

# Utilization of Apparel Waste for the Development of Acoustic Insulation Material

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## ABSTRACT

*The textile sector contributes significantly to global waste accumulation, with fabric scraps and offcuts often ending up in landfills, exacerbating environmental pollution. At the same time, the need for sustainable acoustic insulation materials is increasing, as conventional insulation relies on non-renewable resources that have adverse environmental effects. This research aims to repurpose textile waste into efficient acoustic insulation using a dry-laid nonwoven technique combined with thermal bonding. Various layering combinations were examined to determine their impact on sound absorption, offering a promising alternative to traditional insulation materials.*

**Keyword:** *Textile Waste, Acoustic Insulation, Nonwoven Fabric, Sustainability, Thermal Bonding*

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## 1. INTRODUCTION

The disposal of textile waste remains a pressing issue due to the large quantities generated in the apparel industry. Fabric remnants, offcuts, and other discarded materials pose environmental concerns when disposed of in landfills. Simultaneously, industries such as construction and automotive require effective soundproofing solutions, often depending on synthetic insulation materials like foam and fiberglass, which have environmental drawbacks. This study explores a sustainable approach to developing acoustic insulation by utilizing apparel waste, thus promoting circular economy practices and reducing dependency on synthetic alternatives.

## 2. LITERATURE REVIEW

The growing concern over **textile waste accumulation** has led to extensive research on recycling methods and alternative applications, particularly in **acoustic insulation**. Studies indicate that textile-based nonwoven materials exhibit **excellent sound absorption properties** due to their porous structure.

## 2.1 Textile Waste in Acoustic Insulation

Nonwoven composites made from recycled textiles have been found to offer **sound absorption comparable to traditional materials** such as foam and fiberglass. The **fibrous nature of textiles** enhances sound dissipation by increasing **tortuosity** and **internal friction**, reducing sound wave propagation.

## 2.2 Mechanical and Chemical Recycling of Textile Waste

- **Mechanical Recycling** involves processes like **cutting, shredding, garneting, and needle-punching**, allowing waste fabrics to be transformed into insulation materials. Challenges include **fiber degradation and contamination**.
- **Chemical Recycling** (e.g., **de polymerization, hydrolysis, and glycolysis**) enables the recovery of high-quality fibers, making it suitable for blended textiles. However, it is **energy-intensive** and requires **strict contamination control**.

## 2.3 Acoustic Performance of Recycled Textiles

Studies have shown that thicker and denser nonwoven fabrics provide better sound absorption, especially in low-frequency ranges. Multi-layered structures combining textiles with nonwoven materials further enhance performance.

## 3. MATERIALS AND METHODS

### 3.1 Sourcing of Materials

- **Textile Waste: Fabric scraps, offcuts, and embroidery backing materials** were collected from garment industries.
- **Fabric Scraps and Offcuts:** Collected from garment manufacturing, these materials are repurposed into insulation layers.
- **Embroidery Backing Materials:** Tear-away, cut-away, and water-soluble backing materials are recyclable and add reinforcement to nonwoven insulation.
- **Recycled Synthetic Fibers:** Polyester and nylon-based fabrics provide durability, making them suitable for long-lasting insulation.
- **Natural Fiber Waste:** Cotton, wool, and hemp fibers contribute to eco-friendly and biodegradable acoustic solutions.
- **Blended Textiles:** Polyester-cotton blends are commonly used and can be separated through mechanical or chemical recycling.
- **Binder Fibers:** Thermally bondable fibers were introduced to provide **structural stability**.

### 3.2 Sample Preparation

The **dry-laid method** was employed to process recycled fabrics into **nonwoven composites**. Thermal bonding was used to bind fibers together.

### 3.3 Experimental Setup

Three different sample configurations were tested:

- **Sample A:** A **single-layer 15mm nonwoven fabric**.
- **Sample B:** A **fabric layer with 15mm nonwoven**, fabric facing the sound source.
- **Sample C:** **Two fabric layers** enclosing a **nonwoven layer**.
- Additional variations included **30mm and 45mm nonwoven thicknesses**.

### 3.4 Testing and Analysis

The sound absorption performance was assessed using an **impedance tube method**, measuring **sound absorption coefficients** at varying frequencies.

## 4. RESULTS AND DISCUSSION

### 4.1 Effect of Layering on Acoustic Performance

- **Sample A (single-layer nonwoven)** showed **moderate absorption**, particularly at high frequencies.
- **Sample B (fabric + nonwoven)** exhibited **improved sound absorption**, effectively reducing mid-range noise.
- **Sample C (two fabric layers + nonwoven)** provided **the highest absorption**, particularly at **low frequencies**.

### 4.2 Influence of Thickness

Increasing **nonwoven thickness** (from 15mm to 45mm) led to a **significant enhancement** in sound absorption, particularly for **low-frequency noise**.

### 4.3 Sustainability and Practical Applications

- The results confirm that **recycled textile-based acoustic insulation** is a **viable alternative to synthetic materials**.
- Potential applications include **construction (walls, ceilings, flooring), automotive interiors, and industrial noise control**.

## 5. Structural Properties of Textile-Based Acoustic Insulation

- **Porosity:** High porosity allows sound waves to penetrate and dissipate within the fiber network, improving sound absorption.
- **Thickness:** Increased thickness enhances low-frequency noise absorption, making layered textile composites highly effective.
- **Density:** A balance between density and air permeability is essential to optimize sound insulation.
- **Tortuosity:** The complex fiber arrangement increases sound wave path length, leading to higher energy dissipation.
- **Fiber Diameter:** Finer fibers enhance surface interaction, improving overall sound-absorbing capabilities.
- **Material Composition:** Combinations of synthetic and natural fibers enhance performance, durability, and recyclability.

## 6. Thermal Insulation Properties of Recycled Textile Materials

- **Dual Purpose:** Textile waste-based insulation materials not only provide **soundproofing** but also serve as **thermal insulators**, making them a **versatile solution** for energy-efficient applications.
- **Heat Retention:** The **air gaps and fiber arrangement** in nonwoven textiles **trap heat effectively**, reducing heat loss in cold environments and preventing overheating in warm conditions. This feature makes it ideal for **climate-responsive architecture**.
- **Moisture Control:** Unlike **fiberglass insulation**, which tends to trap moisture and promote mold growth, textile-based insulation is **breathable** and allows moisture to escape, reducing the risk of **condensation-related damage**.
- **Sustainability:** By using recycled textiles, this insulation significantly **reduces environmental impact**, as it repurposes fabric waste instead of relying on synthetic materials that require **energy-intensive production**.
- **Industrial and Domestic Uses:** Textile-based insulation is widely used in **eco-friendly construction**, **automotive thermal shielding**, and **protective gear** that requires **temperature regulation**.
- **Comparison to Conventional Insulation:** Fiberglass, polyurethane foam, and mineral wool require **chemical processing** and have **limited recyclability**, whereas textile-based insulation is a **low-carbon alternative** that is **easier to handle and install**.

## 7. Environmental Impact and Life Cycle Assessment (LCA)

- **Waste Reduction:** The textile industry produces **millions of tons of waste annually**, and repurposing fabric scraps into insulation helps **divert waste from landfills** and reduces overall environmental pollution.
- **Lower Carbon Footprint:** Traditional insulation materials, such as **foam and fiberglass**, require **high energy consumption** during production, whereas textile-based insulation **reuses existing materials**, significantly cutting down on **CO<sub>2</sub> emissions**.
- **Water Conservation:** Textile manufacturing is **water-intensive**, particularly in dyeing and finishing processes. Recycling fabric waste into insulation **eliminates the need for new production**, thus reducing **water consumption**.
- **Health Benefits:** Conventional insulation materials contain **harmful chemicals and synthetic fibers** that can cause **skin irritation and respiratory issues**. In contrast, textile-based insulation is **non-toxic**, making it safer for **workers, occupants, and the environment**.
- **Circular Economy Model:** Unlike fiberglass, which has **limited recyclability**, textile-based insulation can be **recycled again or biodegraded**, ensuring **sustainability across its entire lifecycle**.
- **Durability and Longevity:** Textile insulation is **highly durable**, resisting wear and tear over time, making it a **cost-effective and sustainable choice for long-term applications**.

- Evaluation of **carbon footprint reduction** by repurposing textile waste.
- **Water and energy savings** compared to virgin material production.
- **End-of-life disposal and recyclability** of textile-based acoustic panels.
- **Reduces waste** by repurposing discarded textiles, lowering landfill impact.
- Cuts down on **carbon emissions and water consumption** compared to producing new materials.
- Textile-based insulation can be **recycled again** or biodegraded if made from natural fibres.
- Safer alternative to **fiberglass**, which poses health risks from airborne particles.

## 8. Fire Retardancy of Textile-Based Insulation

- **Flammability Concerns:** Some textile fibers, particularly **cotton and polyester**, are **highly flammable**, making fire retardancy a **critical requirement** for insulation applications.
- **Fire-Resistant Treatments:** Chemical coatings such as **boron compounds, ammonium phosphate, and phosphorus-based flame retardants** can significantly **reduce flammability** by creating a **protective layer** that slows down combustion.
- **Natural Fire-Resistant Fibers:** Wool, for example, has **inherent fire-resistant properties** due to its **high nitrogen and moisture content**, making it a **safe and sustainable option** for insulation.
- **Reduced Toxicity:** Unlike **fiberglass insulation**, which releases **toxic fumes when burned**, properly treated textile-based insulation emits **fewer harmful gases**, ensuring **safer indoor air quality**.
- **Compliance with Fire Safety Standards:** Textile-based insulation is tested under **ASTM E84 (surface burning characteristics)** and **ISO 1**
- Assessing the **flammability of nonwoven composites** and possible **fire-retardant treatments**.
- Comparison with **traditional insulation materials** in terms of **fire resistance**.
- Some textile fibers burn quickly, so **fire-resistant treatments** are needed.
- **Boron compounds and phosphorus-based coatings** can improve fire resistance.
- Unlike **fiberglass, which releases toxins when burned**, treated textiles can be safer.
- Meets **fire safety standards** like ASTM E84 and ISO 11925-2 for building materials

## 13. COMPARISON OF MECHANICAL AND CHEMICAL RECYCLING FOR TEXTILE WASTE

### Mechanical Recycling

- **Process:** Cutting, shredding, garneting, and needle-punching to convert fabric waste into fiber-based insulation.
- **Advantages:** Energy-efficient, cost-effective, and maintains fiber integrity.
- **Challenges:** Limited to single-fiber textiles and may produce lower-quality fibers.

### Chemical Recycling

- **Process:** Depolymerization, hydrolysis, and solvent-based fiber separation to recover raw materials.
- **Advantages:** Produces high-quality fibers and works for blended textiles.
- **Challenges:** High energy consumption and potential chemical waste management issues.

## 9. Challenges and Innovations in Recycling Textile Waste For Acoustic Insulation

- **Contamination in Textile Waste:** Dyes, finishes, and mixed fibers pose challenges in recycling; advanced sorting technologies are required.

- **Durability and Longevity:** Research is ongoing to improve the **resistance of recycled insulation to moisture, fire, and degradation.**
- **Biodegradable Binders:** New developments in **bio-based adhesives** enhance sustainability without compromising performance.
- **Smart Insulation Materials:** Integration of **nanotechnology and phase-change materials (PCMs)** can create temperature-adaptive insulation.
- **Scalability and Mass Production:** The need for **automation in fiber processing** is key to making textile-based insulation a mainstream solution.

## 10. Cost Analysis and Economic Feasibility

- **Cost-benefit analysis** of using recycled textiles for acoustic insulation.
- **Potential market demand** in industries such as **construction, automotive, and interior design.**
- **Government incentives and policies** supporting sustainable materials.
- **More affordable** than traditional insulation since it uses waste materials.
- Demand for **eco-friendly materials** is growing, making it a **profitable industry.**
- **Government incentives** encourage using recycled materials in construction.
- **Initial processing costs** can be high, but long-term savings in material and energy costs make it worthwhile.

## 11. Future Research Directions

- **Technical limitations** such as **durability, moisture resistance, and mechanical strength.**
- **Scaling up production** for commercial applications.
- **Advanced manufacturing techniques**, including **nanotechnology and bio-based binders.**
- **Moisture absorption** can lead to mold growth; water-resistant coatings are needed.
- Research is ongoing to enhance **durability, fire safety, and strength.**
- **Scaling up production** is a challenge; automation can help lower costs.
- Future developments include **smart insulation with temperature regulation properties.**

## 12. Industrial Applications and Case Studies

- Real-world applications in **green buildings, automobiles, and soundproofing solutions.**
- **Case studies** of companies or projects successfully using **textile waste for insulation.**
- **Construction:** Used in **walls, ceilings, and floors** for sound and thermal insulation.
- **Automotive:** Applied in **car interiors** to reduce noise and improve energy efficiency.
- **Aviation:** Lightweight textile-based insulation is used for **aircraft cabins.**
- **Case Study:** Companies like **Metisse in the Netherlands** successfully use **cotton-based insulation** for homes and offices.

## 13. Conclusion

Converting textile waste into acoustic insulation presents an innovative solution to both waste management and sustainable product development. The results highlight that nonwoven techniques combined with thermal bonding can create effective insulation materials while reducing landfill waste. Future research should focus on improving durability and fire resistance to enhance commercial viability.



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