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Exploring the distinct physico-mechanical characteristics of bio-polymer based chambray fabric

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Abstract: Denim is known for its strength and longevity whereas chambray is softer, more comfortable and often used for trendy garments. This research work compares the physical and mechanical properties of bio-polymer based organic cotton (100%) denim and organic cotton (100%) chambray fabric. While the both fabrics had identical warp and weft counts, denim had a higher EPI and PPI despite having a comparable construction. Denim has a higher (5.65%) Grams Per Square Meter (GSM) than chambray which in turn allows for greater dye absorption. While chambray had a lower tensile and bursting strength than bio-polymer based 100% cotton denim in the warp direction, the weft direction showed the reverse. Additionally, denim performed much better in the tear strength test (6.29%). Chambray fabric, on the other hand exhibited less pilling behavior. The abrasion resistance test yielded excellent results for chambray fabric. The results show that denim is stronger, more compact, and more durable, making it better suited for tough conditions. In contrast, chambray offers a softer feel, better breathability, and greater comfort in summer, along with a distinct look for coloration.

Keywords: tensile strength; fabric construction; abrasion resistance; comfort performance; organic cotton; pilling behavior.

INTRODUCTION

Modern consumers' demand for absolute bio-polymer based comfortable apparel in today's cutting-edge is growing simultaneously. Contemporary consumers seek not only trendy design but also opt for comfort apparel for

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everyday use.[1,2] The cozy embrace of fabric is like slipping into a cocoon. Its softness and cooling effect provide relief in regular daily life use.[3] Bio-polymer based materials like cotton have been the prime choice for users from the beginning of modern civilization.[4] Hence, there is a wide range of cotton fabrics available in the market. However, these fabrics vary from one to another according to manufacturing techniques, construction and designs. Additionally, manufacturers along with buyers are in a race to introduce new fabrics designs and construction to provide additional functions to consumers so that they can solve the real life challenges as per consumers demand for bio-polymer based materials.[5]

Since chambray evolved from cambric, its origins can be traced back to the mid-1500s. Cambric, originally fashioned from linen which is an airy plain weave fabric. Cambrai, a northern French region that was formerly part of Flanders where the cloth was first manufactured.[6] Shirting, handkerchiefs, and elaborate needlework and lace were common uses for cambric, a high-quality fabric. On the other hand, Denim is a fabric that is comfortable, fashionable, affordable and durable which make it ideal for many garments and accessories. A lighter cotton twill fabric, denim is recognizable by its diagonal weave or texture and traditionally dyed indigo blue.[7] Chambray, a 100% cotton plain-weave soft fabric with diagonal ridges has a white weft and a light blue warp. Chambray, with its blue warp and white weft, is often mistaken for denim. Though similar to denim, chambray is lighter and woven differently. The fabric is thinner and softer than denim.[8]

Numerous knitted fabrics have been the subject of substantial investigation in bio-polymer based textile research, with a focus on qualities, uses, and performance indicators.[9–11] The investigation of chambray fabric is severely understudied. Research on knitted fabrics has been extensive but chambray has been largely disregarded in favor of denim, cellulosic fibers and polyester. More research into the unique properties, performance features, and possible uses of chambray fabric deserves consideration due to this void in the existing literature.

The research work explores the physical traits of bio-polymer based chambray fabric compared to denim fabric with different areas maintaining the same construction parameters such as EPI, PPI, tear strength, bursting strength, abrasion resistance, pilling nature and fastness properties. The research attempts to offer a thorough comprehension of bio-polymeric chambray fabric and its possible uses in various domains such as design, textiles, and fashion. The purpose of this research work is to fill a knowledge vacuum in textile science and add to the existing body of knowledge. The findings should then inform fabric design, industry applications, and future research.

EXPERIMENTAL

Materials

100% cotton yarns are used as bio-polymer to prepare chambray fabric of 1/1 plain structure and denim fabric of 3/1 twill structure for the present study. Both chambray and denim fabric's warp yarns were Indigo dyed and the weft yarns were kept undyed. both warp and weft yarns were sourced from Simtex Industries PLC. EPI and PPI of grey denim fabric are 98 and 50 respectively. The warp count and weft count of grey denim fabric are 32/2 Ne and 21/2 Ne individually. The same specifications are maintained for chambray fabric.

Experimental apparatus

Air jet loom (Picanol Omni plus 800, China) and rapier loom (Picanol OptiMax-I, China) were used for weaving chambray and denim fabric respectively. Mechanical properties were assessed through a tear tester (Thwing Albert, USA), tensile strength tester (James H. Heal,UK), bursting strength tester (James H. Heal,UK), and abrasion and pilling tester (M235, UK).

Determination of EPI and PPI

Counting glasses were used to inspect samples. A square-shaped part of the counting glass helped count yarns per inch. This measurement was essential for analyzing woven fabric density and quality. The warp direction of the fabric's lengthwise threads was used to determine EPI. The weft direction of the threads flowing widthwise across the fabric was used to calculate PPI. These measures illuminated the woven material's structure and properties.

Determination of GSM

The test technique began with 48-hour fabric conditioning to guarantee adequate relaxation, following test method BS 2471:1978.[12] Five 100-square-centimeter test specimens were carefully cut from each sample using a GSM cutter. Each specimen was weighed carefully on an electric scale and multiplied by 100 to calculate GSM.

Determination of tensile strength

Test standard ISO-139342 was adopted to determine the tensile strength.[13] The bio polymer based manufactured fabric was conditioned for 48 hours before testing to ensure relaxation. Next, a 200 by 100-millimeter cloth sample was properly created. Two fabric ends were secured and fastened into jaws. Using a 100-millimeter gauge, the upper and lower front jaws were 25 by 25 millimeters and the upper and lower back jaws 25 by 50. Using a load cell, the force range was calibrated for the breaking point. The specimen was carefully positioned between the upper and lower jaws and pre-tensioned to straighten the lower end. The fabric ruptured after stretching. This was done five times for warp and weft to ensure thorough testing and analysis.

Determination of tear strength

According to ISO 13937-1, the fabric was conditioned for 48 hours to guarantee optimal relaxation before testing. Fabric samples were then cut from the warp and weft directions using a steel plate to precise specifications. Samples measuring 60 by 100 millimeters were taken from the weft and warp directions, respectively. A systematic strategy was used to gather five warp and weft samples for testing. To achieve accurate and consistent results, all parameters were properly set before testing. The fabric was loaded with 3200 grams (326.9 Newtons) during the tear test. Two jaws that fit a 20-millimeter slit secured the fabric. The tear test used a C-type pendulum to break the fabric apart.

Determination of abrasion

Bio polymer based manufactured fabric durability testing was meticulously done according to ISO 12947-3:1999.[14] At first, the fabric was conditioned for 48 hours to relax. After that, a sample cutter neatly cut 38-millimeter samples. To test these samples were placed in golden rings. Pushing down on each specimen's polyurethane foam provided pressure. To ensure accuracy, specimen holders were properly set up in the testing machine and all counters were calibrated to zero before testing. Sample weights were taken at 250, 500, 750, 1000, 1250, 1500, and 2000 cycles during testing. These measurements were crucial for computing each sample's mass loss %, which provided ISO 12947-3:1999-compliant fabric abrasion resistance and durability statistics.

Assessment of pilling

The bio polymer based manufactured fabric was conditioned for 48 hours before testing to ensure relaxation. After cutting the test specimen using a pilling cutter, 140-millimeter samples were taken. Two samples were prepared for the pilling table and specimen holder. The gadget was wrapped in a rubber specimen holding ring and a 140-millimeter specimen disk was placed on top, allowing excess material to dangle over the edge. A 90-millimeter felt was also used. After rolling the rubber ring up the loading block, the specimen holder was removed. Before starting the machine, all counters were checked for zero. The fabric's pilling resistance was assessed using a 5-point scale at 125, 500, and 2000 cycles.

Determination of bursting strength

Test standard ISO 13938-1:1999 approach assessed the fabric's bursting strength.[15] The bio polymer based manufactured fabric was conditioned for 48 hours to relax. After that, a one-yard swatch was carefully split into 125-millimeter test specimens. After that, the specimens were carefully placed between the testing device's top and bottom clamps to avoid wrinkles. Turning the hand wheels clockwise ensured homogeneous specimen compression in the clamps. The fabric was held tightly and pressured until it ruptured at a specific pressure. All pressure and time data from the testing machine were carefully collected.

RESULTS AND DISCUSSION

Impacts of bio-polymer based chambray and denim fabric on EPI and PPI

Denim has a higher average EPI of 114 than chambray, which is obvious from the appearance which is seen in Figure 1. Additionally, chambray has a lower average PPI of 61 than denim. According to a study, denim fabric features a weft count of 20 Ne and has PPI of 50.[16] In the present study, the weft count is 21 Ne, resulting in a higher yarn density per inch due to its finer nature and aligning closely with traditionally utilized denim fabrics. The entire width and total number of warp threads determine the EPI. Once the fabric enters the relaxation condition, it begins to compress. The compactness and tear strength of fabrics with a higher EPI are superior to those with a lower EPI. Fabrics with a lower EPI rating also tend to be more comfortable. The lower porosity between the yarns in denim's 3/1 twill weave structure means that there is less space for the yarns to compress after relaxation that leads to a higher EPI. Chambray fabric has a lower EPI than other fabrics, but it can compress more yarns per inch because of its greater interlacement point and higher porosity between yarns. Because of its finer weave and increased breathability, chambray fabrics are ideal.

Fig 1. Impacts of chambray and denim fabric on EPI and PPI.

Impacts of bio-polymer based chambray and denim fabric on GSM

Compared to 100% bio-polymeric cotton chambray, 100% bio-polymeric cotton denim has a higher GSM as shown in Figure 2. GSM is a straightforward metric way to measure a fabric's weight. The higher GSM of denim fabric is due to the fact that, despite having similar yarn counts to chambray fabric, denim fabric contains two more warp yarns and one more weft yarn per inch. Denim with a higher GSM of 163.50 is less breathable than chambray which is 153.75. Studies show that an off-white 3/1 "Z" twill cotton-spandex fabric (97.8% cotton, 2.2% spandex) has GSM of 345.[17] As a result, chambray can be preferred for light dresses and denim for rough denim.

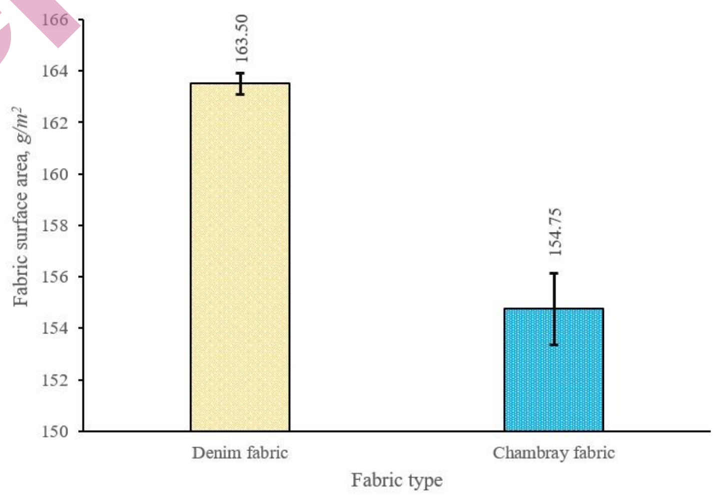

Fig 2. Analysis of GSM of chambray and denim fabrics.

Impacts of bio-polymer based chambray and denim fabric on tensile strength

Denim has a greater tensile strength in the warp direction than bio-polymer based chambray, as shown in Figures 3(a) and 3(b). Results were better with twill-structured denim fabric with a mean maximum force of 421.75N than with chambray fabric with 364.5 N because of the higher ends per inch. Less porosity, a high interlacement point, and a high cross over point are the three factors that contribute to a higher tensile strength. These mentioned factors are higher for plain structured fabric than for denim due to the higher EPI in denim. Therefore, denim with a 3/1 twill structure is stronger with an elongation of 18.14% in the warp direction than chambray about 16.61%, which has lower tensile strength. Previous study shows that the polyester denim sample exhibited the highest tensile strength (378.06 N in the warp direction, 371.28 N in the weft direction) due to its higher crystallinity, while the cotton denim sample had the lowest (321.03 N in the warp direction, 201.9 N in the weft direction). The CVC denim and PC denim samples showed similar strengths (304.25 N and 317.47 N).[16]

Bio-polymeric denim has a lower weft-direction tensile strength than bio-polymer based chambray, as shown in Figures 3 (c) and 3 (d). In PPI, the weft threads are not subjected to a sizing process or other specialized chemical treatment to boost strength. Instead, those are used in smaller quantities. Chambray and denim both have the same warp and weft counts and a comparable quantity of weft yarn. Chambray outshines denim in weft direction tensile strength with a mean maximum force of almost 280 N due to its lower porosity, higher interlacement point, and higher cross over point. The weft-direction tensile strength of chambray-woven fabrics is higher which is 18.29% than denim-woven fabrics which is 15.73% with the same percentage of cellulosic fibers.

Impacts of bio-polymer based chambray and denim fabric on tear strength

Figure 4 shows that compared to denim, chambray has a greater tear strength in both the warp about 18.42 N and weft directions about 21.27 N whereas denim fabric warp and weft tear strength is 12.68 N and 11.93 N respectively. A study showed that denim is composed of 100% cotton and features a 3/1 twill weave structure. It has undergone a normal wash process. The warp yarn strength is measured at 16.00 N, while the weft yarn strength is 9.86 N. For performance under heavy loads, a higher tear strength is necessary. It is making sure that holes in the fabric don't get bigger too quickly. On the other hand, chambrayis denser and thicker than 3/1 plain weave denim due to its 1/1 twill structure. The lower tear strength of chambray compared to denim is a result of its less compactness and interlacement. The fabric's tear strength allows it to withstand continuous friction.

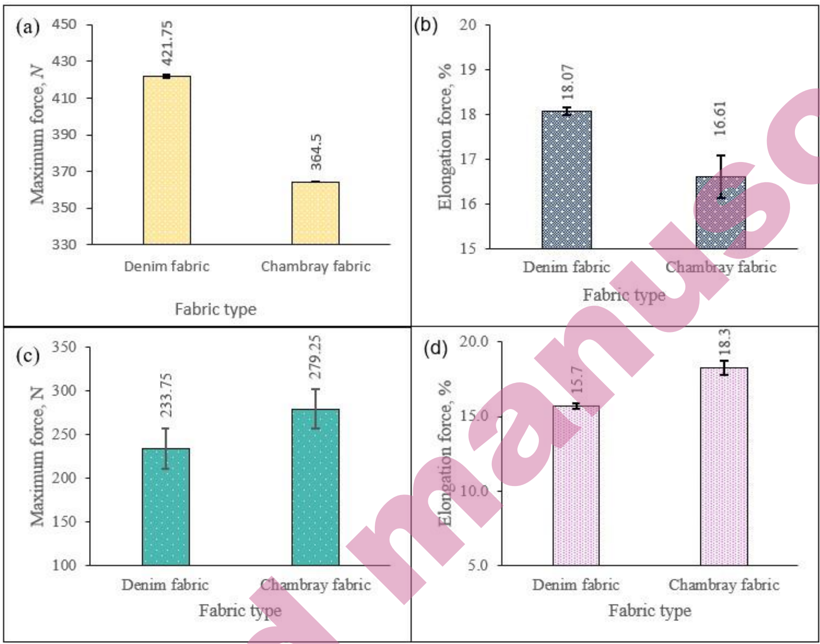

Fig 3. Warp wise tensile strength (a) maximum force and (b) elongation force and weft wise tensile strength (c) maximum force and (d) Mean elongation force of chambray and denim fabric.

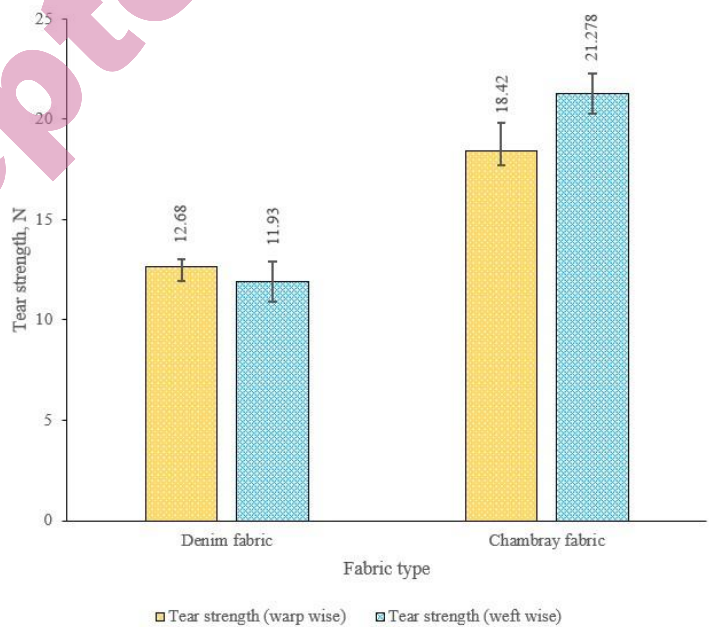

Fig 4. Analysis of tear strength of chambray and denim fabrics.

Impacts of bio-polymer based chambray and denim fabric on pilling resistance

TABLE I shows that compared to denim made entirely of cotton, 100% bio-polymeric cotton chambray resists pilling better. On the front side of the material, pilling occurred. Variations in denim and chambray are graded using a pilling assessment replica after they undergo rotational rubbing action on their faces. Denim exhibits a moderate to severe degree of pilling after 200 cycles, while chambray displays an extremely fine degree of pilling, according to the pilling replica. The study shows that the raw denim exhibited a fabric weight of 163.7 g/m² and demonstrated a pilling value of 5.[18] With 500 cycles, denim fabric grades start to show signs of slight pilling, while chambray grades show signs of slight to very slight pilling. After the 2000 cycle, the quality of denim drops to a 3 or 4 (moderate to slight pilling), while the quality of chambray fabric stays the same. As a result, denim's quality declines sharply after 250, 500, or 2000 cycles, while chambray's quality changes slightly. Therefore, chambray outperforms denim in terms of pilling resistance.

TABLE I. Pilling resistance of chambray and denim fabrics.

Sample Identity	Cycle	Grade	Comment
100% Cotton Denim fabric	250	4-5	Slight pilling to very slight pilling
	500	4	Slight pilling
	2000	3-4	Moderate pilling to slight pilling
100% Cotton Chambray fabric	250	5	Very slight pilling
	500	4-5	Slight pilling to very slight pilling
	2000	4-5	Slight pilling to very slight pilling

Impacts of bio-polymer based chambray and denim fabrics on abrasion resistance

The mass loss percentage is higher for 100% cotton denim than for 100% cotton chambray, as illustrated in Figure 5. The fabric's face surface is the one that gets abrasive. Increased GSM and fabric friction led to mass loss. Despite having comparable thread counts, denim boasts two more warp threads and one more weft thread per inch than chambray. This increases the friction, contact surface area, and GSM of denim. Compared to chambray, which has a lower EPI and PPI as well as a smaller surface contact area the reason for its low friction and lower mass loss percentage results in more mass loss per cycle for denim. One of the factors that affects mass loss (%) is the weave structure. Comparing denim and chambray, it is found that denim's 3/1 twill structure makes it more compact and has a higher GSM with an average mass loss percentage of 2.471, while chambray's 1/1 plain or poplin structure makes it less compact and has a lower mass loss percentage. According to a study, the abrasion resistance of 100% cotton denim fabric with a 3/1 Z twill weave decreased by approximately 9.3% after successive abrasion cycles. This reduction highlights the impact of prolonged mechanical stress on the fabric's durability.[19] Chambray is more comfortable than denim despite having less abrasion resistance.

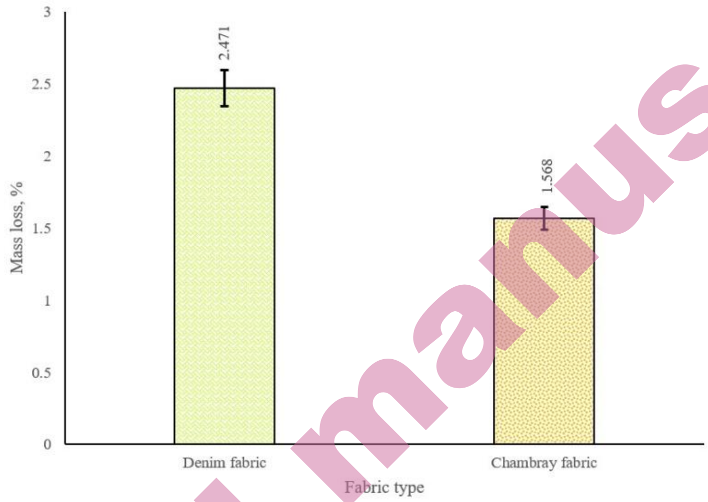

Fig 5. Analysis of abrasion resistance of chambray and denim fabrics.

Impacts of bio-polymer based chambray and denim fabrics on bursting strength

Figure 6 clearly shows that denim fabric outperforms chambray fabric in terms of bursting strength with 825 KPa. The fabric's bursting strength indicates the environmental factors that could lead to a rupture. Due to its higher EPI and PPI, denim can cover the porosity between its yarns, making the fabric more. Due to the reduced number of EPI and PPI, the bursting strength of chambray fabric is lower which is 695 KPa. However, the plain weave fabric with a warp density of 17 and weft density of 12 demonstrates a bursting strength of 113.06 kPa [20]. Increased bursting strength is another benefit of the weave structure, which supports the fiber. The bursting strength is directly proportional to the structure thickness as a result thinner structure has a lower bursting strength. Hence, compared to chambray fabric with a 1/1 plain weave, denim with a 3/1 twill structure is stronger.

Fastness properties of bio-polymer based denim and chambray fabric

Samples of 100% cotton denim were subjected to color fastness testing in dry conditions. The results are displayed in TABLE II. Colorfastness is likely indicated by the intensity or level in the "Dry" column, which ranges from 4 to 5. These ratings are accompanied by qualitative descriptions in the "Comment" column. A rating of 4 was given to most of the samples, which means good color fastness. One sample's color fastness was rated as good to excellent, with a range of 4 to 5.

According to these results, the denim samples show good color fastness when it is dry, and some of them may even be very resistant to color bleeding and fading.

Results from wet-condition color fastness tests on denim samples made of 100% cotton are shown in TABLE II. A rating of 1 was given to most of the samples, meaning these samples couldnot hold color well when exposed to water. A colorfastness rating of 1–2 for one sample indicates a very poor to poor quality. All samples showed inadequate performance in resisting color bleeding and fading when exposed to moisture, highlighting a major challenge with color retention in wet conditions.

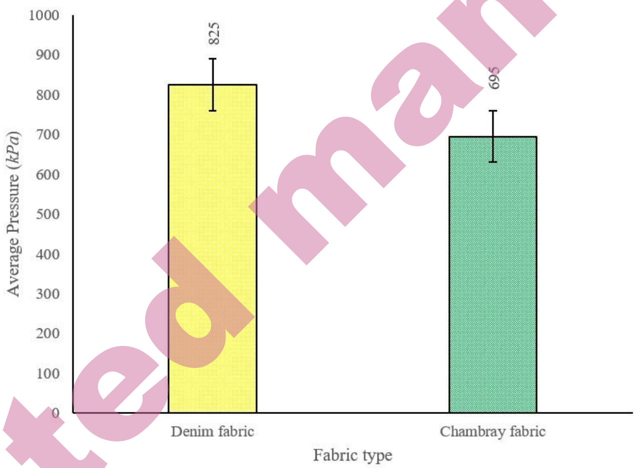

Fig 6. Analysis of bursting strength of chambray and denim fabrics.

TABLE II also presents the findings of color fastness testing conducted on chambray fabric samples in dry conditions. Two samples were rated 4-5, indicating that their color fastness ranged from good to excellent. In addition, one sample attained a rating of 4, indicating satisfactory color fastness, while another sample obtained a rating of 5, indicating exceptional color fastness. The dataset indicates that most of the chambray samples show satisfactory to excellent color retention when exposed to dry conditions. Additionally, certain samples display exceptionally high resistance to color fading or bleeding. TABLE II presents the outcomes of color fastness testing carried out on chambray samples in wet conditions. Two samples were rated 1-2, indicating that color fastness ranged from very poor to poor. In addition, two additional samples were given a rating of 1, indicating extremely low color fastness when exposed to wet conditions.

TABLE II. Rubbing fastness of denim and chambray fabrics in dry and wet conditions.

Fabric type	No. of obs.	Grade	Evaluation
Dry rubbing			
Denim fabric	1	4	Good
	2	4	Good
	3	4-5	Good to excellent
	4	4	Good
Wet rubbing			
Denim fabric	1	1	Very poor
	2	1-2	Very poor to poor
	3	1	Very poor
	4	1	Very poor
Dry rubbing			
Chambray fabric	1	4-5	Good to excellent
	2	4	Good
	3	5	Excellent
	4	4-5	Good to excellent
Wet rubbing			
Chambray fabric	1	1-2	Very poor to poor
	2	1-2	Very poor to poor
	3	1	Very poor
	4	1	Very poor

CONCLUSION

The research work is an approach towards demonstrating the comparison of mechanical and physical properties of bio-polymer based materials such as 3/1 twill denim & 1/1 plain chambray fabric. Though the yarn count & fabric appearances are similar for both fabrics, the mechanical properties like tensile strength, tearing strength, mass loss percentage, abrasion and pilling behavior show different results. According to the results obtained from various tests in this research work, it has been found that the tensile strength of denim fabric in the warp direction is higher than chambray fabric. Which results in less porosity and high interlacement points in bio-polymer based chambray fabric. On the other hand, bio-polymer based denim has higher EPI than chambray, it has a higher porosity and a higher crossover point than the 1/1 plain chambray fabric. So, 3/1 twill denim fabric shows higher strength in the warp direction. But on the other hand, chambray fabric has a higher tensile strength in the weft direction than denim. As a result, chambray aids in the design process. Denim has higher tear strength in both warp and weft direction than chambray. bio-polymer based chambray fabric shows better pilling quality than denim fabric. Also, abrasion resistance and bursting strength were higher in denim fabric. The results obtained were classified according to the finished constructions of both types of fabrics and the properties of the yarn. According to the findings from different test results, it will be helpful to decide the suitability of bio-polymer based materials such as denim and chambray fabric for specific end-use.

Authors contributions: Nasrin Akter, Md. Reazuddin Repon and Shaima Islam have contributed to conceptualization, methodology, data collection and original draft preparation. Arnob Dhar Pranta has contributed to resources, data analysis and original draft preparation. Md. Ruhul Amin, Nurzod Yunusov and Salim Madrahimovich Otajonov have contributed to editing and reviewing. Md. Reazuddin Repon has supervised all stages of preparing the manuscript. All authors have read and agreed to the published final version of this article.

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И З В О Д

ИСТРАЖИВАЊЕ ИСТАКНУТИХ ФИЗИЧКО-МЕХАНИЧКИХ КАРАКТЕРИСТИКА БИО-ПОЛИМЕРА НА БАЗИ ЧАМБРЕ ТКАНИНЕ

NASRIN AKTER[1], MD. REAZUDDIN REPON[2], ARNOB D. PRANTA[3,4], MD. RUHUL AMIN[1], NURZOD YUNUSOV[5], SALIM M. OTAJONOV[5]

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Тексас је познат по својој снази и дуговечности, док је чамбре мекши, удобнији и често се користи за одеће у тренду. Овај истраживачки рад упоређује физичке и механичке особине био-полимера на бази органског памука (100%) тексаса и органског памука (100%) чамбре тканине. Док су обе тканине имале идентичне основе и потке, тексас је имао већи EPI и PPI упркос томе што има упоредиву конструкцију. Тексас има већи (5,65%) грама по квадратном метру (GSM) него чамбре што заузврат омогућава већу апсорпцију боје. Док је чамбре имао нижу затезну чврстоћу и чврстоћу на пуцање од 100% памучног тексаса на бази био-полимера у правцу основе, у смеру потке је било обрнуто. Поред тога, тексас је био много бољи у тесту чврстоће на кидање (6,29%). Чамбре тканина, с друге стране, показала је мање пилинг понашања. Тест отпорности на абразију дао је одличне резултате за чамбре тканине. Резултати показују да је тексас јачи, компактнији и издржљивији, што га чини погоднијим за тешке услове. Насупрот томе, чамбре нуди мекши осећај, бољу прозрачност и већу удобност током лета, заједно са посебним изгледом за обојеност.

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