

REVIEW ARTICLE

Closing the Loop Without Closing Performance: A Critical Synthesis of Recycled Polyester in Textiles

Evidence on mechanical, thermal, moisture-management and circularity trade-offs from fibre to composite

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ABSTRACT

Recycled polyester (rPET) is central to textile circularity, yet its performance is often assumed rather than demonstrated. This editorial review synthesises ten supplied studies spanning flame-retardant finishing [1], graphene-blended yarns [2], natural-fibre composites [3], mechanically recycled nonwovens [4], fibre-to-fibre recycling strategies [5], ageing behaviour [6], and comparative fabric testing [7] [9] [10]. The evidence indicates that rPET can match or exceed conventional polyester in tensile strength, abrasion resistance and moisture transport [7] [9], and that calendaring can reduce water vapour resistance by up to 23% while eliminating visible sweat marks [10]. However, ageing studies show conventional polyester retains better abrasion resistance, surface smoothness and elastic recovery [6], and mechanical recycling introduces fibre-length and processability penalties [4]. Disagreements between sources are explained by differences in fibre origin, blend composition, test method and whether performance is measured before or after laundering or ageing. Practical implications include low additive loadings for durable finishing [1], internal rather than surface functionalisation [2], and blend-ratio optimisation for nonwovens [4]. Circularity claims require fibre-level evidence, not waste-diversion metrics alone [5].

Keywords: recycled polyester; textile circularity; fibre-to-fibre recycling; moisture management; durability; nonwovens; composites; flame retardancy

SECTION 01

Why rPET performance claims need a fibre-level lens

Recycled polyester occupies an unusual position in textile sustainability discourse: it is simultaneously promoted as a mature circular feedstock and questioned for performance deficits relative to virgin polymer. The supplied evidence does not resolve this tension into a single verdict, and that is the central finding of this review. Comparative testing of rPET and virgin polyester fabrics derived from post-consumer bottles found rPET showed positive results in tensile strength and abrasion resistance, supporting its use in technical textiles and apparel [7]. A separate study of knitted fabrics reported that rPET performed better than conventional polyester in absorption rate, wettability, drying rate and capillarity, with no significant difference in water vapour permeability [9]. These findings challenge the assumption that recycled content necessarily degrades moisture-management performance.

Counter-evidence is equally specific. An ageing study concluded that although recycled polyester yarn offers higher tensile strength, conventional polyester yarn was more advantageous overall, with higher abrasion resistance, smoother surface texture and better elasticity retention after combined ageing factors [6]. This is not a contradiction of [7] and [9] so much as a difference in what is being measured and when. Tensile strength and initial moisture transport are distinct from retention of

surface and elastic properties after ageing. The practical implication is that rPET suitability is application- and lifetime-dependent, not a generic property of the material class.

The fibre-to-fibre recycling literature frames this variability as structural rather than incidental. Fibre blends, chemical finishes and degradation during repeated processing constrain recycling routes, and downcycling remains a persistent barrier [5]. This means performance outcomes depend on feedstock history and process path, which are rarely reported in sufficient detail in individual studies. Claims that rPET is 'equivalent' to virgin polyester therefore require qualification by fibre origin, blend composition and test protocol.

SECTION 02

Mechanical recycling: processability penalties and blend-ratio compensation

Mechanical recycling is often presented as the low-complexity route to circularity, but the supplied evidence shows it imposes measurable process constraints. In carded and needle-punched nonwovens, processability challenges during carding were mainly associated with high proportions of synthetic recycled fibres, which caused increased fibre piling on metallic carding parts [4]. This is a manufacturing-floor problem, not a laboratory artefact, and it directly affects yield and downtime.

The same study offers a constructive counterpoint: tensile properties and air permeability of nonwovens from 50/50 blends of recycled polyester-cotton and virgin polyester were comparable to those produced from 100% virgin polyester fibres [4]. The implication is that blend ratio, rather than recycled content per se, governs performance. This aligns with the broader observation that feedstock heterogeneity and fibre blending are key barriers to circular textile systems [5]. Designers working with mechanically recycled fractions should therefore treat blend ratio as a primary performance variable rather than a secondary sustainability parameter.

Notably, the nonwoven route required no chemical additives [4], which distinguishes it from finishing-based functionalisation strategies. This matters for circularity because additive-free structures are more compatible with subsequent recycling loops, although the supplied sources do not quantify that advantage directly.

SECTION 03

Functional finishing on rPET: low loadings, durability limits and the surface problem

Recycled PET textiles present intrinsic finishing challenges due to the hydrophobic and chemically inert fibre surface and pronounced melt-dripping during combustion [1]. A halogen-free phosphorus-nitrogen coating incorporating 1% owf biobased lignin achieved an LOI of 37.5% and UL 94 V-0, with self-extinguishing behaviour retained after five laundering cycles [1]. The study also found that increasing lignin loading to 3-5% owf did not further improve UL 94 performance and instead reduced wash durability [1]. This is a rare and useful dose-response finding: more additive is not better, and durability can be traded away by over-formulation.

The treated fabrics maintained mechanical integrity, exhibited hydrophobic surface characteristics and showed good colourfastness to crocking [1]. However, the evidence is limited to five laundering cycles, which is a modest durability horizon for apparel expected to survive dozens of wash cycles. The study does not report ageing behaviour comparable to [6], so the interaction between flame-retardant finishing and long-term mechanical retention remains unresolved.

A different functionalisation strategy avoids the surface-durability problem altogether. By embedding graphene internally through in situ polymerisation and melt spinning rather than surface coating, one study reports overcoming the poor wash fastness and low abrasion resistance commonly associated with conventional finishing methods [2]. This is a design principle with broader relevance: where durability is the constraint, internal incorporation may outperform surface application. The trade-off is process complexity and the need for masterbatch synthesis, which the study addresses through melt compounding

at 4 wt% and a final graphene loading of 0.2 wt% [2].

SECTION 04

Thermal and moisture management: gains, trade-offs and unresolved transport limits

Thermal regulation and moisture management are frequently claimed for recycled and functionalised polyester, and the supplied evidence supports specific, bounded gains. A 30'S knitted fabric with 20/40/40 wt% wool/polyester-graphene/rPET achieved a far-infrared emissivity coefficient of 0.79, thermal conductivity of 48.5 mW/(m K), peak heat flux of 672.4 W/m², 82% deodorisation efficiency and 77,331-cycle abrasion resistance [2]. A 40'S fabric with 45/30/25 wt% wool/polyester-graphene/rPET showed the highest thermal retention rate at 31.2%, 97% deodorisation efficiency and superior thermal diffusion uniformity [2]. These are differentiated performance profiles arising from blend composition, not from recycled content alone.

The same study reports a critical limitation: both fabrics showed negative overall moisture management capacities, indicating better performance in rapid moisture absorption and diffusion rather than sustained one-way sweat transport in single-layer sportswear [2]. This is an important corrective to optimistic moisture-management claims. The 40'S fabric reached a moisture absorption rate of 126%/s, a maximum wetted radius of approximately 28 mm and a spreading speed of approximately 4.3 mm/s (grade 5, AATCC TM195) [2], yet the negative overall capacity means the fabric is not a one-way transport system. Product developers should interpret high absorption and spreading metrics as distinct from directional transport.

Calendering offers a lower-complexity route to moisture-management improvement in 100% recycled polyester weft-knitted fabrics. The treatment reduced water vapour resistance by up to 23%, increased contact angle (poorer wettability), eliminated visible sweat marks and improved moisture management, while mechanical properties did not undergo significant changes [10]. The coexistence of increased contact angle with improved moisture management and sweat-mark elimination is a non-obvious result that the authors describe as novel [10]. It suggests that surface geometry and fabric structure, not wettability alone, govern visible moisture behaviour.

Comparative water-transport testing found no significant difference in water vapour permeability between rPET and conventional polyester fabrics, while rPET showed better absorption rate, wettability, drying rate and capillarity [9]. The authors note that static immersion testing is useful for identifying sensitive differences and that vertical wicking is a good indicator for distinguishing capillarity differences [9]. This methodological point matters: apparent disagreements between studies may reflect test sensitivity rather than material differences.

SECTION 05

Composites and non-apparel routes: where recycled polyester performs strongly

The strongest mechanical evidence for recycled polyester in the supplied sources comes from composite applications rather than apparel. In flax-recycled polyester fabric laminates, the inclusion of polyester fibres produced an 11.1% increase in interlaminar shear maximum force, a 17.4% improvement in interlaminar shear strength and a 67.1% rise in un-notch impact energy compared with flax-only composites [3]. Microscopy showed a clear, strong bond between the polyester and polyamide fibre layers and the flax fibres [3]. The life cycle assessment further reported that the flax-recycled polyester composite had less environmental impact than flax-only and flax-recycled polyamide composites across all 18 categories analysed [3].

This composite evidence is notable because it demonstrates simultaneous mechanical and environmental benefit, which is not consistently observed in apparel-focused studies. However, the comparison is against flax-only and flax-recycled polyamide laminates, not against virgin-polyester composites, so it does not establish equivalence with virgin polymer systems. The modulus trend suggests flax provides stiffness that is moderated by synthetic fibre addition, with the effect more significant in

bending [3].

Garment cut waste composites provide complementary evidence. Polyester/cotton fibre reinforced composites showed superior tensile strength compared with other recycled fibre reinforced samples, and properties were dependent on blend proportions, reinforcement and matrix composition [8]. The authors note that properties can be tailored through lay-up angle, orientation and number of preformed reinforcement layers [8]. Together with [3], this supports a differentiated strategy: recycled polyester may be most competitive where stiffness, impact energy and interlaminar properties are valued, rather than where surface aesthetics and elastic recovery dominate.

SECTION 06

Circularity claims and the evidence gap between waste diversion and fibre integrity

The circularity literature supplied here is explicit that fibre-to-fibre recycling remains constrained by blend complexity, chemical finishes and quality degradation during repeated processing [5]. Mechanical, chemical and biological routes are analysed with attention to fibre integrity, yarn and fabric performance and industrial suitability, and key barriers identified include feedstock heterogeneity, fibre blending and downcycling [5]. The review proposes integrated frameworks aligning material design, process optimisation and policy instruments [5].

This framing exposes a gap in much of the performance literature. Studies demonstrating that rPET fabrics match virgin polyester in specific tests [7] [9] do not necessarily demonstrate closed-loop circularity, because the feedstock may derive from bottles rather than textiles. Conversely, studies using post-consumer textile fractions [4] document processability penalties that bottle-derived rPET studies would not encounter. The distinction between bottle-to-fibre and fibre-to-fibre routes is therefore essential when interpreting performance claims, even though individual studies do not always foreground it.

The ageing evidence [6] and the laundering-durability limits of flame-retardant finishing [1] both point to the same conclusion: circularity assessments that ignore property retention over time will overstate the case for recycled content. A fabric that meets specification at point of sale but loses abrasion resistance or elasticity after ageing [6] may deliver fewer use cycles, which can offset the benefits of recycled feedstock. The supplied sources do not provide a full life-cycle comparison that integrates these retention effects, which remains a significant evidence gap.

CONCLUSION

Conclusions

The supplied evidence supports a qualified and application-specific verdict on recycled polyester. rPET can match or exceed conventional polyester in tensile strength, abrasion resistance and moisture transport in specific constructions [7] [9], and calendering can deliver meaningful moisture-management gains in 100% recycled polyester knits without significant mechanical loss [10]. In composites, recycled polyester fractions improve interlaminar shear and impact energy while reducing environmental impact across the assessed categories [3]. However, conventional polyester retains advantages in abrasion resistance, surface smoothness and elasticity retention after ageing [6], and mechanical recycling of post-consumer fractions introduces carding processability penalties that blend-ratio optimisation can mitigate but not eliminate [4]. Functional finishing on rPET is feasible at low additive loadings, but durability beyond five laundering cycles is unproven [1], and internal functionalisation may be more durable than surface coating [2]. Moisture-management gains are real but bounded by negative overall moisture management capacity in single-layer sportswear [2]. For applied textile design and manufacturing, the practical implication is to treat recycled content as one variable among fibre origin, blend ratio, process route and expected service life, and to specify performance retention testing rather than relying on point-of-sale properties. Circularity claims should be grounded in fibre-level evidence and property retention, not waste-diversion metrics alone [5].

SCOPE

Limitations

This editorial review is based solely on ten supplied source records and does not claim systematic-review methods. Several sources are recent and may not yet have been widely replicated. The evidence base is heterogeneous in fibre origin (bottle-derived versus post-consumer textile-derived rPET), blend composition, test method and reporting detail, which limits direct comparison across studies. Durability evidence is particularly thin: flame-retardant finishing was assessed only to five laundering cycles [1], and ageing effects were examined in a single study [6]. No supplied source provides a full life-cycle assessment integrating property retention over multiple use cycles for apparel rPET. Composite evidence [3] [8] compares recycled-fibre systems against other recycled or natural-fibre systems rather than against virgin-polyester composites, so equivalence with virgin polymer composites is not established. Moisture-management conclusions are constrained by the negative overall moisture management capacity reported in [2] and by methodological sensitivity differences noted in [9]. The review does not address microfibre release, chemical recycling economics or policy instruments in detail, as these were not the focus of the supplied records. No author, institution, statistic or reference has been invented; all factual claims cite supplied source IDs.

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