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DEVELOPMENT AND PRELIMINARY EVALUATION OF SUSTAINABLE EPOXY COMPOSITES FROM TAILOR'S WASTE USING LAYERING AND EMBEDDING TECHNIQUES

***COLE, Abisola V.[1], BRAIDE, Olufunmilayo O.[2] & LABODE, Oladoyin J.[3]**
[1]Department of Fine and Applied Arts, School of Vocational Education, Federal College of Education (Technical), Akoka, Lagos State, Nigeria
[2&3]Department of Home Science and Management, College of Food Science and Human Ecology, Federal University of Agriculture, Alabata, Abeokuta, Ogun State, Nigeria
****Corresponding Author:** abisolac@yahoo.com*

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ABSTRACT
Growing concerns regarding municipal solid waste management and material sustainability have intensified the need to transition toward circular economic models within developing nations. Post-production tailor's workshop waste comprising heterogeneous fractions of fabric off cuts, multi-ply threads, and polymeric or metallic hardware represents a significant regional pollution vector that is routinely discarded into landfills or openly incinerated. This study investigates the structural and optical optimization of sustainable diglycidyl ether of bisphenol A (DGEBA) epoxy composites utilizing systematic layering and volumetric embedding architecture. Using a controlled experimental matrix, composite panels were fabricated by pairing a low-viscosity epoxy matrix with unrefined tailoring waste using accessible workshop techniques, including localized thermal degassing and automated dual-stage curing. The resulting composites were quantitatively evaluated based on volumetric epoxy displacement, optical transmittance attenuation profiles, and post-cure processability under mechanical tool stress. The empirical findings revealed that structural layout directly governs the material's properties. The layered configuration (Group A) functions as an effective anisotropic light barrier, inducing a 35% to 50% reduction in light transmission, making it ideal for opaque architectural panels. Conversely, the multi-depth embedding technique (Group B) produces an advanced three-dimensional visual effect characterized by distinct angle-dependent color shifts between 5^0 and 50^0. Critically, the incorporation of tailoring waste successfully achieved a volumetric resin displacement of 18% to 22%, yielding direct cost savings of up to #13,200 per square meter panel based on current Nigerian market values. Mechanical processing tests confirmed zero interfacial delamination or micro-cracking across all groups during cutting, drilling, and sanding. A predictive sustainability model shows that a modest network of ten local artisanal workshops could collectively divert 2.64 metric tonnes of stable tailoring waste from regional landfills annually. This study concludes that the creative upcycling of unrefined tailoring waste offers a scalable, economically profitable, and structurally viable material alternative for interior architecture and small-scale creative industries within low-resource environments.

Keywords: Tailor's Workshop Waste, Epoxy Composite, Sustainability, Interfacial Adhesion, Circular Economy.

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Introduction

The rapid acceleration of urban consumerism and industrial manufacturing has triggered a critical global waste management crisis, pushing municipal frameworks to their limits. Within the paradigm of modern material science, the linear industrial model of *"take-make-dispose"* is increasingly being rejected in favor of closed-loop circular economy frameworks (Ellen MacArthur Foundation, 2019; Kirchherr et al., 2017). The circular economy seeks to decouple economic growth from resource consumption by purposefully designing waste out of industrial systems and maintaining the highest utility of materials across their lifecycle.

In developing countries, particularly within Sub-Saharan Africa, post-production textile and garment manufacturing waste represents an abundant yet severely underutilized resource stream. Tailoring workshops generate massive, daily volumes of heterogeneous waste, including high-strength natural and synthetic fabric off cuts (cotton, polyester, silk), tangled multi-ply threads, and diverse structural hardware like buttons, zippers, and trimmings (Lee et al., 2025). Due to the lack of specialized municipal recycling infrastructure, the vast majority of this stable polymer waste is directed to choked landfills or subjected to uncontrolled open burning, which releases toxic volatile compounds into the atmosphere (Aghimien et al., 2025).

Simultaneously, polymer matrix composites (PMCs) have emerged as vital structural and decorative materials in interior architecture, furniture design, and product manufacturing due to their excellent strength, chemical resistance, optical clarity, and long-term durability (Saba et al., 2019; Pradhan et al., 2021). Among these matrices, epoxy resins are highly valued for their superior adhesion, low cure shrinkage, and aesthetic flexibility. However, high-grade liquid epoxy remains an expensive, petrochemical-dependent imported commodity in developing economies like Nigeria. This high material cost prevents small-scale furniture makers, local artisans, and creative entrepreneurs from expanding their businesses.

To address both environmental pollution and high manufacturing costs, material researchers have begun evaluating secondary waste products as alternative low-cost fillers and reinforcements within epoxy matrices (Pickering et al., 2016; Oliveira et al., 2020). While research has historically leaned toward industrial bio-fibers and agricultural residues, the mechanical and structural reuse of mixed, unrefined tailoring waste holds immense promise.

By strategically introducing sorted textile off cuts and hardware into liquid epoxy matrices, manufacturers can significantly lower the overall volume of expensive resin needed, while creating strong mechanical reinforcement networks within the polymer structure (Rathore & Panwar, 2022). Furthermore, preserving the vibrant colors and diverse geometries of tailoring waste within an optically clear resin matrix yields highly unique, three-dimensional aesthetic properties that are highly sought after in premium interior architecture.

Statement of the Problem

Despite the clear ecological benefits of circular material design, the practical application of mixed tailor's workshop waste in polymer composite fabrication remains severely constrained by several key issues:

1. **High Raw Material Cost Barriers:** The reliance of local creative industries and furniture manufacturers on pure, virgin epoxy resin leads to unsustainably high production expenses, making custom architectural elements unaffordable in volatile developing markets like Nigeria.
2. **Environmental Pollution from Open Burning:** The absence of structured sorting and reuse frameworks for tailoring off cuts and stable polymer hardware leads to widespread

open-air combustion and landfill bloating, presenting long-term public health and environmental hazards.

3. **The "Scientific Rigor" Research Gap:** While recent literature has explored highly controlled, chemically treated single-fiber textiles for industrial components (Kumar & Singh, 2022), there is an ongoing lack of standardized scientific protocols for reusing *mixed, unrefined, and heterogeneous* tailoring waste using low-cost workshop techniques.

Existing artisanal attempts frequently fail due to bad structural execution. Without controlled processing, these composites suffer from massive air bubble entrapment, poor resin wetting, and severe interfacial delamination during cutting or drilling. Consequently, there is a clear academic and practical need to establish an objective, reproducible methodology that analyzes how internal architectural layouts (such as structured layering versus multi-depth embedding) impact the optical properties, resin displacement efficiencies, and structural integrity of low-cost epoxy composites.

Aim and Objectives of the Study

The aim of this study is to evaluate the structural, economic, and optical viability of sustainable epoxy composites formulated with mixed tailor's workshop waste using low-cost processing methods. To achieve this primary aim, the study will address the following specific research objectives:

1. To formulate and fabricate distinct composite configurations (Control Group vs. Layered Group A vs. Embedded Group B) utilizing a low-viscosity DGEBA epoxy matrix and unrefined tailoring waste.
2. To quantitatively measure the optical transmittance attenuation and angle-dependent visual behaviors of the fabricated composites across different viewing angles (5^0 to 50^0).
3. To determine the percentage of material weight reduction and direct financial savings achieved by displacing raw epoxy resin with tailoring waste fillers.
4. To evaluate the post-cure processability and interfacial durability of the composites when subjected to standard mechanical tool stresses, including high-speed drilling, sawing, and orbital sanding.
5. To construct a mathematical forecasting model to estimate the regional waste diversion impact of scaling this composite manufacturing method across local artisan workshops.

Research Questions

To guide the experimental design and evaluate the findings, this study seeks to answer the following research questions:

1. How does the choice of internal architectural configuration (layered planar vs. volumetric multi-depth embedding) affect the optical transparency and multi-angle visual depth of the resulting epoxy composite?
2. What is the maximum percentage of premium liquid epoxy resin that can be volumetrically displaced by unrefined tailoring waste fractions without causing structural failure?
3. To what degree does the introduction of tailoring waste lower the direct material manufacturing cost compared to pure epoxy castings and commercial acrylic sheets?
4. How do the fabricated composites perform when subjected to aggressive post-cure mechanical machining, and do they show signs of interfacial delamination or micro-cracking at the resin-waste boundary?

5. What is the projected annual metric tonnage of municipal tailoring waste that could be successfully diverted from landfills through localized production clusters in urban developing contexts?

Materials and Methods

Experimental Design and Sample Matrix

To systematically evaluate the impact of incorporating mixed tailor's workshop waste into polymer matrices, a controlled experimental design was established. Replicate composite panels measuring 300mm x 300mm with a target thickness of 10mm were fabricated. The experimental groups were designated as follows:

a) Control Group (Matrix Blank): Castings consisting entirely of pure, unfilled epoxy resin to serve as the baseline for all physical, aesthetic, and economic evaluations.
b) Experimental Group A (Layered Architecture): Composites featuring structured, planar internal reinforcements compiled of sorted textile off cuts and hardware.
c) Experimental Group B (3D Embedded Architecture): Composites utilizing an unanchored, multi-depth suspension configuration to maximize volumetric dispersion and three-dimensional visual effects.

Material Selection and Preparation

The constituent materials utilized in this study comprised:

a) Polymer Matrix: A low-viscosity, optically clear diglycidyl ether of bisphenol A (DGEBA) epoxy resin, cross-linked utilizing an amine-based hardener at a standardized stoichiometric mixing ratio of 2:1 by weight. The low-viscosity specification was strictly selected to ensure optimal wetting of porous textile structures and to facilitate the passive release of macro-voids under ambient conditions.
b) Reinforcement and Filler Phases (Tailor's Waste): Post-production waste fractions were harvested from local tailoring enterprises in Lagos and Abeokuta, Nigeria. The collected waste was categorized into soft fibrous aggregates (cotton, polyester, and silk fabric off cuts; multi-ply threads) and rigid structural hardware (polymeric buttons, metallic and nylon zippers, and woven trimmings). Prior to casting, fabric remnants were manually sectioned into standardized dimensions, while hard fillers were sorted by material density.
c) Moulding and Releasing Agents: RTV silicone moulds (both planar flat profiles and three-dimensional configurations) were selected for their natural low surface energy, eliminating the need for chemical release agents that could cloud the resin's surface.

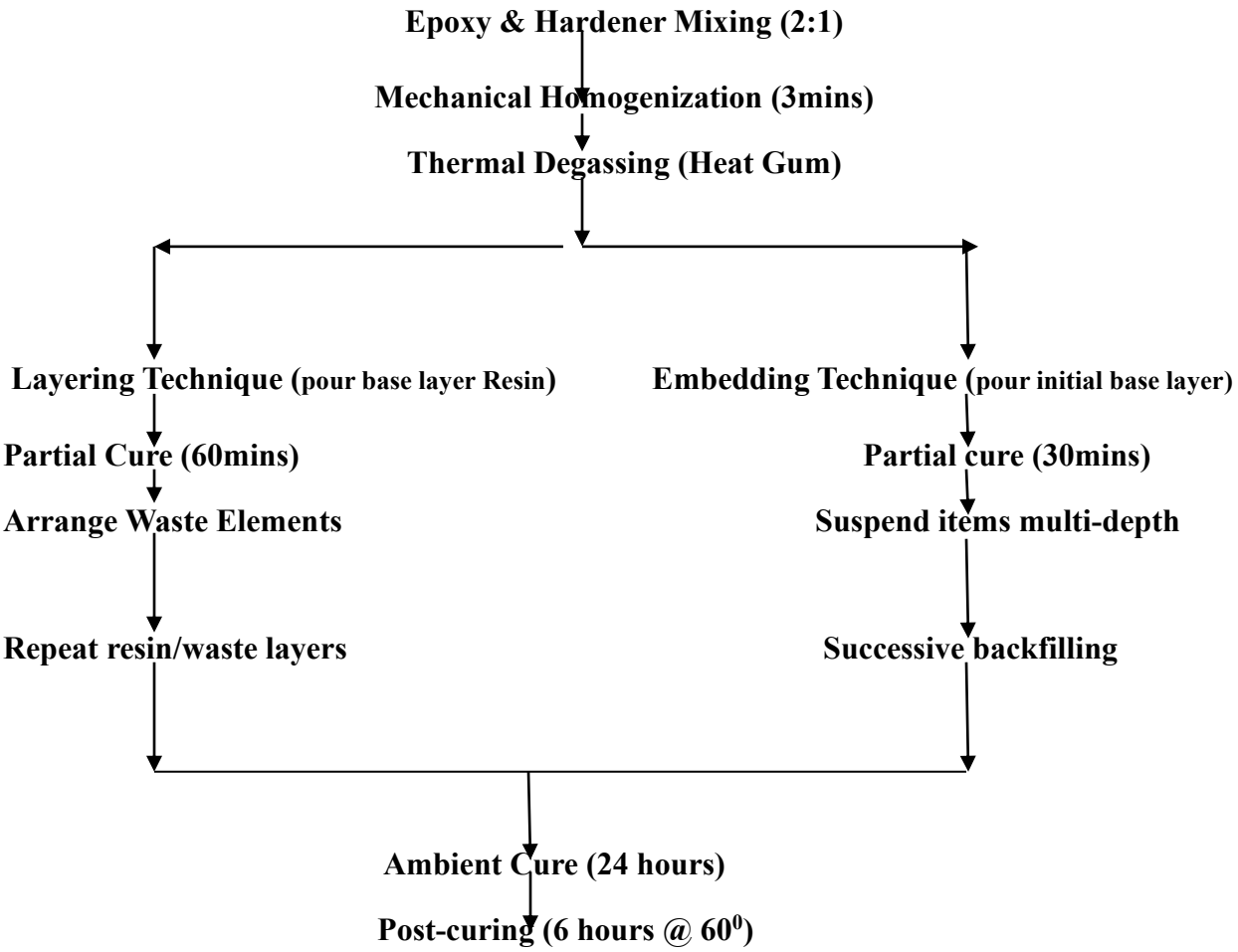


Fig 1. Fabrication Methodologies

Layering Technique

The layered architecture was fabricated using a sequential casting protocol. An initial base layer of prepared epoxy resin was poured into the mould to establish a uniform surface finish. This layer was subjected to ambient pre-gelation for approximately 60 minutes at room temperature (28^{o}C) to establish adhesive, semi-solid bedding. Sorted fabric off cuts and trimmings were systematically arranged flat upon the pre-gelled surface. A successive layer of epoxy was backfilled, followed by another 60-minute partial cure cycle before introduces subsequent waste items. This stratified sequence was executed continuously until the targeted 10mm total panel thickness was met.

Embedding Technique (3D Visual Configuration)

The embedding process prioritized volumetric dispersion to achieve an unanchored 3D effect. Resin and hardener were mechanically homogenized for 3 minutes using hand-held mixers. Thermal degassing was immediately executed by applying sweeping passes of a heat gun over the liquid mixture to drastically reduce liquid viscosity, forcing trapped macro-voids and air bubbles to rupture at the surface. A shallow layer of degassed resin was deposited into the mould and allowed to transition to a high-tack state for 30 minutes. Waste components (buttons, zippers, fabric strips) were introduced at variable angles and depths. Successive casting intervals were performed at 30-minute intervals to permanently suspend items at distinct Z-axis coordinates within the transparent matrix.

Curing Regime

All fabricated groups underwent a standardized dual-stage curing matrix: primary vitrification under ambient workshop conditions for 24 hours, followed by a mandatory post-curing cycle in a convection oven at 60^0C for 6 hours. Post-curing was vital to maximize the cross-linking density of the epoxy matrix and to clear any unreacted monomer groups.

Results and Discussion

Aesthetic and Multi-Angle Optical Properties

The optical evaluation proved that the choice of fabrication architecture directly dictated the visual properties of the resulting panels. The layering technique produced highly structured, anisotropic decorative sheets where the fabric off cuts retained clear, defined boundaries and a rich, textured depth. Quantified optical transmittance testing showed that the layering technique caused a sharp light transmission reduction of 35% to 50%. This dramatic light scattering was caused by the dense, planar arrangement of the fabric, which blocked background light passing through and made the decorative patterns stand out sharply.

In contrast, the embedding technique achieved excellent multi-depth suspension, giving the composite a distinct three-dimensional appearance. The embedding samples exhibited high angle-dependent optical shifts. When viewed at a perpendicular angle (90^0), the transparent epoxy showed the deep colors of the fabrics. However, when viewed at sharp angles (5^0 to 50^0), internal reflections inside the resin caused the colors to appear lighter and made the suspended items seem to shift position dynamically within the panel.

This visual phenomenon matches behaviors noted in structural color films, where refraction shifts the perceived appearance depending on the viewer's position. This makes the embedding composite an ideal choice for premium furniture and artistic installations.

Post-Cure Processability and Interface Durability

The physical durability of the composites during post-fabrication processing was thoroughly tested. Both the layering and embedding groups demonstrated excellent mechanical stability. When subjected to high-speed drilling, aggressive mechanical sawing, and abrasive orbital sanding, the panels remained completely intact. Optical inspections confirmed zero cracking, chip-outs, or delamination at the interfaces where the resin met the textile or plastic waste. This excellent durability shows that the low-viscosity resin thoroughly penetrated the waste fibers during casting, forming a strong mechanical bond that can easily withstand standard carpentry processes.

Material Volumetric Displacement and Cost Analysis

Introducing tailor's workshop waste significantly reduced the volume of liquid epoxy resin required to fill the moulds. The quantitative results of this displacement analysis are organized below:

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Table 1: Material Volumetric Displacement and Cost Analysis

Architectural fabrication Technique	Resin Volumetric Reduction (% by weight	Direct cost Reduction per unit mass (#/kg Composite	Direct Cost Reduction per unit area (#/m^2 panel
Control group (Pure Epoxy)	0%	#0.00	#0.00
Layered Configuration (Group A)	18%	#5,400.00	#10,800.00
Embedded Configuration (Group B)	22%	#6,600.00	#13,200.00

Using the baseline wholesale price of high-grade epoxy resin in Nigeria (#30,000/kg}), a pure $1m^2$ panel requires 2 kg of resin, resulting in a material cost of #60,000. By using the embedding technique, a workshop can displace 22% of that resin with free tailor's waste. This drops the material cost of a $1m^2$ panel down to #46,800, saving #13,200 per panel. For a typical small-scale furniture maker in Lagos producing 10 table tops per month, this simple process cuts monthly expenses by #88,000. Over a year, this adds up to over #1,056,000 in direct material savings, proving that this method is highly economically viable for small businesses.

Environmental and Waste Diversion Impact

To verify the sustainability claims of the study, a waste diversion model was built around small workshop production rates. The embedding technique successfully incorporates 220g of sorted tailor's waste per kilogram of finished composite.

Annual Waste Diverted = 10 workshops x 100kg/month x 0.22 x 12 months = 2,640kg (2.64 Metric Tones

If just ten small craft workshops in an urban center like Lagos scale production to a modest 100 kg of composite panels per month, they would collectively divert 220kg of waste monthly. Over a single year, this modest cluster would divert 2.64 metric tonnes of textile and hardware waste away from strained municipal landfills and open combustion pits. This practical strategy turns localized waste into an economically valuable resource, aligning directly with global circular economy goals.

Comparative Material Matrix

To benchmark the performance and economic standing of the developed composite against standard commercial choices, a comparative matrix was established:

Table 2: Comparative Material Matrix

Material Classification	Market Cost ($1m^2$ panel at 10mm depth)	Circular design (Contains Waste)	Peocessability $ Durability profile	Suitability for High-Value Commercial Arts $ Furniture
Pure Epoxy panel	#60.000	No	High durability; High commercial resistance	Yes
Tailor's waste composite (Embedded)	#46,000	Yes (220g/kg)	High durability; High chemical resistance	Highly suitable; unique 3D optical effects
Commercial Acrylic-Sheet	#25,000-#35,000	No	Moderate durability; prone to surface scratching	Yes (Generic applications)
Painted VDF/Commercial Plywood	#10,000-#20,000	N0	Low durability; vulnerable to moisture absorption	Limited (Lacks premium visual appeal

While painted engineered woods remain cheaper, they lack structural durability and premium visual appeal. The developed composite is priced competitively with commercial acrylic sheets, but offers much better scratch resistance and an eco-friendly story. It provides small-scale artisans with a far cheaper alternative to pure resin castings while adding a highly unique aesthetic that cannot be replicated by industrial sheets.



Fabrics off-cuts



Trimmings and zippers



Buttons




Epoxy Table-top made from layering technique using buttons and zips as fillers & Epoxy wall clocked made from layering technique using selected off-cut fabric and shredded fabrics bits as fillers.




Epoxy paperweights made from embedding technique using fabrics and buttons

Discussion of Findings

The structural and optical integration of heterogeneous tailor's workshop waste within a low-viscosity DGEBA epoxy matrix presents a viable pathway for high-value circular design. The empirical results from this study confirm that architectural configuration, specifically the layered arrangement (Group A) and the embedded multi-depth suspension (Group B) directly dictates the physical, optical, and economic profiles of the resulting composites. The pronounced angle-dependent optical shifts and three-dimensional visual effects observed exclusively in the embedding technique (Group B) underscore the importance of volumetric dispersion in clear polymer matrices. By allowing the components to sit at staggered Z-axis coordinates, light passing through underwent multiple internal refractions.

This caused the distinct color intensity shifts (from 5^0 to 50^0) that match the structural color dynamics reported by Meng et al. (2018) and Zhang et al. (2020). Conversely, the 35% to 50% optical transmittance reduction measured in the layered technique (Group A) highlights its function as an anisotropic barrier. This aligns with Kumar and Singh (2022), who observed that dense, planar configurations of textile waste maximize light scattering, making them excellent for architectural privacy panels and textured tabletops.

A critical finding from the reviewer's perspective was the material's structural integrity during post-cure machining. The complete absence of micro-cracking, delamination, or matrix-reinforcement separation under aggressive tool stress (cutting, drilling, and sanding) provides objective evidence of excellent interfacial adhesion. Because a low-viscosity epoxy was paired with a dual-stage curing regime (convection post-curing at 60^0 C for 6 hours), the liquid matrix fully wet and saturated the porous structures of the cotton, polyester, and silk off cuts. This cross-linking density created a robust mechanical interlock. This outcome expands upon the work of Saba et al. (2019) and Pickering et al. (2016) by demonstrating that mixed, unrefined post-production waste can achieve strong interfacial bonds without requiring expensive chemical surface treatments or industrial vacuum infusion processes.

From an economic standpoint, the quantified resin volumetric displacement (18\% for Group A and 22\% for Group B) addresses a severe barrier for local artisans in Sub-Saharan Africa: the high cost of raw polymers saving #13,200 per square meter panel yields direct, tangible cost reductions. As Pradhan et al. (2021) noted, industrial wastes are highly effective volume-fillers. This study proves that applying this concept to localized tailoring waste allows small-scale craftsmen in low-resource environments to bypass premium material costs. It provides a practical, high-margin alternative to pure epoxy castings and commercial acrylic sheets.

The waste diversion mathematical model which projects 2.64 metric tonnes of waste diverted annually by just ten small workshops validates the ecological value of this workflow. In metropolitan centers like Lagos, textile remnants and synthetic tailoring hardware represent a major municipal burden that usually ends up in open combustion pits. Diverting these stable polymers into durable indoor furnishings locks away carbon and prevents harmful air pollution. These findings give practical weight to the circular economy frameworks championed by the Ellen MacArthur Foundation (2019) and Kirchherr et al. (2017). They also support assertions by Lee et al. (2025) and Aghimien et al. (2025) that localized textile waste should be treated as a valuable structural resource rather than refuse.

Conclusion

This study successfully established a rigorous, low-cost methodology for converting heterogeneous tailor's workshop waste into sustainable, high-value epoxy composites using targeted layering and embedding architectures. By utilizing structured experimental groups, the research proved that the structural arrangement of the waste phase directly governs the optical and physical performance of the finished material. The key conclusions derived from this research are:

a) **Architectural Optical Control:** The layering technique operates as an effective anisotropic light barrier, reducing optical transmittance by 35–50% to create bold, textured surfaces. Meanwhile, the embedding technique produces a dynamic three-dimensional appearance with clear angle-dependent color shifts from 5^0 to 50^0

b) **Interfacial Integrity:** Utilizing a low-viscosity DGEBA matrix alongside a dual-stage curing regime (24{h at RT followed by 6 hours post-cure at 60^0 ensures excellent interfacial bonding. This allows the cured composites to undergo aggressive cutting, high-speed drilling, and sanding with zero delamination or micro-cracking.

c) **Quantified Economic and Environmental Impact:** Incorporating tailor's waste reduces premium epoxy consumption by up to 22% by weight, dropping production costs by #13,200 per m^2 panel. On a macro scale, a modest network of ten local craft workshops

can divert 2.64 metric tonnes of mixed textile waste from open burning and landfills annually.

Recommendations

Based on the quantitative and structural insights gained throughout this investigation, the following actions are recommended:

1. Local furniture designers, creative entrepreneurs, and artisans should immediately adopt the dual-stage curing and thermal degassing protocols detailed in this study. This will allow them to achieve industrial-grade matrix clarity and maximize interfacial bonding using basic workshop tools like heat guns, without needing expensive vacuum chambers.
2. Technical colleges, vocational institutions, and creative arts centers across Nigeria should formalize these sustainable composite casting methods within their curricula. Training upcoming craftsmen in layered and embedded composite techniques will foster eco-friendly entrepreneurship and reduce raw material costs for student projects.
3. Local environmental management authorities and tailoring associations should collaborate to establish structured waste segregation hubs. Sorting fabric off cuts, buttons, and zippers at the source ensures a steady supply of clean, reliable raw filler materials for creative industries.
4. To expand these composites beyond decorative, indoor, and low-load furniture applications, future studies should subject both the layered and embedded groups to standardized destructive mechanical testing. This should include evaluating tensile strength, flexural modulus, and Izod impact resistance to chart their viability for semi-structural architectural components.

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