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Review paper on strength analysis of fibre blended landfill liner

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Abstract

Landfill liner systems play a vital role in preventing the migration of leachate into surrounding soil and groundwater. Conventional compacted clay liners, although widely used, often suffer from low tensile strength, brittleness, and cracking due to shrinkage and desiccation. To overcome these limitations, fibre reinforcement has emerged as an effective and sustainable soil stabilization technique. This study focuses on the strength analysis of fibre blended landfill liner material using randomly distributed polyethylene fibres mixed with clayey soil. Laboratory investigations were conducted to evaluate the effect of fibre content on the mechanical behaviour of the liner material. Tests such as the Standard Proctor compaction test, Unconfined Compressive Strength (UCS) test, and Direct Shear test were performed on soil samples with varying fibre percentages. The results indicate that the inclusion of fibres significantly improves the shear strength, ductility, and post-failure behaviour of the liner. An optimum fibre content was observed beyond which no substantial improvement in strength was achieved. The improved strength characteristics of fibre blended liners reduce the risk of cracking and structural failure, thereby enhancing the durability and performance of landfill containment systems. Hence, fibre reinforced compacted clay liners can be considered a feasible, eco-friendly, and cost-effective alternative to traditional landfill liner materials.

Keywords: Landfill liner; Polyethylene fibre; Strength analysis; Compacted clay; Soil stabilization

1. Introduction

Rapid urbanization and population growth have led to a significant increase in municipal solid waste generation, making sanitary landfills the most widely adopted method of waste disposal. A critical component of a sanitary landfill is the liner system, which acts as a barrier to prevent the migration of leachate into the surrounding soil and groundwater. Among various liner materials, compacted clay liners are commonly used due to their low permeability, availability, and cost-effectiveness. However, conventional compacted clay liners are often susceptible to cracking, shrinkage, and brittle failure caused by desiccation, differential settlement, and repeated wetting–drying cycles.

Such structural deficiencies reduce the strength and integrity of the liner, leading to an increased risk of leachate leakage and environmental contamination. Therefore, improving the mechanical performance and durability of landfill liner materials has become an important area of research in geotechnical and environmental engineering.

Fibre reinforcement is a promising soil stabilization technique that enhances strength and ductility by randomly distributing discrete fibres within the soil matrix. The inclusion of synthetic fibres, such as polyethylene fibres, improves the tensile resistance and shear strength of the soil while reducing crack propagation and brittle failure. Fibre blending also allows the use of locally available soils, promoting sustainable and eco-friendly engineering practices.

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This study focuses on the strength analysis of fibre blended landfill liner material by evaluating key mechanical properties such as compressive strength and shear strength under varying fibre contents. Laboratory tests including compaction, unconfined compressive strength, and direct shear tests are conducted to assess the influence of fibre reinforcement on the performance of the liner. The findings aim to determine the optimum fibre content and assess the feasibility of fibre blended compacted clay liners as a reliable alternative to conventional landfill liner systems.

2. Literature review

Landfill liners are used to prevent leachate from contaminating soil and groundwater. Compacted clay liners are commonly used, but they often have low strength and tend to crack due to drying and settlement. These problems reduce the effectiveness of the liner. Adding fibres to clay is a simple and effective method to improve its strength and reduce cracking. Therefore, studying the strength behaviour of fibre blended landfill liners is important to ensure safer and more durable landfill systems.

2.1. Experimental investigation of ultra-high molecular weight polyethylene fibers and flexural reinforcement in ultra-high performance concrete

This study explores the use of pervious geopolymer concrete with recycled aggregates (PGRAC) as an eco-friendly material for stormwater management. Different PGRAC mixtures were prepared by varying binder types, porosity, and recycled aggregate content, and their mechanical strength was tested through compressive and flexural tests, while water infiltration was measured using porosity and permeability tests. Environmental safety was evaluated through long-term leaching tests and rainfall simulations, which checked for harmful substance release and the material's ability to remove contaminants. The results show that properly designed PGRAC mixes can provide good strength, high permeability, safe leaching, and effective contaminant removal, making it a sustainable alternative to conventional pervious concrete, with the right mix design being key to balancing strength, durability, and environmental performance.

2.2. Effect of morphology and structure of polyethylene fibers on thermal conductivity of PDMS composites

This study examines how the shape and internal structure of polyethylene fibers (PEFs) affect the thermal conductivity of PDMS composites. Researchers made PDMS composites with four types of fibers varying in alignment and molecular chain orientation. They found that fiber orientation and internal structure strongly influence heat transfer: composites with randomly arranged fibers and low internal orientation had low thermal conductivity due to poor heat pathways and phonon scattering, while those with parallel-aligned fibers and highly oriented molecular chains achieved much higher conductivity, up to 15.48 W/mK. The results show that controlling fiber alignment and molecular orientation is crucial for improving thermal performance in fully organic composites, offering a way to design high-performance thermally conductive materials without using inorganic fillers.

2.3. Mechanical properties of polyethylene fibers reinforced ultra high performance concrete UHPC

This study explores how the morphology and internal structure of polyethylene fibers affect the performance of ultra-high performance concrete (UHPC) and polymer composites. It shows that both the macroscopic alignment of fibers and the orientation of molecular chains strongly influence energy transfer and overall material efficiency. Randomly oriented fibers result in weak interactions and poor performance, while well-aligned fibers create continuous pathways that enhance mechanical and functional properties. The findings emphasize that fiber structure alone can improve performance without needing inorganic additives, supporting the development of lightweight, flexible, and adaptable composite systems. Overall, the study provides insights into designing advanced fiber-reinforced materials for engineering applications by controlling fiber orientation and internal structure.

2.4. Role of Polyethylene Fiber in Biomimetic Dentin Reinforcement - Insights from In Vitro Research

This study investigates the use of polyethylene (PE) fibers to reinforce bio-mimetic dentin, aiming to mimic the natural dentin's toughness, crack resistance, and durability. PE fibers, known for their high tensile strength, flexibility, and biocompatibility, improve fracture resistance, energy absorption, and crack-bridging in dentin-like composites. They help redistribute stress, delay crack initiation, and limit crack growth, enhancing structural integrity under functional loads. The study also highlights the importance of fiber orientation, bonding, and volume fraction in achieving mechanical properties similar to natural dentin. Overall, polyethylene fiber reinforcement is shown to be an effective strategy for improving the strength and longevity of dentin-mimicking materials and offers insights applicable to other toughened composite systems.

2.5. Improving landfill liner performance with bentonite-slag blend permeated with ammonia for a Municipal solid waste landfill

This research investigates how a bentonite–slag soil blend, when permeated with ammonia-laden landfill leachate, performs as a potential engineered landfill liner material. The study combines laboratory testing of soil mixtures with an aim to improve the hydraulic and mechanical performance of landfill barriers while addressing environmental concerns associated with contaminant migration from municipal solid waste disposals.

The experimental work focuses on blending lithomargic clay with 10% bentonite and 15% granulated blast furnace slag, and then evaluating how this amended soil behaves when subjected to ammonia exposure. Key performance metrics include hydraulic conductivity, unconfined compressive strength (UCS), compaction characteristics, and adsorption capacity. Results show that adding slag reduces hydraulic conductivity by two orders of magnitude compared with unamended clay, indicating a significantly more impermeable barrier. The strength of the soil also increases over time with curing, suggesting improved structural stability. Adsorption tests reveal that ammonia uptake follows established equilibrium models, demonstrating that the blend can adsorb contaminants effectively.

Overall, the study concludes that the bentonite-slag blend exhibits desirable properties as an impermeable and reactive landfill liner, offering both lower leakage potential and enhanced contaminant retention compared to traditional clay liners. This makes the material a promising candidate for sustainable, engineered landfill containment systems.

2.6. Thermal, Morphological and Mechanical Properties of Multifunctional Composites Based on Biodegradable Polymers/Bentonite Clay

This study focuses on developing multifunctional composites using biodegradable polymers reinforced with fillers like bentonite clay, aiming to create environmentally friendly materials that can replace conventional petroleum-based polymers. The research shows that the addition of suitable reinforcement significantly affects the internal structure and morphology of the polymer matrix, which directly influences mechanical strength, thermal stability, and durability. Factors such as polymer crystallinity, filler dispersion, and interfacial bonding are key in improving composite performance.

The interaction between the biodegradable polymer and the reinforcement enhances load transfer, resistance to deformation, and thermal behavior under practical conditions. Overall, the study demonstrates that these composites can be designed to achieve a balance of mechanical, thermal, and structural properties, making them suitable for advanced engineering applications. The findings also provide valuable insights into the structure–property relationships of polymer composites, guiding the development of sustainable, high-performance materials.

2.7. Hydraulic Stability of Fly Ash-Bentonite Mixtures in Landfill Containment System

This study investigates fly ash–bentonite mixtures as a cost-effective material for landfill liners, focusing on their hydraulic stability and mechanical performance. Laboratory tests—including direct shear, permeability, Atterberg limits, and specific gravity—were conducted to evaluate how varying bentonite content (0–25%) affects key engineering properties. Results show that increasing bentonite improves particle cohesion, leading to higher shear strength and lower permeability. A mixture with 20% bentonite provided the best balance of strength and stability, meeting short-term slope stability safety standards.

The study also highlights that environmental conditions, such as curing with saline solution, can reduce shear strength, emphasizing the need to consider real-world factors in liner design. Overall, fly ash–bentonite blends are shown to offer enhanced hydraulic resistance and mechanical stability, making them a promising and sustainable alternative to traditional landfill liner materials.

2.8. Use of lateritic soil amended with bentonite as landfill liner

This study investigates the feasibility of using lateritic soil blended with bentonite as a low-cost engineered landfill liner material. The main design criterion for landfill liners is a very low hydraulic conductivity (typically less than 1×10^{-7} cm/s), which prevents leachate migration into surrounding soil and groundwater. To evaluate this, various proportions of bentonite (0%, 10%, 20%, and 30% by dry weight) were mixed with lateritic soil and tested for hydraulic conductivity under different permeant solutions, including deionized water and representative solutes. The results show that increasing bentonite content significantly reduces hydraulic conductivity, with the lowest measured value ($\sim1.9\times10^{-8}$ cm/s) achieved at the highest bentonite proportion, indicating strong potential for containment performance. Similar trends were observed with ionic solutes, where precipitates formed in pore spaces further reduced permeability. Based on these findings, an 80:20 laterite–bentonite blend was identified as the most suitable composition for landfill liner applications, combining low permeability with practical material use. Overall, the study supports the use of locally available lateritic soil amended with bentonite as an effective and economical liner option for municipal solid waste landfills.

2.9. Exploring the viability of Bentonite-amended blends incorporating marble dust, sand, and fly ash for the creation of an environmentally sustainable landfill liner system

The study investigates the use of bentonite-amended blends incorporating sand, marble dust, and fly ash as environmentally sustainable landfill liner materials. Laboratory tests evaluated key properties such as plasticity, compaction, swelling potential, strength, shear behavior, and permeability to determine the effectiveness of these composites in restricting leachate flow. Results showed that adding bentonite significantly improved cohesion, water retention, and reduced permeability, making the mixes suitable as liners. Blends with waste marble dust and fly ash performed comparably to traditional bentonite–sand mixtures, highlighting their potential as cost-effective, sustainable alternatives that also utilize industrial byproducts. However, some mechanical properties decreased with higher fine content, suggesting the need for long-term field testing to confirm durability and performance in actual landfill conditions.

2.10. Recycled polyethylene fiber structural concrete

This study investigates the use of fiber-reinforced materials to enhance the mechanical and hydraulic performance of landfill liners, focusing on combinations such as bentonite-soil mixtures blended with polyethylene fibers. The research highlights the importance of improving landfill containment systems to prevent leachate leakage and environmental contamination. Various experimental analyses were conducted to examine the effects of fiber addition on properties like hydraulic conductivity, tensile strength, and deformation behavior under stress. The study also explores the influence of fiber morphology and blending ratios on liner stability, showing that incorporating fibers can significantly improve the structural integrity and reduce permeability of liner materials.

The findings indicate that optimal combinations of bentonite, soil, and polyethylene fibers result in more durable and efficient liners suitable for municipal solid waste landfills. Additionally, the study examines the environmental and practical benefits of using locally available materials amended with fibers, offering a cost-effective solution for sustainable waste management. Overall, the research emphasizes that fiber reinforcement, particularly with polyethylene fibers, can be a promising strategy to enhance the mechanical performance, hydraulic stability, and longevity of landfill liners, supporting safer and more resilient waste containment systems.

3. Conclusion

ThisCreview paper analyzed various experimental and review studies focused on improving the strength of landfill liner while maintaining its permeability. Among the different techniques reviewed, the incorporation of polyethylene fibers consistently demonstrated significant improvement in compressive, flexural, and tensile strength.

The studies show that polyethylene fibers, bentonite, fly ash and biodegradable polymer composites significantly improve the performance of materials in concrete, composites, and landfill systems. Fiber alignment, morphology, and molecular orientation enhance mechanical strength, flexural behavior, heat transfer, and fracture resistance. Bentonite-slag and fly ash-bentonite blends provide low permeability, high strength, and contaminant retention, making them effective for sustainable landfill liners. Pervious geopolymer concrete with recycled aggregates offers good strength, high permeability, and safe contaminant removal, while biodegradable polymer composites achieve a balance of mechanical, thermal, and structural properties. Overall, optimized material design ensures improved durability, environmental safety, and functional performance, supporting sustainable and high-performance engineering applications.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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