in color fastness to washing on Non-washed, Acid washed, Cool dyed and Dip dyed

E. Effect on Color Fastness to Rubbing (Dry and Wet): According to ISO 105-X12, 2016 rubbing fastness test was evaluated for all the garment pieces (Sample size: 10 cm× 4 cm). It was found that the dry rubbing fastness was in between fair and good for Acid wash and cool dyeing, and for Dip dyeing it was much better. On the contrary, for wet rubbing Acid washed garment was in poor condition. Due to the abrasion and oxidation of Alkaline KMnO4 the less infused dye stuff came out.

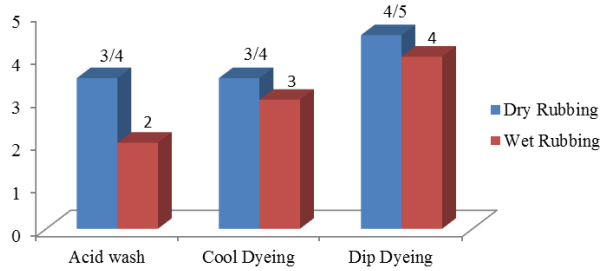

Fig.7. Change in color fastness to rubbing on Non-washed, Acid washed, Cool dyed and Dip dyed

F. Effect on Color Fastness to Perspiration Test:

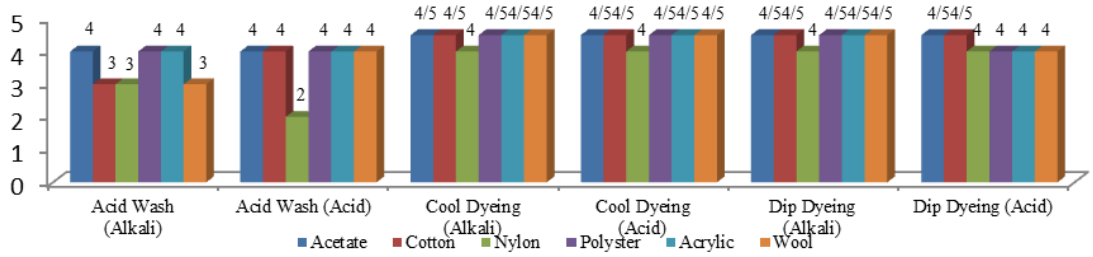

Fig.8. Change in color fastness to perspiration on Non-washed, Acid washed, Cool dyed and Dip dyed Garments

Color fastness to perspiration helps to determine the tendency of a dyed fabric to fade or to stain while in the perspired state. Usually, some dyed fabric, showed color staining susceptibility towards perspiration. This test took part to determine the resistance of color of dyed textile to the action of acidic and alkaline perspiration. Here, the perspiration test was carried out following the test procedure ISO-105-E04. Both alkali and acid tests were carried out for each sample.

G. Effect on Color Fastness to Water Test: Color fastness to water test was performed following the test procedure ISO -105-E01. It was observed that the fastness properties were satisfactory for Cool Dyeing and Dip dyeing but for Acid wash, there remained a possibility of further color staining while washing with water only.

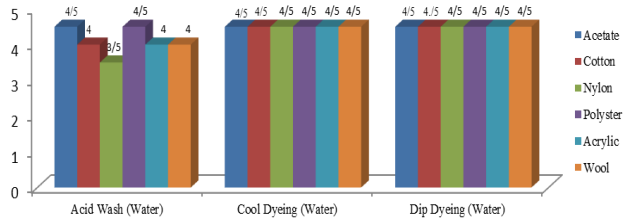

Fig.9. Change in color fastness to water on Non-washed, Acid washed, Cool dyed and Dip dyed Garments

H. Effect of fabric Handfeel: Regarding the handfeel of the fabric, Acid washed garment exhibited softer feel, while holding them between the thumbs. Between cool dyeing and dip dyeing, cool dyed garment showed a bit harsh feel than dip dyed garment. Because fixation of dyestuffs were more for dip dyeing than cool dyeing process.

V. Discussion

Numerous physical and mechanical parameters are assessed and observed to understand the reasons behind the variation in quality during industrial acid wash cool dyeing and dip dyeing processes. For acid washing, the garment is subjected to double time processing, first dyeing and then washing. Also, during acid washing, a garment is introduced with $KMnO_4$ (and H_3PO_4) soaked thermocol ball. Due to the frictional action between these thermocol balls, cylindrical action of the machine and oxidation reaction on cellulosic contents by the aforementioned chemicals, degradation of color and deterioration in fiber surface occurs.

Moreover, as a result of the change in tension of the constituent molecules decreases the stitch length of the knitted structure, this eventually increases in GSM than the other two processes. Also, chemical actions extended washing cycle and frictional forces increase course and wales placement distortion, this resulting in dimensional changes like shrinkage and spirality. On the other hand, for cool dyeing and dip dyeing as there is less chemical process involved hence increase in fabric weight is lower (7%) compared to Acid washed garment (12%).

Besides, with the increase of weight, therein lies a possibility of an increase in bursting strength for acid washed garment. But on the contrary, the presence of alkaline potassium permanganate solution along with the thermocol ball reacts with the primary wall of cellulose, which ultimately loosens and breaks them. It also, partially affects the secondary wall.

For that reason, within cellulose, the internal bonding force among the molecules gets weakened which results in lower tensile strength. Hence, weaken the bursting strength of the acid washed garment.

Maximum strength loss (15.86%) occurred in the case of Acid washed T-Shirt. (-0.71%) for Cool dyed and (1.04%) for dip dyed t-shirt. For Cool dyed t-shirt, the value is negative as the bursting strength increases than the non-wash sample. As the T-Shirt is introduced with dye bath without any corrosive material the loop becomes closer to each other as a result the fabric becomes more compact than earlier and eventually increases the bursting strength. However, for dip dyed item, bursting strength is not decreased significantly as there, because fewer chemical processes are being involved and also, dyeing is done in an open bath.

Similar issues happened with the fastness properties as well. During acid washing, alkaline $KMnO_4$ hydrolyzed the cotton surface. At first, by attacking the projecting fibre and then stroked on the inner fibre portion. As yarn is constituted with fibre, it was gradually hydrolyzed with time. As a result, the primary wall (outer layer) of the cotton fiber became unstable and broke down comparatively faster due to the frictional action (mechanical forces) of the rotating cylinder of the washing machine. With time the places where $KMnO_4$ soaked thermocol balls came in contact with fabric, fading occurred. As a result of colorfastness to washing, rubbing and perspiration tests, and acid washed garment is showing the inferior result in comparison with cool dyeing and dip dyeing.

VI. Conclusion

In response to the growing demand over knitted garment wash, this study investigated and characterized quality issues associated with acid washing, cool dyeing, and dip dyeing. The purpose of this study was to evaluate the scientific reasoning behind the complications while in production and with the finished garment. This study also reveals that, though customers may ask for similar wash effects over the same fabrication, still precautionary steps are mandatory to ensure the uniform desired level of quality. It is also revealed that, in sense of look and versatility, acid washed garment will come forward, but regarding quality assurance, it requires more care and cautious steps while in production. This study offers several implications for both production people and apparel customers. In some instances, factories can frame their production unit to use pre-shrunk fabric, pattern adjustment while in acid washing to avoid any unwanted issues with this wash. Although the present analysis provides an understanding of the effect of different wash effect on knitted garments, the experiment is conducted only over a small lot of garments. So far, for most of the cases, the test results were within the tolerance level. But, it can be predicted that during bulk production the differences can be more significant, which can lead to a disaster in production in the long run. Hence, this study is a little approach towards optimization in current stages of production. More implementation is required towards sustainable practices in the textile and clothing business for a greener world.

VII. Nomenclature

GSM: GSM is a unit to specify the weight of a fabric. The meaning of GSM is 'Gram per square meter'. This is the metric measurement of the weight of a fabric. With GSM calculation we can evaluate whether a fabric is light or thicker.

RFD: Meaning, Ready for Dye. RFD fabric passed through different preparatory processes like scouring, bleaching, equalizing etc. generally this fabric used for garment dyeing or washing.

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AUTHORS PROFILE

Md. Shohan Parvez is currently working as a lecturer at the Department of Textile Engineering, Khulna University of Engineering & Technology (KUET). He completed his graduation from Mawlana Bhashani Science and Technology University in Textile Engineering. Earlier back, we worked in renowned factories and buying offices for more than 5 years. His concentration areas are Apparel manufacturing, Washing and finishing treatments, Apparel merchandising, E-Textiles, Surface modification, Sustainable textiles, Nano-technology in textiles.

Md. Ishtiaque Rahman is a grad student from the Department of Textile Engineering, KUET. His specialization is in Apparel Manufacturing and Engineering, Garment processing and finishing treatments, Merchandising.

Tarikul Islam is currently working as a Lecturer of the Department of Textile Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh. He has completed his B.Sc. in Textile Engineering from Mawlana Bhashani Science & Technology University, Tangail-1902, Bangladesh. Also, pursuing his M.Sc. in Textile Engineering in Bangladesh University of Textiles, Dhaka, Bangladesh. After completed his graduation, he worked as a Management Trainee Officer at Vertex Group (Nov, 2015-April, 2016). In 2016, he decided to change his passion and joined as Lecturer at Port City International University, Chittagong, Bangladesh (April, 2016- March, 2018) and after that joined as a Lecturer at BGMEA University of Fashion & Technology, Dhaka, Bangladesh in March, 2018. His research interest is Polymer and Composite, Natural Dyes, Biobased Materials, Production Planning & Control, Quality Management etc.

S.M. Razwan Ahmed is currently working in Square Denims Limited (Washing Unit) as a Denim Wash technician. He has strong expertise in both dry & wet washing processes. Apart from these, he has also good technical over knit washing treatments.