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Assessment of Various Comfort Properties of Fabrics Made from Hemp and Flax (linen) in Comparison to their Cotton Blends

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Abstract:

Hemp and flax fibers are very popular within the textile industry due to their superiority in terms of sustainability, strength, and durability. However, these fibers are associated with difficulties as a result of their stiffness, rigidity, and coarser nature especially during the spinning process. Therefore, during the spinning process, hemp and flax are blended with cotton fibers in different proportions to improve on the fiber properties. The main purpose of this study is to investigate the effect of blending cotton on the mechanical and comfort properties of hemp and linen fabrics. 100% hemp, 100% linen, 100% cotton, 50% hemp/50% cotton and 50% linen/50% cotton fabrics are investigated. The air permeability, tensile strength, and thermal properties of these fabrics are determined and compared to understand the effect of adding cotton to hemp and flax fibers on the final properties of the fabrics.

Keywords — **Hemp, Linen, cotton, sustainability, Comfort properties.**

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I. INTRODUCTION

Owing to a major impact towards environmental unsustainability, the textile industry is increasingly adopting use of natural sustainable raw materials during the manufacturing of several textile fabrics. According to several reports, textile industry is the world's second largest polluter contributing 40% per annum with 20% land pollution from nonbiodegradable synthetic raw materials. In addition to biodegradability, hemp and flax are very strong fibers as compared to other natural fibers such as cotton and wool, with the latter having strength ranging from 502.04 to 595.65 MPa and earlier from 412 to 566 MPa [1, 2]. Also, hemp and flax are long fibers, with hemp fibers having a length between 1-2 meters [3].

Hemp, also known as Cannabis sativa L., distinguished from marijuana by its low delta-9-tetrahydrocannabinol (THC) content (typically less than 0.3% dry weight) is among the oldest cultivated crops, with its originality dating way back more than 10,000 years ago in Asia [4, 5]. It is mainly characterized with rapid growth with a cycle of about 90 to 120 days, typically adaptable to diverse climates, and has low water/pesticides requirements as compared to many crops [6, 7].

Flax, Linum usitatissimum L. earliest domestic human usage is traced back more than 8,000 years ago [8]. It grows in cool, temperate climates with deep, well-drained soils; moderate water needs (less than cotton) with a growth cycle around 90 to 100 days [9]. Flax fibers are used to manufacture linen fabrics in the textile industry.

Both hemp and flax offer compelling sustainability advantages over conventional cotton, including reduced water consumption, minimal pesticide requirements, and enhanced carbon sequestration during cultivation [10-12]. However, their inherent limitations such as higher fiber rigidity and stiffness, surface roughness, elevated unevenness, etc. hinder the spinning process [13, 14]. Blending these bast fibers with cotton reduces their disadvantages especially during different textile processing stages.

Recently, various studies have been conducted to investigate the effect of blending hemp and flax with cotton on different properties of final fabrics. For example, Sanad, S.H., reported improved moisture absorption in flax fabrics blended with cotton as compared to 100% cotton knitted fabric [15], whereas Liu et al., reported larger hemp/cotton capillary height and wetted area values as compared to those of pure cotton fabrics [16]. Still on the same issue, Behera, B., reported higher total hand valve (THV) in linen fabrics blended with cotton and viscose as compared to that of pure line [17], Ahirwar, M. and B. Behera observed a higher pilling effect and better crease recovery angle in a 50:50 hemp/cotton as compared to that of pure cotton fabric of similar construction [18], and many other studies.

In this current study, performance properties of 100% hemp, 100% linen, 100% cotton, 50% hemp/ 50% cotton and 50% linen/50% cotton fabrics are compared to determine whether hemp or flax blends better preserve cotton-like performance while enhancing processability, sustainability, and identify the optimal bast fiber for textile applications.

II. EXPERIMENTS

A. Materials and Samples preparation

Plain woven fabrics of 100% hemp, 100% linen, 100% cotton, 50% hemp/50% cotton, and 50% linen/50% cotton with identical areal density and construction were purchased from Qingdao Yu Chung Shing Textiles Co. LTD. These were cut into 5 cm × 5 cm squares using a precision fabric cutter.

B. Air permeability test

The air permeability of all fabric samples (100% hemp, 100% linen, 100% cotton, 50% hemp/50% cotton, and 50% linen/50% cotton) was determined in accordance with the standard test method GB/T 5453-1997 (equivalent to ISO 9237:1995). Sample were cut into 10cm × 10 cm squares using a precision fabric cutter Measurements were conducted using a YG461E automatic air permeability tester (Ningbo Textile Instrument Factory, China). This test quantifies the volume of air passing vertically through a known area of fabric under a prescribed pressure difference over a unit of time. For each test, a pressure drop of 100 Pa was applied across a standard test area of 25 cm^2. To ensure statistical reliability and account for any local variations within the fabric, ten random measurements were taken for each sample type. The final air permeability value for each fabric, expressed in millimetres per second (mm/s), was calculated as the mean of these ten individual readings.

C. Tensile testing of fabrics

The tensile properties in both the warp and weft directions were conducted using a YG026MB-250 multi-functional electronic fabric strength tester (Wenzhou Darong Textile Instrument Co., Ltd., China), in accordance with the Chinese standard GB/T 3923.1-2013. Fabric samples were precision-cut into rectangular strips with dimensions of 5cm × 20 cm. Each sample was mounted with a gauge length of 40 mm between the clamps and subjected to a constant tensile speed of 100 mm/min until rupture. To ensure accuracy and statistical significance, each material variant was tested three times, and the average values for maximum force (in Newtons) and corresponding elongation (in millimeters, later converted to percentage) were calculated. All testing was performed under standard atmospheric conditions, maintained at 20 ± 2°C and 65 ± 5% relative humidity, to preclude the influence of environmental variations on the results.

D. Thermal conductivity measurement

The thermal conductivity of the fabrics was determined in accordance with the standard test method ASTM D7984 using a C-Therm TCI

Thermal Conductivity Analyzer (C-Therm Technologies Ltd, Canada) employing the modified transient plane source (MTPS) technique.

The instrument operates by applying a known electrical current to its spiral sensor, which functions simultaneously as a heat source and a resistance temperature detector (RTD). The resulting temperature rise at the sample-sensor interface induces a change in the sensor's voltage, which is monitored to calculate the thermal effusivity. The instrument's software then derives the thermal conductivity directly from this effusivity measurement.

Prior to testing, all fabric samples were conditioned for 24 hours at 21 ± 1 °C and 65 ± 2% relative humidity. For each measurement, a square specimen of 5 cm × 5 cm was prepared and placed onto the sensor's active surface. Then a consistent compressive force of 10.7 kPa was applied to ensure optimal thermal contact and eliminate air gaps. Three measurements were taken for each fabric sample, and the results were averaged to ensure accuracy and reproducibility.

III. RESULTS AND DISCUSSIONS

A. Air Permeability Properties of the Fabrics

As in Fig.1 (a), 100% linen fabric has the highest air permeability, followed by 100% hemp, 50% linen/50% cotton, 50% hemp/50% cotton, 100% cotton respectively. Air permeability is a measure of how easily air can pass through a fabric. Flax fibers making up linen fabric more porous as compared to hemp and cotton. This allows more air to pass through the final fabric as compared to fabrics made of hemp, cotton and their blends. While pure linen and hemp maximize airflow due to their structural porosity, blending introduces discontinuities that reduce permeability as a result of morphological mismatches exacerbating the fabric density.

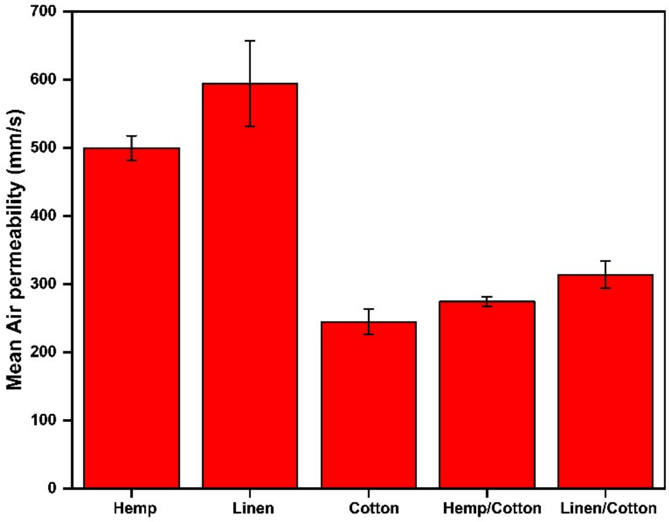

Fig.1. Air permeability of 100% hemp, 100% linen, 100% cotton, 50% hemp/50% cotton, and 50% linen/50% linen fabrics.

B. Tensile Properties of the Fabrics

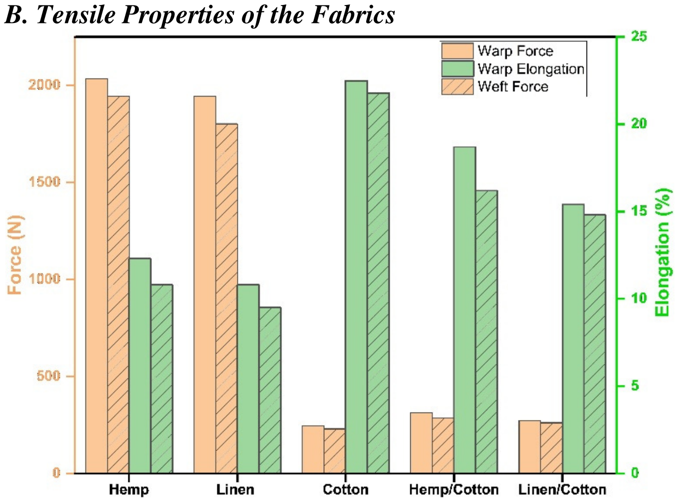

Fig.2. Force and elongation for 100% hemp, 100% linen, 100% cotton, 50% hemp/50% cotton, and 50% linen/50% linen fabrics.

The force-elongation behavior reveals significant anisotropy across all materials, with warp direction exhibiting substantially higher strength but lower elongation compared to weft. In the warp direction, 100% hemp demonstrates the greatest strength (~1,900 N) and stiffness but limited ductility (12% elongation), while 100% cotton shows the inverse relationship: lowest strength (~1,200 N) but highest elongation (16%). 100% linen exhibits intermediate warp strength (~1,700 N) with moderate elongation (10%). Weft properties are markedly reduced, with strength values 40-60%

lower than warp counterparts. Cotton maintains the highest warp and weft elongation, illustrating distinct fiber-dependent deformation mechanisms.

Blending bast fibers with cotton creates synergistic improvements in mechanical performance. The 50% hemp/50% cotton blend preserves 84% of hemp's warp strength while increasing elongation by 17% versus pure hemp, achieving an optimal balance for strength-critical applications. Both blends demonstrate more gradual failure behavior than pure bast fibers, indicating enhanced energy absorption.

C. Thermal conductivity of the Fabrics

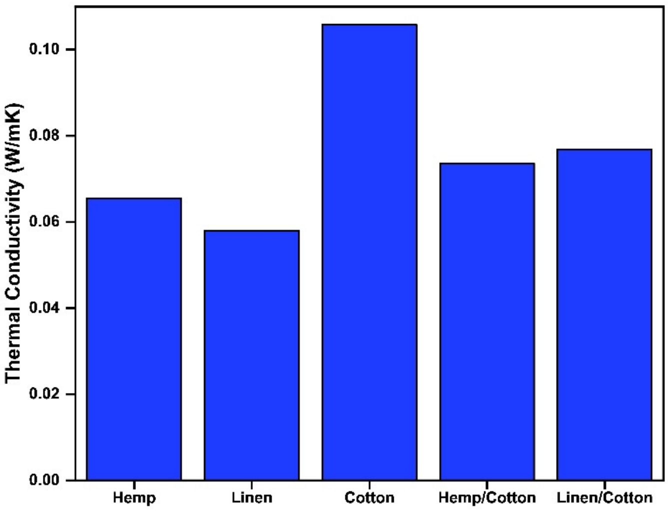

Fig.3 Thermal conductivity of 100% hemp, 100% linen, 100% cotton, 50% hemp/50% cotton, and 50% linen/50% linen fabrics.

The Bast fibers (hemp and linen) exhibit superior thermal conductivity relative to cotton due to their highly ordered crystalline cellulose domains and lower microfibrillar angles. Hemp's dominance over linen arises from its reduced lignin content (3–5% vs. flax's 2.2–5%) and straighter fibril alignment, facilitating efficient phonon-mediated heat transfer. Conversely, cotton's amorphous polymer chains and kinked ribbon-like morphology create tortuous thermal pathways. In blended fabrics, conductivity decreases yet remains elevated compared to pure cotton. The hemp/cotton blend outperforms linen/cotton due to hemp's intrinsically higher conductivity and more compatible interfacial bonding with cotton. Consequently, hemp blends better preserve thermal functionality while leveraging cotton's mechanical benefits—suggesting hemp's superiority for cooling textiles in thermoregulatory applications like sportswear or hot-climate apparel.

IV. CONCLUSIONS

It is very crucial for the spinning process to be done easily without difficulties for better yarn and fabric properties. Many other studies in literature have proven that mixing certain proportions of cotton fibers to hemp and flax enhances the spinnability of these bast fibers.

This study has proved that, while some properties of hemp and linen fabrics are enhanced, others are comprised as a result of blending these fibers with cotton during the spinning process. The air permeability, strength, and thermal conductivity of 100% hemp and 100% linen is much better than that of 50% hemp/50% cotton and 50% linen/50% cotton fabrics. On the other hand, these bast fibers when blend with cotton, have higher elongation.

It can therefore be concluded that, the proportion or fraction of bast/cotton fibers blend, must be considered according to the final application of the fabrics.

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