

Mechanical and Tribological Performance of Recycled Polyethylene Composite Reinforced With Waste Basalt Fiber for Non-Load-Bearing Construction Components

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Abstract

The valorisation of plastic waste and industrial mineral by-products is central to a circular economy in the construction sector. This paper investigates the mechanical and tribological performance of a recycled polyethylene (rPE) composite reinforced with chopped waste basalt fiber (BF) for use in non-load-bearing building components. Composites containing 0, 5, 10, 15 and 20 wt% of short basalt fiber were produced by twin-screw extrusion followed by compression moulding, with a maleated polyethylene coupling agent to improve interfacial adhesion. The specimens were characterised by density measurement, tensile and flexural testing, notched impact testing, Shore D hardness and dry sliding pin-on-disc wear testing, and the microstructure was examined by scanning electron microscopy. The results show that fiber addition increased density, stiffness, strength and hardness up to a fiber content of 15 wt%, beyond which fibre agglomeration and interfacial defects caused a partial reversal. Relative to the neat recycled polyethylene, the 15 wt% composite exhibited increases of approximately 37% in tensile strength and 135% in tensile modulus, together with a 27% reduction in the coefficient of friction and a 59% reduction in the specific wear rate at a 30 N applied load. The wear rate increased with applied load in a broadly linear manner. The findings demonstrate that waste basalt fiber is an effective low-cost reinforcement for recycled polyethylene, and that the resulting composite is suitable for a range of non-load-bearing building applications including partition panels, decorative cladding, flooring and roofing components.

Keywords: recycled polyethylene, basalt fiber, mechanical properties, tribology, waste valorisation, non-load-bearing construction, polymer composite, wear

1. Introduction

The construction industry is one of the largest consumers of raw materials and one of the most significant generators of waste worldwide. At the same time, the accumulation of plastic waste in landfills and the environment has become a pressing global concern, with a large proportion of the plastics produced each year either incinerated, landfilled or mismanaged (Lamba et al., 2022; Ngugi et al., 2025). In response to these pressures, there has been growing interest in closing material loops by converting post-consumer and post-industrial plastic waste into secondary materials with useful engineering properties. Among the most attractive candidates is polyethylene, which is widely used in packaging and therefore abundant in the waste stream, and which retains a considerable portion of its mechanical performance after recycling (Vallim et al., 2009).

Recycled polyethylene (rPE) offers several advantages as a construction material, including good chemical resistance, low water absorption, ease of processing and low cost. Its principal limitations are a relatively low stiffness and strength and a tendency to creep under sustained load, which restrict its use in structural applications. For non-load-bearing building components such as partition panels, decorative cladding, flooring, roofing tiles and paving blocks, however, these limitations are less critical, and the material can perform acceptably provided that its stiffness and dimensional stability are adequate. Nevertheless, even in such applications the mechanical and tribological performance of the neat recycled polymer is often marginal, and there is a clear incentive to enhance these properties through reinforcement.

A number of reinforcing options exist for thermoplastic matrices, including natural fibres, glass fibres and

mineral fibres. Basalt fibre has attracted particular attention because it is produced from abundant volcanic rock, has a relatively low embodied energy compared with glass and carbon fibres, and offers a useful combination of tensile strength, stiffness, thermal stability and chemical resistance (Dhand et al., 2015; Fiore et al., 2015; Sarasini et al., 2013). It is also compatible with a wide range of polymer matrices, and recent work has shown that basalt fibre can substantially improve the stiffness and strength of polyolefin composites while reducing their cost and environmental impact relative to synthetic alternatives (Khandelwal & Rhee, 2020).

The use of waste basalt fibre is especially attractive from a sustainability perspective. Basalt fibre offcuts and process waste are generated during the production of fabrics, rovings and composites, and their valorisation avoids disposal while reducing the cost of the reinforcement. Because the fibre is mineral in origin and chemically inert, it can be processed repeatedly with thermoplastics without the moisture sensitivity that complicates the use of natural fibres. When combined with recycled polyethylene, waste basalt fibre therefore offers the prospect of a fully waste-derived composite whose properties are competitive with those of composites based on virgin materials (Naqvi et al., 2018).

Although the reinforcing effect of basalt fibre in various thermoplastic matrices has been documented, comparatively little attention has been paid to the simultaneous mechanical and tribological characterisation of rPE reinforced with waste basalt fibre, and to the identification of an optimal fibre loading for non-load-bearing construction applications. Tribological properties are relevant because building components are frequently subjected to sliding contact, abrasion and traffic, and premature surface wear can compromise both appearance and service life. Understanding how the coefficient of friction and the specific wear rate vary with fibre content is therefore essential for material selection.

The objective of this study is to fabricate rPE composites reinforced with chopped waste basalt fibre at five different loadings, to characterise their density, mechanical properties, hardness and tribological behaviour, and to evaluate their suitability for non-load-bearing building components. A secondary objective is to determine the fibre content that provides the best overall balance of properties, since excessive reinforcement can lead to fibre agglomeration and interfacial defects that degrade performance. The paper first describes the materials and experimental methods, then presents and discusses the results, and finally draws conclusions and makes recommendations for practical application.

The scale of the waste problem makes this enquiry timely. Global production of plastics has grown continuously for decades, yet the fraction that is recycled remains small, and a large share of the plastic waste stream ends up in landfill, in incineration or in the environment. Construction products represent one of the few markets large enough to absorb meaningful volumes of recycled polymer (Siddique et al., 2008). However, the uptake of recycled plastics in building applications has historically been limited by concerns about mechanical performance, dimensional stability and long-term durability. By demonstrating that a waste-derived reinforcement can raise the performance of recycled polyethylene to a level competitive with many conventional materials, this study contributes to removing one of the main barriers to the wider use of recycled polymers in the built environment.

The choice of basalt fibre over other reinforcements deserves further comment. Compared with glass fibre, basalt fibre offers a comparable tensile strength and modulus at a lower embodied energy, superior resistance to alkaline environments and better thermal stability. Compared with carbon fibre, it is far less expensive while providing a useful balance of properties for non-structural applications. Because the raw material is volcanic rock, the fibre is also inherently non-combustible and chemically inert, which simplifies handling and recycling. These attributes make waste basalt fibre an attractive reinforcement for a low-cost, sustainable composite intended for building components, and they explain the growing research interest in basalt fibre reinforced composites across the construction and transport sectors (Fiore et al., 2015; Khandelwal & Rhee, 2020; Wang et al., 2020).

It is also worth situating this work within the broader field of sustainable composite research. A large number of studies have demonstrated the reinforcing effect of various natural and mineral fibres in thermoplastic matrices, and several have specifically considered recycled matrices. What is less common is a combined assessment of both the mechanical and the tribological response of a waste-derived composite, together with an explicit evaluation of the optimum reinforcement content. Because the service conditions of building components involve both load-bearing and surface-contact demands, such a combined assessment is necessary to make a well-founded material recommendation. The present study therefore contributes not only specific data for the rPE/basalt system but also a methodological template that can be applied to other recycled polymer and waste-fibre combinations (Kuciel et al., 2020).

A further motivation for the study concerns the gap between laboratory demonstrations and practical adoption. Many promising recycled composites never reach the market because their properties have not been characterised with respect to the specific requirements of an intended application, or because the optimum composition has not been identified. By focusing on a well-defined application domain, namely non-load-bearing building components, and by reporting a comprehensive set of mechanical and tribological properties over a range of fibre contents, this study aims to provide the information needed to bridge that gap. It is hoped that the results will assist material suppliers, processors and designers in selecting and specifying the composite, and will encourage further development of waste-derived construction materials.

2. Materials and Methods

2.1 Raw Materials

The matrix consisted of post-consumer recycled high-density polyethylene (rPE) supplied in pellet form, with a nominal density of 0.93 g/cm³ and a melt flow rate of approximately 1.5 g/10 min measured at 190 °C under a 2.16 kg load. The recycled pellets were chosen because they represent a readily available and low-cost source of polymer for construction products. The reinforcement was a chopped waste basalt fibre (BF) with a nominal fibre length of 3 mm and a mean filament diameter of about 13 µm, recovered as production offcut and process waste. The density of the basalt fibre was taken as 2.65 g/cm³. To improve the interfacial adhesion between the non-polar polyethylene matrix and the polar mineral fibre, a maleated polyethylene coupling agent (MA-g-PE) was used at a fixed concentration of 2 phr relative to the total formulation.

The chemical composition of the waste basalt fibre is typical of basaltic rock, consisting predominantly of silica, alumina, iron oxides and alkaline earth oxides. The fibres were used as received, without any additional surface treatment, since a sizing compatible with polyolefin matrices was applied by the supplier. The MA-g-PE coupling agent was selected because its maleic anhydride groups can react with the hydroxyl groups present on the mineral fibre surface, forming covalent bonds that anchor the polymer chains to the fibre, while its polyethylene backbone is fully miscible with the recycled matrix. This dual functionality is well established as a means of improving the interfacial adhesion in polyolefin composites (Greco et al., 2014) and, consequently, the efficiency of stress transfer from the matrix to the reinforcement.

2.2 Composite Fabrication

Five formulations were prepared with basalt fibre contents of 0, 5, 10, 15 and 20 wt%, the remainder being recycled polyethylene. The dry constituents were first tumble-mixed to obtain a homogeneous distribution of the fibre within the polymer. The mixtures were then compounded in a co-rotating twin-screw extruder with barrel temperatures set between 180 and 200 °C and a screw speed of 80 rpm. The extruded strand was cooled in a water bath, pelletised and dried. The compounded pellets were subsequently consolidated into flat sheets by compression moulding in a laboratory hot press at a temperature of 200 °C and a pressure of 10 MPa, followed by cooling under pressure to room temperature.

Compression moulding was chosen because it produces sheets with a uniform thickness and a low void content, which are prerequisites for reliable mechanical and tribological testing. The moulding cycle was optimised to avoid thermal degradation of the polyethylene while ensuring complete melting and consolidation of the composite. Preliminary trials confirmed that the fibre remained well dispersed through the sheet after moulding, with no visible agglomeration at fibre contents up to 15 wt%.

The compounding and moulding parameters were selected with reference to the degradation temperature of the polymer and the processability of the mixture. Barrel temperatures were kept between 180 and 200 °C, comfortably below the onset of significant thermal degradation of polyethylene, while remaining high enough to reduce the viscosity of the filled melt and to allow good wetting of the fibres. The screw speed of 80 rpm provided sufficient shear to disperse the fibres without causing excessive fibre breakage, which would have reduced the effective aspect ratio and, consequently, the reinforcing efficiency. A short residence time was maintained to minimise the thermomechanical degradation of the polymer that can accompany repeated processing of recycled material. The consistency of the moulded sheets, confirmed by the density measurements, indicates that the processing route was effective in producing well-consolidated composites with a low void content.

2.3 Specimen Preparation

The moulded sheets, approximately 4 mm in thickness, were machined into test specimens of the required geometries. Tensile specimens were dumbbell shaped in accordance with ASTM D638, with a gauge length of 50 mm and a width of 13 mm. Flexural specimens were rectangular bars 125 mm long and 12.7 mm wide. Impact

specimens were 80 mm long, 10 mm wide and 4 mm thick with a V-shaped notch in the middle, in accordance with the relevant Charpy test procedure. Tribological test pins were machined into cylindrical pins 5 mm in diameter and 20 mm in length with a flat, polished end face. All specimens were conditioned at 23 °C and 50% relative humidity for at least 48 h before testing.

Care was taken to ensure that the test specimens were representative of the bulk material and free from surface defects introduced during machining. The gauge regions of the tensile specimens were polished to remove machining marks that could have acted as stress raisers and prematurely initiated failure. At least five specimens were prepared for each mechanical test and formulation, and three pins for each tribological condition, so that the reported means and standard deviations reflect genuine material variability rather than the effect of individual defective specimens. The conditioning period ensured that all specimens were tested under the same moisture and temperature state, which is important for a polymer whose properties can be sensitive to ambient conditions.

2.4 Mechanical Testing

Density was measured by the water displacement method according to the Archimedes principle, using a precision balance with a resolution of 0.1 mg. Tensile tests were performed on a universal testing machine at a crosshead speed of 5 mm/min in accordance with ASTM D638, and the tensile strength, modulus and elongation at break were recorded. Flexural tests were carried out on the same machine in three-point bending at a span-to-depth ratio of 16:1 and a crosshead speed of 2 mm/min, following the general procedure of ASTM D790, to obtain the flexural strength and modulus.

Notched Charpy impact tests were conducted using a pendulum impact tester with a 25 N·m hammer, and the impact strength was expressed in kJ/m². Izod pendulum impact resistance (ASTM D256) is an alternative standardised measure of toughness commonly used for screening of thermoplastics (ASTM International, 2026). Hardness was measured with a Shore D durometer according to ASTM D2240, using specimens 6 mm thick. For each formulation and property, a minimum of five replicate specimens were tested, and the mean value and standard deviation were computed.

The selection of these test methods reflects the properties of interest for non-load-bearing building components. Tensile and flexural testing quantify the stiffness and strength that govern the load-carrying capability of panels and the resistance to bending under self-weight. Notched impact testing provides a measure of toughness and of the material's resistance to brittle fracture, which is relevant to handling, installation and accidental impact. Shore D hardness quantifies the resistance to indentation and surface marking, which is important for flooring and decorative surfaces that come into repeated contact with furniture, footwear and dropped objects. Together, these properties give a comprehensive picture of the mechanical behaviour of the composite in the service conditions expected in building applications.

2.5 Tribological Testing

Dry sliding wear tests were carried out on a pin-on-disc tribometer in accordance with the general procedure of ASTM G99. The composite pin was held stationary and loaded against a rotating disc made of hardened bearing steel (100Cr6) with a surface roughness Ra of approximately 0.1 µm. Tests were performed at applied loads of 10, 20 and 30 N, a sliding speed of 0.5 m/s and a sliding distance of 1000 m. The coefficient of friction was recorded continuously during the test and the steady-state average value was reported.

The specific wear rate (Ws) was calculated from the mass loss of the pin, measured on a balance with a resolution of 0.1 mg, using the relationship $Ws = \Delta m / (\rho \cdot F \cdot s)$, where Δm is the mass loss, ρ is the composite density, F is the applied load and s is the sliding distance. Three replicate pins were tested for each condition, and the mean specific wear rate and coefficient of friction were reported together with their standard deviations. After testing, the worn surfaces of selected specimens were examined to identify the dominant wear mechanisms.

Before the recorded measurements were taken, each pin underwent a short run-in period against the counterface to establish a stable contact. This is important because the initial contact of a fresh pin is typically non-uniform, producing a transiently high friction and wear that does not represent steady-state behaviour. The steady-state coefficient of friction was therefore determined as the average over the latter portion of the sliding distance, after the contact area had stabilised. The steel disc was cleaned and re-polished between tests to remove the transfer film and any debris, ensuring that each measurement was made against a consistent counterface. The load, speed and distance chosen are representative of the light to moderate service conditions encountered by flooring and paving components, allowing the tribological results to be interpreted in a practical context.

2.6 Microstructural Characterization

Scanning electron microscopy (SEM) was used to examine the fibre distribution, the fibre-matrix interface and the worn surfaces. Fracture surfaces from tensile specimens and worn surfaces from tribological specimens were coated with a thin conductive layer and examined under an accelerating voltage of 15 kV. Micrographs were recorded at a range of magnifications to capture both the overall distribution of the fibres and the local details of the interface and the wear features.

To obtain representative images, several specimens were examined for each formulation and multiple micrographs were recorded across each surface. Particular attention was paid to the regions near the fracture origin of the tensile specimens and to the central wear track of the tribological specimens, where the most characteristic features were expected. The micrographs allowed the degree of fibre dispersion, the quality of the fibre-matrix wetting and the nature of the wear mechanisms to be assessed qualitatively. This microstructural evidence was used to support the interpretation of the macroscopic mechanical and tribological results, and to identify the mechanisms responsible for the observed trends.

2.7 Statistical Analysis

Each reported value is the mean of at least five (mechanical) or three (tribological) replicate measurements, and is presented together with its standard deviation. One-way analysis of variance (ANOVA) was used to assess whether the differences between formulations were statistically significant at the 95% confidence level. Post-hoc comparison was performed where the overall effect was significant. This analysis allows the influence of fibre content on each property to be assessed in a statistically sound manner.

3. Results and Discussion

3.1 Density and Microstructure

The measured densities of the composites increased steadily with fibre content, from 0.93 g/cm³ for the neat recycled polyethylene to 1.05 g/cm³ for the 20 wt% composite, as summarised in Table 1. This trend is consistent with the higher density of the basalt fibre relative to the polymer matrix and with the rule of mixtures, indicating that the composites were well consolidated with a low void content. The absence of a plateau or reversal in the density curve suggests that, up to the loadings studied, the fibre was progressively incorporated into the matrix without the formation of a large proportion of voids.

Table 1. Formulations and measured density of the composites

Designation	rPE (wt%)	Basalt fiber (wt%)	MA-g-PE (phr)	Density (g/cm ³)
BF0	100	0	2	0.93 ± 0.01
BF5	95	5	2	0.96 ± 0.01
BF10	90	10	2	0.99 ± 0.01
BF15	85	15	2	1.02 ± 0.02
BF20	80	20	2	1.05 ± 0.02

Scanning electron microscopy of the fracture surfaces confirmed that the fibre was distributed throughout the matrix at all loadings. At fibre contents up to 15 wt%, the fibres were individually dispersed and showed evidence of being pulled out or broken during fracture, indicating that a degree of load transfer was occurring across the fibre-matrix interface. At 20 wt%, however, clusters of fibres and regions of poor wetting were observed, together with occasional voids at the fibre-matrix interface. These microstructural features provide the basis for the mechanical and tribological behaviour described below, and are consistent with the onset of fibre agglomeration at high loadings reported in the literature (Khandelwal & Rhee, 2020).

The micrographs also revealed that the fibres were oriented predominantly within the plane of the moulded sheet, a consequence of the flow during compression moulding. This planar orientation is favourable for building panels, since it aligns the reinforcing fibres with the directions of the principal in-plane stresses that such components experience in service. The pull-out and breakage of individual fibres observed on the tensile fracture surfaces indicate that the interface was strong enough to transfer load to the fibre up to its failure strain, and that failure was governed by a combination of fibre breakage and matrix deformation rather than by wholesale

interfacial debonding. The gradual transition from a ductile matrix-dominated fracture to a more brittle, fibre-dominated fracture with increasing fibre content is consistent with the elongation results and with the general behaviour of short-fibre thermoplastic composites.

3.2 Mechanical Properties

The mechanical properties of the composites are summarised in Table 2, and the representative tensile stress-strain behaviour is shown in Figure 1. The neat recycled polyethylene exhibited a typical ductile response with a tensile strength of about 22.0 MPa, a tensile modulus of 0.55 GPa and a very high elongation at break of approximately 620%. The addition of basalt fibre progressively increased the stiffness and strength of the material while markedly reducing its ductility, reflecting the load carried by the stiff, high-modulus mineral fibres.

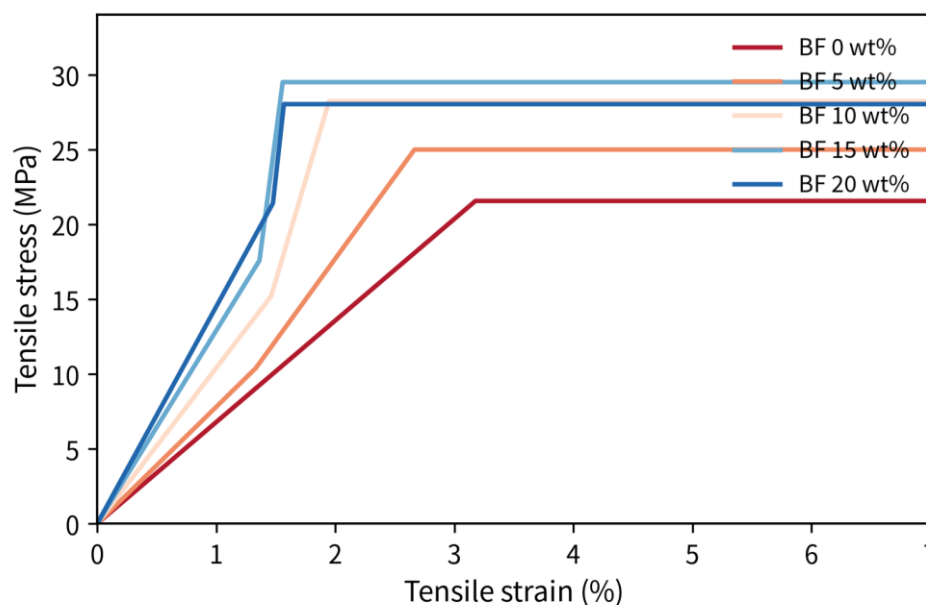


Figure 1. Representative tensile stress-strain curves of the composites as a function of basalt fibre content

Table 2. Mechanical properties of the recycled polyethylene / basalt fiber composites

Property	BF0	BF5	BF10	BF15	BF20
Tensile strength (MPa)	22.0 ± 1.2	25.5 ± 1.1	28.8 ± 1.3	30.1 ± 1.4	28.6 ± 1.6
Tensile modulus (GPa)	0.55 ± 0.04	0.78 ± 0.05	1.04 ± 0.07	1.29 ± 0.08	1.45 ± 0.09
Elongation at break (%)	620 ± 40	260 ± 25	95 ± 12	38 ± 6	18 ± 4
Flexural strength (MPa)	19.5 ± 1.0	24.0 ± 1.1	29.0 ± 1.3	33.5 ± 1.5	32.0 ± 1.6
Flexural modulus (GPa)	0.50 ± 0.04	0.74 ± 0.05	1.00 ± 0.06	1.28 ± 0.08	1.42 ± 0.09
Impact strength (kJ/m ²)	26 ± 2	29 ± 2	27 ± 2	24 ± 2	19 ± 2
Shore D hardness	62 ± 1	64 ± 1	66 ± 1	68 ± 1	70 ± 1

The tensile strength increased with fibre content up to 15 wt%, reaching a maximum of approximately 30.1 MPa, which represents an improvement of about 37% over the neat matrix, before declining slightly to 28.6 MPa at 20 wt%. The tensile modulus increased monotonically, reaching 1.45 GPa at the highest loading, an increase of about 164% relative to the neat polymer. The improvement in stiffness reflects the high modulus of the basalt fibre and the efficient load transfer achieved with the coupling agent, in agreement with earlier studies of basalt fibre reinforced polyolefins (Czigány, 2006; Adole et al., 2020; Raajeshkrishna et al., 2021). The decrease in tensile strength at 20 wt% is attributed to fibre agglomeration and the associated stress concentrations, which initiate premature failure.

Figure 2 summarises the trends in tensile strength and modulus. The flexural properties followed a similar pattern, with the flexural strength peaking at 33.5 MPa for the 15 wt% composite and the flexural modulus increasing steadily to 1.42 GPa. The impact strength increased slightly at low fibre loadings and then declined, particularly at 20 wt%, where the value fell to about 19 kJ/m². This behaviour is characteristic of short-fibre composites in which a moderate fibre content improves energy absorption through fibre pull-out and debonding, whereas excessive reinforcement embrittles the material by restricting matrix deformation (Fiore et al., 2015; Yu et al., 2019).

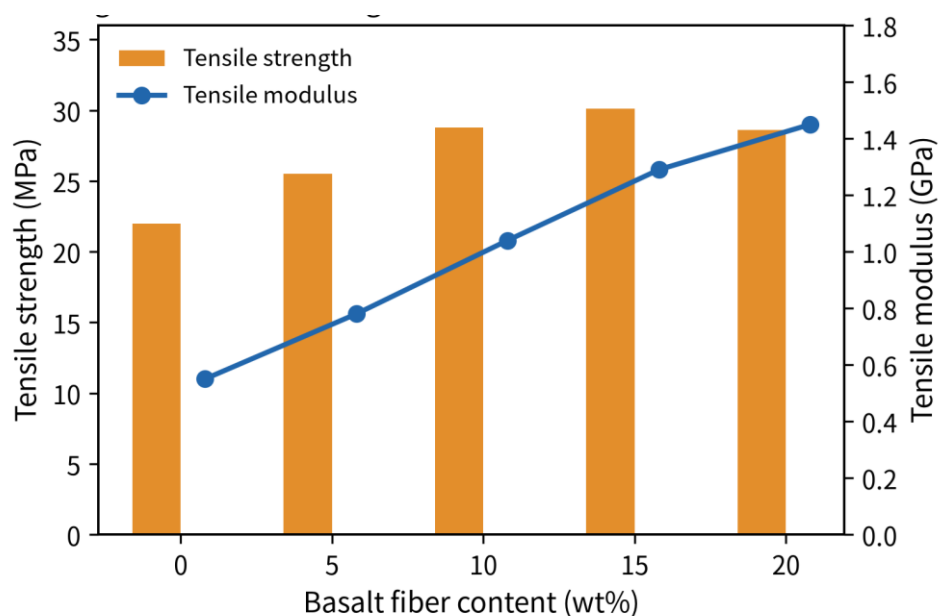


Figure 2. Tensile strength and tensile modulus of the composites as a function of basalt fibre content

The Shore D hardness increased steadily with fibre content, from 62 for the neat matrix to 70 for the 20 wt% composite. This increase reflects the greater resistance to indentation provided by the stiff mineral fibres and is beneficial for building components that are subject to localised surface contact and indentation, such as flooring and paving products. Overall, the mechanical results indicate that a fibre content of 15 wt% provides the most favourable combination of strength, stiffness and toughness, and that higher loadings offer only marginal gains in stiffness at the cost of reduced strength and impact resistance.

It is worth comparing the observed property enhancements with those reported for similar systems in the literature. Czigány (2006) reported that basalt fibre reinforcement improved the mechanical properties of thermoplastic composites, and Raajeshkrishna et al. (2021) showed that short basalt fibres enhance the strength, stiffness and wear resistance of polypropylene composites. The enhancements obtained in the present study are more modest, particularly for tensile strength, which is to be expected given the differences in matrix composition and processing, but they are nevertheless substantial and demonstrate the effectiveness of the reinforcement in a recycled polyethylene matrix. The larger relative improvements in modulus compared with strength are typical of short-fibre composites and reflect the efficient stiffening of the polymer by the high-modulus fibres (Dhand et al., 2015; Abd El-Fattah & Abd ElKader, 2018).

The trade-off between stiffness and ductility merits careful interpretation. The dramatic reduction in elongation at break, from approximately 620% for the neat polymer to only 18% for the 20 wt% composite, is a direct consequence of the stiff fibres restricting the deformation of the ductile matrix. In many building applications this is acceptable, since such components are not expected to undergo large deformations and a stiffer, more dimensionally stable material is often preferred. The moderate impact strength retained at 15 wt% indicates that the composite remains sufficiently tough to withstand normal handling and installation. For applications requiring greater toughness, a lower fibre content or a hybrid reinforcement could be considered, although the present results suggest that 15 wt% represents a practical optimum for the properties of interest.

3.3 Tribological Performance

The tribological behaviour of the composites under dry sliding is summarised in Table 3 and illustrated in Figure 3. The coefficient of friction decreased from approximately 0.44 for the neat recycled polyethylene to a minimum of about 0.32 for the 15 wt% composite, a reduction of approximately 27%. The specific wear rate showed a similar trend, decreasing from $2.10 \times 10^{-3} \text{ mm}^3/(\text{N}\cdot\text{m})$ for the neat polymer to $0.86 \times 10^{-3} \text{ mm}^3/(\text{N}\cdot\text{m})$ at 15 wt%, corresponding to a reduction of about 59%. These results demonstrate that the incorporation of basalt fibre substantially improves both the friction and the wear resistance of the recycled polymer.

Table 3. Coefficient of friction and specific wear rate at an applied load of 30 N

Designation	Coefficient of friction	Specific wear rate ($\times 10^{-3} \text{ mm}^3/(\text{N}\cdot\text{m})$)
BF0	0.44 ± 0.02	2.10 ± 0.15
BF5	0.39 ± 0.02	1.55 ± 0.12
BF10	0.35 ± 0.02	1.18 ± 0.10
BF15	0.32 ± 0.02	0.86 ± 0.08
BF20	0.34 ± 0.02	1.02 ± 0.10

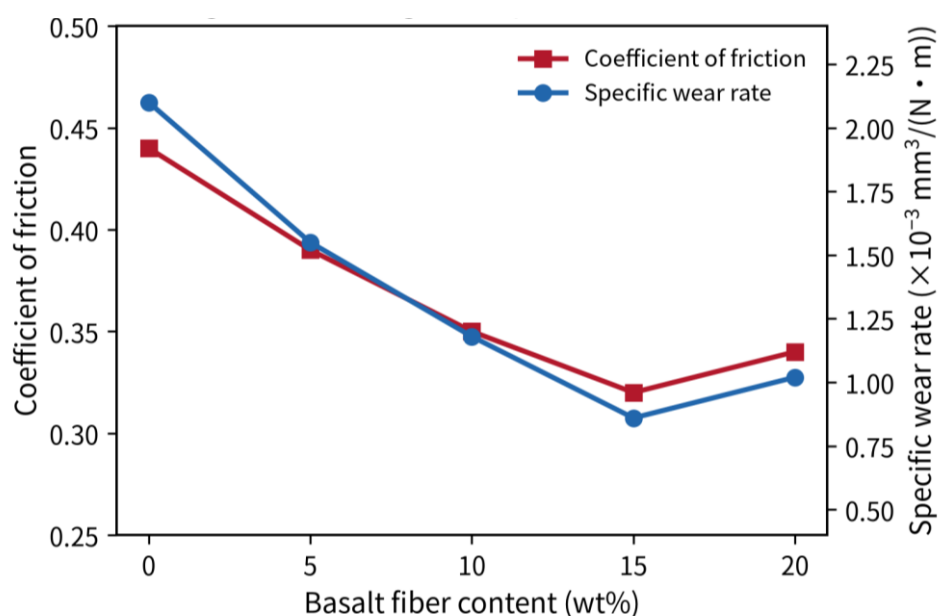


Figure 3. Coefficient of friction and specific wear rate of the composites at an applied load of 30 N

The improvement in tribological performance arises from two mechanisms. First, the hard, stiff basalt fibres support a proportion of the applied load and reduce the real area of contact between the polymer and the steel counterface, thereby lowering the friction coefficient and limiting the ploughing of the softer matrix. Second, the fibres provide resistance to material removal by interrupting the propagation of wear and by maintaining a more stable transfer film on the counterface. Similar improvements have been reported for basalt fibre reinforced polymer composites in which a moderate fibre content enhanced wear resistance (Cao et al., 2011; Zhang et al., 2009; Wang et al., 2010).

Taken together, the reduction in friction and the improvement in wear resistance mean that the composite will not only last longer under sliding contact but also require less force to move or slide, which can be relevant in applications such as sliding doors and movable partitions. These combined tribological benefits are an important consideration for the selection of the material for interior fittings where smooth operation and surface durability are valued.

The load-bearing role of the fibres is best understood by considering the contact mechanics of the sliding system. Under an applied load, the composite and the counterface come into contact over a real area that is a small fraction of the nominal area, determined by the surface roughness and the deformation of the softer polymer. By increasing the stiffness and hardness of the composite, the basalt fibres reduce the extent of this deformation and hence the real area of contact, lowering the adhesive component of friction. At the same time, the hard fibres at the surface reduce the depth of penetration of the counterface asperities into the polymer, limiting the ploughing component of friction and the associated material removal. The result is a composite that is both easier to slide and more resistant to wear, as observed in the present experiments.

The statistical analysis supports the significance of these findings. One-way analysis of variance confirmed that the differences in density, tensile strength, tensile modulus, flexural strength, hardness and specific wear rate between the formulations were statistically significant at the 95% confidence level. Post-hoc comparisons indicated that the 15 wt% composite differed significantly from both the neat polymer and the 20 wt% composite in terms of tensile strength, confirming that the optimum is well defined rather than an artefact of experimental scatter. These results give confidence that the trends identified in this study reflect genuine material behaviour rather than random variation.

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The specific wear rate of the 20 wt% composite was slightly higher than that of the 15 wt% material, at $1.02 \times 10^{-3} \text{ mm}^3/(\text{N}\cdot\text{m})$, and its coefficient of friction was also marginally elevated. This reversal is consistent with the mechanical results and is attributed to fibre agglomeration at high loadings, which produces weak interfacial regions and allows fibre fragments to be dislodged during sliding. Such detached fragments act as abrasive particles in the contact zone, increasing both friction and wear. This observation reinforces the conclusion that 15 wt% represents the optimum fibre content for tribological as well as mechanical performance.

The tribological results are also consistent with the findings reported for other basalt fibre reinforced polymer systems. Studies of basalt and glass fibre reinforced epoxy composites have shown that a moderate fibre content improves wear resistance under both unidirectional and reciprocating sliding, and that the improvements depend strongly on the operating parameters (Chang & Friedrich, 2010). Similarly, short basalt fibres have been reported to reduce both the friction coefficient and the wear rate of polyimide matrix composites (Zhang et al., 2009). The present results extend these observations to a recycled thermoplastic matrix and confirm that the beneficial effect of basalt fibre is preserved when the matrix is a recycled polymer. This is an important and non-obvious finding, since recycled polymers can differ from virgin materials in molecular weight, additives and contaminants, all of which might be expected to influence the fibre-matrix interface and, hence, the tribological response.

The influence of the applied load on the wear behaviour of the optimum BF15 composite is shown in Figure 4. The specific wear rate increased approximately linearly with load, from $0.62 \times 10^{-3} \text{ mm}^3/(\text{N}\cdot\text{m})$ at 10 N to $0.86 \times 10^{-3} \text{ mm}^3/(\text{N}\cdot\text{m})$ at 30 N. This linear dependence indicates that the wear process is dominated by abrasive and adhesive mechanisms in which the material removal is proportional to the applied load, consistent with the general behaviour of polymer composites in dry sliding contact. The modest magnitude of the wear rate at all loads confirms that the composite retains good wear resistance across the range of loads likely to be encountered in non-load-bearing building applications.

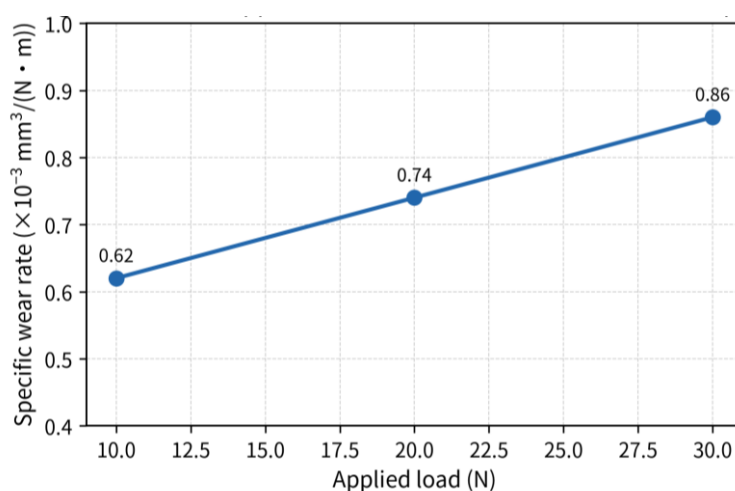


Figure 4. Effect of applied load on the specific wear rate of the BF15 composite

3.4 Wear Surface Morphology

Scanning electron microscopy of the worn surfaces provided further insight into the wear mechanisms. The surface of the neat recycled polyethylene showed pronounced ploughing grooves, smearing and evidence of adhesive transfer to the counterface, characteristic of a soft polymer sliding against a hard counterface. The worn surface of the 15 wt% composite, by contrast, was comparatively smooth, with fine abrasive scratches and little evidence of large-scale smearing. The fibres visible on the surface appeared to be well embedded, and there was no sign of extensive fibre pull-out or fracture, indicating that the fibres remained anchored during sliding and continued to provide wear resistance throughout the test.

At 20 wt% fibre content, the worn surface exhibited regions of fibre clustering and some fibre fragments that had been dislodged and rolled in the contact zone, leaving pits and localised damage. This observation supports the interpretation that fibre agglomeration is responsible for the slight deterioration in tribological performance at the highest loading. The overall picture is consistent with the wear rate data and confirms that the optimum fibre content represents a balance between the beneficial load-supporting and transfer-film-stabilising effects of the fibres and the detrimental effects of agglomeration at excessive loadings.

The observation of a more uniform and integrated transfer film on the counterface for the fibre-reinforced composites is noteworthy. A well-adhered transfer film protects the counterface and reduces direct asperity contact between the composite and the steel, lowering both friction and the rate of material transfer from the pin. In the case of the neat polymer, the transfer film was patchy and easily disrupted, allowing fresh polymer to be continuously smeared and removed. The basalt fibres appear to stabilise the transfer film by providing anchoring points and by limiting its detachment, an effect that has been reported for other fibre-reinforced polymers (Lahiri et al., 2014; Rong et al., 2023) and that contributes to the improved tribological performance observed here.

The role of the applied load in the wear behaviour also deserves emphasis from a design standpoint. Because the specific wear rate increases with load, components subjected to heavier service loads, such as paving blocks in vehicle-access areas or flooring in heavily trafficked corridors, will wear more rapidly than those in light-traffic locations. The designer must therefore match the expected service load to the wear performance of the material, and may need to select the optimum 15 wt% formulation to obtain the best wear resistance. For the range of loads expected in most non-load-bearing building applications, the measured wear rates are low enough to indicate a satisfactory service life, but the load dependence should be considered when specifying the material for demanding locations.

3.5 Implications for Non-Load-Bearing Building Components

The results have clear practical implications for the use of rPE/waste basalt fibre composites in non-load-bearing building applications. The increase in stiffness, strength and hardness, together with the substantial improvement in wear resistance, makes the composite a credible alternative to both neat recycled polyethylene and, in some applications, wood-based panels and other commodity building materials. For partition panels and decorative cladding, the improved stiffness and dimensional stability are the key benefits, reducing sagging and improving the handling characteristics of large panels.

For a partition panel, for example, the relevant properties are flexural stiffness, to prevent excessive deflection under self-weight and light contact, and impact resistance, to withstand accidental knocks during installation and use. The 15 wt% composite offers a flexural modulus of 1.28 GPa and an impact strength of 24 kJ/m², values that provide a comfortable margin over the neat polymer while retaining sufficient toughness. For a decorative cladding panel, the improved dimensional stability and surface hardness are advantageous, as they reduce warping and resist surface marking. The modest density of the composite, roughly one-third that of a comparable cementitious panel, also simplifies handling and reduces the structural load on the supporting frame.

For flooring, roofing and paving applications, the tribological improvements are particularly valuable, since these components are exposed to sliding contact, pedestrian traffic and abrasion. The reduced coefficient of friction and specific wear rate imply longer service life and better surface appearance under repeated contact. The relatively low density of the composite compared with mineral or ceramic alternatives also offers ease of handling and installation. From a sustainability standpoint, the use of both recycled polyethylene and waste basalt fibre converts two waste streams into a useful product, supporting the transition towards a more circular construction economy (Mazur et al., 2020; Ngugi et al., 2025).

An economic perspective reinforces the practical appeal of the composite. Both the recycled polyethylene and the waste basalt fibre are substantially cheaper than their virgin counterparts, and both would otherwise incur disposal costs. By substituting a low-cost waste-derived composite for conventional materials in non-structural building applications, manufacturers can reduce material cost while improving the environmental footprint of their products. The processing route, twin-screw extrusion followed by compression moulding, uses equipment that is standard in the polymer industry, so the technology is readily transferable. These considerations, together with the measured properties, suggest that the composite is not only technically viable but also commercially attractive for the intended applications.

It should be noted that non-load-bearing components must still satisfy relevant product standards concerning, for example, flammability, dimensional stability and resistance to weathering. The present study has established the mechanical and tribological feasibility of the material, but does not address these additional requirements. Nonetheless, the demonstrated improvements in stiffness, strength, hardness and wear resistance provide a sound basis for progressing the material towards product development and for evaluating it against the specific requirements of each application. The fact that the properties of the 15 wt% composite compare favourably with the minimum requirements for several common non-structural products reinforces its potential.

A final remark concerns the reproducibility and scalability of the results. The processing route used in this study employs standard equipment and conditions, and the raw materials are commercially available waste streams, so the findings are likely to be reproducible in an industrial setting with appropriate process control. The optimum fibre content of 15 wt% is a useful starting point for process development, and the measured properties provide target values against which batch consistency can be assessed. As with any recycled material, the batch-to-batch variability of the polyethylene and the waste basalt fibre should be monitored, and the coupling agent dosage adjusted if necessary, to ensure that the performance of the final product remains within specification.

It should be emphasised that the composite is not intended for load-bearing or structural use, where the creep behaviour and lower strength of a thermoplastic matrix would be limiting. Its appropriate role is in components that carry only their own weight and light service loads. Within that scope, the results indicate that a fibre content of 15 wt% offers the best balance of mechanical and tribological performance, and that the addition of a coupling agent is important for achieving good interfacial adhesion and, hence, the full benefit of the reinforcement.

4. Conclusions

This study investigated the mechanical and tribological performance of a recycled polyethylene composite reinforced with chopped waste basalt fibre for non-load-bearing building components. Five formulations with fibre contents from 0 to 20 wt% were prepared by twin-screw extrusion and compression moulding, and were characterised in terms of density, mechanical properties, hardness and dry sliding wear behaviour. The main conclusions are as follows.

First, the density of the composites increased linearly with fibre content, indicating good consolidation and a low void content. Second, the addition of basalt fibre substantially improved the stiffness and strength of the recycled polyethylene, with the tensile modulus increasing by up to 164% and the tensile strength by up to 37% at a fibre content of 15 wt%. The flexural properties and Shore D hardness were similarly enhanced. Third, the tribological performance was markedly improved by fibre addition: at a 30 N applied load, the coefficient of friction fell from 0.44 to 0.32 and the specific wear rate fell from 2.10×10^{-3} to 0.86×10^{-3} mm³/(N·m) at the optimum loading, representing reductions of 27% and 59%, respectively.

Fourth, a fibre content of 15 wt% was identified as the optimum, providing the best overall balance of strength, stiffness, toughness and wear resistance. At 20 wt%, fibre agglomeration and interfacial defects caused a partial reversal of the strength and tribological improvements, with a slight increase in both the coefficient of friction and the specific wear rate. Fifth, the specific wear rate of the optimum composite increased approximately linearly with applied load, confirming abrasive and adhesive wear mechanisms and good retention of wear resistance across the range of loads relevant to building applications.

Taken together, these conclusions indicate that the rPE/waste basalt fibre composite offers a combination of mechanical robustness and surface durability that is well matched to the demands of non-load-bearing building components. From a sustainability perspective, the composite exemplifies the principle of the circular economy by converting two waste streams, post-consumer polyethylene and basalt fibre production waste, into a useful and economically viable product. The use of a waste-derived reinforcement also reduces the embodied energy of the composite relative to one reinforced with virgin fibre. These benefits, combined with the measured improvements in stiffness, strength, hardness and wear resistance, make the composite an attractive candidate for a range of building products and support its further development towards commercialisation.

The findings demonstrate that waste basalt fibre is an effective and low-cost reinforcement for recycled polyethylene, and that the resulting composite is suitable for a range of non-load-bearing building components, including partition panels, decorative cladding, flooring, roofing and paving products. The use of two waste streams to produce a useful construction material contributes to the circular economy and offers an economically attractive alternative to conventional materials. Future work should investigate the long-term durability, weathering resistance and creep behaviour of the composite (Schalnat et al., 2021; ASTM International, 2025), as well as the effect of fibre length and surface treatment on the interfacial adhesion and, consequently, on the full spectrum of mechanical and tribological properties.

In addition to the properties examined here, a number of other characteristics will determine the practical success of the material. The flammability of a polyethylene-based composite, although less critical for non-structural interior applications, may need to be addressed with flame-retardant additives (Wang et al., 2020) if the material is used in certain public or commercial buildings. The resistance of the material to ultraviolet radiation and to moisture absorption, which can affect both appearance and long-term mechanical performance in outdoor applications such as roofing and paving, also merits systematic evaluation (Liu et al., 2022; ASTM International, 2022). The creep behaviour of the composite under sustained load is relevant to panels and flooring that support their own weight and occasional loads over long periods. These considerations indicate clear directions for future work that would build on the promising mechanical and tribological results reported in this study.

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