

Comparative Study of Relevant Mechanical and Comfort Properties Between Same Structured Solid Dyed and Yarn Dyed Woven Fabrics

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ABSTRACT

The purpose of this study is to investigate the mechanical and comfort properties of solid-dyed and yarn-dyed fabrics of the same construction. Two plain fabrics (solid dyed and yarn dyed) and two oxford fabrics (solid dyed and yarn dyed) were made on an air jet loom. After finishing, tested the mechanical and comfort properties of all samples. A Scanning electron microscopy (SEM) was used to thoroughly investigate the microstructural parameters of woven fabrics. Yarn-dyed fabrics exhibit higher tensile strength than solid-dyed fabrics, with a 13.46% increase in warp direction and 29.48% in weft direction for plain fabrics, and an 8.98% increase in warp and a 0.72% decrease in weft for oxford fabrics. Yarn-dyed fabrics show higher tear strength than solid-dyed fabrics, with a 3.76% increase (warp) and 32.18% increase (weft) for plain fabrics, and a 9.54% increase (warp) and 1.94% decrease (weft) for oxford fabrics. Stiffness, abrasion, softness, and warmth properties are greater in solid-dyed fabric due to the mercerizing process because mercerizing treatment improved these properties. The findings of the experiment, although the fabric construction is the same, the fabric properties appear different due to the different manufacturing processes.

Keywords: Fabric manufacturing process, Mechanical properties, Comfort properties



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1. Introduction

Fabric is a pliable structure made of fibers, filaments or yarns by weaving, knitting & chemical bonding processes etc. Two sets of yarns, known as the warp and weft, are interlaced at a correct angle to create woven fabric. Warp yarns continue to run longitudinally along the fabric's length, whereas weft yarns continue to run transversely. The coloration of woven fabrics can determine their various varieties, including yarn dyed, solid dyed and printed fabrics. Yarn-dyed fabrics are those in which each individual yarn is colored before weaving to provide a unique colorful effect or check or striped pattern in the fabric. Solid dyed fabric is dyed continuously, creating a single-colored appearance, while printed fabrics use one or more colors/dye particles to specific areas based on design, pattern, repeat, and color [1]. Woven fabrics are manufactured for a variety of end uses, each with unique performance requirements. The performance and suitability of woven fabric for a given purpose are determined by its chemical and physical structures. The useful life of cotton-woven fabric is impacted by variations in its mechanical properties, which include tensile strength, tearing strength, abrasion resistance, pilling resistance, and stiffness [2]. Fabric comfort is a complex phenomenon involving psychological, tactile, and thermal aspects. Psychological comfort is influenced by garment style, fit, and fashion, while tactile comfort is directly related to fabric handle properties. Thermal comfort is the factor governed by the movement of heat, moisture, and air through the fabric [3]. Many

researchers have investigated the woven fabric mechanical and comfort properties phenomenon [4]. For instance, Khandual et al. found that singeing process removes any unwanted fluffy surface or fine fiber ends that protrude from the textile surface [5]. Jantip et al. found that bleaching with hydrogen peroxide (H₂O₂) in alkali medium decreases the strength of cotton fabric and also decreases the strength during the dyeing process [6]. Nassif et al. explained that the scouring process and bleaching process significantly decrease the tearing strength of grey woven fabrics by approximately 6.7% and 26.7%, respectively, primarily due to fabric shrinkage and compactness [7]. Adamiak, M. ed., found that the mercerization process increases the abrasion resistance [8]. Patil et al. found that Mercerization improves tensile strength and crystallinity, leading to improved tactile comfort. Low-stress mechanical properties, such as tensile energy, bending rigidity, and shear rigidity, indicate toughening of mercerized fabrics. However, the tactile comfort is slightly improved due to high extensibility and resiliency. Also explain that mercerization increases cotton fibers' swelling and straightening, increasing fiber radius and stiffness, which is influenced by cellulose crystallinity and fiber cross-sectional shape [9]. Mukhopadhyay, Ghosh, and Bhaumik explained that after bleaching and dyeing, the tear strength of fabrics decreased [10]. Most of the past literature examined the impact of wet processes, parameters, and chemicals on fabric properties. However, there is a lack of research on mechanical and

comfort properties comparison between yarn-dyed and solid-dyed fabrics and manufacturing processes. To fill the research gap, this study aims to compare the mechanical and comfort properties of solid-dyed and yarn-dyed fabric.

2. Material and Method

2.1 Materials

2.1.1 Plain Fabrics

In this study, two types of plain fabrics such as solid dyed and yarn dyed plain fabrics were made on a Toyota air jet loom (Japan) equipped with a crank shedding mechanism at Silver Composite Textile Mills Ltd. in Gazipur. The same construction is maintained for both solid-dyed and yarn-dyed fabrics. 50/1 CCW (Combed Compact Yarn for Weaving) cotton yarns are used to make the fabric and the yarns are manufactured by the ring spinning technology. This yarn is purchased from Thiagarajar spinning mills, India. Yarn details are given in Table-1. Fabric weave structure and finish fabric samples are given in Fig-1 (a) and Fig- 2 (a, b).

Table 1 Yarn details are used for both solid-dyed and yarn-dyed plain fabrics.

Yarn Code	Yarn Type	Yarn count	Actual Count	Strength (RKM)	Elongation at break %	IPI %
Warp & Weft	Compact	50	50.46	29.52	5.57	15

Plain fabric specification: Ends per inch (EPI) x picks per inch (PPI) / (Warp count x Weftcount) x Fabric Width

Plain fabric construction: 148x100 /50x50 x 57”

2.1.2 Oxford Fabrics

In this study, two solid-dyed Oxford fabrics and two yarn-dyed Oxford fabrics were produced. The same construction is maintained for all samples. All samples were made on an air jet Picanol Summum (Belgium) weaving machine at Silver Composite Textile Mills Ltd. in Gazipur. The machine was equipped with a cam shedding mechanism. 40/1CCW (Combed Compact Yarn for Weaving) cotton yarns are used in the warp direction, and 16/1 CCW (Combed Compact Yarn for Weaving) yarn is used in the weft direction to make the fabric, and the yarns are manufactured by the ring spinning technology. 40/1 CCW and 16/1 CCW both yarns are purchased from India. Yarn details are given in Table-2. Fabric weave structure and finish fabric samples are given in Fig-1 (b) and Fig-2 (c, d).

Table 2 Yarn details are used for both solid-dyed and yarn-dyed Oxford fabrics.

Yarn Code	Yarn Type	Yarn count	Actual Count	Strength (RKM)	Elongation at break %	IPI %
Warp	Compact	40	40.17	24.5	5.09	123
Weft	Compact	16	15.89	21.03	6.1	34

Oxford fabric specification: Ends per inch (EPI) x pick per inc (PPI)/(Warp count x Weftcount) x Fabric Width

Oxford fabric construction: (106x60) /40+40x16 x 57”



Fig.1 Weave structure of samples

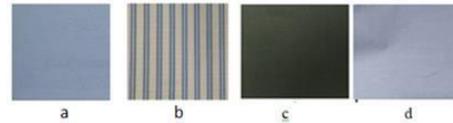


Fig.2 Finished fabric of all samples, (a) Solid dyed plain fabric (b) Yarn dyed plain fabric (c) Solid dyed oxford fabric (d) yarn dyed oxford fabric

2.2 Method

Flow chart of yarn dyeing process

Grey yarn → Soft winding → Scouring and Bleaching → Peroxide killer → Neutralization →

Dyeing → Neutralization → Soaping → Finishing

Wet process sequence of solid and yarn dyed fabric Yarn-dyed fabrics are those in which each individual yarn is colored before weaving to provide a unique colorful effect or check or striped pattern in the fabric. After making the grey fabric in weaving, the solid dyeing is done continuously, creating a single-colored appearance. The wet process sequence of solid-dyed and yarn-dyed fabric is given in Fig.3.

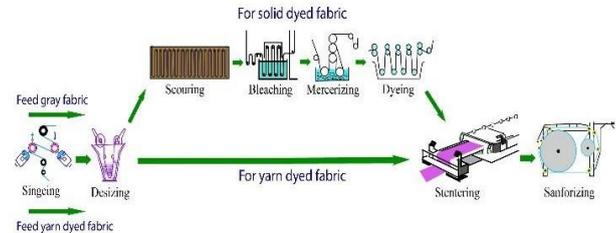


Fig.3 Wet process sequence of samples

Table 3 Standard test methods of the fabric properties

Fabric properties	Standard fabric testing method
Surface morphological analysis	SEM Test
Tensile strength	ISO 13934-2-2014
Tear strength	ISO 13937-2 auto-stop
Stiffness properties	ASTMD1388
Pilling resistance	EN ISO 12945-2
Abrasion resistance	BS 5690
Comfortability	FTT

2.2.1 Atmosphere for conditioning and testing

After finishing, all samples were conditioned for 24 hours before testing at 65 +/- 2% relative humidity and 20 +/- 2°C temperature

2.3 Characterization

2.3.1 Surface morphological analysis

Fabric surface morphological properties were tested using a scanning electron microscopy (SEM) machine. The origin of apparatus is Netherlands, Model Phenom Pro. This test is used to evaluate the microstructural parameters of fabrics, such as fiber orientation, diameter, length, crimp, and cross-sectional shape, as well as fabric non-uniformity and defects.

2.3.2 Tensile strength test

The tensile strength of fabrics was tested using the ISO 13934-2-2014 method and the grab method. A Titan 5 universal strength tester was used, with a sample size of 20 cm x 10 cm and calibrated to break samples at 50 mm/minute. Tear strength test

The tear strength properties of fabrics were tested using the ISO 13937-2 auto-stop method. A Titan 5 universal strength tester was used for the experiment. The origin of apparatus is England, Jaw Separation: 100mm, Load cell: 5000N. The sample size for the experiment was 20 cm x 5 cm. There were three warp-way and three weft-way (one for each plain and Oxford) samples taken. The device was calibrated to break the sample at a speed of 100 mm/minute, and a tested length of 7.5 cm was used.

2.3.3 Stiffness testing

A stiffness test is used to evaluate the fabric's resistance to bending. The Stiffness properties of fabrics were tested using the ASTM D1388 method. A Stiffness (MESDAN s.p.a) tester was used for the experiment. The origin of apparatus is Italy. The sample size for the experiment was 6"x1". Samples hang and flex due to weight, stopping pushed contact with a sliding plate at 41.5° bending angle.

2.3.4 Pilling test

Small, fluffy balls of fiber that form on a fabric's surface are called pilling. Pills are formed when loose fibers rub against one another or other surfaces, such as your skin. The propensity of the fabric to surface fuzzing and pilling was determined using the EN ISO 12945-2 method. A Martindale tester was used for the experiment. The origin of apparatus is UK, Brand: James Heal, Model: 1305. Three specimens were taken for each sample for the experiment, and the average result was counted. Each specimen tested by 2,000 revolutions.

2.3.5 Abrasion test

Abrasion is a mechanical breakdown of fabric components that results in the loss of performance attributes such as strength and weight. A Martindale tester was used for the experiment. The origin of apparatus is UK, Brand: James Heal, Model: 1305. Three specimens were taken for each sample for the experiment, and the average result was counted. Each specimen tested by 3,000 revolutions with 9 KPA weight.

2.3.6 Comfortability assessment

The Fabric Touch Tester (FTT) is a device that measures physical properties related to touch feels of textiles like knitted and woven fabrics. It measures compression, thermal, bending, and surface properties within 5 minutes. The instrument has dimensions of 51 cm in width, 59 cm in depth, and 84 cm in height. Fabrics are cut in an L shape and placed on the instrument's bottom plate. The upper plate is set at a higher temperature to mimic skin and textile temperature differences. The compression and bending sensors are fed with the tested fabrics' input, and readings are computed using FTT software. Three specimens were taken for each sample for the experiment and sample size L shape (31x31 cm).

3. Result and Discussion

3.1 Comparative analysis of Surface morphological properties:

Scanning electron microscopy (SEM) images are used to evaluate the microstructural parameters of woven fabrics, such as fiber orientation, diameter, length, crimp, and cross-sectional shape, as well as fabric non-uniformity and defects. Fig.4 & 5 show the more fiber orientation and roundness of both plain and Oxford solid dyed fabrics than yarn dyed fabrics. Because mercerization increases cotton fibers' swelling and straightening, increasing fiber radius and stiffness, which is influenced by cellulose crystallinity and fiber cross-sectional shape [9].

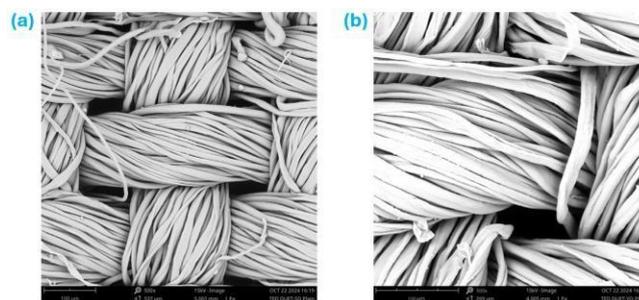


Fig.4 SEM of plain fabrics (a) Solid dyed plain fabric, (b) Yarn dyed plain fabric

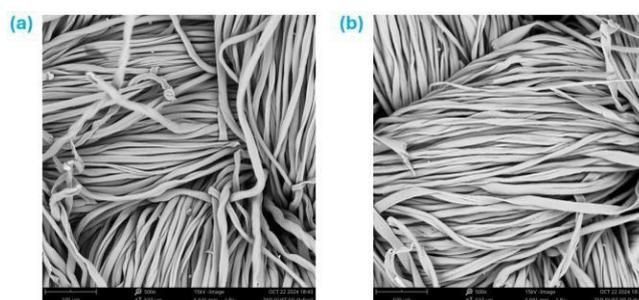


Fig.5 SEM of oxford fabrics (a) Solid dyed oxford fabric, (b) Yarn dyed oxford fabric

3.2 Mechanical properties

3.2.1 Comparative analysis of tensile strength

Fig.6 shows the comparison of tensile strength between yarn-dyed and solid-dyed woven fabrics. It can be seen that the comparatively tensile strength of yarn-dyed fabrics (warp and weft both ways) is higher than that of solid-dyed fabrics because in the finishing stage after weaving, the bleaching and dyeing process is not done in yarn-dyed fabric, which is done in solid-dyed fabric. Bleaching with hydrogen peroxide (H_2O_2) in alkali medium decreases the strength of cotton fabric and also creases the strength during the dyeing process [6]. Warp-way tensile strength (both yarn-dyed and solid-dyed fabric) is greater than weft-way strength due to the fact that the number of threads per inch in the warp direction is greater than the weft direction.

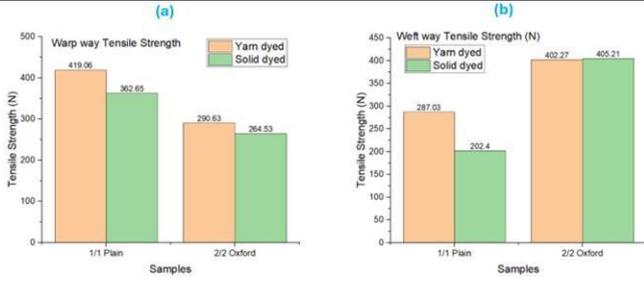


Fig.6 Comparative analysis of tensile strength: (a) Warp way tensile strength, (b) Weft way tensile strength

3.2.2 Comparative analysis of tearing strength

Fig.7 shows the comparison of tearing strength between yarn-dyed and solid-dyed woven fabrics. It can be seen that the comparatively tearing strength of yarn-dyed fabrics (warp and weft both ways) is higher than that of solid-dyed fabrics because of the scouring and bleaching process, which is done in solid-dyed fabric but not in yarn-dyed fabric. The scouring process and bleaching process significantly decrease the tearing strength of grey woven fabrics by approximately 6.7% and 26.7%, respectively, primarily due to fabric shrinkage and compactness [7]. Comparatively, warp-way tearing strength (both yarn-dyed and solid-dyed fabric) is greater than weft-way strength due to the fact that the number of threads per inch in the warp direction is greater than the weft direction.

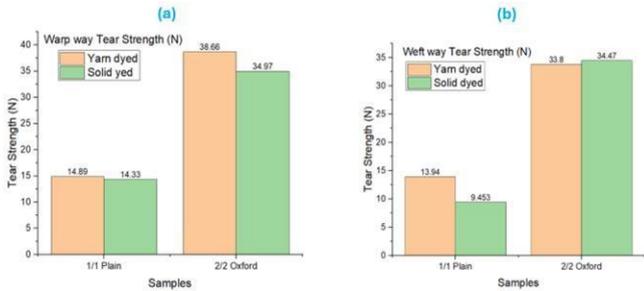


Fig.7 Comparative analysis of tearing strength: (a) Warp way tear strength, (b) Weft way tear strength

3.2.3 Comparative analysis of stiffness analysis

Fig.8 shows the comparison of stiffness properties between yarn-dyed and solid-dyed woven fabrics. It can be seen that the comparatively bending length of yarn-dyed fabrics (warp and weft both ways) is lower than that of solid-dyed fabrics due to the mercerizing. Mercerization increases cotton fibers' swelling and straightening, increasing fibre radius and stiffness, which is influenced by cellulose crystallinity and fibre cross-sectional shape [9].

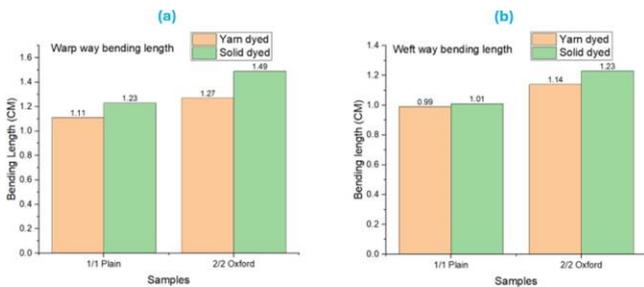


Fig.8 Comparative analysis of stiffness properties: (a) Warp way bending strength, (b) Weft way bending strength

3.2.4 Comparative analysis of pilling properties

Table 4 showed the same result between yarn-dyed and solid-dyed fabrics because the fabrics had good singeing and used good yarn quality. Singeing process to remove any unwanted fluffy surface or fine fiber ends that protrude from the textile surface as a result increases pill resistance [5].

Table 4 Grading of pilling rating

Samples	Pilling rating (yarn dyed)	Pilling rating (solid dyed)	Comments	Fabric quality
1/1 Plain	4-5	4-5	Slight Pilling	Very Good
2/2 Oxford	4-5	4-5	Slight Pilling	Very Good

3.3.5 Comparative analysis of Abrasion Resistances

This study evaluated the abrasion resistance of all samples by measuring the percentage of fabric weight loss. Fig.9 showed more weight loss in yarn-dyed fabrics than solid-dyed fabrics. As the weight loss increases, the abrasion resistance of the yarn-dyed fabrics decreases during the fact-mercerizing process. The abrasion resistance increases with the mercerization process and decreases with the use of silicone softeners [8]. Mercerization process of cotton fiber with caustic soda converts the fiber from bean shape to circular shape. As a result, the surface of the fabric becomes smooth and the weight loss of the fabric due to friction is reduced [9].

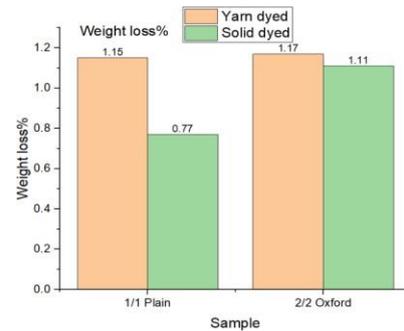


Fig.9 Comparative analysis of weight loss%

3.2.6 Comfortability assessment (softness & warmth properties)

Table 5 shows the comparison of softness and warmth properties between yarn-dyed and solid-dyed woven fabrics. It can be seen that the comparatively softness and warmth value of yarn-dyed fabrics (warp and weft both ways) is lower than that of solid-dyed fabrics due to the mercerizing. Mercerizing is done in solid-dyed fabric but not in yarn-dyed fabric. Mercerization enhances comfort in fabrics by decreasing moisture absorption, wicking, and enhancing aesthetic comfort. It creates space between clothes and skin, allowing air flow and a cooler feel. Mercerized fabrics also increase thermo-physiological comfort, making them suitable for summer clothing. Overall, mercerization treatment enhances the comfort of cotton fabrics [9].

Table 5 Grading of Softness, Warmth properties

Comfort properties	Sample	Outer		Inner	
		Yarn dyed	Solid dyed	Yarn dyed	Solid dyed
Softness	1/1 Plain	0.23	0.15	0.14	0.16
	2/2 oxford	0.21	0.23	0.09	0.26
Warmness	1/1 Plain	0.58	0.56	0.23	0.13
	2/2 oxford	0.35	0.69	0.05	0.17

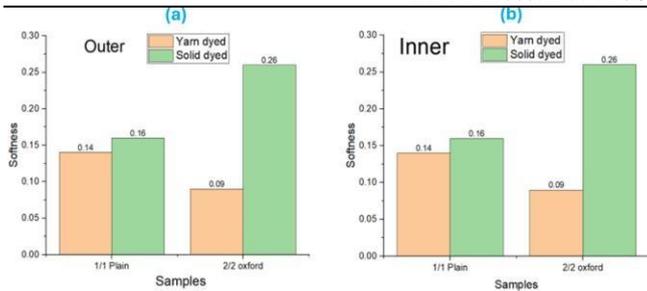


Fig.10 Comparative analysis of softness: (a) Outer (b) Inner

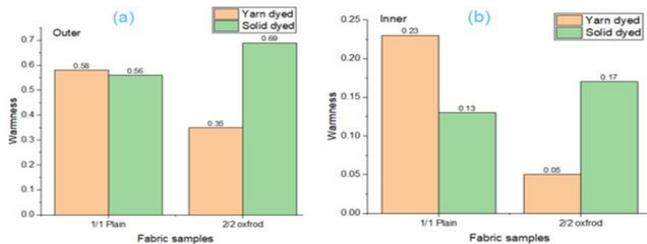


Fig.11 Comparative analysis of warmth: (a) Outer (b) Inner

4. Conclusion

Industrially, the manufacturing methods of solid-dyed and yarn-dyed fabrics are different. To make the yarn-dyed fabric, each yarn is dyed separately before weaving to provide a unique colorful effect or check or stripe pattern in the fabric. For solid dyed fabric, after weaving, grey fabric is dyed continuously and creates a single-colored appearance in the fabric. The purpose of this study is to investigate the mechanical and comfort properties of solid-dyed and yarn-dyed fabrics of the same construction. Two plain fabrics (solid dyed and yarn dyed) and two oxford fabrics (solid dyed and yarn dyed) were made on an air jet loom. After finishing, tested the mechanical and comfort properties of all samples. A Scanning electron microscopy (SEM) was used to thoroughly investigate the microstructural parameters of woven fabrics. Yarn-dyed fabrics exhibit higher tensile strength than solid-dyed fabrics, with a 13.46% increase in warp direction and 29.48% in weft direction for plain fabrics, and an 8.98% increase in warp and a 0.72% decrease in weft for oxford fabrics. Yarn-dyed fabrics show higher tear strength than solid-dyed fabrics, with a 3.76% increase (warp) and 32.18% increase (weft) for plain fabrics, and a 9.54% increase (warp) and 1.94% decrease (weft) for oxford fabrics. Stiffness, abrasion, softness, and warmth properties are greater in solid-dyed fabric due to the mercerizing process because mercerizing treatment improved these

properties. The findings of the experiment, although the fabric construction is the same, the fabric properties appear different due to the different manufacturing processes.

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References

- [1] Islam, S., Chowdhury, S. and Akter, S., 2018. The experiential analysis of woven fabric for reproduction. *Journal of Textile Science and Technology*, 4(1), pp.18-48.
- [2] Jahan, I., 2017. Effect of fabric structure on the mechanical properties of woven fabrics. *Advance Research in Textile Engineering*, 2(2), p.1018.
- [3] Nayak, R.K., Punj, S.K., Chatterjee, K.N. and Behera, B.K., 2009. Comfort properties of suiting fabrics.
- [4] Özdemir, H., 2017. Thermal comfort properties of clothing fabrics woven with polyester/cotton blend yarns. *Autex Research Journal*, 17(2), pp.135-141.
- [5] Khandual, A., Baciú, G., Luximon, A. and Rout, N., 2016. Objective evaluation of singeing efficiency by digital image processing. *The Journal of the Textile Institute*, 107(2), pp.273-281.
- [6] Jantip, S., Porntip, S.B. and Suwanruji, P., 2012. Effect of pretreatment and dyeing processes on the physical properties of Poly (Lactic acid)/Cotton blended fabric. *Advanced Materials Research*, 486, pp.253-259.
- [7] Nassif, N.A.A., 2019. Effect of different wet processing stages on physical properties of cotton woven fabrics. *Fibres Text*, 4, pp.13-18.
- [8] Adamiak, M. ed., 2012. Abrasion resistance of materials. *BoD—Books on Demand*. pp.247-264.
- [9] Patil, S., Mahapatra, A., Gotmare, V.D., Patil, P.G., Bharimalla, A.K. and Arputharaj, A., 2019. Effect of different mercerization techniques on tactile comfort of cotton fabric. *Indian Journal of Fibre & Textile Research (IJFTR)*, 44(2), pp.217-222.
- [10] Mukhopadhyay, A., Ghosh, S. and Bhaumik, S., 2006. Tearing and tensile strength behaviour of military khaki fabrics from grey to finished process. *International journal of clothing Science and technology*, 18(4), pp.247-26