ANALYSING MECHANICAL PROPERTIES OF A TRI PLY TWISTED COTTON, HEMP, PINEAPPLE YARNS AND ITS SUSTAINABLE HANDLOOM FABRIC FOR MEDICAL APPLICATION

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ABSTRACT

This research explores the creation and functional evaluation of a sustainable woven matte fabric manufactured from ply twisted 100% cotton, hemp, and pineapple yarns for wound dressing. Employing a handloom based, environmentally friendly process, the study combines the distinctive characteristics of each natural yarn type to engineer a textile that prioritizes mechanical strength, efficient moisture management, and optimal breathability. In particular, the unconventional incorporation of pineapple yarn introduces a new dimension to medical textiles, broadening the spectrum of renewable options for wound care materials. By advancing the application of twisted yarn technology and under-utilized natural resources, this work highlights a promising direction for next generation ply twisted yarns and fabrics eco-friendly medical dressings with the potential for further refinement and clinical integration.

***Keywords**: Natural yarn, Ply twisted bio-materials, Yarns-Cotton, Hemp, Pineapple., Sustainable Handloom fabric*

INTRODUCTION

Textiles play an essential role in the development of effective wound dressing materials, where properties such as strength, absorbency, and breathability are vital for promoting healing and ensuring patient comfort. In medical textiles, wound dressings are designed to provide mechanical protection, moisture regulation, and breathability to facilitate optimal wound healing and patient comfort (*Patel et al,2020*). While cotton has long been the preferred material for medical dressings due to its softness and high moisture absorption, there has been increasing exploration into alternative natural fibers that might offer additional or complementary advantages. Hemp is recognized for its notable tensile strength and inherent antimicrobial properties, while pineapple yarn is gaining attention for its light-weight nature and efficient moisture management. By combining yarns from different natural sources, it is possible to create wound dressing materials that integrate the beneficial characteristics of each fiber type, potentially out performing conventional single fiber dressings. In this study, three types of yarns such as Cotton, Hemp, and Pineapple 20s count were individually purchased from the market. These yarns were then twisted together to produce a single, unified twisted yarn, combining the properties of each original yarn. The research process began with this yarn-twisting stage, intentionally focusing on the integration of pre-existing yarns rather than the development or processing of fibers. Using the traditional Pit Handloom technique, fabrics were woven from the ply twisted yarn. The resulting fabric samples were subsequently evaluated for a set of properties essential to wound care applications, including tensile strength, elongation, moisture absorbency, and air permeability. By investigating the performance of these fabrics made from twisted combinations of cotton, hemp, and pineapple yarns. This study aims to provide insights that support the advancement of sustainable, high performance wound dressing materials in the field of medical textiles.

METHODOLOGY

The study was focused on the impact of the spun and ply twisted yarns and its handloom woven fabric from the selected ply twisted cotton, hemp, pineapple yarns for medical application.

YARN SELECTION

Hundred percent Cotton (100% C), Hemp (100% H) and Pineapple (100% P) yarns of 20s count were individually sourced and purchased from specialized textile market from Salem and Tiruppur. Each yarn was selected for its unique properties, beneficial to medical application. This ensured quality and consistency in the material produced and helped throughout the study.

YARN TWISTING

Yarn twisting is the act of giving fibers a spiral arrangement to create a single strand of yarn (*Palaniswamy et al, 2005*).The selected three hundred percent 20s count Cotton (100% C), Hemp (100% H) and Pineapple (100% P) yarns were taken individually to be twisted together to form a single ply 100% CHP yarn (Plate 1). A mechanical twisting machine was used to do the twisting. This process involved feeding all three yarns simultaneously into a twisting device, ensuring even distribution and consistent integration throughout the resulting twisted yarn. The mechanical method allowed precise control over both twist level and yarn tension, producing a uniformly blended strand that retained the distinctive qualities of each fiber.

PLATE 1: TWISTING PROCESS OF SINGLE PLY 100% CHP YARN

FABRICATION PROCESS

Handloom weaving is the craft of producing textiles through a manually operated loom. This age old practice dates back to ancient civilizations and continuous to be vital aspect of numerous cultures globally, each showcasing its distinct style of handloom weaving. Handloom weaving was selected to weave from the spun ply 100% CHP yarn. For this purpose, a typical Pit-handloom was used. A pilot study was conducted in the handloom developed trail sample. The 100% CHP yarn was woven into fabric using Plain weave structure which produces a flat, balanced surface, was chosen for weaving. This approach helped maintain the combined properties of the twisted yarn and ensured the fabric was suitable for medical application.

TESTING AND EVALUATION

Evaluation was carried out to find out the yarns mechanical properties on 100% C, 100% H and 100% P individual yarns along with spun ply 100%CHP yarn. The performance of ply twisted 100% CHP yarn into 100% CHP^{H} plain woven fabric sample was subjected through a series of standardized tests suitable to medical application. Each test was conducted under controlled laboratory conditions, following standard textile testing procedures.

YARN TESTING

Yarn testing is defined as the systematic evaluation of yarn properties such as tensile strength, twist, evenness, and elongation to determine its quality and performance for specific end use applications (*Kadolph et al, 2011*). 100% C, 100% H, 100% P and ply twisted 100% CHP yarn were subjected to evaluate the yarn tests such as Lea Strength and Elongation , Yarn Count and Yarn Twist were conducted.

LEA STRENGTH AND ELONGATION TEST

The lea strength of the 100% C, 100% H , 100% P and ply twisted 100% CHP yarn were assessed using the Lea Strength Tester (Plate 2), a ASTM D1578 method for evaluating the tensile properties of yarn hanks. After conditioning the samples at 21°C and 65% relative humidity for 24 hours, each yarn was wound into hanks of 120 yards (one lea) and mounted in the testing apparatus. When loaded for lea strength, as the hank is pulled apart, ruptures at a point recording the maximum breaking force in pounds $/^{2}$ inch. Along with, the elongation at break was also noted in percent increase in hank length from the original state to the point of rupture, reflecting the yarn’s ability to stretch under tensile load. In addition to tensile strength, elongation at break was assessed by measuring the percentage increase in hank length from its original state to the point of rupture. This value reflects the yarn’s ability to stretch under tensile load, with higher elongation indicating greater flexibility, which is important for handling and performance in medical applications. Together, the combined evaluation of tensile strength and elongation provides a comprehensive assessment of each yarn’s mechanical properties, directly informing their suitability for advanced medical application uses.The average result is tabulated under results and discussion.

PLATE 2: LEA STRENGTH TESTER

YARN COUNT

100% C, 100% H , 100% P yarns were purchased individually with 20s count. The yarn count of the twisted single ply 100% CHP yarn was measured using the Beasley balance tester ASTM D2260, a specialized instrument designed for quick and accurate determination of yarn linear density (Plate 3). The twisted single ply 100% CHP yarn, conditioned for 24 hours at standard atmospheric conditions (21°C, 65% relative humidity), was carefully cut to the required length as specified for the Beesley balance method. Each piece was then placed on the balance arm until equilibrium was achieved, and the corresponding reading was noted to calculate the yarn count, typically in English cotton count (Ne). This approach enables precise measurement of yarn fineness, providing valuable data for fabric design and ensuring consistency in textile manufacturing Ten readings were taken, analysed and average result was recorded under results and discussion.

PLATE 3: BEESLEY BALANCE YARN COUNT TEST

YARN TWIST TEST

The yarn twist of the 100% C, 100% H and 100% P and ply twisted single ply 100% CHP yarn were assessed using a twist tester (Plate 4) ASTM D1423. After conditioning the yarn samples for 24 hours at 21°C and 65% relative humidity, each yarn specimen was secured in the tester. The twist tester was used to determine the number of twists per unit length (typically turns per inch or turns per meter) by untwisting the yarn until the fibers were parallel or by the reverse twist method. Measurements were recorded for both the S-twist and Z-twist directions, providing an accurate representation of the yarn's construction. This test is critical for understanding the twisting process which affects yarn strength, flexibility, and the surface characteristics necessary for medical textile applications. Ten readings were taken and analysed under results and discussion.

PLATE 4: YARN TWIST TESTER

FABRIC TESTS

The handloom fabric woven with ply twisted 100% CHP yarn into 100% CHP^H fabric was subjected to mechanical tests such as Fabric Tensile Strength and Elongation, Moisture Absorption and Air permeability tests. These tests were conducted on the developed fabric

TENSILE STRENGTH AND ELONGATION

The Tensile Strength of the woven 100 % CHP^H fabric sample was evaluated using a Universal Tensile Testing Machine following ASTM D5035 standard. Fabric strips of standard size were conditioned under controlled atmospheric conditions before testing. Each sample was securely clamped in the machine, and a steady uni axial force was applied until the fabric ruptured. The maximum force required to break the sample was recorded as its Tensile Strength, expressed in Kg/cm^2. Simultaneously elongation was noted in cm. This test was conducted according to standard protocols to accurately assess the fabric's ability to withstand mechanical stress, which is critical for wound dressing applications. Ten readings were taken, results analysed under results and discussion.

MOISTURE ABSORBENCY

The moisture absorbency of the woven 100% CHP^H fabric sample was tested using the SDL Atlas M290 Moisture Management Tester (MMT), as shown in Plate 5. This machine measures the quickness and effectiveness of the fabric absorbency and moisture spreading. Each test used a set amount of liquid, and the machine automatically recorded results such as absorption rate and spreading speed. The test was conducted following the manufacturer's standard procedures to ensure accuracy and consistency for wound dressing applications. Ten readings were taken and results analysed and discussed under results and discussion.

PLATE 5: SDL ATLAS M290 MOISTURE MANAGEMENT TESTER (MMT)

AIR PERMEABILITY

The Air Permeability of the woven 100% CHP^H fabric sample was measured using 11056-1984 by Air Permeability Tester (Plate 6) . Testing was conducted on a 100% CHP^H sample area of 125 × 125 cm² at an accredited laboratory (AIC-NIFT TEA, Tiruppur). The test determines the passage of air flow through the fabric, which is crucial for medical application materials to ensure breathability and comfort. Ten readings were taken and results analysed under results and discussion.

PLATE 6:AIR PERMEABILITY TESTER

RESULTS AND DISCUSSION

The results and discussion for the developed 100% C, 100% H ,100% P ,100% CHP yarns and 100%CHP^H handloom fabric are discussed, analyzed for Lea Strength and Elongation, Yarn Count, Yarn Twist, Tensile Strength and Elongation, Moisture Absorption and Air Permeability tests.

ANALYSIS OF LEA STRENGTH AND ELONGATION, YARN COUNT AND YARN TPI

The analysis of the 100% C, 100% H, 100% P, 100% CHP yarns which were tested for Lea Strength and elongation, Yarn Count, Yarn TPI are discussed in Table I. Table II shows the ANOVA comparison for selected yarns and Table III Indicates the TUKEY HSD POST HOC test for multiple comparisons.

TABLE I - YARN TESTS

Selected for the study Yarns	Lea Strength		Lea Elongation		Mean Yarn Count	Yarn TPI	
	Mean Lea Strength (lbs/²inch)	Std Dev	Mean Lea Elongation (%)	Std Dev		Mean Yarn TPI	Std Dev
100% C	53.1	3.96	4.37	0.17	20	16.4	1.51
100% H	55.5	2.22	4.44	0.18	20	16.1	1.6
100% P	50.7	2.79	4.45	0.16	20	17.9	2.23
100% CHP	61.2	1.14	4.52	0.15	24	18.1	1.37

The Table I, reveals distinct difference in lea strength across 100% C ,100 % H,100 % P 100% CHP yarns exhibited superior mechanical and structural characteristics relative to the other yarns. Specifically, the 100% CHP yarn demonstrated the highest mean lea strength of 61.2 lbs/²inch per lea strength when compared to 100% H, 100% C, 100% P having average mean lea strength of 55.5 lbs/²inch per lea, 53.1 lbs/²inch per lea, 50.7 lbs/²inch per lea for the respective yarns. The elongation at break for 100% CHP,100% C, 100% H, 100% P yarns shows that all four yarn types exhibit very similar average elongation values, ranging from approximately 4.52%, indicating consistent results for each yarn. This suggests that, despite differences in yarn twist, the flexibility and stretch ability of all yarn samples are comparable. Such uniform elongation properties are beneficial for textile medical application. This enhancement is attributable to the higher yarn count of 24s in the 100% CHP yarn, compared to a count of average mean count 20s in the other yarns, indicating a thicker and potentially more robust yarn construction. Additionally, the 100% CHP yarn showed a greater mean yarn TPI of 18.1 relative to the average mean TPI showed by 100%P, 100 %C ,100%H having 17.9,16.4,16.1 TPI respectively, suggesting enhanced fiber cohesion and interlocking within the yarn structure. These structural factors likely contribute synergistically to the observed improvement in lea strength. The findings underscore the critical role of optimized yarn count and twist in achieving enhanced yarn performance.

TABLE II- ANOVA COMPARISON FOR YARN TESTS

Yarn Tests	**Source**	**df**	**Sum of Squares**	**Mean Square**	**F-value**	**P-value**
Lea Strength	Between Yarns	3	607.28	202.43	27.28	0.00021*
Lea Elongation	Between Yarns	0.113	3	0.03767	1.40	0.26
Yarn Count	Between Yarns	3	120	40	~9.51e+29	0.000*
Yarn Twist (TPI)	Between Yarns	3	31.28	10.43	3.57	0.023*

The Table II shows the one-way ANOVA for the four different yarns selected. The one-way ANOVA which reveals the 100% C, 100% H , 100% P and 100% CHP yarn in terms of lea strength and elongation, yarn count, yarn twist. The lea strength varied significantly among yarn types, as shown by an F-value of 27.28 and a p-value of 0.00021, indicating a highly significant effect of fiber composition and processing on tensile properties. The F-value of 1.40 compares the mean square variability between the yarns. The associated p-value of 0.26 is greater than the conventional significance level of 0.05, indicating that the observed differences in elongation among the four yarn types are not statistically significant. The yarn count showed a statistically significant difference reflecting the distinct structural characteristic of the 100% CHP yarn having 24 as higher yarn count compared to the others as 20s , which contributes to its superior strength. Yarn twist exhibited a significant variation as well F = 3.57, p = 0.023, though the effect size was smaller than for strength and count. These variations in twist reflect differences in fiber interaction and yarn formation processes. Overall, the results underscore the functional impact of twist and yarn structure on mechanical and physical properties, with 100% CHP yarn demonstrating enhanced strength and optimized characteristics relative to the other natural fiber yarns examined.

TABLE III- TUKEY HSD POST HOC TEST FOR MULTIPLE COMPARISONS OF YARN TESTS

Yarn Tests	Comparison	Mean Difference	p-value	Significance
Lea Strength	100%C vs 100%H	-2.41	0.23	Not Significant
	100%C vs 100% P	2.48	0.21	Not Significant
	100%C vs 100% CHP	-8.13	<0.001	Significant
	100%H vs 100% P	4.89	0.005	Significant
	100%H vs 100% CHP	-5.72	0.001	Significant
	100% P vs 100% CHP	-10.61	<0.001	Significant
Lea Elongation	100%C vs 100%H	-0.07	0.73	Not Significant
	100%C vs 100% P	-0.08	0.68	Not Significant
	100%C vs 100% CHP	-0.15	0.32	Not Significant
	100%H vs 100% P	-0.01	0.99	Not Significant
	100%H vs 100% CHP	-0.08	0.74	Not Significant
	100% P vs 100% CHP	-0.07	0.77	Not Significant
Yarn Count	100%C vs 100%H	0	1	Not Significant
	100%C vs 100% P	0	1	Not Significant
	100%C vs 100% CHP	-4	<0.001	Significant
	100%H vs 100% P	0	1	Not Significant
	100%H vs 100% CHP	-4	<0.001	Significant
	100% P vs 100% CHP	-4	<0.001	Significant
Yarn TPI	100%Cvs 100%H	0.3	0.64	Not Significant

	100%C vs 100% P	-1.47	0.06	Not Significant
	100%C vs 100% CHP	-1.28	0.1	Not Significant
	100%H vs 100% P	-1.77	0.03	Significant
	100%H vs 100% CHP	-1.58	0.05	Significant
	100% P vs 100% CHP	0.19	0.98	Not Significant

The result from Table III which exhibits the Tukey Honestly Significant Difference (HSD) post hoc analysis was conducted to explore pair wise differences among the yarn types for lea strength and elongation, yarn count, and yarn twist. The results demonstrate that 100% CHP yarn possesses significantly greater tensile strength than 100% C, 100% H and 100% P yarns which shows $p < 0.001$ for all comparisons. Additionally, 100% H yarn shows significantly higher strength than 100%P yarn having $p = 0.005$, while the difference between 100% C and 100% H or 100% C and 100 % P yarns were not statistically significant. There is no meaningful statistical difference in the elongation averages across the various selected yarns. For yarn count, the 100% CHP yarn features a significantly higher count 24 compared to the other yarns which all share the same count 20, reflecting a statistically significant difference $p < 0.001$. No significant differences were observed among 100% C, 100% H and 100% P yarn counts. Regarding yarn twist, significant differences were found between 100% H and 100% P shows $p = 0.03$ and between 100% H and 100% CHP shows $p = 0.05$, with 100% H yarn exhibiting relatively lower twist levels. Other pair wise comparisons for yarn twist did not reach statistical significance. These outcomes highlight the 100% CHP yarn's superior mechanical and structural properties and show that while 100% H and 100% P yarns vary notably in twist and strength, 100%C occupies an intermediate position. The distinct yarn counts and twist levels contribute to variations in tensile performance among these natural and twisted yarns, underlining the importance of fiber selection and processing in yarn manufacturing.

ANALYSIS OF MECHANICAL PROPERTIES FOR THE PLY TWISTED 100% CHP^H HANDLOOM FABRIC

The handloom fabric CHP^H plain woven with 100% CHP yarn was assessed for their Tensile Strength and Elongation, Moisture Absorption Test and Air Permeability tests.

TABLE IV- MECHANICAL PROPERTIES OF THE 100% CHP^H FABRIC

Woven Handloom Fabric	**100%CHP^H Fabric Tensile Strength (kg/cm²)**	**100%CHP^H Fabric Elongation (%)**	**100%CHP^H Fabric Moisture Absorbency (%)**	**100%CHP^H Fabric Air Permeability (cc/sec/cm²)**
100%CHP^H	127.4	9.2	36.55	50.72

The results from Table IV shows that the fabric sample 100%CHP^H has a tensile strength of 127.4 kg/cm², indicating excellent mechanical durability suitable for medical applications. With an elongation of 9.2%, the fabric can flex and adapt to body movements, enhancing comfort without compromising integrity. Its moisture absorbency of 36.55% confirms efficient uptake and management of fluids, making the fabric ideal for maintaining a moist healing environment. An air permeability of 50.72 cc/sec/cm² ensures effective breathability, promoting ventilation and reducing the risk of bacterial growth. Altogether, these properties establish the fabric as a robust, flexible, moisture-managing, and highly breathable material, well suited for medical applications.

CONCLUSION

The development of ply twisting of three distinct natural yarns cotton, hemp, and pineapple made it possible to create a fabric with twisted yarns, that enhances tensile strength, elongation, and breathability while facilitating the development of extremely practical, long-lasting and cozy for medical application. Mechanical strength, and moisture management are essential qualities for a successful medical application which are promisingly combined in the developed 100% CHP^H fabric. While its controlled elongation enables the fabric to gently adhere to body contours without sacrificing integrity, its high tensile strength gives it more time to sustain and resistance to tearing during usage. Its superior ability to absorb moisture helps to keep the wound area as wet as possible, which promotes quicker healing and shields the surrounding skin from external injury. Superior air permeability also guarantees proper ventilation, which lowers the possibility of bacterial development and patient discomfort. This eco-friendly handloom fabric's synergistic twist of cotton, hemp, and pineapple yarns makes it a high-performance, sustainable choice for advanced wound care, that satisfies both patient centered and functional needs. Overall, the study leads to the credence to use this 100%CHP^H fabric made of twisted natural yarns as an environmentally responsible and highly effective for medicinal application. To further improve the material's therapeutic usefulness and performance, future research might concentrate on evaluating long-term biocompatibility, examining the impacts of antimicrobial treatments, and optimizing the yarn ratios.

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