Influence of Textile Properties on Mechanical Characterization of `Woven Sisal Fabrics and sawdust polymer composites bricks analysis using ANOVA and Multi Objective Decision-Making Techniques

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Abstract: Natural plant fibres are increasingly being used in composites as reinforcement due to their favorable environmental considerations. In these composites, the fiber and fabric properties play a significant role in enhancing composite properties. Fiber arrangement is controlled by converting the fiber into yarn and fabric. This optimizes the simplicity with which reinforcement may be handled throughout the production of composites, as well as the fibre alignment. This paper aims at the characterization of woven sisal fabrics. Three different types of woven fabrics were analyzed to comprehend the impact of textile mechanical properties like fabric stretch, flexural strength, tensile strength and recovery in warp and weft directions. All three woven fabrics' tensile characteristics and elongation were found to be better in the weft direction than the warp direction. As the gram per centimeter square increased, the flexural modulus increased as well. Crimp in the warp and weft directions directly correlates to the fabric's stretch and recovery. The bursting strength of the fabric depends on the grams per centimeter square, cover factor, and yarn linear density. Three woven sisal fabrics with cover factors of 53 to 93% in the warp and weft orientations are appropriate for composite reinforcement. The results also reveal that load carrying capacity is enhanced by adding fabric in sawdust bricks and superior strain value. The bending characteristics of the sawdust composites have shown considerable impact on the woven design as well as grams per unit area. Combinative Distance-based Assessment

(COMDAS) Multi Objective Optimization Techniques used to study the ranking for sisal fabric mechanical properties.

Keywords: Sisal fiber, Sisal yarn, Woven sisal fabric, Tensile properties, Polymer composite reinforcement, ANOVA analysis.

Introduction

Nowadays, researchers are investigating eco-friendly natural materials, cost-effective and favorable mechanical properties [1]. Natural fibre composites are the subject of increased research since they are bio-based, sustainable, and can take the place of synthetic fiber-reinforced plastics [2,3]. The potential of utilizing natural fiber as textile materials in India and worldwide was reported for engineering composites applications [4,5] New materials with good mechanical properties are produced when natural fibres derived from plants are used as reinforcement in polymer composites. These materials have many applications in the automotive and building industry, mainly for less-load bearing components [6, 7]. However, woven textile materials can overcome the challenge of keeping the reinforcement material aligned during the processing of composites. Generally, the fibres are often transformed into yarn, and this yarn is then utilised to create various woven structures. By using this woven fabric, the mechanical strength of composites can be enhanced [8]. These fabrics are employed in several applications such as weather protection panels, mechanical parts in vehicles, aerospace, and building construction as well [9].

Martha et al. researched on bamboo fibers reinforced vegetable-based polyurethane and observed that the mechanical properties improved by the addition of bamboo fiber reinforcement with and out reinforcement [10]. Sajjad et al. also observed that bamboo has the potential to replace steel bars [11]. Fotini and Maria also found that recycling materials in construction are a safe way to achieve sustainability [12-13]. Giuseppe et al. investigated tensile strength of flax fabrics reinforced cement-based composites under different environmental conditions. Due to fibers and fabrics reinforced in cement-based composites, there is no significant reduction in tensile strength even after exposure to various environmental conditions [14]. Rezania further noted that the mechanical properties and setting time of shotcrete were improved with the use of Glass Fibre Reinforced Polymer (GFRP). The optimal diethanolamine level is close to 0.3% of the dry weight of cement and 0.5% GFRP [15]. Demin et al. used five different leaves combined with cement-based materials as heat-insulating materials and observed excellent thermal insulation with surface modifications [16]. Engineered Cementitious Composites (ECC) with PP (Polyprofline) and PVA

(Polyvinalalcohal) fibers' static and dynamical mechanical characteristics were studied by Jia et al. and seen that compressive strength increased by adding PVA fiber on comparison with respect to PP fiber. The tensile strength and ultimate tensile strain of PP-PVA-ECC increase with increasing PP volume ratio (with a PVA volume ratio of 1.0%). With increase of PP in PP-PVA-ECC, impact strength also increases (with a PVA volume ratio of 1.0%) [17]. These researches work demonstrated that natural fiber and fabric strengthen cement-based composites [18]. Reem et al. also studied on hemp fibers and noticed that natural fibers add strength to walls [19]. However, strengthening the mechanism of cement-based composite is on the base of the bonding between fiber/fabric [20] and the structural properties of fiber and textile fabric. The impact of textile structural qualities on cement-based composites has received little attention in the literature.

However, just a few scholars have previously sought to examine the significance of fabric properties on composites, and Ping et al. studied the influence of stuffer (x-direction) and filler yarn (y-direction). They exhibited that Young's modules in filler yarn direction are higher than in the stuffer yarns direction, with a lower strain rate in filler yarn direction [21]. The type or volume percent of the z-reinforcement had no impact on the composites' in-plane Young's modulus, according to Mouritz's investigation into the impacts of a woven z-binder, stitch, or pin [22]. According to Cevallos et al., the behaviour of composites is primarily influenced by the fibre type, fibre content, and fabric geometry [23]. These fabric properties -cover factor, gram per unit area (GSM), and woven patterns and yarn properties - yarn orientations, yarn crimp, and yarn linear density - have an impact on composite behaviour. GSM and woven pattern majorly recognize fabric properties, depending on all other properties.

The polymer used in the composites processing also plays a dominant role due to its adhesives, biodegradability, mechanical properties, thermo-mechanical properties, and durability of the polymer at elevated temperatures. Many researchers are used polyester [24,25], vinyl ester [26,27], epoxy [28,29] etc are very commonly used polymers in preparation of composites. However, these polymers are non-biodegradable in nature, so-called partially biodegradable due to their reinforcement. Polyvinyl alcohol is an alternative polymer used as a matrix material during composite preparation due to its flexibility at room temperature. Several researchers cross-linked Polyvinyl alcohol (PVA) with various other copolymers/blenders and found that cross-linking mechanical and thermal properties are improved by cross-linking. To enhance the properties, glutaraldehyde (GA) are cross-linked at various percentages and found that 20% GA in PVA gives better mechanical and thermo-mechanical properties.

First off, relatively few scholars have reported about how fabrics affect the mechanical characteristics of natural fibre fabric. Prior to using or converting textile fibres into composites, it is crucial to do study on their mechanical properties. Secondly, PVA cross-linked with GA is a promising polymer with good mechanical properties. In this work, the properties of two plain kinds of fabric and one weft rib type of fabric have been characterized concerning; (i) fabric physical properties, (ii) fabric appearance structure, and (iii) mechanical properties viz. tensile strength, rigidity, or bending strength, stretch, and recovery (conducted both in warp and weft directions), bursting strength to inspect the significant behavior and their suitability of all three fabrics for sawdust composite bricks fabrication. Additionally, these fabrics are employed as reinforcement in polyvinyl alcohol/glutaraldehyde composites made from sawdust to study the effects of textile properties.

Materials and Methods

Materials

From plants in the southern region of India's Karnataka state, sisal fibres are extracted. Three different types of plain woven fabrics (two plain and one weft (filler) rib) are made using these sisal fibres at M/s OM Textile Industries India's Bengaluru, Karnataka. To obtain equivalent qualities for all fibres, sisal fibre is extracted from the leaves in the same plantation. Under typical climatic conditions, these fibres are sun-dried for seven days, washed many times in freshwater, and then sun-dried for four days. The extracted fibres are turned into yarn, and the process of hand-weaving turns the yarns into fabric. Figure 1 illustrates the plain-woven and weft rib fabric structures graphically. Filling rib, however, also belongs to the category of plain woven fabrics. However, one warp yarn is crossed with two filling yarns. Table 1 lists the fundamental characteristics of several sisal-woven fabrics. Weft Rib (WR or WR300), Plain 1 (P1 or P160), and Plain 2 (P2 or P300) are the three sisal woven textiles that were chosen. Fig. 1 illustrates the schematic image of the plain woven structure. While Fig. 2 depicts the views of the P1, P2, and WR woven sisal materials employed in the current work.

Physical properties of woven sisal fabrics, such as thickness, fabric count, or fabric density help to characterise them. The linear density and crimp (for warp and weft) of the sisal yarns were used to identify them. These fabrics were characterised by the employment of numerous textile industry standard techniques that are normally applied to the textile industry. Table 2 depicts the list of standards that are expended to describe all three woven sisal fabrics at the Department of Fashion and Apparel Design in Solladevahalli, Bangalore, and the Central Silk Technological Research Institute (CSTRI), both in Bangalore, Karnataka, India.

Polyvinyl alcohol purchased from M/S. Leo Chem India, Bengaluru, Karnataka, India. One of the most useful protein cross-linking reagents is glutaraldehyde, which is furnished through M/S. Leo Chem India, Bengaluru, Karnataka, India.

Table 1: Representation of various woven fabric of sisal textile fabric analyzed and their basic properties as per supplier (M/s. OM Textile Industries)

Sl. No	Woven type	Code	Mass per unit area	No of yarns per cm	
				Warp(P)	Weft(T)
1	Plain 1	P 1	160	18	20
2	Plain 2	P 2	300	12	12
3	Weft rib	WR	300	22	11

Table 2: Standard methods accustomed determine material properties

Methods	**Properties**	**Testing**	**Standard method**
Yarn Testing Methods	Twisting strength of the yarn	Untwist-retwist method	IS: 832-1985
	Yarn crimp	Yarn crimp and yarn take-up in woven fabrics	ASTM: D3883
	Yarn size	Yarn number (linear density)	ASTM: D1907
Fabric Basic Properties Testing Methods	Fabric density	Warp (end) and filling (pick) count of woven fabrics	ASTM: D3775
	Fabric weight	Mass per unit area (weight) of fabric	ASTM: D3776
	Fabric thickness	Thickness of textile materials	ASTM: D1777
Fabric Mechanical Properties Testing Methods	Tensile Strength	Fixing fabric two ends	IS: 1969-1985
	Stiffness Strength	Bending through the angle of 41.5^0	ASTM D 1388-96
	Bursting Strength	79.8mm diameter of subjected to bursting	IS: 1966-1976
	Fabric Stretch and recovery test	Applying and removing the load	ASTM D 1388-96
Sisal fabric reinforced sawdust composites	Bending Strength	Span length of 150 mm and crosshead speed 1.27 mm/min	ASTM C67

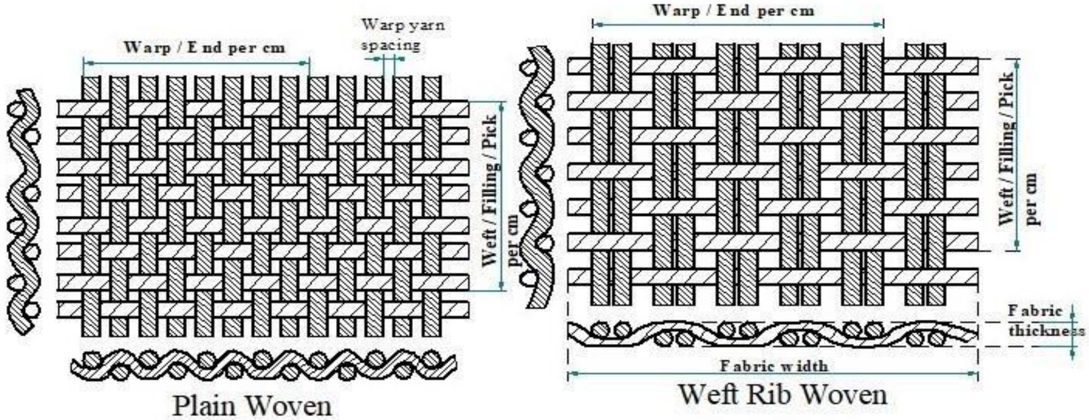

Figure 1: The plain and weft-rib woven fabric structure.

Preparation sisal fabric reinforcement composites

Prepared sisal fabrics (shown in Fig. 2) are employed to prepare fabric reinforced sawdust composites. Schematic diagram of the processing of reinforcement in sawdust-based composites is showed in Fig. 3. Initially, paper dust and sawdust are as displayed in Fig. 3(a) were mixed for various weight percentages to prepare the solid blocks. The mixture is dipped in 80:20 percentages of polyvinyl alcohol (PVA) and glutaraldehyde solution. Then stirred with mechanical stirrer for 10min at 400 rpm, further poured in the wooden mould of 200 x 100 x 100 mm dimension (as per ASTM C62 standard). The solid block are prepared by applying pressure using a mechanical screw jack represented in Fig. 3 (b). Ten trials were used in each variation to study the weight percentage effect and found that 40 percent of paper dust with 60 percent exhibit better-bending properties. The three fabrics were reinforced in 40:60 weight percentage of paper and sawdust bricks (PSDB) in both the top and bottom sides of the block and the application of the same is shown in Fig. 3(c).

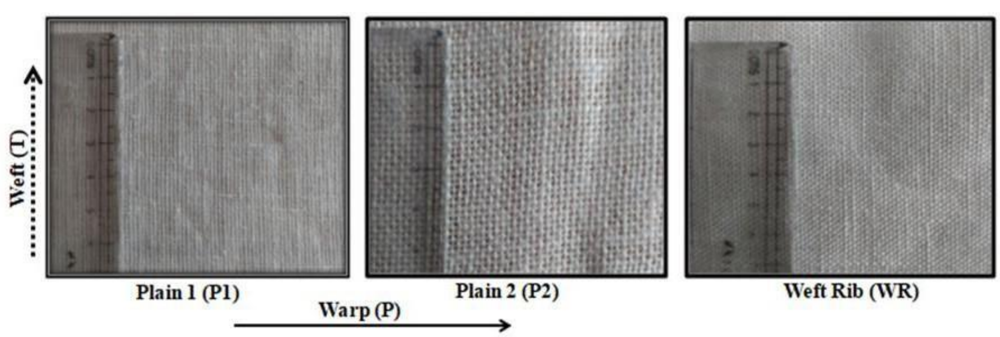

Figure 2: Woven sisal fabric employed for this work.

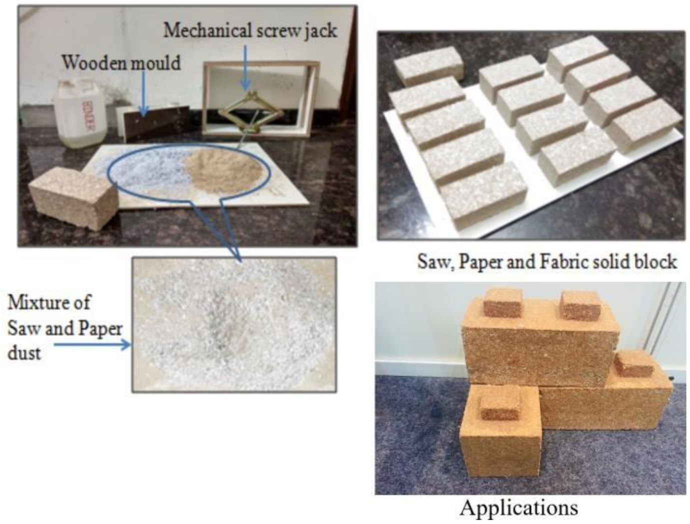

Figure 3: Schematic representation of processing of saw and paper dust, fabric reinforced solid blocks.

Sisal Fiber Strength

A bunch of fibers are selected randomly from the extracted sisal fibers. These bunches were well washed using distilled water and cut into 350 mm length. One fiber from each bunch is selected, and tensile properties of each were analyzed by using an Instron 3366 UTM by maintaining a gauge length of 220 mm with 2.5 mm/min rate of loading. The environment is maintained with 50% humidity at 20°C.

Sisal year properties

Twisting Strength

The spiral arrangement of yarn in woven fabric is commonly quantified as the number of turns per unit length of yarn, typically measured in turns per meter. To discover the yarn twist, a direct counting method, known as the untwist-retwist method, is employed. For each woven sample, five specimens measuring 500 mm in length were randomly selected from various sections of the fabric. The twist test adheres to the IS: 832-1985 standard, with a gauge length of 250 mm. A deadweight of 0.5g/tex is applied to the specimen, and the tension is maintained until the desired elongation is achieved, with ±0.5 mm accuracy.

Yarn crimp

Following the rules outlined by ASTM D3883 standards, yarn crimp is evaluated as a physical property. The fabric is cut with a length of 300 mm in the weft direction and a length of 200 mm in the warp direction in order to measure the crimp. The fabric is designated with two parallel lines that are 200 mm apart and run parallel to the yarns (Y1 designates the breadth of the fabric). To determine the amount of yarn crimp, at least ten yarns from the cut fabric must be carefully unravelled (Equation 1).

$$Yarn\ Crimp\ (\%), C\ = \frac{Y_2 - Y_1}{Y_1} \times 100 \text{ ....(Eqn. 1)}$$

Where,

Y1: Length of the yarn in the fabric, Y2: Measured length of the yarn after unraveling without external force, c: Yarn crimp, expressed as a percentage.

Yarn linear density

The determination of the linear density of the prepared yarn is conducted in accord with the ASTM D1907 standard. To measure the linear density, a min. of ten unrevealed yarns, each having a length of 1 meter, are selected (Equation 2).

$$Yarn\ size\ (tex), N\ = \frac{w \times k}{l} \text{ ....(Eqn. 2)}$$

l: Length of the yarn in meters, w: Yarn weight in grams., k: Constant value representing the conversion factor from grams to tex (k = 1000 m/g).

Characterisation of Woven fabric

Yarn density / Fabric density

The degree to which yarns are spaced closely together in a fabric can significantly affect the fabric's properties. The number of yarns in a fabric, also known as the fabric count, is referred to as yarn density or fabric density. The number of yarns in both the warp and weft directions can be determined using the ASTM D3775 standard. To achieve this, lay the fabric out on a glass surface and use a pick counter to count the yarns that are longer than 20 mm.

Weight and thickness of fabric

In the current study, fabric weight are found as per ASTM: D3776. Five specimens were employed to measure in gram/square meter or grams/unit area (GSM) (g/m^2). The thickness of measured in thirty different locations as per, ASTM: D1777 20 mm away from selvage edge using Askhi make (least count of 0.01 mm) thickness indicator.

Mechanical properties fabrics

Tensile strength

The Universal Testing Machine (UTM) (Instron) was used to discover the tensile characteristics of sisal fabrics. Maintaining an equal amount of yarn in both directions allows for the preparation of the test specimens. When assessing the specimen's cross-sectional area, the width and thickness are taken into account. The tensile test is carried out in accordance with IS: 1969-1985 to get the impact of mass per unit area and woven structure using an Instron machine with gauge dimensions of 200 mm x 50 mm and a speed of 3 mm/min. The specimen is held in place between two clamps on the tensile testing machine in such a way that each clamp gripped a constant number of yarns, the load was uniformly distributed across each yarn, and the load was applied longwise to the specimen by moving one clamp between the others til the specimen fails.

Flexural rigidity of the fabric

A bending moment known as flexural rigidity is needed to achieve a specific curvature in mg-cm. Fabrics were cut with dimensions of 152.4 x 25.4 mm in accordance with ASTM D 1388-96. The fabric is hung from the horizontal platform in a cantilever-like fashion. Its own weight causes it to be constrained downward along the length. Shirley stiffness testing is another name for this cantilever principle test technique. The fabric's flexural rigidity is determined after the fibre is permitted to bend at 41.50 angle under its own weight.

Bursting strength of the fabric

All three fabrics' bursting strengths had been assessed using IS: 1966–1976 criteria. The test samples were formed into a circle with a diameter of 79.8mm, and the region is free of fabric selvages and folds. The test object is maintained over the diaphragm to lay in a flat and tension-free condition and is secured firmly with holder. Pressure is applied to the test specimen until the fabric bursts. The pressure that remains after subtracting the mean busting pressure from the initial diaphragm pressure is known as the bursting strength.

Fabric stretch and recovery test of fabric

Tests for fabric stretch and growth were performed in accord with ASTM D 1388-96. A piece of fabric is stretched for the required amount of time from its original length (L1) to a specified extension length (L2). After the load was released, the fabric didn't extend to its original length. However, after release (L3), the fabric's length extends. The distance between the specimen's benchmarks before stretching and its length after the relaxation period was employed to calculate the fabric growth over time. The percentage of fabrics' stretch and fabric growth were computed using the below equations.

$$Fabric\ stretch = {(L_2 - L_1)}/{L_1} \times 100$$

$$Fabric\ growth = {(L_3 - L_1)}/{L_1} \times 100$$

Bending/flexural properties of sisal fabric reinforced sawdust composites

The solid bricks of 200 x 100 x 100 mm dimension were prepared as per ASTM C62 standard. Bending properties of Sisal Fabrics Reinforced Saw and Paper Dust (SSPDB) were also measured using Universal Testing Machine (UTM) (Instron) according to ASTM C67. To determine the effect of mass per unit area and the woven structure of sisal reinforced bricks, span length of 150 mm and crosshead speed 1.27 mm/min were used. The ten-set of identical samples were tested in each combination.

Results and Discussion

Single Fiber Test

The tensile behavior of sisal fibers is presented in Fig. 4. The load versus extension curve clearly shows non-linearity in the beginning, which was unique for all samples. The load versus extension indicates that a higher initial load for a small increase in extension. The further small non-linear region was observed at point B. Further increase in the load, the extension occurs linearly with an increase in load. At the initial stage in the load-displacement diagram non-linear region is observed. It could be ascribed to the weak strength of sisal fiber at primary cell walls. The higher tensile resistance is reported in sisal fiber due to the existence of approximately 73% cellulose, as mentioned in many literatures and lowest variability in the tensile results, as also presented using Weibull modulus in literature on comparison to other natural fibers [30]. The maximum (ultimate) load corresponds to the peak point at the rupture of fibers. The summary of average values and their Standard deviation as presented in Table 3.

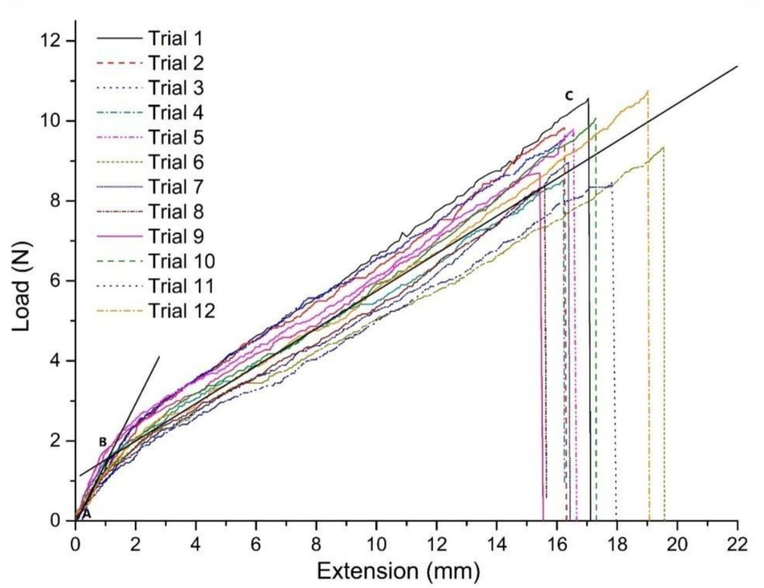

Figure 4: Single sisal fiber tensile testing results load versus extension

Table 3: Summary of average values and standard deviation of the tensile properties of sisal fibers

	Minimum	Maximum	Mean	Variance	Standard deviation	Standard error
Load in N	8.38	10.57	9.384	0.474	0.688	0.229
Extension in mm	15.43	19.55	16.687	1.199	1.095	0.365

Sisal yarn characterization

Twist of yarn

Numerous aspects, including water absorption, pilling resistance, abrasion resistance, fabric strength and feeling effect (hard or soft), are influenced by the yarn twist. To determine the impact of reinforcement materials on composites, sisal textiles were prepared. The prepared fabrics showed right-handed angle twists. It is important to determine the yarn's type of twist because it affects the properties of the fabric andto composite properties. It has been proven that all three sisal fabrics have S type twist. The range of yarn twists, or full spiral threads, per metre, is 425 to 645.

Yarn crimp

The interlacing of the warp and weft yarns causes the yarn in the fabric to wave. Additionally, it is well recognised that the yarn crimp of a woven fabric is a significant factor that influences the majority of its physical characteristics, including the fabric's thickness and weight [31].

Yarn linear density

The fabric weight/GSM has a strong relationship with yarn size or yarn linear density. To account for this, the warp and weft yarn linear densities of the three fabrics were evaluated, and the findings are displayed in Table 4 for all the fabrics under discussion. As opposed to Plain 2, which has a yarn count of 182.3 tex in the warp and 166.8 tex in the weft direction, Plain 1 has a yarn count of 80.1 tex in the warp and 85.1 tex in the weft direction. An analogous fabric is weft rib, which has a warp direction tex of 65.3 and a weft direction tex of 182.9.

Sisal fabric basic physical properties

Fabric density

The quantity of warp and weft yarns used to create the specified length of fabric is what determines the fabric density. Fabric density, which is related to fabric compactness, provides information about yarn spacing. The usual properties of two plain fabrics are connected to their relative fibre densities in fabric and weight. The metric system was employed to find the number of yarns that were in millimeters (mm). Based on Table 1 both plain fabrics with different densities were found. i.e., plain 1 has 36 warps/20 mm and 40 wefts/20 mm, and Plain 2 has 24 warps/20 mm and 24 wefts/20 mm. Similarly, the weft rib was measured, and this is has 44 warps/20 mm and 22 wefts/20 mm.

Weight and thickness of fabric

Due to restrictions in the weaving technique, processing natural sisal fibre was tricky, and maintaining the same mass per area was particularly difficult. The weight of the fabric, however, affected a lot of the output properties. It is crucial to gauge the fabrics weight. The supplier's descriptions on specifications for the chosen fabrics are that plain 1 fabric should weigh 160 g/m2, while plain 2 and weft rib fabric should weigh 300 g/m2. Plain 1 fabric weighed less (161.02 g/m2) than Plain 2, which weighed 296.6 g/m2, and weft rib fabric, which weighed 300.45 g/m2, as presented in Table 4.

The results are presented in Table 4, and the fabric measurement results also provide insight into how plain 1 and plain 2 fabrics were created to achieve the same woven structure with various GSMs. Additionally, Plain 2 and weft rib fabrics provide insight on how mechanical characteristics change with woven structure. When it is mechanically equal in both warp and weft direction, this is also influenced by a number of warp and weft yarns. Table 5 lists the total weight of the yarn used for the warp or weft. In section 3.4, it is discussed how the crimp, yarn linear density, and number of yarns all have different mechanical properties.

According to the fault/defect observation in the fabric, none of the three textiles had any missing picks along the length of the fabric for at least 5 m. The missing pick is referred to as missing or out of order yarn in the fabric that is woven. The width of the fabric had an empty line running across it, and this flaw typically appeared in order in fabrics. In the present study, three textiles were evaluated, and it was found that all of the fabrics had the free from loom's (weaving machine) problem [43]. The made fabrics therefore displayed superior quality and were outstanding in the loom. The threads in the fabrics were not homogeneous (containing a lot of thick and thin yarns) due to variances in the cross-sectional dimensions of the manufactured fabrics (Fig. 2).

The measured thickness of the fabrics are as presented in Table 4. The Plain 1, Plain 2, and weft rib fabrics, respectively, have fabric thickness 0.42mm, 0.73, and 0.72 mm.

Weft rib structure, which is very similar to plain structure in terms of effect, was preferred. Nevertheless one warp yarn and two yarns were employed. Referring to Table 4, the yarn size chosen for each of the three fabrics was simply the mean of the tests run. These kinds of yarn irregularities and inconsistencies are predicted in the fabric because these fabrics are made from natural fibres. A massive production line called "spin" was used to produce the yarns. As is common knowledge, obtaining the necessary yarn size requires a number of drawing steps. It is very challenging to obtain the desired yarn size and even the perfect drawing is made because natural fibres have irregularities [3].

Fabrics weight in warp and weft directions are presented in Table 5.

Table 4: Textile properties of different fabrics

Sl. No	Woven type	Fabric thickness in mm	GSM	Cover factor (%)		Yarn Count in Tex		Yarn crimp (%)		Number of yarns per cm	
				Warp (**P**)	Weft (**T**)	Warp (**P**)	Weft (**T**)	Warp (**P**)	Weft (**T**)	Warp (**P**)	Weft (**T**)
1	**Plain 1**	0.42	161.02 ±0.17	79.18 ±0.46	91.78± 0.69	80.1 ±0.56	85.1 ±1.67	7.23 ±0.26	9.54 ±1.12	18 ±0.95	20 ±1.06
2	**Plain 2**	0.73	296.60 ±1.75	74.28 ±2.80	80.24± 3.75	182.3 ±4.43	166.8 ±8.41	6.53 ±0.97	11.06 ±1.09	12 ±0.74	12 ±0.67
3	**Weft rib**	0.72	300.45 ±1.67	82.12± 3.09	53.01± 3.06	65.3 ±2.51	182.9 ±4.04	10.05 ±0.94	5.96 ±1.22	22 ±1.03	11 ±1.05

Table 5. Fabrics weight in warp and weft directions.

Fabric types		Plain 1	Plain 2	Weft Rib
Weight (g/m^2)	Total weight of warp	70.57	153.72	113.95
	Total weigh of weft	90.45	142.88	186.50
Fabric Weight (g/m^2)		161.02	296.6	300.45

Mechanical Characterisation of fabrics

Tensile Strength

For a better comprehension of the findings, Fig. 6 load-elongation curve for woven sisal fabric is separated into three phases. A gradual slope is represented by the curve's beginning stage. The fabric reaches a settlement at the conclusion of this stage, then increases linearly until it reaches the third stage, often known as the peak. Due to internal crossover in between the fabric's warp and weft yarns and decrimping and crimping interchanges at the first stage of the curve, elongation dramatically rises with moderate load. When the sisal fabric is stretched in either of its two principal directions, the crimped yarns are seen to straighten in the force's direction. The fabric's yarns also continue to round out and become less flattened. Yarn and fibre elongation took place at this step. Elongation, however, is quite minimal when compared to the initial stage. Owing to the twist, the fibre in the tighter, stronger yarn develops build-in pressure and resists tensile force, resulting in the small amount of elongation of the yarn. The typical yarns to the direction forces are ignored at this point. The load-carrying capacity and yarn breakdown are demonstrated at the completion of this stage.

Initial curves have risen in Fig. 5, which can be ascribed to the interchange between crimping and de-crimping. The load-elongation diagram's initial slope, nevertheless, results from a higher crimp percentage in the weft direction (9.54) and a lower crimp percentage in the warp direction (7.23). This is also a result of the manufacturing effect, which consistently results in better weft properties than warp directional properties [44]. It is also observed that the curve rose steeply from the first decrimping and crimping state until their peak (final point) were attained. Even though there are the same number of yarns in the warp and weft, the P1 type of fabric in Fig. 5 fails at 481.2 N in the warp and 655.9 N in the weft, indicating that the weft direction demonstrated superior properties (1.3 times) than the warp direction. This is dependent on the fact that weft (85.1) has a larger yarn linear density (yarn count) than warp (80.1). As a result, the majority of the weft specimens had stretched to their settled form at about 12 to 14 mm elongation, while the warp facet of the material had minimized to about 9 to 10 mm.

This also clearly demonstrated the minimal variance in the highest (ultimate) tensile load in the warp and weft as compared to P1 in the P2 type of woven fabric with warp 869.2 N and weft 952.8 N. Although the weft has a lower yarn linear density than the warp (166.8), the weft has a greater ultimate tensile load than the warp. Fabric fabrication is primarily responsible for this. Both types had identical structures on comparison to P1 and P2, but their grams per square metre were 161.02 and 296.6, respectively. The tensile results made it abundantly evident that although the fabric's weight is larger, its capability for withstanding loads rises correspondingly. However, the ultimate point's tensile modulus is reduced. Less warp elongation/strain is seen than in plain woven fabrics. The influence of the twist in the yarns per metre length might be the reason for this.

Both P2 and WR have almost the same gram per square meter and the ultimate tensile load apart from WR warp direction. Among these fabrics, WR weft exhibits the highest tensile strength, which is 1.6 times that of warp direction of the same woven fabric. This is caused by the interlocking of the two weft-direction yarns over the warp yarns (higher yarn density). This may suggest that plain-woven configurations have an effect on fabric's mechanical behaviour [42].

Since the input variable for the fabric (Table 6) cannot be precisely controlled, the experimental findings obtained are insufficient to assess the importance of output outcomes as tensile ultimate load and elongation in both the warp and weft orientations. To examine the significant differences between the mean values, inferential statistical analysis is required when concluding about a population based on sample data. For all types of fabrics, the analysis of variance (ANOVA) is performed using Microsoft Excel to determine the significant differences between warp and weft directions. Each fabric's confidence levels were set at 95%, and the hypothesis was predicated on the P-value. Because the P-value is equal to 0.000 in all different types of fabrics, there has been a noticeable difference between the warp and weft directions. The findings are considered to be 'insignificant' or 'not significant' if the P-value is more than 0.05. Table 8 makes it abundantly evident that the load on each of the three fabrics has a considerable impact in both the warp and weft directions. The same is true for Table 10, which exhibits that ultimate point elongation significantly affects both the warp and weft directions.

The variance of the weft direction is less than warp direction, as indicated in Table 7, yet the average value of the warp direction is bigger than weft direction. This shows, P1 kind of fabric's weft direction has a higher load-carrying capacity than the warp direction. When compared to warp direction, the variance is higher in weft direction. Likewise, weft direction of the P2 type of sample is more than warp directions. But when compared to P1 and P2, P2 fabric shows superior load bearing ability and better load withstanding capacity in the weft direction. This finding demonstrates that the gram per unit affects the tensile stress and strain characteristics of the fabric.

The woven patterns of the P2 and WR fabrics are plain and weft rib, however they have the same gram per unit area. Even if the number of the woven pattern in the warp and weft directions is equal in P2, the weft direction of the fabric exhibits greater qualities. In the P2 and WR fabrics depicted in Table 9, the extension in the weft direction is greater than the warp direction. This in addition support the idea that yarn linear density and crimp have an impact on the fabric's ability to withstand tensile stress and strain. However, WR fabric has less variation than P2 fabric in both the warp and weft directions. This occurs as a result of the fabric's coarseness-related cover factor. Combinative Distance-based Assessment (COMDAS) Multi Objective Decision-Making Techniques used to study the ranking as shown in Table 9. The Plain 2 weft direction shows maximum properties by concentering minimum GSM.

The P-value of ANOVA results in Table 10 shows P1 and WR fabric highly significant than P2 fabric. But the extension value of all the fabrics between the groups is significant.

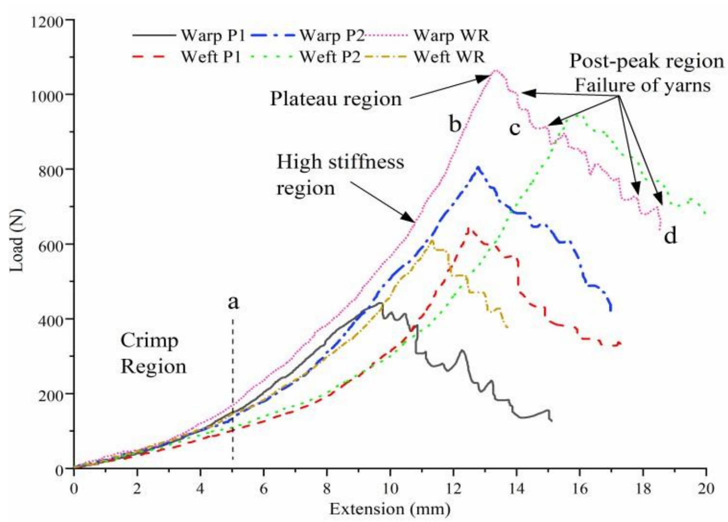

Figure 5: Tensile load-extension response of plain 1, plain 3, and weft rib fabrics in weft and warp directions.

Figure 6: The fabric fracture after tensile test, (a) Fractures yarns P1 based fabric, (b) magnified fracture area, (c) magnified fracture area of P2, and (d) magnified fractured area of WR.

Table 6: Tensile Properties of fabrics

Type of fabric	Directions	Ultimate Point		Breaking Point		Ultimate Point		Tensile Modulus (N/mm^2)
		Load (N)	Elongation (mm)	Load (N)	Elongation (mm)	Stress (N/mm^2)	Strain	
Plain 1	Warp	481.2 ±21.5	9.67±0.39	159.72±83.5	14.74±1.28	22.91±1.02	0.048±0.0019	474.743
	Weft	655.9 ±13.1	13.51±0.69	322.53±39.0	20.24±1.55	31.23±0.62	0.068±0.0034	463.237
Plain 2	Warp	869.2 ±31.0	12.88±0.50	405.80±79.3	19.14±2.02	23.81±0.85	0.064±0.0025	370.233
	Weft	952.8 ±8.0	15.85±0.35	471.60±72.8	21.55±0.21	26.10±0.21	0.079±0.0018	329.419
Weft Rib	Warp	672.0±48.2	11.02±0.30	223.40±98.4	14.77±0.96	18.66±1.34	0.055±0.0015	339.405
	Weft	1074.5±10.0	13.21±0.18	421.81±103.3	20.40±1.21	29.84±0.28	0.066±0.0009	451.716

Table 7: Summery ANOVA results for sisal fabrics ultimate point load

Groups (Type of fabric)	Direction of fabric	Count	Sum	Average	Variance
P1	Warp	10	4812.03	481.203	462.394
	Weft	10	6559.701	655.9701	171.4066
P2	Warp	10	8698.44	869.844	959.933
	Weft	10	9533.58	953.358	62.89973
WR	Warp	10	6720.455	672.0455	2318.698
	Weft	10	10745.45	1074.545	99.6327

Table 8: ANOVA ultimate point load

Type fabric	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
P1	Between Groups	152717.8	1	152717.8	481.9112	1.92E-14	4.413873
	Within Groups	5704.206	18	316.9003			
	Total	158422	19				
P2	Between Groups	34872.94	1	34872.94	68.18894	1.56E-07	4.413873
	Within Groups	9205.495	18	511.4164			
	Total	44078.44	19				
WR	Between Groups	810031.3	1	810031.3	669.9093	1.08E-15	4.413873
	Within Groups	21764.98	18	1209.165			
	Total	831796.2	19				

Table 9: Summary ANOVA results for sisal fabrics ultimate point elongation

Groups (Type of fabric)	Direction of fabric	Count	Sum	Average	Variance	*Ranking*
P1	Warp	10	96.72105	9.672105	0.151658	**6**
	Weft	10	135.1842	13.51842	0.470769	**3**
P2	Warp	10	128.8684	12.88684	0.2527	**4**
	Weft	10	158.5526	15.85526	0.12377	**1**
WP	Warp	10	110.2105	11.02105	0.091074	**5**
	Weft	10	132.1842	13.21842	0.033557	**2**

Table 10: ANOVA ultimate point elongation

Type fabric	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
P1	Between Groups	73.97073	1	73.97073	237.6846	8.14E-12	4.413873
	Within Groups	5.601849	18	0.311214			
	Total	79.57258	19				
P2	Between Groups	44.05765	1	44.05765	234.0569	9.26E-12	4.413873
	Within Groups	3.388226	18	0.188235			
	Total	47.44587	19				
WR	Between Groups	24.14215	1	24.14215	387.4174	1.27E-13	4.413873
	Within Groups	1.121681	18	0.062316			
	Total	25.26383	19				

Stiffness Strength

According to ASTM D 1388-96, the fabric stiffness or bending strength was assessed (see Table 2). To comprehend how self-weight affects overhanging, the flexural rigidity of sisal woven fabric is determined. The stiffness strength of fabric of the P1 type is 2105.1 mg-cm in the warp direction and 545.3 mg-cm in the weft direction. This is because the weft side yarn cover factor is greater than the warp side yarn cover factor, and the weft side yarn count (yarn strength) is higher (85.1) than warp direction. Due to overhanging (self-weight), the fabric's weft direction weight rose (Table 5) and its flexural strength decreased (Table 11).

Alike to P1, plain-woven variants P2 displayed the same flexural behaviour. Weft direction of the fabric has a higher weight than warp direction. However, because there were 65.3 yarns in the warp direction in WR type structures, the flexural strength was reduced.

Bursting Strength

The amount of force needed to cause a fabric to rupture is known as the "bursting strength," and Table 11 records an average of 10 readings. Bursting strength is related to the yarn count and yarn density of the fabric because it depend on the cover factor of fabric interns. A strong cover factor is required for the reinforcing textiles so that resin may permeate them. These bursting characteristics relate to tensile and flexural strength in addition to high and low velocity impacts. Thus, a bursting tester must be used to describe the fabric materials. Despite having plain woven structures, the P1 and P2 fabrics have different fabric weights. P1 and P2 had bursting strengths of 1.36 MPa and 2.47 MPa, respectively. The fabric weight (P1-161.02 g/m2 and P2-300.45 g/m2), yarn linear density (P1-80.1 tex and P2-182.3 tex), and cover factor (P1-79.18% and P2-74.28%) all contribute to the variation in bursting strength. Compared to P2 fabric, P1 type of fabric thin (yarn linear density) and more liable to break at thin places because these fabrics have thin and thick areas. It has been seen that the fracture has occurred in a region of thin yarn, where there is less yarn coverage in the fabrics. Though, it might be suggested that the cover factor and yarn strength were the key determinants of bursting strength.

The weight and cover factor of P2 and WR types of woven fabrics were nearly identical, with variations in the amount of yarns used in the warp and weft directions (the wove structure). P2 and WR had bursting strengths of 2.47 MPa and 2.43 MPa, respectively. In comparison to P2 and WR, it was discovered that variations in bursting strength were minimal. The number of yarns in the warp was lower than the weft in the WR woven structure, nevertheless. The failure was being caused by the warp yarns, which were discovered to be being pulled away from the fabrics. Though, a pair of long yarn floats in WR can endure applied forces vertically during bursting strength tests. Burst strength is seen to depend on the strength of the warp and weft yarns in addition to P2 and WR cover variables that relate to bursting strength. P2 and WR fabric have greater bursting strengths than P1 fabric. It is due to the fact that these weaves' fabric weight, average float length, and cover factor were all larger than those of P1, and that the linear density of the yarns in P2 and WR woven structures was also higher.

Fabric stretch and recovery

Since sisal fabrics are employed as a reinforcing material to make composites, they were put under constant load for a considerable amount of time. Therefore, it is essential to determine the fabric's stretch and recovery (growth) before reinforcing. According to Table 11, all three fabrics have a higher proportion of fabric stretch in the weft direction than the warp. This is a outcome of plain woven fabrics' higher weft-to-warp crimp percentage. The fabric growth for P1 type fabrics was 42% in the warp and 40% in the weft. However, in the weft and warp directions of fabric of type P2, the percentages are 47% and 26%, respectively. The weft direction of P2 exhibits the highest fabric growth in the case of P1 and P2. This could be because of the highest crimp in the P2 weft direction or due to change in GSM. P2 and WR had the same GSM, but due to the woven structure, WR weft direction demonstrated the lowest fabric growth. Because of this, even while crimp % influences how much a fabric stretches and grows, it also relies on the fabric's gsm and woven structure.

Table 11: Flexural strength and stretch and growth of fabrics

	Directions	Plain 1	Plain 2	Weft Rib
Stiffness Strength (mg-cm)	Warp	2105.1	2307	1146.7
	Weft	545.3	771	456.5
Turns per meter	Warp	584	433	436
	Weft	645	425	528
Bursting Strength (MPa)		1.36	2.47	2.43
Fabric stretch (%)	Warp	0.40	0.8	0.27
	Weft	3.5	1.9	2.6
Fabric growth (%)	Warp	0.17	0.21	0.09
	Weft	1.4	0.9	0.55

Flexural Properties of sawdust fiber-reinforced composites

Flexural properties of PSDB and sawdust reinforced composites were assessed using a three-point bending mode. Nagamadhu et al. observed that 20 volume percentage of GA in PVA shows maximum mechanical and thermo-mechanical properties. This research work used 20 volume percentages of GA in PVA as a matrix material to prepare sawdust composite bricks.

Three fabrics (P1, P2, and WR fabrics considered in the previous section) are used to sawdust polymer bricks. To examine the influence of gram per unit area on bending properties, sawdust bricks, P1, and P2 fabric-based sawdust bricks are tested as both are made of the same woven pattern. To study the influence of woven patterns on bending properties of sawdust composites, P2 and WR fabric-based sawdust bricks are tested as both are the same gram per unit area, but woven patterns are different.

Several textile properties influence composite strength in that major direction of the fabric. The warp and weft direction of the fabric used to analyze the effect of textile structural properties on composite bricks.

Fig. 7 displays the flexural stress-strain plot of sawdust polymer composites. Initially, stress increases with a small change in strain, load-carrying capacity increase up to 100MPa. Observed that, stress is directly propositional to strain up to 100 MPa with 3.75 corresponding strain. Further, increasing load stain increases with a small change in stress value and reaches ultimate stress. Table 12 shows that sawdust bricks' average ultimate point stress is 143.4 MPa and the corresponding strain value is 8.75 for 10 trials. Further, the load stress value decreases, leading to the breaking of sawdust bricks.

P1 and P2 fabric-based composite bricks are tested in both directions and detected that warp direction of the P2 composite exhibits the highest strength shown in Fig. 7 and Table 12. This might be due to yarn count, P1 fabrics lower yarn count (80.1 warp) than P2 (182.3 warp). The ultimate stress of P1 fabric-based composite increased by 1.51 and 1.83 times in warp and weft directions, respectively, in comparison to neat sawdust composite. Whereas in P2 based composite, The ultimate stress rose by 1.64 and 1.57 time in warp and weft directions, respectively, in comparison to neat sawdust composites. The ultimate point strain of neat sawdust bricks is 8.75

by adding P1 fabric on both the top and bottom side of the bricks strain improved by 1.73 times in warp and 2.18 times in weft direction as presented in Table 14.

Similarly, by adding P1 fabric on both the top and bottom side of the bricks strain improved by 2.04 times in warp and 2.79 times in weft direction. The improvement in strain in the case of P2 based composites is due to yarn crimp and yarn twists in the fabric. As the yarn is finner, a strain is very less and can be improved by increasing the linear density. This clearly demonstrates that fabric reinforcing at both top and bottom enhances the strength of the bricks almost double; however, it depends on fabric materials and its properties. This discussion indicates that gram per unit area of the fabric significantly influences the mechanical properties of sawdust bricks.

P2 and WR fabric-based composite bricks are tested in both directions (shown in Fig. 7) and observed that warp direction of WR sawdust composites bricks shows better properties than other combinations and also neat sawdust composite bricks. The strength of warp direction of WR composite shows in enhancement by 2.15 times to neat sawdust composite bricks. This clearly unveils that even though P2 and WR woven fabrics are the same gram per unit area mentioned in Table 12, the load-carrying capacity changes also based on the woven pattern.

The ultimate point strain of neat sawdust bricks is 8.75, by adding P2 fabric on both the top and bottom side of the bricks strain improved by 2.04 times in warp and 2.79 times in weft direction. Similarly, by adding WR fabric on both the top and bottom side of the bricks strain improved by 2.36 times in warp and 1.55 times in weft direction. The improvement in strain in case of P2 based composites is owing to yarn crimp and yarn twists in the fabric. As the yarns are finer, the strain is very less and can be improved by increasing the linear density. This can be observed in warp and weft directions of WR pattern. The strain is enhanced by 2.36 times in warp and only 1.55 times in weft direction of WR fabrics, indicating woven pattern also influences the mechanical properties of composites.

The ANOVA results of composite bricks are analyzed and discovered to be more than 95% confidence level. Both ultimate point stress and strain values are significant, as displayed in Table 13 and 15, and the F-value are less than 0.05.

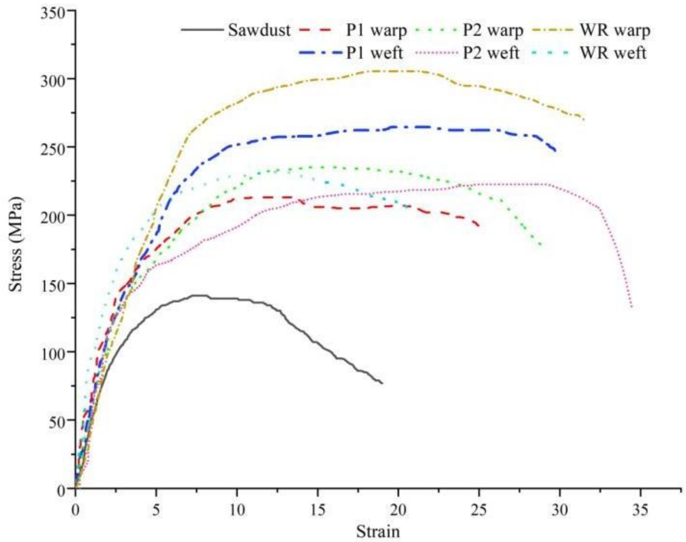

Figure 7: Stress-strain plot for plain 1, plain 2, and weft rib reinforced sawdust bricks in comparison with neat sawdust bricks in warp and weft directions.

Table 12: Summary ANOVA results for ultimate point stress

Groups	*Count*	*Sum*	*Average*	*Variance*
Sawdust	10	1434	143.4	14.71111
P1 warp	10	2169	216.9	18.76667
P1 weft	10	2618.818	261.8818	13.42697
P2 warp	10	2345.744	234.5744	18.18346
P2 weft	10	2249.5	224.95	8.302778
WR warp	10	3076	307.6	40.51359
WR weft	10	2264.667	226.4667	12.35061

Table 13: ANOVA ultimate point strain

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	147635.3	6	24605.89	1364.231	1.1E-64	2.246408
Within Groups	1136.297	63	18.03646			
Total	148771.6	69				

Table 14**:** Summary ANOVA results for ultimate point strain

Groups	*Count*	*Sum*	*Average*	*Variance*
Sawdust	10	87.5	8.75	2.021111
P1 warp	10	151.2105	15.12105	9.729791
P1 weft	10	191.0588	19.10588	5.580778
P2 warp	10	178.0526	17.80526	8.486958
P2 weft	10	243.8421	24.38421	6.418623
WR warp	10	206.2	20.62	5.352148
WR weft	10	135.2	13.52	2.553878

Table 15: ANOVA ultimate point strain

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1564.041	6	260.6735	45.45503	4.7E-21	2.246408
Within Groups	361.2896	63	5.734755			
Total	1925.33	69				

Findings and Conclusion

In-depth characterization of woven sisal fabrics is presented in the paper. Numerous results were discovered to be significant in predicting and interpreting the properties of composites reinforced with sisal fabric. Nevertheless it's necessary to comprehend the physical textile properties affect a fabric's mechanical properties.

- P1 type of fabric with fabric density of 18 x 20 and a yarn count of 80.1 in warp and 85.1 in weft direction. This resulted in the variation of mechanical properties in both warp and weft directions. Conversely, the weft directions owned the better properties than the warp direction.
- P2 type fabric owned same kind of fabric density in warp and weft direction (12 X 12), although the mechanical properties were better in weft direction due to the yarn count (182.3 x 166.8).
- WR type of fabric with fabric density (11 warp and 22 weft) and yarn count (65.3 warp and 182.9 weft) presented improved mechanical properties in the warp direction. This evidently shows that fabric density and yarn count have influenced the textile properties.
- In both P2 and WR have same grams per unit area, however different textile mechanical properties evidently shows that woven structure also had its impact.
- Cover factor of three fabrics are varied in both warp and weft directions. The WR weft possesses the lowest cover factor, and P1 weft direction processes highest cover factor.

Which is influenced by fabric tensile, flexural, bursting strength of the fabrics, higher the cover factor higher would be the strength.

- Highest fabric stretch and recovery were found based on fabric crimp percentage, higher the crimp, the higher the fabric stretch.
- Three fabrics are reinforced at top and bottom of the sawdust bricks and found that strength is improved by more than 2 times in both warp and weft directions.
- The gram per unit area and woven pattern of the fabric are influenced significantly by sawdust bricks' mechanical properties.
- The reinforcing fabric in bricks strain withstanding capacity improved, as the gram per unit is of the fabric increases strain improved significantly and marginally improved in stress are observed.

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