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Study of Behaviour of the Woven Jute Fabrics under Compression Load

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Abstract. *This study investigates the compression behaviour of plain weave and twill weave jute fabrics under varying pressures, emphasizing their structural and deformation characteristics, highlighting jute as a sustainable and eco-friendly fibre for future technical applications. Experimental data reveal that plain weave fabrics exhibit rapid thickness reduction at low pressures (0–5 kPa), stabilizing at a compact state with a final thickness between 0.8 mm and 1.0 mm. In contrast, twill weave fabrics display higher initial thickness (2.0 mm) due to greater yarn linear density, with a gradual thickness reduction across the pressure range, stabilizing between 1.3 mm and 1.5 mm beyond 10 kPa. The negative power law fitting models were successfully applied to predict the compression behaviour. The newly developed three-layer fabric structure accounts for the highly stiff protruding fibres and incompressible core, which comprises 65% of the total thickness, with the outer layers contributing 17.5% each. This study provides the significant role of weave structure, crimp, and layer composition in fabric compressibility, providing insights for applications specifically for technical textiles.*

Keywords*: Woven jute fabrics, sustainable material, compression, layer-structure*

1. INTRODUCTION

Jute is a natural fibre obtained from the bark of the Corchorus capsularis plant. It is a popular choice for textile applications due to its biodegradable, renewable, and sustainable nature. Woven jute fabrics are widely used in various industries such as textile, packaging, and composites. Understanding the mechanical properties of woven jute fabrics is essential for their application in these industries. Low-load compression is a critical property of woven fabrics that affects their performance in various applications. The analysis of the pressure-thickness relationship may shed light on the structure of fabrics where the typical pressure- thickness curve for textile material is shown in Figure 1. Compression is a complex phenomenon that involves the interaction between the fabric and the external forces applied. Hearle (1967) defined compression as the decrease in intrinsic thickness with an appropriate increase in pressure, while compressibility is the ratio of compression to intrinsic thickness expressed as a percentage. Several methods have been developed to measure compression, including those proposed by Schiefer (1933), Knapton and Lo (1975), and de Jong et al. (1986). Compressional deformation occurs when a fabric is subjected to opposing forces in a direction normal to the plane of the fabric. Several methods have been developed to measure the compression properties of fabrics. Schiefer (1933) used a compress meter to evaluate the thickness compressibility and compressional resistance of textiles. Knapton and Lo (1975) suggested a method using a thickness gauge at several pressures to measure the compressional property of fabrics. Hebert et al. (1963) defined compressional resilience as the ratio of energy expended by the fabric in recovering from deformation to the energy absorbed in deforming the fabric. Studies of compression properties of textile material made up of different fibres of Viscose, Acetate, Nylon, Silk, Polyster, Wool, Wool blend, Cotton, P/C, Linen, P/W blend, Commercial fabrics, Suitings, Polypropylene, Polyurethane, PET Nylon, Aramid, Worsted, Acrylic, Nylon spectra, Kevlar, Fibre glass, Shingosen fabrics and Rubber filaments are made (Arasu et. al. 2021) but very limited information is there regarding compression properties of woven jute fabric. Several attempts have been made to describe the pressure-thickness curve by many researchers (Hoffman and Beste, 1951; Bogaty et al., 1953; De Jong et al., 1986; van Wyk, 1946; Carnaby, 1980). De Jong et al. (1986) developed a mechanical model to describe compression curves on woven fabrics with pressures ranging from 2 to 5000gf/cm2 (0.196 kPa to 490.33 kPa). The concept breaks down the fabric into three layers: an incompressible core layer and compressible surface layers on either side. A five-layer structure was proposed by Hu (2004) based on the layer theory, where the cotton fabric structure were divided into three zone i.e. two first outside layers, two secondary outside layers and one incompressible core and all the measured values are taken by KES system as it provides many important parameters associated with fabric compressibility (Kawabata, S; (1980).

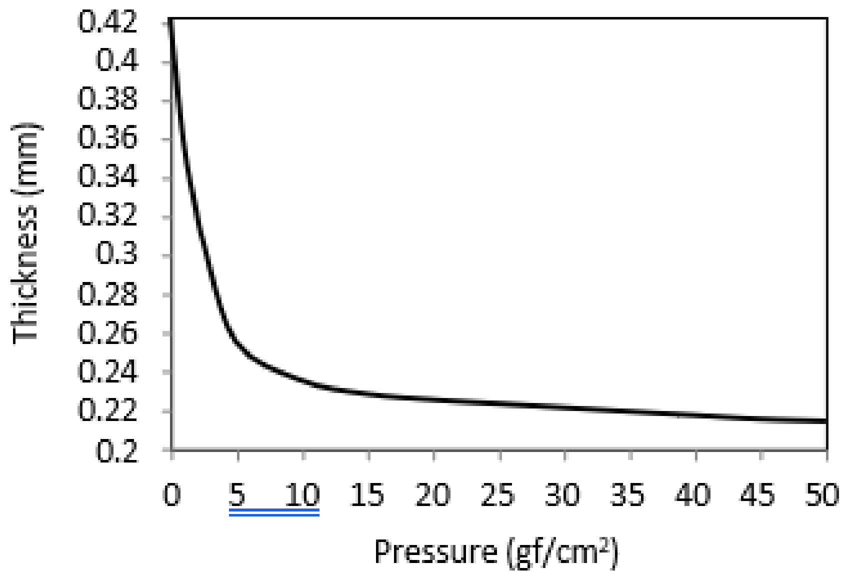

FIGURE 1. Typical pressure-thickness curve of woven fabrics (Hu, 1997)

The present study investigates the behaviour of woven jute fabric under compression. An attempt has been made to predict the pressure-thickness curve by previous models and other non-linear regression methods and compare with the measured data. The phenomena under compression can lead us to understand the structural change of woven jute fabrics used in many technical applications such as under compression molding composite manufacturing process. A new model has been developed specifically for jute fabrics due to its inherent high fibre stiffness compared to wool and cotton

2. MATERIALS AND METHODS

Materials

Samples considered for this study were 100% woven jute fabric. These fabric samples are divided into two groups. In first group, those numbered as S1-S5 are the 1/1 plain weave commonly known as hessian fabrics and second group, those numbered as S6 and S7 are the 2/1 twill weave commonly known as sacking fabrics. Here the sacking fabric S6 is having double warp yarns and single weft yarn but for S7, warp yarn are single and double weft yarns. These samples are manufactured as commercial fabrics in Hooghly Infrastructure Ltd. (Unit: Hukumchand Jute Mill), West Bengal, India.

Methods

The thickness of woven jute fabrics both plain and twill weave were measured using Mitutoyo digital thickness gauge at four different pressure foot level of 1kPa, 5kPa, 10kPa and 15kPa. The thickness at zero pressure were obtained from the fabric cross-section by Wild Leitz M3Z Combistereo microscope at 6X optical magnification and its measurement were taken by Motic 2.0 image analysing software attached to a computer system. The fabrics were placed in the thickness gauge, the pressure foot brought down and held for about 30 second. Table 1 indicates the specification of the fabric samples taken for this present study comprising the thread density, areal density and thickness at four pressure level.

TABLE 1. Construction details of jute fabric samples and measured thicknesses

Samples	Thread density (per dm) warp × weft	Nominal linear density of yarn (lbs/spy) warp × weft	Crimp % warp × weft	Areal density (g/m²)	Thickness (mm) from cross-section	Thickness (mm) at 1kPa	Thickness (mm) at 5kPa	Thickness (mm) at 10kPa	Thickness (mm) at 15kPa
S1	38 × 25	8.0 × 9.0	2.18 × 2.66	199.25 (3.25)	1.56 (4.02)	1.06 (3.12)	0.95 (3.45)	0.90 (2.78)	0.89 (3.01)
S2	38 × 30	8.5 × 8.5	2.8 × 3.19	216.5 (3.8)	1.25 (4.16)	1.03 (3.2)	0.99 (4.25)	0.93 (3.44)	0.90 (2.65)
S3	45 × 37	8.0 × 8.0	1.96 × 3.27	238.25 (3.6)	1.21 (3.44)	0.97 (2.6)	0.85 (3.76)	0.80 (2.93)	0.80 (3.41)
S4	45 × 33	9.0 × 8.0	3.3 × 2.8	242.5 (3.5)	1.20 (4.45)	0.99 (3.15)	0.94 (4.82)	0.91 (4.64)	0.889 (4.25)
S5	54 × 58	7.0 × 7.0	2.4 × 3.03	280.0 (2.8)	1.11 (3.01)	0.96 (2.85)	0.89 (2.85)	0.82 (3.24)	0.82 (3.13)
S6	63 × 27	9.2 × 24	2.85 × 6.8	495.25 (3.12)	2.11 (4.28)	2.11 (3.43)	1.58 (4.62)	1.38 (4.57)	1.37 (4.42)
S7	44 × 50	13 × 15	4.01 × 2.8	4.67 (4.25)	2.10 (3.86)	2.01 (3.98)	1.54 (4.22)	1.44 (4.31)	1.43 (4.45)

Figures in the parentheses show the coefficient of variation (%)

3. RESULTS AND DISCUSSION

Pressure-Thickness curve for woven jute fabrics

The plain weave fabrics (samples S1, S2, S3, S4, and S5) demonstrate a relatively uniform and rapid reduction in thickness under low pressure (0–5 kPa). The thickness stabilizes beyond this range as the pressure increases as shown in Figure 2. The observed stabilization of thickness at higher pressures suggests that the structure reaches a compact state with limited further deformation. The average final thickness for plain weave fabrics lies approximately between 0.8 mm to 1.0 mm, indicating a denser and less deformable structure. The twill weave fabrics are having higher thickness compared to plain weave due to its constituent yarn linear density which is quite higher compared to the plain weave fabrics as shown in table 1. The twill weave fabrics (samples S6 and S7) exhibit a more gradual reduction in thickness across the pressure range. The initial thickness values are higher (2.0 mm) compared to plain weave fabrics, and compression behaviour shows a slower rate of reduction. At pressures beyond 10 kPa, the twill fabrics achieve a steady thickness, around 1.3 mm to 1.5 mm. Plain weaves demonstrate faster compression under low pressures because of tighter yarn interlacement, whereas twill weaves deform gradually over the entire pressure range due to their flexible and less interlaced

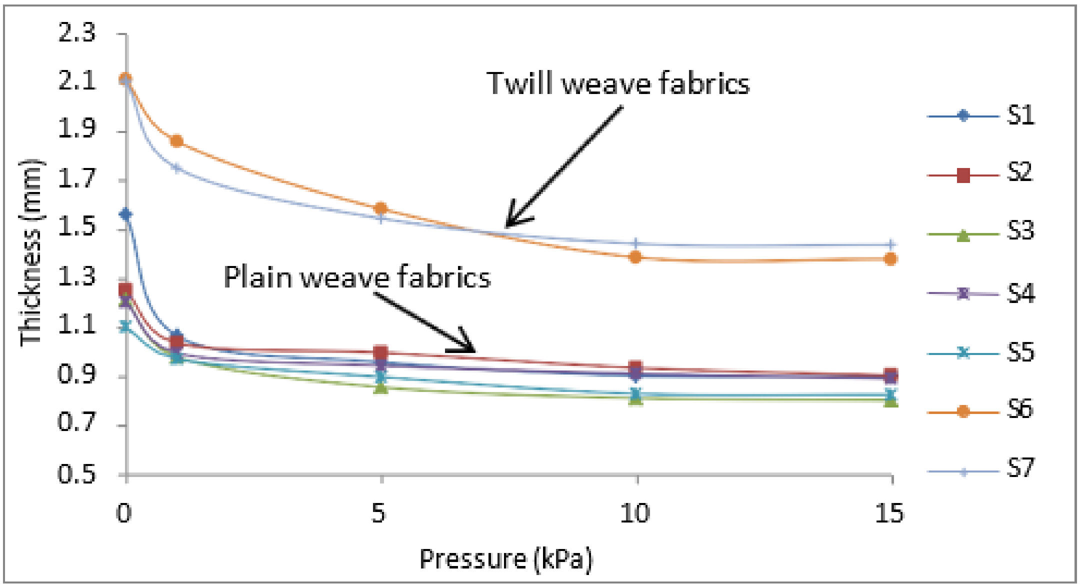

FIGURE 2. Thickness-pressure curve for jute fabric samples

FIGURE 3. a) top-view of S5, b) cross-section view of S5

Fitting of Pressure-Thickness curve: The earlier researcher‟s attempted fitting of an non-linear regression, exponential function or power function to predict compression curves, where in non-linear model is based on Levenberg-Marquardt non-linear-regression method were used to improve the fit of equation 1. De Jong et al.(1986) and Postle et al.(1988) also used this equation to analyse the mechanics of wool-fabric compression.

$$P = \frac{\lambda}{(t-t\ )^3} \qquad (1)$$

where, λ is the proportionality constant, t is the fabric thickness and t' is the incompressible core thickness As per De Jong et al. (1986) shown in Figure 6, the fabric is consisted of three layers: a relatively incompressible core layer in contact with much more compressible surface layers on either side. These two surface layers (the face and back of the fabric) follow van Wyk‟s law. Hu and Newton (1997) show the comparison of wool fabric by De Jong et al. (1986) and their cotton fabric samples. They have found the initial part of the compression curve does not show good agreement with their theoretical equations but the later part has a very good agreement. They have divided the cotton fabric structure into five layers, the two primary outer-layer on either side of the fabric containing hairy fibres and crimp crown above the average thickness, the secondary layers on either side of a fabric represent another two compressible layers, which form the firm structure of the fabric, t' represents the incompressible core of a fabric as shown in Figure 7. Therefore, in this present study the highest pressure taken was 15 kPa (Pmax) to calculate λ and t' as per equation 2 (Hu, 2004).

$$t' = t_m \quad \frac{2E}{P} \quad 1 - \frac{8E^3}{P^2} \qquad (2)$$

where, tm is the thickness at maximum presuure, E is the energy absorbed by the fabric with zero pressure to maximum pressure applied and P is the pressure exerted on the sample.The jute fabric show totally different nature subject to under compression. The exponential function shown by Hu and Newton (1997) was not successful not only for woollen and cotton fabrics but also for jute fabric. Therefore, after taking 30 readings for each fabric sample, power fitting has been obtained and applied to predict the compression curve for two groups of jute fabric samples which shows very good agreement with the experimental thickness having R2 value of 0.89 to 0.99. The power equation for plain weave and twill weave are given as follows:

$T = 0.974P^{-0.034}$ for plain weave fabric (hessian) and,
$T = 1.633P^{-0.040}$ for twill weave fabric (sacking)

where, T is the thickness (mm) and P is the pressure (kPa).

From Figure 4 and 5, it is observed that the power equation obtained above fits very well with the experimental thickness of the fabric sample both for plain and twill weave structure. Here it can observed that initially at lower pressure (upto 1 kPa), the curve slightly deviate from the experimental data, but shows very good fitting when it gradually approaches higher pressure levels (5 kPa to 15 kPa) which corroborates with the conclusion made by previous researchers (de Jong *et al.* 1986; Hu and Newton, 1997).

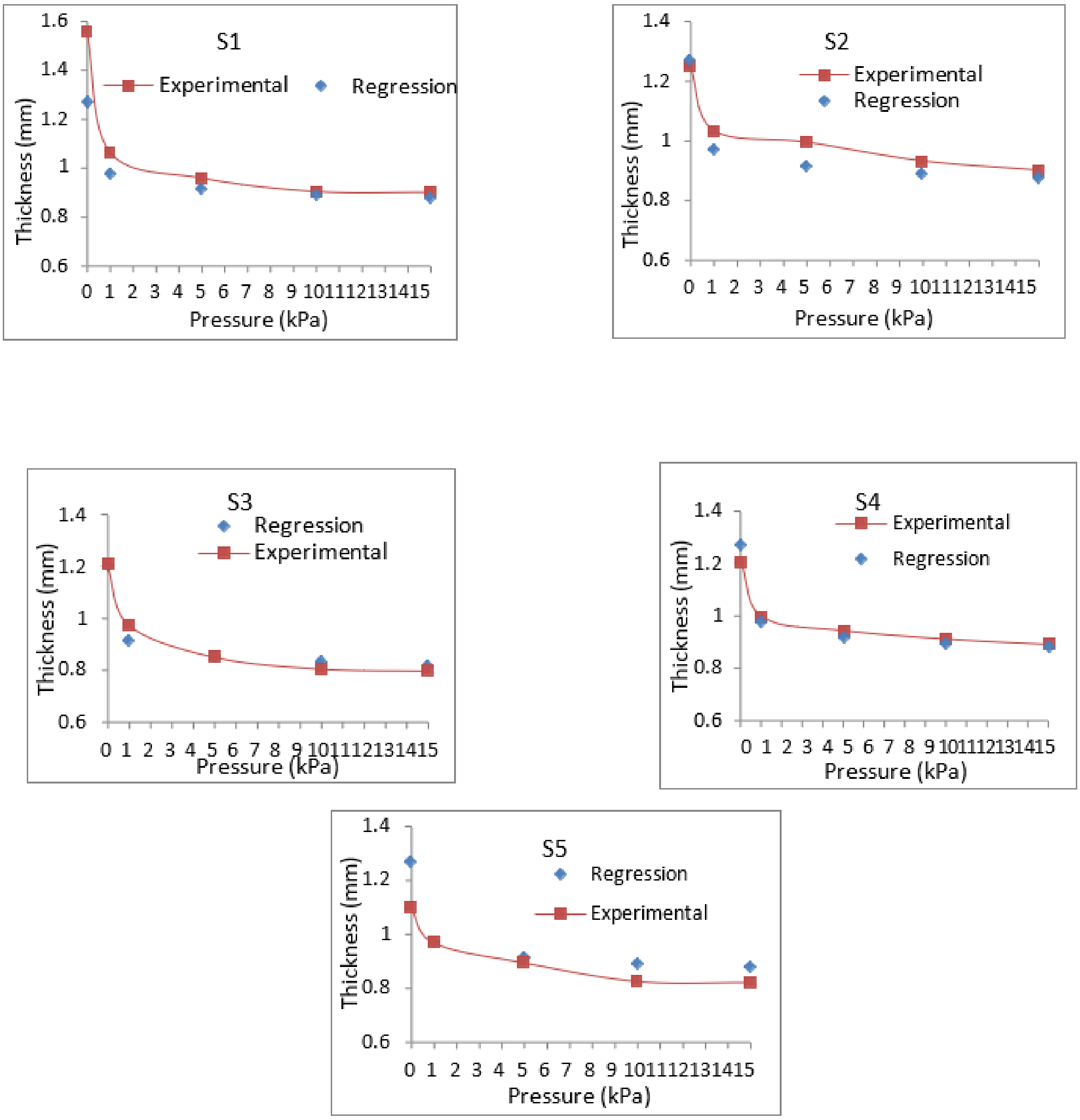

FIGURE 4. Comparison between regression and experimental pressure-thickness of plain jute fabric

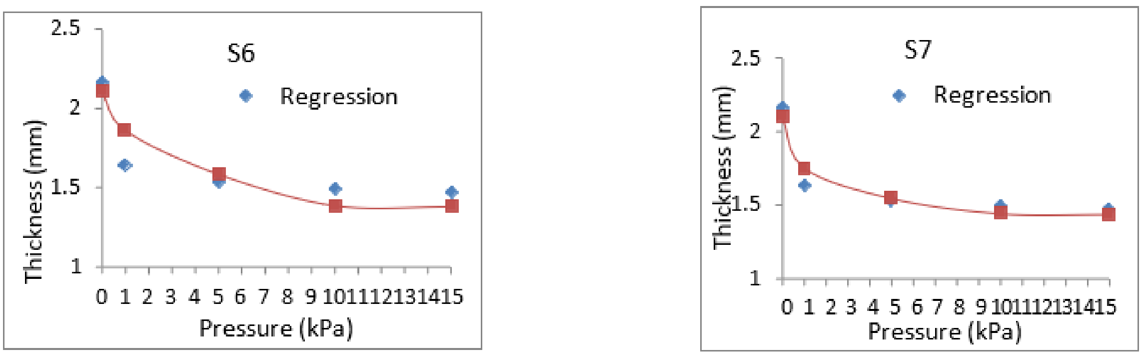

FIGURE 5. Comparison between regression and experimental pressure-thickness of twill jute fabric

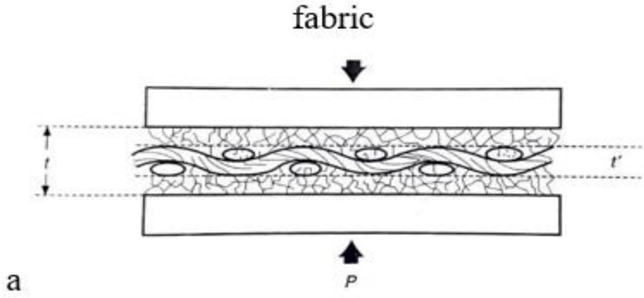

FIGURE 6. Three-layer structure of woven fabrics proposed by de Jong *et al.* (1986)

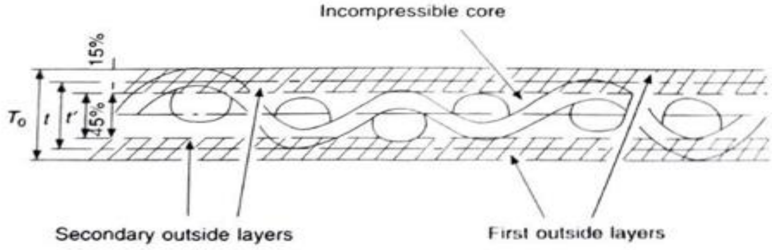

FIGURE 7. Five-layer structure of woven fabric by Hu and Newton (1997)

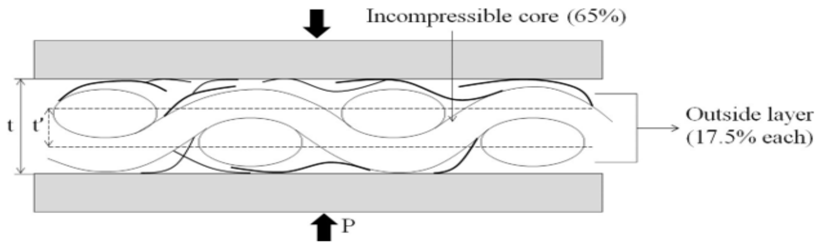

FIGURE 8. Three-layer structure of woven jute fabric

Therefore, a new model has been developed for jute woven fabric, which is divided into three-layer structure, the outer layer on either side of the fabric containing highly stiff protruding fibres along with crimp crown, and incompressible core of the fabric denoted by t' as shown in Figure 8. This layer model is very similar to the original fabric sample as shown in Figure 3 b. The crimp of the jute fabric is comparatively very low still influencing the compression behaviour under pressure. Table 2 shows the percentage of each layer of the fabric. The incompressible core layer possesses about 65% of the whole fabric thickness, which indicates that the fabrics are highly incompressible, the outside layers possess about 17.5% each, which shows that the irregularity of the fabric surface is very considerable.

TABLE 2. Distribution of fabric layer thickness

Group 1 samples (Plain weave hessian fabrics)					
Sample	λ	*t'*	*t*	*t'/t×100*	*100-(t'/t×100)*
S1	2.51×10^{-5}	0.86	1.56	55.64	44.36
S2	1.46×10^{-5}	0.80	1.25	64.02	35.98
S3	1.38×10^{-5}	0.79	1.21	65.31	34.69
S4	1.31×10^{-5}	0.80	1.20	72.76	27.24
S5	9.95×10^{-5}	0.81	1.10	67.73	32.27
	Average			65.02	34.98
Group 2 (Twill weave sacking fabrics)					
S6	5.1×10^{-4}	1.3476	2.11	63.86	36.13
S7	1.35×10^{-4}	1.4092	2.102	67.04	32.95
	Average			65.45	34.54

Figures in the parentheses show the coefficient of variation (%)

4. CONCLUSION

The compression behaviour of plain weave and twill weave jute fabrics was analysed under applied pressures ranging from 0 to 15 kPa. The plain weave fabrics demonstrated rapid compression due to their tighter yarn interlacement, stabilizing at a lower thickness (0.8–1.0 mm). In contrast, twill weave fabrics, characterized by higher yarn linear density and flexible interlacement, exhibited gradual compression behaviour, stabilizing at higher thickness levels (1.3–1.5 mm). A new negative power law model was developed to predict the compression behaviour of jute woven fabrics with high accuracy ($R^2 = 0.95$). Furthermore, a three-layer structural model was proposed to explain the fabric's compression characteristics, where the incompressible core accounts for 65% of the thickness, while the outer layers with stiff protruding fibres contribute 17.5% each. This model provides a detailed understanding of the role of fabric structure and layer composition in thickness reduction under compression. The findings of this study are pivotal for industries utilizing woven jute fabrics in applications where compressive performance and thickness retention are critical, such as in textile composites, cushioning, and packaging systems.

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