Mechanical Properties of Jute-Cotton Blended Woven Fabric

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Abstract

In terms of economic significance, jute fiber, a naturally occurring mixture of cellulose, hemicellulose, and lignin, is second only to cotton. Fibre-reinforced polymer composites have long dominated a diverse array of applications due to their high specific strength and modulus. In this regard, research has been conducted on the use of jute and cotton fiber. Not only are natural fibers durable and lightweight, but they are also inexpensive. This experiment aims to determine the mechanical properties of jute and jute/cotton blend fabrics. Using ASTM and ISO testing standards, the specimens' tensile strength, breaking elongation, tearing strength, stiffness, and pilling resistance were evaluated. The effects of various variables on breaking force, breaking elongation, and tearing strength were investigated using regression analysis. It was discovered that the 65/35 jute/cotton blend fabric with 50 EPI, 20 PPI yarn density, and 350 GSM exhibited the best tensile strength, pilling resistance, and stiffness. This research will open up new avenues for the development of versatile, functional textile products made from jute and cotton.

Keywords: *woven fabric, jute-cotton blend, breaking strength, breaking elongation, tearing strength, stiffness, pilling*

1. Introduction

Jute is a plant-based natural fiber. The long, soft, and gleaming fibers are spun into coarse, strong threads that can be used for a variety of purposes. In terms of production, jute is only second to cotton. It is sometimes referred to as the "golden fiber" due to its vibrant color and low cost (Islam, M et al., 2018). Jute's intrinsic qualities include high tensile strength, low extensibility, long durability, luster, and a long staple length. It is a long-lasting textile fiber. It creates novel items that aid in the preservation of the environment and ecological balance. Jute fiber has several distinct physical properties, including high tensile strength, bulkiness, sound and heat insulation, low thermal conductivity, and antistatic properties (Yu, C. 2015). Jute fiber is completely biodegradable and recyclable, and it has a high tensile strength but a low extensibility (Islam, M et al., 2018). Jute fiber is better suited for the creation of technical textiles in specific industries due to these properties. Jute fiber is composed of 60% cellulose and 22% hemicellulose (Singh, H., et al., 2018). Cellulose is a polysaccharide composed of D-glucose units that are 1,4-linked. Hemicelluloses are polysaccharides similar to cellulose but with distinct compositions and structures. Hemicelluloses contain the majority of D-pentose sugars as well as a small percentage of L-sugars (Hashmi, S. 2014). Cotton is the world's most important natural textile fiber, as well as a cellulosic textile fiber. It is used to make clothing, furniture, and other items. Native cotton is the purest form of natural cellulose. The composition consists of proteins, oils and waxes, pentose and pectin, minerals, and natural coloring substances (McCall, E. R. et al., 1951). Jute is a multicellular plant. Because it contains lignin and cellulose, jute is a lingo-cellulosic fiber. Thermal and electrical conductivity, biological deterioration, mildew and moth susceptibility, heat, cold, and radiation resistance, sun and light reactivity, and so on. Jute fibers have excellent thermal and mechanical properties when compared to other natural fabrics. Jute fiber has gained international attention due to its inherent properties that are similar to those of glass fiber (low density, high tensile modulus, low elongation at break). Many experts have

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studied the chemical composition of jute fiber. Jute fibers have excellent thermal and mechanical properties when compared to other natural fabrics. Jute fiber has gained international attention due to its inherent properties that are similar to those of glass fiber (low density, high tensile modulus, low elongation at break). Tensile properties are an important material property in structural design. Tensile strength and modulus of composites are more matrix and fiber dependent. Tensile strength is determined by factors such as matrix strength and chemical stability, in addition to fiber strength and modulus. Tensile, flexural, inter-laminar shear, impact, and hardness are among the mechanical properties of FRP composites(John, M. J. et al., 2008). The fine nature of jute micro/nanofibrils (JNF) and excellent stress transfer at the matrix/JNF interface were responsible for the increase in tensile strength (Das, K. et al.,2011). To investigate the tensile behavior of short jute fiber reinforced polypropylene composites, anhydride grafted polypropylene was used as a coupling agent. Because of improved polymer matrix and interfacial adhesion strength, the tensile strength of jute/PP composites increased with ageing under humid conditions (Das, K. et al.,2011). According to Gowda et al. (2016), only jute fiber-based composites outperform wood fiber-based composites in terms of mechanical properties. Gowda et al. investigated the longitudinal and transverse tensile characteristics of jute fabric reinforced polyester composites, averaging 29 Kj/m2 for jute-polyester composites and 1.76 Kj/m2 for polyester resin specimens. The tensile strength and modulus of longitudinal composite were found to be nearly five times that of polyester resin and twice that of transverse laminate (Gowda, T. M. et al., 1999). Tao et al. found that short jute/PLA composites had a 30% increase in flexural strength. The addition of fiber and efficient stress transfer between PLA and natural fiber may be responsible for the improved flexural strength of the composite (Tao, Y. U., et al., 2009). Cross-wounded jute/Biopolcomposites had 79 percent higher bending strength than single and double wound composites (Mohanty, A. K. et al., 2000). Ray et al. investigated the flexural behavior of jute/vinylester composites. At 30°C, the maximum strength of vinylester composites reinforced with jute fibers was found to be 4 hours (Ray, D. et al., 2001). Satapathy et al. discovered that the flexural strength of jute epoxy composites increased with fiber loading (Satapathy, A. et al., 2010). Albuquerque et al. investigated the impact strength as a function of fiber content of longitudinally oriented jute roving reinforced polyester composites. Longitudinal composites' impact strength and tensile properties increased linearly with fiber loading (De Albuquerque, A. C. et al., 2000). Jawaid et al. investigated the impact properties of hybrid composites reinforced with oil palm EFB and jute fiber. In terms of impact strength, pure EFB composites outperform hybrid composites (Jawaid, M. et al., 2011). The mechanical properties of natural fiber reinforced polymer composites were improved by Begum et al. When they compared natural fiber reinforced polymer composites to glass fiber reinforced polymer composites, they discovered that the larger volume fraction of natural fiber provided equal mechanical quality. They also discussed how environmentally friendly natural fiber reinforced polymer composites are (Begum, K. et al., 2013). S.V. Joshi and colleagues investigated natural and glass fiber composites. Natural fiber composites are often more eco-friendly than glass fiber composites, according to the researchers, because natural fiber production has fewer environmental impacts than glass fiber production. Natural fiber composites are made with less polluting polymers. Lightweight natural fiber composites improve fuel efficiency and reduce pollution, particularly in automotive applications(Joshi, S. et al., 2004). According to Sanjay et al., adding natural fibers to GFRP improves characteristics and can be used as an alternative material for GFRP. The mechanical properties of jute and glass fiber reinforced polymer composites were investigated. They discovered that using jute and glass fiber reinforced epoxy composites could save them up to 30% on costs. To determine the composite's facture condition, an electron microscope tasting was performed (Sanjay, M. R. et al., 2015). Rafiquzzaman, M. I.S. Prétot, and colleagues demonstrate hemp/epoxy replacing glass/epoxy in Naca cowlings. A more measured approach is recommended (Rafiquzzaman, M. et al., 2016). Mechanical properties were evaluated, and increased amounts of carbon fiber outperformed equal amounts of glass fiber (Jagannatha, T. D. et al., 2015). Several studies have been conducted to investigate the tensile properties of jute/cotton yarns. Several studies have been conducted to investigate the relationship between jute/cotton mixed yarn breaking toughness and gauge length. Tensile behavior of yarns at different lengths is important for warping, sizing, beaming, and weaving. The breaking tenacity of blended yarn at various gauge lengths is predicted using two-parameter Weibull distribution models (Xia, Z. et al., 2010). Azad et al. state that when jute-cotton blends are spun in a rotor system, the qualities of 50:50 blended yarn are nearly identical to 100% cotton spun yarn (thin-thick places and hairiness). The authors go on to say that coarse count yarn (10s) in an 80:20 (cotton-jute) blend exhibits a similar tendency. Their published data, however, revealed that the quality of blended yarns degraded as the amount of jute increased. However, at higher counts, the 80:20 (cotton-jute) combination outperforms the 50:50 ratio (A. K. Azad et al., 2006). Fabrics made from sulphonated jute with cotton, rayon, acrylic, polyester, and silk waste had better drape and flexural rigidity than 100% cotton fabrics, according to Islam et al. Both basic and reactive dyes increased the dye-ability of these materials by 20%. To make fine yarn, sulphonated jute fibers were mixed with cotton in three different ratios: 50:50, 60:40, and 70:30. The study shows that incorporating jute into the blend increases the toughness and CSP of the yarns. Less jute in a yarn decreases elongation, which is thought to decrease breaking elongation. Sulphonated cotton-jute blended yarn, on the other hand, has slightly higher breaking elongation than 100% sulphonated jute yarn (Ali, M. et al., 2001). Salam, M. A. Salam et al. compared the qualities and usability of blended curtains to 100% cotton curtains of comparable fabrication. The study concluded that, when compared to 100% cotton curtains, jute-cotton mixed (50:50) curtains were not only less expensive but also more durable, except when washed repeatedly (Salam, M. A., et al., 2007). It is worth noting that when jute and cotton are combined, the fiber toughness is more sensitive to gauge length than overall length, because fragmentation occurs more quickly during yarn extension. The toughness of jute-cotton mixed yarns decreases with increasing jute content. They discovered that the percentage of jute increases the mass irregularity, thick and thin spots of blended yarns using the Uster evenness test on jute-cotton blended yarns. The great potential of jute may be explored with the advent of fabric engineering by studying the effects of changing one or more important property factors like pick density on the physical, mechanical, and hydraulic qualities of woven jute fabric samples. M Karahan and R Eren studied the impact of fabric properties on static water absorption in terry fabrics. According to their findings, terry textiles made of two-ply ring carded yarns absorb the most water, while terry textiles made of two-ply open-end yarns absorb the least. Increasing the warp and weft densities decreases terry cloth water absorption while increasing the pile length increases it (Karahan, M. et al., 2006). They investigated the effect of weave configurations on the mechanical properties of woven cotton fabrics under low stress. The study yielded two groups of fabrics with the same warp and weft count and sett. In the first group, we looked at five fabrics, and in the second, we looked at eleven. The low-stress mechanical properties of the fabrics were investigated, and correlation coefficients were calculated. While shear, crease recovery, tensile strength, and air permeability had a strong correlation, hand value had a weak correlation. The properties of the second fabric group corresponded well with bending rigidity and hysteresis (Sankaran, V. S. 2012). He investigated the impact of weft parameters on weaving performance and fabric quality. He has demonstrated that TPI and yarn count are critical criteria for determining weaving performance and fabric properties. The experiments used fabrics with three different PPI and weft counts. The research shows that a high cover factor reduces weaving performance. Threads per inch were divided by the square root of the English cotton count to determine weaving performance. When the count and threads/inch of one yarn series change, the crimp percent, or consumption of both yarn series, changes. Fabric strength increases with increasing threads/inch, as expected, but the increase is greater at higher threads/inch (Haque, M. M. 2009). They investigated the effect of weft yarn type and pick density on the tearing strength of woven cloth. The purpose of this research was to discover how yarn type and pick spacing affect woven fabric rip resistance as measured by the Elmendorf Tear Test. Tear strength was tested on each sample using three different weft yarns and three different pick spacings. Pick spacing improves warp way tearing strength (P. Pal, D. G. 2011). Prof. Swapan Kumar Ghosh investigated the impact of pick density variation on the physical, mechanical, and hydraulic properties of three different types of jute fabric samples woven from single, plied, and parallel weft threads. He created seven fabric samples on the multi-phase, curvilinear, shuttleless S4A loom. All fabric samples' physical, mechanical, and hydraulic properties were determined, and the effect of pick density variation on these qualities was noted (Ghosh, S. K. et al., 2007). F Afroz and M Islam investigated the tensile properties of woven cotton-tencel fabric (Afroz, F., & Islam, M. M. 2021). Other researchers discovered that different fiber blend ratios have a significant impact on the fabric's pilling resistance (Hossain, M. S. et al., 2021). Another study found that different fabric manufacturing parameters have a significant impact on fabric mechanical behavior (Hossain, M. S. et al., 2021). Ummey Hani Barsha's research focused on creating a plain-woven fabric out of jute and cotton fiber blends and researching their physical and mechanical properties. Mixed fiber fabrics have superior properties and have the potential to be used globally as a sustainable fashion fabric. The focus of this research was a jute cotton blend fabric with high tensile strength, low pilling, and abrasion resistance. Weft yarn breaks faster than warp yarn in terms of tensile strength. The fabric is reasonably stiff. There is no pill production detected at 125,500 or 1000 cycles. But nothing changed after the disclosure (Barsha, U. H. et al., 2018).

Cotton and jute fibers have been studied separately for their mechanical properties in the literature. While some researchers have looked into the tensile properties of jute/cotton blend yarn and composites, there has been little research into the mechanical properties of a woven fabric made from this combination. The mechanical properties of a jute/cotton blend fabric were thoroughly investigated in this paper. It will open up new avenues for research into the development of adaptable, usable products from jute/cotton blend textiles.

2. Experimental

2.1 Materials

The fabrics are made from 100% jute and jute/cotton blended yarns in three different ratio which are enlisted in **Table 3.** The warp yarn had three different linear densities with 11 lbs./spindle, 16 lbs./spindleand20 lbs./spindle values while weft yarn count was fixed to 8 lbs./spindle. The ring spinning method was used to manufacture all of the yarns.

2.2 Sample preparation

All of the fabric samples were woven using power driven shuttle loom. The specifications of woven fabric samples are mentioned in **Table 1**. The fabrics were manufactured using a 1/1 plain weave structure with three different yarn count and densities. These yarn counts and densities were chosen because they are the most typically utilized for jute yarn fabric manufacture.

Table 1: Sample specification for jute/cotton blended fabric

SL No	Composition	EPI	PPI	Warp Count	Weft Count	GSM	Fabric Width
Sample 01	100% Jute	12	11	11 lbs./spindle	8 lbs./spindle	277	53"
Sample 02	75/25 jute/cotton	40	20	16 lbs./spindle	8 lbs./spindle	345	61"
Sample 03	65/35 jute/cotton	50	20	20 lbs./spindle	8 lbs./spindle	350	61"

2.3 Measurement of breaking strength, breaking elongation and tearing strength

The breaking force is the maximum stress a material can take without cracking when it is stretched, divided by the material's initial cross-sectional area. When an outside force pulls on a fabric, it can stretch and change shape, or even break and get damaged. Breaking elongation is the maximum amount that a sample can stretch before it breaks when a tensile force is put on it. The ASTM D5034 grab test method was used to test the breaking force and the length. During a grab test, the center of the width of the specimen is held between two clamps. The test involves cutting slits on both sides of the specimen halfway along its length. This cuts all of the strands around the part of the specimen that is held between the two clamps. By pulling down on the specimen, a force of about 0.37 lb is put on it. The automated machine keeps track of the average breaking load and length right away. Using the EN ISO 13937-2 standard, a universal strength tester was used to measure the ability to tear. Tear resistance is a parameter that shows how strong a material is when put under static or moving force. Different standards show how to test for tears in different ways. They are different in how samples are made, their shape and size, how they are clamped, the length of torn fabric distance, and how the tear force is read and calculated.

2.4 Measurement of pilling resistance

This pilling test was performed in accordance with ISO 12945-02. The Martindale Abrasion and Pilling Tester were used to mismeasure the abrasion and pilling resistance of a fabric. It consists of six testing plates to which abrasive textiles are attached; these six testing plates are attached to the base plate of the instrument. There is a set of weights used to apply the appropriate amount of pressure to test specimens.

3 Result and discussion

It was found that the contact area between warp and weft was increased when the yarn was made coarser and the density was also raised. The frictional forces between the two sets of yarns were increased due to the larger contact area, which reduced the amount of fiber slippage upon yarn failure. Consequently, the yarns' tensile strength was increased. Fabric's tensile strength grew as a result of the increased density and GSM of the coarser yarn. In contrast, when yarns are made finer and the density of the yarn is lower, the contact area between the warp and the weft is smaller because the diameter of the yarn is smaller. This means that less yarn comes into contact with the warp and weft. During yarn failure, the frictional forces between the two sets of yarn were lessened, which caused morefibers to slip. Consequently, finer yarn with a lower density and GSM was found to have a lower tensile strength.

3.1 Analysis of breaking force

Figure 1 represents the breaking force of the specimen. It was indicated that 100 percent jute-12 EPI-11PPI fabric (sample 01) had an initial breaking force of 224.2N, while a 75/25 jute/cotton blend-40EPI-20PPI fabric had a value of 310.3N. (Sample 02). The 65/35 jute/cotton blend fabric with 50EPI-20PPI had the highest breaking force of 375N. (Sample 03). The greatest breaking force value was 375N for samples with warp counts of 20 lb/spyndle, weft counts of 8 lb/spyndle, and weights of 350 GSM, while the lowest value was 224.2N for samples with warp counts of 11 lb/spyndle, weft counts of 8 lb/spyndle, and weights of 227 GSM.

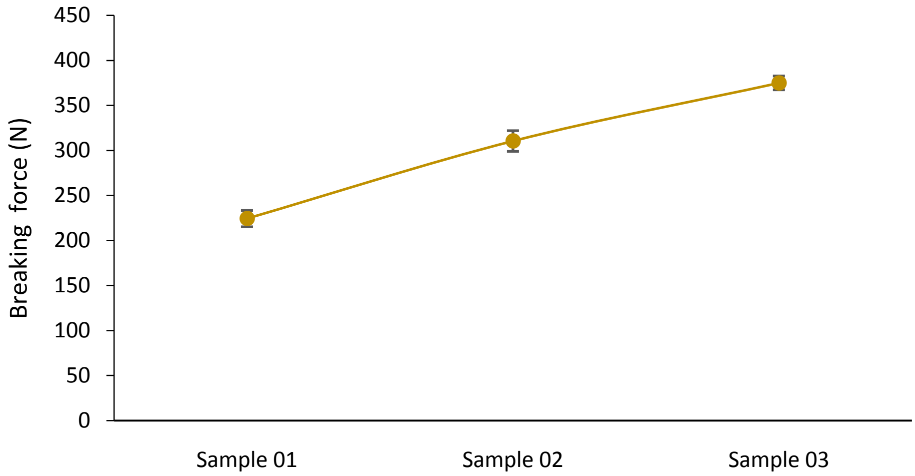

Figure 1: Breaking strength of jute/cotton blended specimen.

3.2 Analysis of breaking elongation

Figure 2 illustrates breaking elongation of the specimen. It was revealed that 100 percent jute-12 EPI-11PPI fabric (sample 01) had an initial breaking elongation of 8.372mm, while a 75/25 jute/cotton blend-40EPI-20PPI fabric had a value of 28.3mm. (Sample 02). The 65/35 jute/cotton blend fabric with 50EPI-20PPI had the highest breaking elongation of 31.3mm. (Sample 03). The greatest breaking elongation was found in samples with warp counts of 20 lb/spyndle, weft counts of 8 lb/spyndle, and weights of 350 GSM, while the lowest was found in samples with warp counts of 11 lb/spyndle, weft counts of 8 lb/spyndle, and weights of 227 GSM.

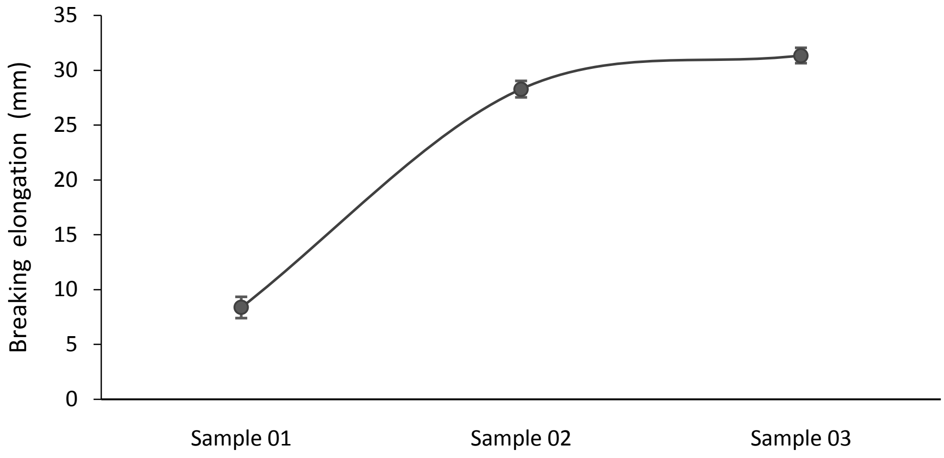

Figure 2: Breaking elongation of jute/cotton blended specimen.

3.3 Analysis of tearing strength

Figure 3 depicts the tearing strength of the specimen. It was seen that the initial tearing strength of a 100% jute-12 EPI-11PPI fabric (sample 01) was 14.6N, while the value climbed to 19.7N for a 75/25 jute/cotton blend-40EPI-20PPI fabric (sample 02). The highest tearing strength was 60.6N for the 65/35 jute/cotton blend fabric with 50EPI-20PPI (sample 03). Samples with warp counts of 20 lb/spyndle, weft counts of 8 lb/spyndle, and weights of 350 GSM had the highest tearing strength, whereas samples with warp counts of 11lb/spyndle, weft counts of 8 lb/spyndle, and weights of 227 GSM had the lowest.

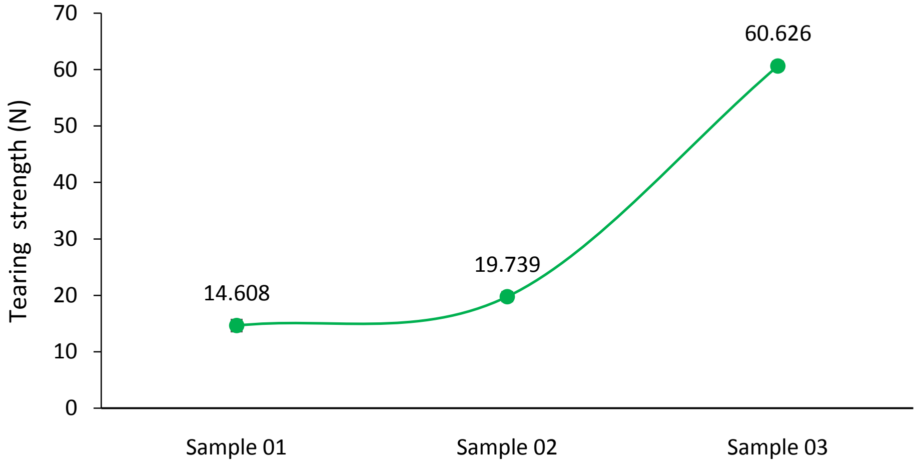

Figure 3: Tearing strength of jute/cotton blended specimen.

3.4 Analysis of stiffness

Figure 4 represents the stiffness of the specimen by bending length & flexural rigidity. It was indicated that 100 percent jute-12 EPI-11PPI fabric (sample 01) had a 9cm bending length & flexural rigidity value of 1893.21. While a 75/25 jute/cotton blend-40EPI-20PPI fabric (Sample 02) had bending length & flexural rigidity value of 11.7cm & 5383.66 respectively. The 65/35 jute/cotton blend fabric with 50EPI-20PPI (Sample 03) had the highest bending length of 12.5cm

& 7005.45 flexural rigidity.It was clearly indicated that the jute-cotton blend fabric with higher yarn density and GSM offered the higher bending length and flexural rigidity compared to 100% jute fabric with lower yarn density and GSM.

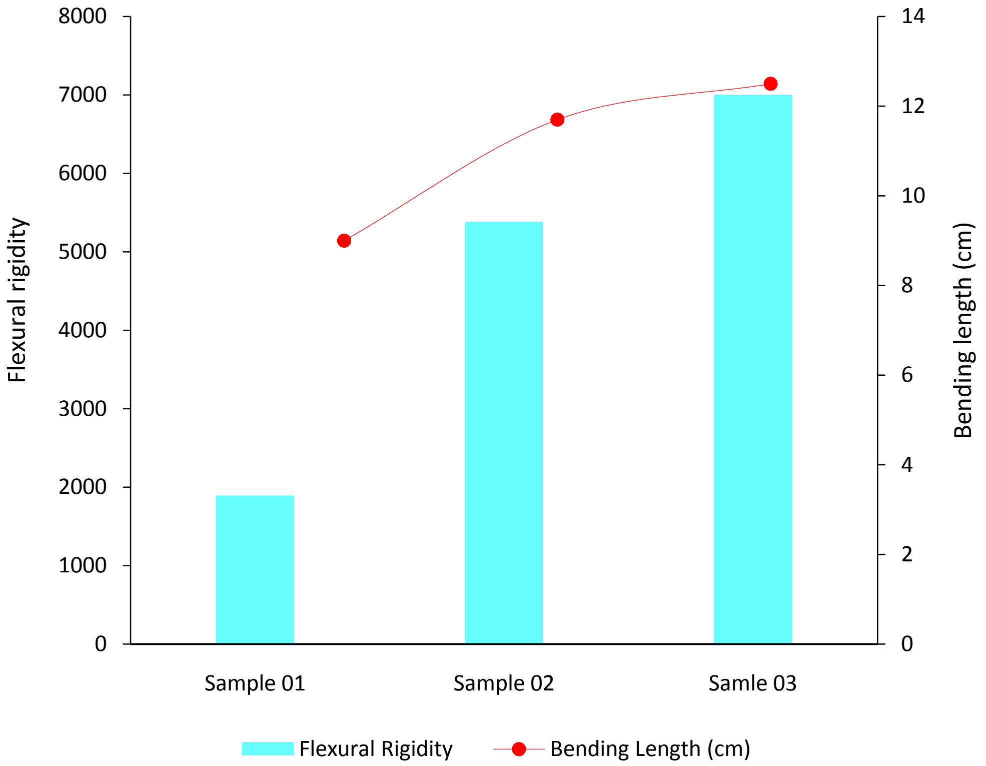

Figure 4: Bending length and flexural rigidity of the specimen.

3.5 Analysis of pilling resistance

This pilling resistance test was carried out in accordance with ISO 12945-02. The test samples for pilling were then compared to the grayscale for pilling. There are five levels on the gray scale that indicate the fabric's condition following the pilling test. The worst grade for pilling is number one. It indicates that the sample fabric has experienced major modifications and has extensive pilling on its surface. After the pilling test, the fabric's look has changed substantially, and a noticeable pill has formed on its surface. In grade 3 pilling, the surface of the fabric exhibits mild fuzz or a few completely formed, isolated pilling. Pilling grade-4 is significantly stronger than the previous grades, with just modest surface differences and mild pilling. However, piling grade 5 shows the best performance among all grades, with no observed alteration and no pilling noted on the fabric's surface. **Figure 5** represents the Pilling of the specimen. It was indicated that 100 percent jute-12 EPI-11PPI fabric (sample 01) had 3.5 grade pilling which means moderate pilling rate. While a 75/25 jute/cotton blend-40EPI-20PPI fabric had a value of grade-5 (Sample 02). The 65/35 jute/cotton blend fabric with 50EPI-20PPI had also grade-5 pilling rate (Sample 03).It revealed that the pilling resistance property improved as the blending ratio and yarn density increased. Since the cotton fiber has a good pilling resistance property, the addition of cotton fiber with jute fiber improved the pilling resistance property of the sample.

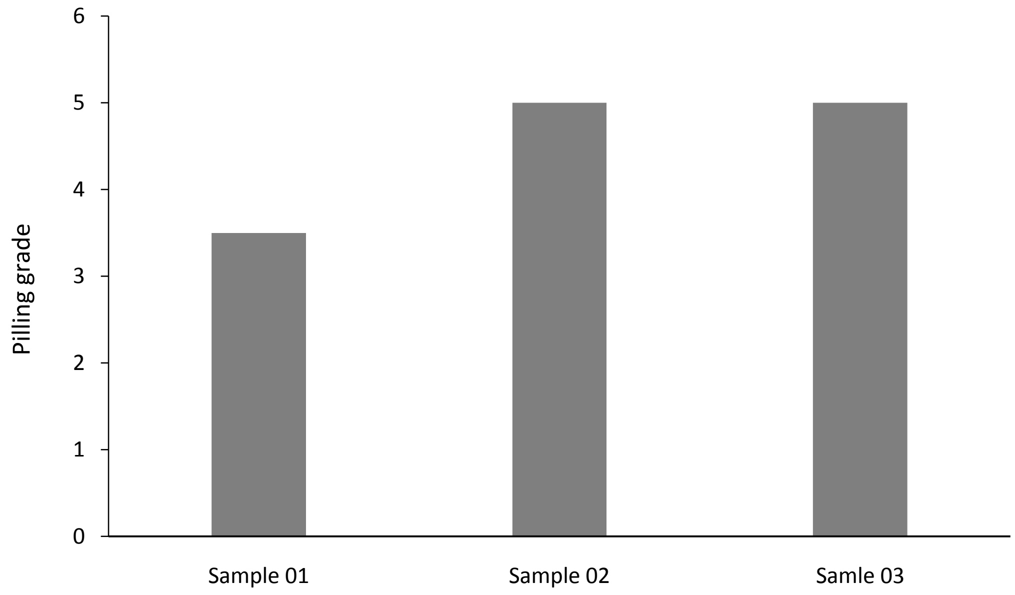

Figure 5: Pilling resistance of the specimen.

3.6 Regression analysis

The stepwise regression technique is used to determine the cause-effect relationship between two variables, Y dependent and X independent variables. Breaking force, breaking elongation and tearing strength were considered dependent variables, while yarn density and yarn countwere considered independent variables. In the "ANOVA table," the significance value was less than 0.01 indicating that the model is valid.

All independent variables projected to affect the breaking force, breaking elongation and tearing strength value were included in the analysis. The modelhad P-values of less than 0.05 for yarn density and yarn count, indicating that all these parameters contribute significantly to the breaking force, breaking elongation and tearing strength (**Table 2-4**). The adjusted R^2 value of the model was found to be near 0.90, as shown in the model summary, which suggests that these parameters explain about 90% of the breaking force, breaking elongation and tearing strength value of jute-cotton fabric. The adjusted R2 indicates that the model's predictive power is reasonable. The equations of breaking force, breaking elongation and tearing strength have been derived from the regression study and is presented below:

$$F=6.45X-10.51Y+262.38 \quad \text{(i)}$$

$$E=4.09X-12.15Y+99.19 \quad \text{(ii)}$$

$$T=3.3X-13.88Y+181.91 \quad \text{(iii)}$$

F=Breaking force, E=Breaking elongation, T=Tearing strength, X=EPI, Y=PPI

Table 2: Regression analysis for breaking force

Regression Statistics	
R Square	0.9933
Adjusted R Square	0.9893
Standard Error	0.7288
Observations	3

ANOVA

	df	**SS**	**MS**	**F**	**Significance F**
Regression	4	11435.48	2858.869	246.9854	0.000007
Residual	0	0	65535		
Total	4	11435.48			

	Standard Error	**P-value**
EPI	1.4877	0.00069
PPI	0.0687	0.000002
Warp Count	0.0437	0.04731
Weft Count	1.283	0.0045

Table 3: Regression analysis for breaking elongation

Regression Statistics	
R Square	0.9877
Adjusted R Square	0.9803
Standard Error	0.9254
Observations	3

ANOVA

	df	**SS**	**MS**	**F**	**Significance F**
Regression	4	1271.91	317.9775	133.4466	0.00003
Residual	0	0	65535		
Total	4	1271.91			

	Standard Error	**P-value**
EPI	1.889	0.001
PPI	0.0873	0.00002
Warp Count	0.0543	0.0046
Weft Count	1.798	0.0038

Table 4: Regression analysis for tearing strength

Regression Statistics	
R Square	0.985
Adjusted R Square	0.976
Standard Error	0.91
Observations	3

ANOVA

	df	SS	MS	F	Significance F
Regression	4	692.4768	173.1192	109.471	0.00006
Residual	0	0	65535		
Total	4	692.4768			

	Standard Error	P-value
EPI	2.2849	0.0017
PPI	0.1055	0
Warp Count	0.1035	0.1967
Weft Count	1.1263	0.0028

4. Conclusion

The experimental study on the investigation of mechanical properties of jute & jute/cotton blended fabric. In this study, the different construction and different GSM on jute & jute/cotton blended fabrics properties especially on tensile strength, breaking elongation, tearing strength, stiffness and pilling resistance were analyzed. Through increasing the yarn density & GSM and reducing the yarn fineness tensile strength of jute/cotton blended fabric can be increased to certain value. Moreover, jute/cotton blended fabric offered higher tensile strength compared to 100% jute fabric.

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Declaration of interest’s statement

The authors declare no conflict of interest.

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