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Alternate Filling Plus Wadding Option For Synthetic Fillers

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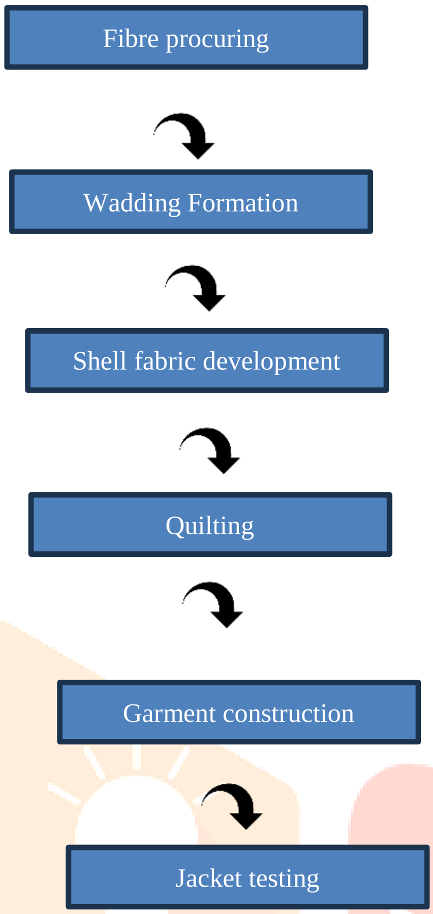
***Abstract*:** synthetic fillers in jackets provide warmth but raise environmental concerns due to their reliance on virgin synthetic fibers with high carbon footprints. this project explores sustainable alternatives by developing a jacket filler from a kapok-recycled polyester blend. kapok, a natural, biodegradable, and hydrophobic fiber, combined with recycled polyester, supports circularity and reduces plastic production. the jacket's shell uses regen agri cotton for durability and protection. this design prioritizes breathability, lightweight insulation, and durability. performance testing assesses the filler's effectiveness compared to conventional synthetics, aiming to reduce garment production's environmental impact and promote eco-conscious innovation in the fashion industry

***index terms* – kapok fibre, eco friendly appaerel, sustainable insulation, recycled polyester**

I. INTRODUCTION

the fashion industry faces increasing pressure to reduce its ecological impact, particularly in outerwear manufacturing where synthetic fillers dominate. synthetic fibers, such as polyester, offer insulation and affordability but are derived from petrochemicals, contributing to greenhouse gas emissions, high energy consumption, and long-term microplastic pollution.this project aims to develop a sustainable filling material by blending kapok fiber—a naturally renewable, biodegradable, and hydrophobic material—with recycled polyester. this combination leverages post-consumer waste, promoting circularity and reducing reliance on virgin synthetics. the blend maintains high performance standards for warmth, durability, and breathability while supporting environmental goals. through performance testing, this project seeks to deliver a practical, eco-friendly solution for outerwear, helping brands meet sustainability targets without sacrificing functionality.

II. Material and methods



2.1 Materials

2.1.1 Kapok fiber

- **source**: kapok fiber is harvested from the seed pods of the ceiba pentandra tree, which thrives in tropical regions of southeast asia, central america, and africa. the kapok tree is a fast-growing, low-maintenance species that does not require extensive irrigation, fertilizers, or pesticides, making it an environmentally friendly resource.
- **specifications**: kapok fiber is known for its unique properties that make it an excellent sustainable filling material. it is naturally hollow, providing exceptional thermal insulation while remaining extremely lightweight. the fiber's density is remarkably low, around 0.35 g/cm^3, contributing to its comfort and ease of wear. kapok is naturally hydrophobic due to its waxy coating, which makes it resistant to moisture absorption. additionally, it is 100% biodegradable, decomposing naturally without polluting the environment. the processing of kapok fiber is low-impact, requiring minimal energy, water, and chemicals, making it an eco-friendly alternative to synthetic fillers. these specifications position kapok as a high-performance, sustainable material ideal for use in outerwear insulation.

2.1.2 Recycled polyester

- **source**: recycled polyester (rpet) is primarily sourced from post-consumer waste, such as discarded pet plastic bottles. these bottles are collected through recycling programs, sorted, and thoroughly cleaned to remove any contaminants. once cleaned, the plastic is shredded into small flakes, melted, and extruded into fibers or yarns. this process diverts plastic waste from landfills and oceans, reducing environmental pollution and promoting a circular economy. some recycled polyester can also come from post-industrial waste, including leftover materials from textile manufacturing processes.

- **specification:** recycled polyester fibers are durable, strong, and resistant to shrinking, stretching, and wrinkling. they have a density of approximately 1.38 g/cm³ and offer excellent moisture-wicking and breathability properties. recycled polyester is abrasion-resistant and maintains its integrity over time. compared to virgin polyester, it reduces energy consumption by up to 50% and lowers greenhouse gas emissions, making it a sustainable and high-performance alternative for textile applications.

2.2 Methods

wadding preparation

- blend 20% kapok fiber and 80% recycled polyester.
- process the blend through carding to form a web.
- layer the web to achieve desired thickness and bond mechanically (needle-punching).
- perform quality checks for thickness, density, and resilience.

shell fabric development

- use a yarn blend of 60% regenerative agriculture cotton and 40% recycled polyester.
- knit the yarn into single jersey fabric via circular knitting.
- process the fabric (scouring, bleaching, dyeing) and apply finishes (softening, anti-pilling).
- conduct quality control for durability, strength, and compatibility with wadding.

quilting process

- layer the outer shell fabric, wadding, and base fabric (single jersey).
- secure layers and stitch using a quilting machine in the required pattern.
- inspect for even distribution and stitching quality.

garment construction

- pattern preparation for jacket components (sleeves, panels, collars).
- cut the quilted fabric according to patterns.
- assemble pieces through stitching.
- add trims like zippers and buttons.
- perform finishing touches and quality checks for durability, insulation, and aesthetics.

2.3 Characterization

Characterization of composite material for jacket construction

1. **physical properties:**
   - **thickness:** measured at five random locations using a digital thickness gauge to ensure uniformity across the sample.
   - **areal density:** calculated by dividing the sample's mass by its area, expressed in grams per square meter (g/m^2), to evaluate the material's weight and consistency.
2. **mechanical properties:**
   - **tensile strength and elongation:** determined through a universal testing machine (utm) following astm d5035 standards to assess the material's ability to withstand stretching and force before breaking.
3. **air permeability:**
   - measured using an air permeability tester, such as astm d737, to evaluate the material's breathability and airflow properties, which are crucial for the comfort of the final garment.
4. **Filtration efficiency:**
   - assessed by passing air laden with particles (e.g., pm2.5, pm10) through the composite material. the filtration efficiency was evaluated according to relevant standards such as **iso 16890** or **ashrae 52.2**, depending on the application.
5. **Thermal stability:**
   - studied using **thermogravimetric analysis (tga)** to assess the decomposition behavior of the composite material at various temperatures, ensuring its durability and performance under heat

3.1 Results

- this chapter provides a summary of the results and analysis of the tests conducted on the quilted jacket and its components. we evaluated the physical parameters of the wadding (web), such as gsm, thickness, air permeability, density, thermal resistance, and thermal conductivity, to assess its quality and insulation performance. these parameters help in understanding the weight, breathability, and thermal efficiency of the jacket. for the shell fabric, tests were conducted to measure color fastness, tensile strength, and other physical properties to ensure durability and resistance to wear and tear. the color fastness test confirmed the fabric's ability to retain color under various conditions like washing and rubbing. the results of these tests were compared with data from other research papers to benchmark the performance of the developed materials. this comparison highlighted the strengths of the materials used and ensured the final quilted jacket meets quality standards for durability, insulation, and comfort.

Results of quilted jacket

Characteristics of kapok/polyester web

sample	gsm	thickness (mm)	density (kg/m3)	air permeability (cm3 /cm2 /s)	thermal resistance (m2 k/w)
kapok/poly 20/80	374.22	4.41	82.83	61.7	0.390
kapok/poly 40/60	331.52	4.17	79.13	86.3	0.330

Comparison of the manufactured nonwovens and commercially available insulators

insulators	density (kg/m3)	thermal conductivity (w/ mk)	thermal resistance (m2 k/w)
kapok/pet nonwovens	79.12– 88.63	0.0166– 0.0221 0	0.350- 0.446
rockwool(rock wool)	40-1200	0.037-0.040	0.27-0.25
perlite(natural glassy volcanic rock)	32-176	0..04-0.06	0.250- 0.166
vermiculite(natural mineral)	64-130	0.063-0.068	0.158- 0.147
glass wool	24-112	0.032-0.035 0.	0.312- 0.285
expanded polystyrene	16-35	0.037-0.038	0.270- 0.263
extruded polystyrene	26-47	0.030- 0.0320	0.330-0.312
polyurethane foam	3181	0.015-0.26	0.50-0.39

RESULTS OF SHELL FABRIC

COLOR FASTNESS OF SHELL FABRIC

S no	Parameter	result	Min grade	comment
1	Colour fastness to crocking	4.5(D)/3.5 (W)	3.5/2.5	Very satisfied
2	color fastness to accelerated laundering	4.5	4	Satisfied
3	color fastness to water	4.5	4	Satisfied
4	color fastness to persipiration	4.5	4	Satisfied

PHYSICAL PARAMETERS OF SHELL FABRIC

Fabric Type	Test Paramater	Remarks	Comment
100% Regen agri cotton-Single jersey	Abrasion Resistance : Martidale method	Pass	No thread breakage
	Bursting strength of fabric : Diaphragm method	Pass	Good bursting strength
	Pilling resistance: Random tumble pilling test	Pass	4 is good pilling rate
	Appearance after 1st actual laundry	Pass	Slight color change of base and slight fuzzing effect was observed
	Appearance after 3rd actual laundry	Pass	Slight color change of base and slight fuzzing effect was observed
	Appearance after 5th actual laundry	Pass	Slight color change of base and slight fuzzing effect was observed
	Loop length	NA	2.65 MM
	Yarn count	NA	30.2 NE
	GSM	NA	160.4

Significance, strengths, and limitations of the proposed work

- The proposed work focused on developing a quilted jacket with sustainable materials, specifically a kapok/recycled polyester blend for wadding and a regen agri/recycled polyester blend for the shell fabric. the performance of these materials was assessed through various physical parameters, including gsm, thickness, density, air permeability, thermal resistance, and thermal conductivity. the results were compared with other commercially available insulating materials to evaluate their effectiveness and sustainability.

4.1 Conclusion

The primary objective of this research was to create a sustainable and high-performance quilted jacket using natural and recycled materials. the findings can be summarized as follows:

kapok/polyester wadding performance: The 20/80 kapok/polyester blend demonstrated a thermal resistance of 0.390 m² k/w with a density of 82.83 kg/m³, making it suitable for insulation applications. the 40/60 kapok/polyester blend showed a slightly lower thermal resistance of 0.330 m² k/w and a density of 79.13 kg/m³, indicating a trade-off between thermal insulation and polyester content. Air permeability increased with higher polyester content, from 61.7 cm³/cm²/s for the 20/80 blend to 86.3 cm³/cm²/s for the 40/60 blend.

Shell fabric properties: The shell fabric, made from regen agri/recycled polyester (60/40), exhibited excellent durability, including:

- Abrasion resistance: passed with no thread breakage.
- Bursting strength: strong bursting resistance.
- Color fastness: satisfactory results for crocking, laundering, water, and perspiration tests (all achieving a grade of 4.5).
- Appearance after laundering: minimal changes after 1st, 3rd, and 5th washes.

Comparison with commercial insulators:

The developed kapok/polyester nonwovens had a thermal conductivity range of 0.0166–0.0221 w/mk and a thermal resistance range of 0.350–0.446 m² k/w. These values are comparable to, or better than, commercially available insulators such as rock wool, glass wool, and polyurethane foam. The eco-friendly nature of the materials and the mechanical bonding process ensured minimal environmental impact. Overall, the proposed work demonstrates the feasibility of developing sustainable, durable, and thermally efficient garments using natural and recycled materials. this approach aligns with modern sustainability goals and offers an alternative to conventional insulation materials.

5.1 suggestions for future work

While the results of this study are promising, there are several opportunities to refine and extend the work: optimization of blend ratios: further research on different kapok/polyester ratios can help optimize the balance between thermal insulation, air permeability, and mechanical strength to cater to various climate conditions.

Alternative bonding techniques:

- Investigate other eco-friendly bonding methods, such as thermal bonding or ultrasonic bonding, to improve the mechanical strength of the wadding without compromising sustainability.

moisture management and breathability:

- Analyze the moisture absorption and wicking properties of the developed materials to enhance comfort for activewear or outdoor applications.

long-term durability testing:

- Conduct extended wear trials and accelerated aging tests to evaluate the long-term durability and performance of the jacket in real-world conditions.

incorporation of other natural fibers:

- Explore blending kapok with other sustainable fibers like hemp, bamboo, or organic cotton to create a wider range of eco-friendly insulation materials.

advanced testing for insulation performance:

- Include thermal imaging and heat loss studies to gain a more detailed understanding of the insulation properties under various conditions.

scaling up production:

- Investigate the feasibility of large-scale manufacturing while maintaining cost-effectiveness and sustainability.
- By addressing these areas, the current work can be further improved and adapted to meet the growing demand for sustainable and high-performance garments. the findings provide a solid foundation for future innovation in eco-friendly textile production.

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