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Design and Durability Analysis of Urban Public Seats Based on Regenerated Polyester Fiber Composites

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Article

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ABSTRACT

To address the urgent need for sustainable development in the textile industry and to provide a high-value-added recycling pathway for waste textiles and polymer scrap, this study focuses on the development of a novel regenerated polyester fiber composite and its potential application in urban public facilities. The composite material is primarily made from regenerated polyester (PET) yarn sourced from post-consumer plastic bottles and waste clothing, produced through specific fiber processing and chemical composite techniques. We conducted systematic durability comparison tests between this new fiber product and traditional materials like pine wood and 6061 aluminum alloy. Experimental results show that the regenerated fiber composite demonstrated excellent abrasion resistance; its wear depth and mass loss were far superior to wood and approached the level of aluminum alloy. After a 1000-hour accelerated aging test simulating long-term environmental impact, the composite's tensile strength decreased by only 8.2%, showcasing exceptional weather resistance. A service life prediction based on the Arrhenius model indicated that the expected service life of this new fiber product could reach 14.2 years. These findings confirm that the regenerated polyester fiber composite, as a high-performance and long-life engineering material, is not only a significant technological achievement in the field of textile recycling but also offers an innovative solution for the application of organic polymer materials in sustainable urban development.

KEYWORDS

sustainable development, recycled polyester, synthetic fibers, fiber products, composite materials

INTRODUCTION

With the acceleration of urbanization, the quality of urban public space has attracted increasing attention. As an important part of urban public facilities, public seats not only provide people with a place to rest but also reflect the image and cultural connotation of the city to some extent. Traditional public seats mostly use stone, metal, wood, and other materials, which are associated with the following issues: stone seats are cold and hard, metal seats are easy to corrode and rust, wood seats are easy to be eaten by insects and decayed, and their production often causes great pressure on the environment [1]. Recycled polyester fiber composite is a new material made by recycling waste polyester fiber, which has good mechanical properties and chemical stability and is easy to dye and process [2]. Its raw materials are widely available and mainly include waste plastic bottles, waste clothing, waste packaging materials. The use of these wastes cannot only realize the recycling of resources but also reduce the pollution of wastes to the environment. The energy consumed to produce recycled polyester fiber composites is lower than that of traditional materials, which is in line with the current concept of sustainable development.

Recycled polyester fiber composites have been widely used in textile, packaging, and other industries. These composites can be used to produce all kinds of clothing and home textile products, which are characterized by environmental protection, comfort, and fashion. They can be used to produce shopping bags, food packaging, etc., which have good moisture-proof and oil-proof properties. These composites are also utilized to produce automobile interiors, electronic components, etc., which exhibit high temperature resistance and corrosion resistance. However, existing related research mainly analyzes the preparation and properties of recycled polyester fiber composites or their application in the textile field. For example, the preparation and performance of materials are the core basis of such research, which is of great significance to the improvement of material properties. Wang [3] carried out experimental analysis on the preparation method and flame-retardant properties of recycled polyester fiber composites. The flame retardant Polyethylene terephthalate, (PET) fiber spun with 5% CEMPA flame retardant effectively improved the properties of the flame retardant polyester fiber when the limiting oxygen index reached more than 27% [3]. Zhu [4] studied the preparation and properties of natural latex film and polyester fiber nonwoven with sound-absorbing composite. The composite had the best comprehensive properties, with a large sound absorption coefficient of 0.8, which effectively broadened the sound-absorbing frequency band and provided important support for the expansion of its application [4]. Xiang [5] studied the preparation methods and properties of recycled polyester hollow fiber-based sound absorption materials. The hollow fiber with a linear density of 10 D had the largest hollowness and the best toughness and sound absorption effect, and the coefficients of sound absorption and noise reduction increased linearly with increasing thickness. This field of research is gradually expanding to multiple application fields. Liu [6] studied the micro-mechanism of recycled polymer strengthening silt and reported that curing time had less influence on the liquid plastic limit than adding fiber and that the plastic index decreased slightly with time. The shrinkage rate in unmodified soil is 1.04 to 1.45 times higher than that in fiber-reinforced soil, indicating that fiber effectively controls shrinkage [6]. Sundarraj [7] pointed out that recycled polyester fiber composite is the most comfortable natural fiber, and it is not only easy to care but also has good air permeability. In this study, the morphological, physical, mechanical, and color fastness properties of the needling technology of the material were analyzed. The CFI Group reported Ambercycle's investment in recycled polyester fiber composite materials and conducted a concrete analysis of one of the investments; they thought that investment in the field of recycled polyester fiber composite materials would increase the production capacity of high-quality materials made from recycled textiles [8].

The research content of recycled polyester fiber composites is still relatively simple, although the application scope is wide. As a material with good performance, this type of composites is expected to solve the shortage of traditional public seat materials, improve the performance and service life of public seats, and contribute to urban environmental protection. Therefore, the present research will use recycled polyester fiber composite materials for the design and durability analysis of urban public seats.

EXPERIMENTAL

Materials

Experimental Group (Recycled Polyester Fiber Composite)

The seat boards were composed of 85% recycled polyester fiber, 15% unsaturated polyester resin (UP-191, with 30% styrene content), and 0.5% blocked amine light stabilizer (HALS-944) as an anti-aging agent. The recycled fibers, sourced from post-consumer plastic bottles, were surface treated with a KH-550 coupling agent to enhance interfacial bonding with the resin matrix.

Control Group 1 (Pine Wood)

The seat boards were made from North American yellow pine (*Pinus ponderosa*), aged 20–30 years and cut along the grain. The wood had an air-dry density of 0.48–0.52 g/cm³ and a grain compressive strength of 35 MPa.

Control Group 2 (Aluminum Alloy)

The seat boards were fabricated from 6061-T6 aluminum alloy, with a chemical composition of 0.4%–0.8% Si, 0.8%–1.2% Mg, and the remainder was Al. The material had a density of 2.7 g/cm³ and an initial tensile strength of 260 MPa.

Seat Panel Preparation

Recycled Polyester Fiber Composite

Recycled plastic bottles were processed into fibers, which were mixed with unsaturated resin and additives in a twin-screw extruder at 120 °C. The resulting mixture was hot-pressed in a mold at 140 °C and 15 MPa for 20 minutes to form a 1200 mm × 600 mm × 20 mm seat board. After trimming, the board surface was ground and coated with a protective layer.

Pine Wood

The wood was kiln-dried to a moisture content of 12% ± 2%. The surface was then sanded to a roughness of Ra 3.2 µm and coated with two layers of water-based polyurethane anti-corrosion paint (total dry film thickness: 50 µm). The final dimensions were 1200 mm × 600 mm × 20 mm.

Aluminum Alloy

The 6061 aluminum alloy was extruded into blanks and subjected to a T6 heat treatment, comprising a solid solution treatment at 520 °C for 1 hour followed by artificial aging at 180 °C for 8 hours. The blanks were cut to the specified dimensions of 1200 mm × 600 mm × 20 mm, and their edges were polished.

Durability and Performance Testing

All test specimens were pre-conditioned for 48 hours at 23 ± 2 °C and a relative humidity of 50% ± 5% before testing. For each test group, a minimum of five specimens were tested, and the results were reported as mean ± standard deviation.

Abrasion Resistance Test

Abrasion resistance was evaluated using a Taber Wear Tester (Model 5135) in accordance with ASTM D4060 [9]. A CS-10 grinding wheel was applied to the material surface with a load of 5N, rotating at 60 rpm for 1000 cycles. Wear was quantified by measuring the wear depth by using a laser thickness gauge, and mass loss was recorded using an analytical balance (accuracy 0.1 mg).

Accelerated Weathering Test

Accelerated weathering was conducted in a QUV accelerated aging chamber following the ISO 16474-3:2005 standard [10]. The samples were exposed to a cycle of 6 hours of UV-A radiation (0.89 $W\cdot m^{-2}\cdot nm^{-1}$ at 340 nm, 60 °C) followed by 2 hours of water spray. The total exposure time was 1000 hours. Material degradation was assessed by measuring the retention of tensile strength and the change in surface color (ΔE) at intervals of 0, 250, 500, 750, and 1000 hours.

Chemical Corrosion Resistance Test

Resistance to chemical corrosion was tested according to ISO 175:2010 [11]. Specimens were immersed in 5% hydrochloric acid (HCl) solution and 5% sodium hydroxide ($NaOH$) solution in a constant temperature shaking water bath (25 ± 1 °C, 100 rpm) for 48 hours. Mass change rate and surface morphology were observed through Scanning Electron Microscopy (SEM) to evaluate stability.

Mechanical Property Testing

Tensile and bending tests were performed on a universal testing machine. Tensile tests were conducted at a speed of 5 mm/min, and three-point bending tests were conducted at 2 mm/min.
Fatigue tests were conducted using a fatigue testing machine at a loading frequency of 10 Hz and a stress ratio (R) of 0.1. The number of cycles to failure at various stress levels was recorded to generate S-N curves for each material.

Service Life Prediction Modeling

The service life projection in this study was primarily used to compare the relative long-term durability of the three materials rather than to produce absolute lifetime values. Because the dominant degradation mechanisms of the materials differ—photothermal oxidation for the composite and wood, and corrosion-related processes for aluminum alloy—the Arrhenius-based
model provides a useful index for comparing trends. Degradation rate constants (k) at the three accelerated temperatures (30 °C, 45 °C, and 60 °C) were obtained from tensile retention data and fitted to the Arrhenius relationship. A relative service-life index was then calculated at an assumed service temperature of 25 °C based on a 50% tensile-strength loss criterion. This index reflects the comparative resistance of the three materials to thermally activated degradation [12,13].

RESULTS

Abrasion Resistance

The abrasion resistance of the three materials was quantified by wear depth and mass loss after 1000 cycles on the Taber Wear Tester. The results are summarized in Table 1. The recycled polyester fiber composite exhibited significantly lower wear than pine wood, and its wear resistance approached that of the 6061 aluminum alloy.

Table 1. Abrasion Resistance Test Results

Material Group	Wear Depth (mm)	Mass Loss (g)
Recycled Polyester Composite	0.12 ± 0.02	0.31 ± 0.05
Pine Wood	0.78 ± 0.09	2.54 ± 0.28
6061 Aluminum Alloy	0.08 ± 0.01	0.22 ± 0.04

Accelerated Weathering

Material degradation under simulated weathering conditions was evaluated by tracking the retention of tensile strength and changes in surface color over 1000 hours of QUV exposure.

The tensile strength retention data (Table 2) indicate that the recycled polyester composite maintained 91.8% of its initial strength after 1000 hours. By contrast, the pine wood samples experienced severe degradation and retained only 45.5% of their strength. The aluminum alloy showed low strength loss. After 1000 hours, total color change (ΔE) was measured. The composite material showed the highest color stability (ΔE = 3.2 ± 0.3), followed by the aluminum alloy (ΔE = 6.8 ± 0.7). The pine wood exhibited significant discoloration (ΔE = 18.5 ± 2.1).

Table 2. Tensile Strength Retention During Accelerated Weathering

Exposure Time (hours)	Recycled Polyester Composite (%)	Pine Wood (%)	6061 Aluminum Alloy (%)
0	100	100	100
250	98.1 ± 0.5	85.2 ± 2.1	99.8 ± 0.1
500	96.5 ± 0.7	71.3 ± 2.5	99.8 ± 0.2
750	94.2 ± 0.9	58.0 ± 2.8	99.7± 0.2
1000	91.8 ± 1.1	45.5 ± 3.2	99.6± 0.3

Chemical Corrosion Resistance

The chemical stability of the materials was assessed by their mass change after 48 hours of immersion in acidic and alkaline solutions (Table 3). The recycled polyester composite demonstrated excellent resistance in both environments. Pine wood suffered substantial mass loss, particularly in the acidic solution. The aluminum alloy showed susceptibility to the alkaline solution but was stable in the acidic solution. The SEM analysis revealed only minor surface roughening on the composite. Pine showed fiber decomposition, and aluminum exhibited pitting corrosion.

Table 3. Mass Change After Chemical Immersion

Material Group	Mass Change in 5% HCl (%)	Mass Change in 5% NaOH (%)
Recycled Polyester Composite	–0.28 ± 0.04	–0.45 ± 0.06
Pine Wood	–15.3 ± 1.2	–9.1 ± 0.9
6061 Aluminum Alloy	–1.1 ± 0.2	–4.8 ± 0.5

Mechanical Properties

The initial mechanical properties and fatigue performance of the materials were determined (Table 4). The 6061 aluminum alloy possessed the highest tensile and bending strength, while the recycled polyester composite was significantly stronger than pine wood in both aspects.

The fatigue test results indicated a clear hierarchy in performance. At a cyclic stress level of 20 MPa, the pine wood specimens failed at an average of 4.5×10^4 cycles. The recycled polyester composite did not fail and showed only stable micro-crack propagation after 5×10^5 cycles. The aluminum alloy showed no signs of failure up to 10^6 cycles at this stress level (Figure 1).

Table 4. Initial Mechanical Properties

Property	Recycled Polyester Composite	Pine Wood	6061 Aluminum Alloy
Tensile Strength (MPa)	52.3 ± 2.1	32.5 ± 3.0	258.1 ± 5.5
Bending Strength (MPa)	45.1 ± 1.8	28.2 ± 2.5	180.4 ± 4.0

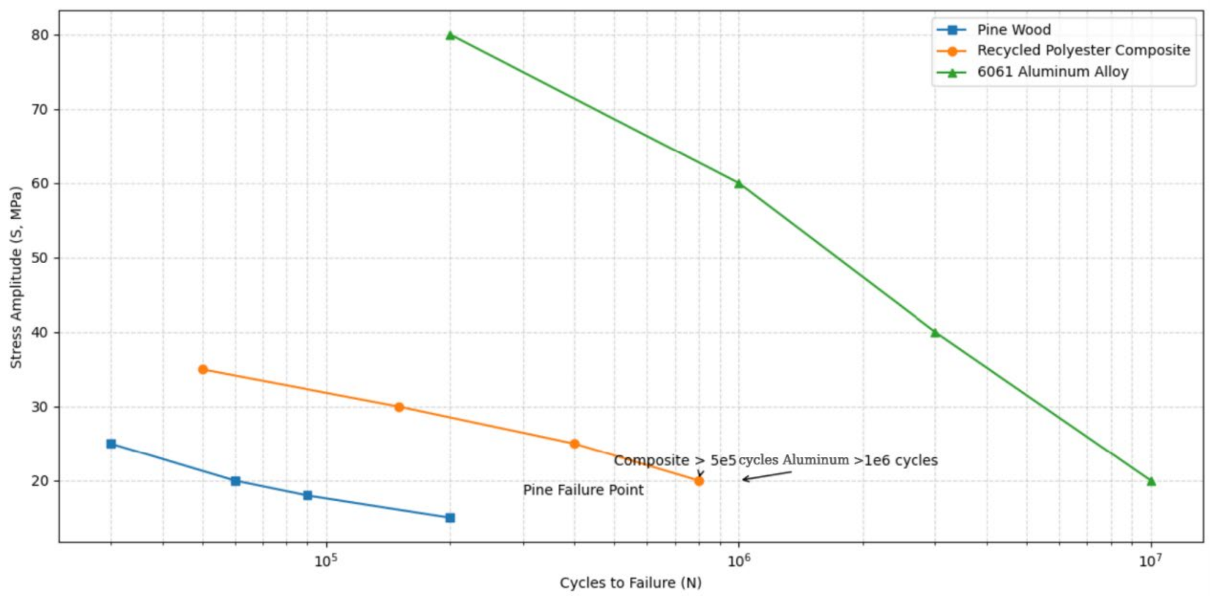

Figure 1. S-N Curves for Seat Materials

Predicted Service Life

Based on the Arrhenius fit of the degradation rate constants obtained from the three accelerated temperatures, a relative service-life index was estimated for the three materials. As illustrated in Figure 2, the regenerated polyester composite demonstrates a markedly longer predicted service life than pine wood, consistent with its lower degradation rate at all accelerated temperatures. Aluminum alloy exhibits the highest long-term stability among the three materials, although the UV-based accelerated aging method used in this study is less sensitive to its actual corrosion-dominated degradation mechanisms. Thus, the materials exhibit a durability sequence in which aluminum alloy demonstrates the highest resistance to degradation, followed by the regenerated polyester composite, with pine wood showing the lowest stability.

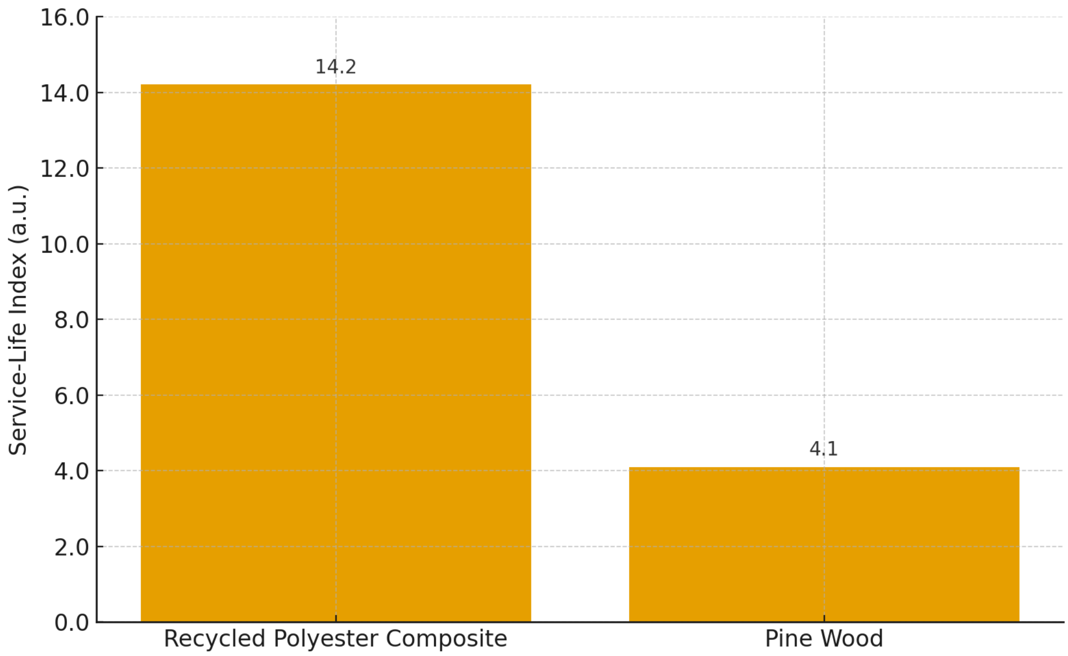

Figure 2. Predicted Service Life of Seat Materials Based on Arrhenius Model

DISCUSSION

Recycled polyester fiber composites offer a superior combination of durability and performance for urban public seating applications compared with traditional pine wood and 6061 aluminum alloy. The advantages of the composite are not confined to a single attribute but are evident across a spectrum of mechanical, chemical, and long-term environmental resistance tests. The excellent wear and chemical resistance of the composite form the first pillar of its durability. Its wear resistance, approaching that of aluminum alloy and vastly superior to pine, can be attributed to the intrinsic toughness of the polyester matrix combined with the structural support of the fiber network. The strong intermolecular forces (van der Waals forces and hydrogen bonds) within the polymer matrix prevent the easy removal of the surface material during friction

[14–16]. By contrast, the porous, anisotropic structure of pine wood leads to rapid fiber pull-out and degradation [17]. The chemical inertness of the composite is reflected by the minimal mass loss in acidic and alkaline environments and originates from the stability of its ester bonds, which are less susceptible to hydrolysis than the cellulosic and hemicellulosic components of wood. Aluminum alloy is resistant to acids to some degree, and its protective oxide layer is vulnerable, particularly to alkaline solutions, leading to measurable corrosion [18,19].

The most significant finding of this study is the composite's exceptional long-term environmental stability, which directly translates to a long service life. The results of the accelerated weathering test are unequivocal: the composite retained nearly 92% of its initial tensile strength after 1000 hours of aggressive UV and moisture cycling. This performance is a direct result of the synergistic effect of the stable polyester backbone and the incorporated HALS-944 light stabilizer, which effectively interrupt photodegradation pathways. This inherent resistance to environmental degradation is the key factor underpinning its predicted longevity.

When the low degradation rate was extrapolated using the Arrhenius model, the predicted service life of the composite reached 14.2 years, which is approximately 3.5 times that of pine wood (4.1 years), whose service life is severely limited by lignin photodegradation and biological decay. Aluminum alloy showed minimal degradation during the UV-based accelerated aging tests, this is expected because its true outdoor deterioration is governed mainly by corrosion and fatigue instead of photothermal oxidation. This model-based prediction provides a quantitative and scientifically defensible basis for asserting the superiority of the material and moves beyond qualitative assessment or subjective estimation. The robust fatigue performance of the composite further supports its suitability for public-use furniture, which endures constant cyclic loading.

In summary, the recycled polyester fiber composite is not merely a sustainable alternative but also a high-performance material. Its structural integrity, chemical resilience, and, most importantly, its scientifically validated potential for an extended service life make it an ideal candidate for next-generation, low-maintenance, and durable urban public facilities.

CONCLUSION

This study conducted systematic design, experimentation, and analysis and successfully demonstrated the feasibility and superiority of using recycled polyester fiber composites in urban public seats. The composite material exhibited outstanding performance across multiple durability metrics, including abrasion resistance, weather resistance, and chemical corrosion resistance. Scientific predictions based on accelerated aging test data and the Arrhenius model indicated a projected service life of 14.2 years for the composite bench—substantially exceeding that of pine wood benches (4.1 years). Furthermore, the proposed bench design integrates principles of ergonomics, aesthetics, and sustainability and offers a novel option for urban public infrastructure that balances functionality, durability, and environmental responsibility.

This study has limitations. The experimental protocols did not encompass all extreme climate conditions, such as prolonged exposure to high-salinity environments or aggressive acidic and alkaline industrial atmospheres. Additionally, the study did not simulate complex real-world factors such as vandalism or biological fouling that may affect the material during actual use. From a design perspective, the current solution adheres to general ergonomic standards but lacks differentiated validation for special user groups such as the elderly and children. Moreover, user acceptance of the aesthetic design has yet to be substantiated by extensive empirical data. Future research in this domain may be deepened in several directions. First, the impact resistance of the material could be enhanced by incorporating 5%–10% toughening agents, or its tensile strength could be improved by 20%–30% through the addition of 15–20% high-strength fibers such as basalt fiber. Second, collaboration with municipal planning departments is recommended to establish pilot feedback mechanisms. This initiative would involve installing benches in various functional zones, such as parks and commercial districts, and collecting dynamic data on comfort, wear, and usage through sensors and surveys to iteratively refine the design. Lastly, further exploration into hybrid applications of this composite with other materials, such as wood–plastic composites and bamboo fiber composites, could enable the development of innovative eco-friendly seating solutions tailored to diverse outdoor settings (e.g., fitness installations, landscape features). Such work should include systematic studies of the mechanical strength, water resistance, and antimicrobial properties across varying blend ratios.

Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

Author Contributions

Ting Wang and Dexin Huang designed the study; all authors conducted the study; Ting Wang and Dexin Huang collected and analyzed the data. Dexin Huang and Ting Wang participated in drafting the manuscript, and all authors contributed to critical revision of the manuscript for important intellectual content. All authors gave final approval of the version to be published. All authors participated fully in the work, took public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or completeness of any part of the work were appropriately investigated and resolved.

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Conflict of Interest

The authors declare no conflict of interest.

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