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Assessment of efficiencies of different additives to improve CBR value for the highway industry

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ABSTRACT

The structural design of flexible or rigid paving layers depends on the strength of the foundation soil, which is expressed by the (CBR). Soil strengthening and improvement techniques vary according to the type of soil, whether it is granular or cohesive. This study is concerned with evaluating the efficiency of three techniques used to improve the properties of granular soil, the first by using natural fibers, the second by using synthetic fibers, and the third by mixing with powders. The study methodology relies on reviewing, studying, classifying and comparing the previously published work in this context to determine the advantages and disadvantages of each of the techniques considered. The study concluded that the efficiency of improvement techniques depends mainly on the dose of additives, whether fibers or powders. In general, previous studies have indicated that the use of natural fibers or powders can improve soil properties up to 250%, while the improvement resulting from using synthetic fibers reaches only 150%. In addition, incorporating more than one improving technique increases the overall efficiency to about 300%. On the other hand, natural fibers are the most environmentally friendly alternative, while powders are the worst, and finally, synthetic fibers are the most durable one.

1. Introduction and background

The highway industry constitutes a crucial element of contemporary infrastructure, encompassing the planning, design, construction, and maintenance of roads and highways. This industry is integral to the transportation network, facilitating connectivity among communities and the movement of goods and people. It significantly contributes to the economy by creating employment opportunities and supporting local businesses. Furthermore, the industry is tasked with the development and upkeep of the intelligent transportation system, which utilizes advanced technologies to enhance the safety and efficiency of roadways.

Pavement design aims to determine the most cost-effective combination of layer thicknesses and material types for pavement construction, taking into account the properties of the subsoil, anticipated traffic load during the road's service life, and climatic conditions. Road pavement comprises multiple layers of meticulously selected materials constructed atop a natural or filled subgrade. As illustrated in Figure 1.1, pavement structures typically include three layers: the top asphalt layer, the base and/or subbase layer, and an underlying capping layer. The granular base and subbase layers must provide both a resilient long-term structure for the pavement and a temporary construction platform. In developing countries, the principal structural component of most

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pavements is formed by thick granular base and subbase layers placed over the subgrade (Figure 1). The asphalt layer is often very thin, serving primarily to protect against water ingress and, for economic reasons, is sometimes omitted entirely.

A pavement structure generally consists of base course and subbase layers, which are essential for the bearing capacity and serviceability of the road. High-quality soil is required as a construction material for this pavement structure. However, natural soils often exhibit unfavorable physical and engineering properties, rendering them unsuitable for high-volume road construction.

Soil and ground improvement techniques are employed as alternative methods to enhance the quality of deficient materials, thereby meeting the necessary criteria for pavement construction. These techniques encompass the use of natural, synthetic, and mixed powders.

The (CBR) Test is a widely used empirical method to assess the strength of soil subgrade, sub-base, and base course materials for flexible pavements. This test measures the resistance of a material to penetration by a standard plunger under controlled density and moisture conditions.

Developed by the California Highway Department in 1928-1929, the CBR test became a standard practice in flexible pavement construction, particularly during and after the Second World War in the USA, and was later adopted globally (Brown, 1996). Despite its widespread adoption, some advanced nations have recently restricted the use of CBR test results for road design due to its empirical nature.

The CBR test is extensively utilized to evaluate granular materials in the base, subbase, and subgrade layers of road and airfield pavements. Initially developed by the California State Highway Department, the test was later adopted by the Army Corps of Engineers for designing flexible pavements and has since been incorporated into numerous international standards (ASTM 2000).

The importance of the (CBR) test is underscored by two key observations: (1) the CBR value has been correlated with fundamental soil properties, including plasticity index, grain-size distribution, bearing capacity, modulus of subgrade reaction, modulus of resilience, shear strength, density, and molding water content; and (2) nearly all pavement design charts classify unbound materials based on their CBR values when compacted in pavement layers. The CBR test remains prevalent in practice due to the availability of these correlations and the substantial experience that engineers have accumulated with them.

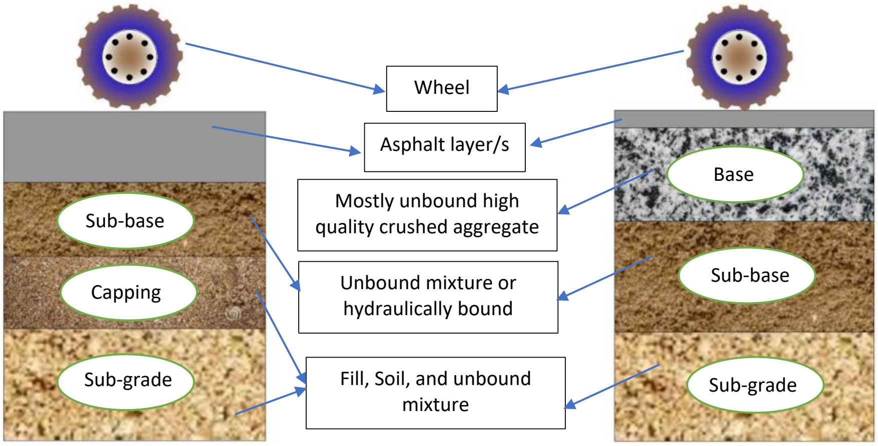


Fig. 1 Schematic pavement structure typical sections and material options (Araya, A. A., 2011)

2. Data collection and research methodology

This review draws upon publications sourced from esteemed academic journals within the geotechnical engineering field to examine the application of soil improvement methods to (CBR) test outcomes. Journals indexed in the Science Citation Index Expanded or the Engineering Index Database, both of which substantially impact geotechnical engineering, were considered. The prior studies were categorized into three distinct groups: (1) natural fibers, (2) synthetic fibers, and (3) mixture powders.

3. Soil improvement

Soil reinforcement entails the use of synthetic or natural additives to improve soil properties. Various techniques are employed to stabilize unstable soils. Consequently, this research categorizes soil reinforcement methods into three distinct groups.

3.1. Improving by natural fibers

Numerous researchers have investigated the use of natural fibers for soil improvement, including jute fiber, coir fiber, rice husk ash, banana fiber, palm fiber, sodium alginate biopolymer, fly ash, and marble dust. These studies have demonstrated the effectiveness of natural fibers in enhancing the (CBR) test values, indicating significant soil improvement. The findings, summarized in Table 1, highlight the impact of these fibers on soil properties.

Singh et al. (2013) examined the improvement of soil using jute fiber and its influence on CBR values. Their results revealed that the inclusion of jute fiber increased the soil's CBR value, with a maximum increase exceeding 200% compared to plain soil at a fiber content of 1%, for fibers with a diameter of 2 mm and a length of 90 mm.

Singh (2013) also investigated soil reinforcement with coir fiber. The study found that both unsoaked and soaked soil CBR values increased with higher fiber content. Notably, the CBR value saw a significant rise at 1% fiber content, with the maximum increase surpassing 205% over plain soil.

Tiwari et al. (2013) explored the reinforcement of fine sand with polypropylene and coir fibers in CBR tests under wet and dry conditions. The load-penetration response indicated that the presence of randomly distributed fibers significantly elevated the CBR values of fine sand under both conditions. The inclusion of 1.5% fiber resulted in up to a 100% increase in CBR values.

Gupta et al. (2014) assessed the effects of waste products, such as marble dust and fly ash, on the subgrade properties of black cotton soil. Laboratory tests involving fly ash, sand-stabilized black cotton soil, and 0–20% marble dust revealed that only 15% marble dust was necessary to enhance the CBR soaking value by nearly 200%.

Sarbaz et al. (2014) investigated the effects of incorporating palm fibers into a soil matrix at random spacing. Date palm fibers and soil were combined for constructing soil roads, particularly in village settings. CBR tests were conducted in both dry and submerged environments, using plain and bitumen-coated fibers. The study demonstrated that the addition of palm fibers significantly increased the CBR strength of sand samples. Additionally, it was observed that specimen failure was governed by sliding strength rather than rupture strength.

Kesharwani et al. (2016) conducted a study on sand mixed with coarse aggregates of varying sizes and proportions, subjected to (CBR) testing. Different ratios of coarse aggregates, sized at 10 mm and 20 mm, were incorporated into the sand to reinforce subgrade layers. Initially, soil samples were prepared and analyzed without coarse aggregates, followed by examinations after mixing with coarse aggregates in weight percentages ranging from 5% to 30%. The CBR test results indicated an increase in the soil's CBR value with a higher percentage of coarse particles. Specifically, the percentage improvements in CBR values at (OMC) ranged from 20.99% to 115.83% for 10 mm coarse aggregates and from 31.30% to 151.94% for 20 mm coarse aggregates. However, as the percentage of coarse aggregates increased, workability issues were encountered due to the higher density of coarse aggregates replacing the soil mass.

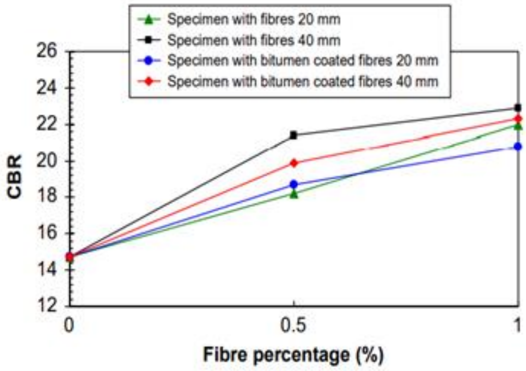


Fig. 2 The influence of using bitumen-coated fibers on the (CBR) strength under moist conditions

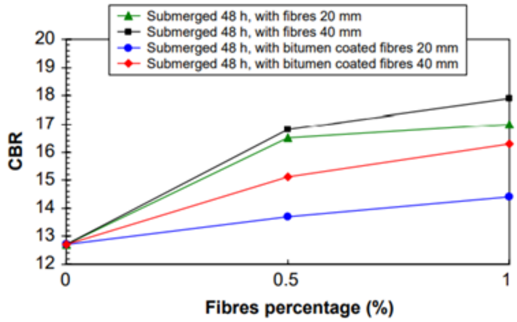


Fig. 3 The influence of using bitumen-coated fibers on the (CBR) strength under submerging conditions

Rahgozar et al. (2018) investigated the impact of incorporating rice husk ash (RHA) and ordinary Portland cement on the geotechnical properties of clay sand from the Sejzi district, east of Isfahan, Iran. An X-ray fluorescence (XRF) test was initially conducted to identify the oxide components present in the RHA, cement, and soil. Subsequently, the study measured the (UCS), (CBR), (OMC), and "maximum dry density (γd)" of the stabilized soil mixtures after 1, 2, and 4 weeks of curing. This analysis included five different soil mixtures, containing (2 to 8%) cement, with varying RHA percentages (0 to 8%). The increase in (CBR) can be attributed to the presence of cement and rice husk ash (RHA) surrounding the soil particles, which enables the soil to withstand greater stresses. This enhancement is further supported by cementing and pozzolanic reactions. Extended drying times and higher cement percentages also contribute to elevated CBR values for a given RHA percentage. Specifically, for treated specimens with lower cement content (2% and 4%), CBR initially increased with RHA increments from 2% to 4% and then decreased with further RHA increase from 4% to 8%. In specimens with higher cement content (6% and 8%), CBR initially rose with RHA increments from 2% to 6% before declining with additional RHA increase from 6% to 8%.

Fatehi et al. (2018) investigated the use of sodium alginate, an environmentally friendly biopolymer, to enhance the strength of sand dunes. The study demonstrated that biopolymer-treated sand exhibited significantly better performance than untreated samples, with CBR values for 1% and 2% biopolymer-treated sand being 2.5 and 4.5 times greater, respectively, than those of untreated samples. The curing environment's temperature was found to impact the compressive strength of biopolymer-treated sand, with the optimal curing temperature being approximately 45°C. Lower and higher temperatures weakened the bond. Additionally, sodium alginate-treated samples gained over 96% of their compressive strength within 14 days as they gradually lost moisture. Despite promising results, further research is needed to evaluate the biopolymer's various applications.

In another study by Fatehi et al. (2019), dune sand was treated with milk-derived casein and sodium caseinate biopolymers, and various laboratory experiments assessed the mechanical properties of the treated sand. The unconfined compression test revealed that increased biopolymer content and curing time enhanced the compressive strength of the biopolymer-treated sand. Curing temperature also played a role, with an optimal maximum temperature of 60°C for sodium caseinate and casein-treated samples. Additional tests, including direct shear, leaching, and CBR, as well as microscopic examination via SEM imaging, indicated that protein-based biopolymers offer substantial advantages over traditional cement and chemical polymers. Casein and sodium caseinate-treated sand showed significant increases in CBR values, with 0.5% and 1% casein-treated samples achieving CBR values 1.8 and 3.16 times greater than natural sand, respectively. Sodium caseinate-treated samples exhibited CBR values ranging from 1.96 to 3.57 times greater than untreated soil.

Gobinath et al. (2020), investigated the impact of using “banana fiber” on the geotechnical characteristics of a composite soil stabilized with sodium silicate. It entailed adding 1% sodium silicate to gravelly sand with different amounts (0.1 to 0.5%) of banana fiber. Results from index properties, (UCS), direct shear, Brazilian splitting, and (CBR) tests were obtained for both reinforced and mixed soil samples. The outcomes reveal that adding 0.5% banana fiber, resulting in a 445% increase in UCS, an 80% in shear strength, a 194% increase in split tensile strength, and a 1083% increase in the soaking CBR.The sodium silicate stabilization of sandy soils with banana fiber reinforcement makes the stabilized soil appropriate for use as a sub-base material for paving roads.

Table 1- Summary of improving the soil by natural fibers

Research & year	The material used in the improvement	Improvement ratio
H. P. Singh et al. (2013)	At 1% Jute fiber content	CBR increase of up to 200%
Singh, H. P. (2013)	At a coir fiber content of 1%	CBR increase of up to 205%
Tiwari, S. K. et al (2013)	1.5% fiber content	CBR increase of up to 100%
Gupta, C. et al (2014)	15% of the marble dust	CBR increase of up to 200%
Sarbaz, H. et al (2014)	1% palm fibers content	CBR increase of up to 40% under submerged condition
Sarbaz, H. et al (2014)	1% palm fibers content	CBR increase of up to 60% under moist condition
Kesharwani, R. S. et al (2016)	sand mixed with 30 % coarse aggregate (20mm) at OMC	CBR increase of up to 151%
Kesharwani, R. S. e al (2016)	sand mixed with 30 % coarse aggregate (20mm) at soaked condition	CBR increase of up to 233%
Rahgozar, M. A. at al (2018)	6% rice husk ash (RHA) and 8% ordinary Portland cement	CBR increase of up to 91%
Fatehi, H. et al (2018)	2 % of sodium alginate	CBR reached to 112%
Fatehi, H. at al (2019)	1% biopolymer	CBR increase of up to 257%
Fatehi, H.et al (2019)	1% of casein	CBR increase of up to 216%
Gobinath, R. et al (2020)	0.5% banana fiber	CBR increase of up to 1083%

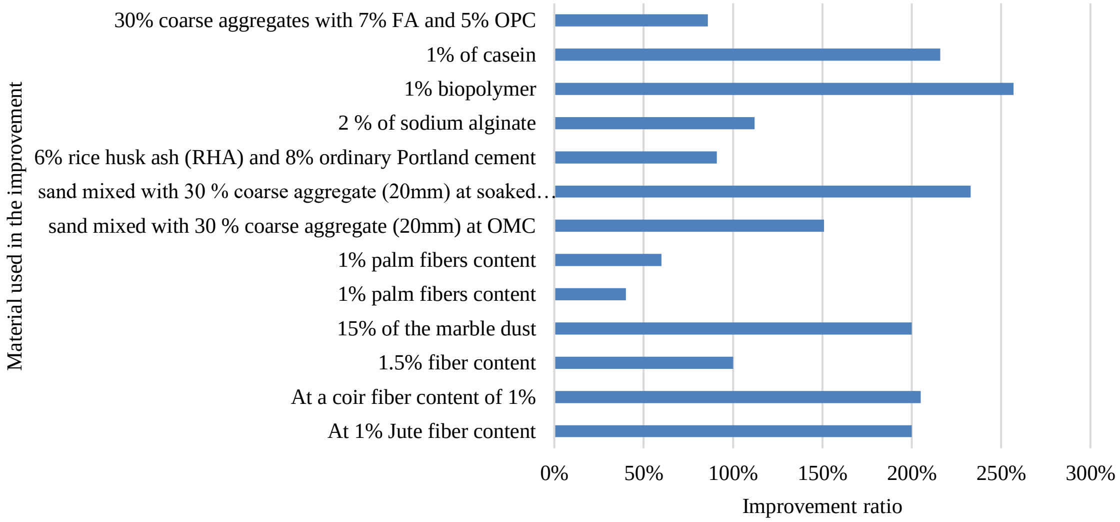


Fig. 4 Improvement ratio of improving the soil by natural fibers

3.2. Improving using synthetic fibers

Soil improvement through the incorporation of synthetic fibers is a technique designed to enhance the engineering properties of soil by introducing artificial fibers. These fibers, typically composed of polypropylene, polyester, or nylon, serve to augment the soil's shear strength and stiffness while reducing deformation and settlement. This method is particularly advantageous in regions where the soil is weak or inadequately compacted, such as areas with high water content or soils disrupted by construction or natural events. Synthetic fibers can be integrated into soil using various methods, including mixing with soil, application to the soil surface, or injection into the soil. This technique is applicable for reinforcing slopes, embankments, and other soil structures, as well as improving the soil's load-bearing capacity and preventing erosion. Table 2 presents the results of several previous studies on soil improvement via synthetic fibers.

Naeini et al. (2008) investigated the reinforcement of granular soils using geotextile as a tensile material. Laboratory (CBR) tests were conducted to examine the "load-settlement" curve of granular soil reinforced with geotextile. Different grading of granular soil samples were chosen and evaluated without reinforcement. The effects of the number of geotextile layers on the bearing strength improvement of reinforced granular soil, as well as the impact of grading on geotextile performance, were examined by placing geotextiles at specific depths within the sample height in one and two layers. The study's findings indicate that incorporating geotextile into granular soils significantly enhances their bearing capacity.

Kumar Pokharel et al. (2009) utilized basic loading equipment to assess the influencing factors of sand reinforced with a single geocell. Geocell, a three-dimensional geosynthetic material with interconnected cells, was used to enhance the characteristics of base courses by providing lateral confinement, which increases strength and stiffness while reducing permanent surface deformation. The research evaluated how the form and type of geocell affected the stiffness and bearing capacity of compacted sand. Experimental results demonstrated that geocell reinforcement increased bearing capacity and stiffness while reducing base course settlement, with the degree of improvement varying based on the type of geocell used.

Choudhary et al. (2010) conducted several (CBR) tests on soil randomly reinforced with high-density polyethylene (HDPE) strips of varying lengths and thicknesses. The inclusion of waste HDPE strips in appropriate amounts significantly improved the strength and deformation behaviour of subgrade soils, as evidenced by the results of the CBR tests.

Hazirbaba et al. (2010) investigated the (CBR) performance of fine-grained soils through experimental analysis, focusing on the effects of geo-fiber and synthetic fluids. The study conducted CBR tests under conditions of non-freezing, freezing, and freeze-thaw cycles. Three different material combinations were examined for soil improvement: geo-fiber alone, synthetic fluid alone, and a combination of synthetic fluid with geo-fiber. Both unsoaked and soaked samples were tested to simulate unsaturated and saturated soil conditions applicable to various field scenarios. Results from unsoaked samples indicated significant enhancement in CBR performance, particularly evident in samples treated with both synthetic fluid and geo-fiber. Conversely, geo-fiber alone demonstrated superior performance in wet conditions. The study also evaluated CBR performance post freeze-thaw cycles, revealing that while synthetic fluid alone was ineffective in mitigating freeze-thaw damage, the combination of geo-fiber with synthetic fluid provided resistance against moderate freezing effects. Samples subjected to freeze-thaw cycles and subsequent soaking showed lower CBR values for treatments using synthetic fluid, whereas those augmented with geo-fibers alone exhibited improved performance.

According to Dhule et al. (2011), local subgrade soil for road construction was modified by incorporating geogrid at varying percentages (1%, 2%, 2.5%, and 3%) and in combination with 2% cement to assess its impact. Various tests including sieve analysis, liquid and plastic limits, Proctor compaction test for maximum dry density and, specific gravity, and laboratory CBR tests under soaked and unsoaked conditions were conducted. Results indicated that the addition of 1%, 2%, 2.5%, and 3% geogrid increased the CBR of unsoaked murum by 50.88, 53.106, 53.901, and 54.06, respectively. Similarly, the addition of geogrid in murum with 2% cement at 1%, 2%, 2.5%, and 3% concentrations yielded CBR values of 45.69, 46.80, and 45.90 under soaked conditions.

Homauoni et al. (2011) conducted a study to investigate the stabilization of dune sand using poly(methyl methacrylate) (PMMA) and polyvinyl acetate (PVA), followed by evaluation using physical and mechanical tests. The (CBR) test was employed to assess the technical properties of the stabilized materials under dry and wet conditions. Results indicated a significant increase in the CBR of the dune sand post-stabilization with both polymers, highlighting their potential to enhance the sand's strength particularly in dry conditions. However, the CBR strength showed a slight decrease in saturated conditions compared to dry conditions, underscoring the composite's stiffness and moisture resistance. This improvement in stability under saturation conditions is critical for preventing premature road degradation due to subgrade erosion or failure. The optimal polymer content was determined to be 3% by weight with a curing period of 28 days, emphasizing the importance of polymer dosage over curing duration in enhancing the CBR strength of dune sands.

Chegenizadeh et al. (2012) investigated the impact of incorporating geosynthetic fibers on the CBR ratio. Laboratory experiments were conducted using silty sand with randomly distributed plastic fibers of varying lengths (10 mm, 20 mm, and 40 mm) and concentrations (0.1% and 0.3%). Results from the CBR tests demonstrated that increasing fiber content and length significantly enhanced the CBR ratio, sometimes more than doubling it for reinforced silty sand. This study concluded that the use of short, randomly distributed fibers is an effective method for improving the engineering properties of pavement subgrade soils.

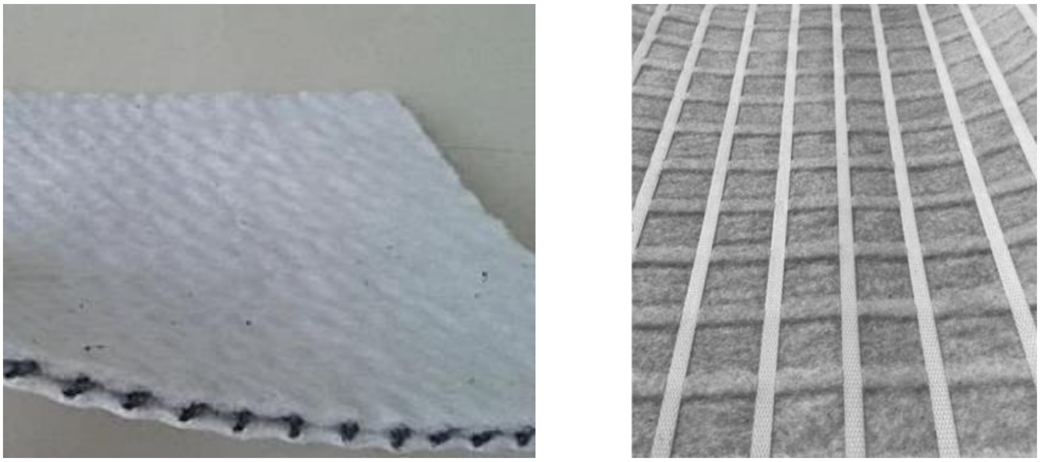
Tejeswini et al. (2013) explored the use of plastic waste materials, such as used shopping bags, as soil reinforcement to enhance subgrade soil performance. The study involved mixing soil with randomly distributed plastic strips of varying lengths and proportions. Controlled CBR tests were conducted to evaluate the reinforced soils, showing that the addition of plastic strips improved soil strength and modified its characteristics, thereby enhancing the subgrade soil's engineering properties.

Cabalar et al. (2014) investigated the utilization of crushed rock mixed with cement and tire buffing (a byproduct of tire re-treading) as sub-base road materials. CBR values were evaluated for different mixtures of crushed rock with varying percentages of tire buffing (0%, 5%, 10%, and 15% by weight) and cement (0%, 1%, 3%, and 5% by weight) under different moisture conditions. The study found that adding tire buffing alone reduced the CBR values, while the addition of cement generally increased them. Combining small amounts of cement with tire buffing led to higher CBR values compared to using tire buffing alone or clean sub-base gravel, indicating potential reductions in pavement design thickness.

These studies collectively illustrate various methods and materials for enhancing the CBR strength of soils, crucial for improving the longevity and performance of roads under varying environmental conditions.

Dasgupta et al. (2014) conducted an evaluation of the efficacy of jute geotextiles as soil reinforcement, focusing on their performance in a 40% sand mixture. The results indicated that the addition of sand improved the (CBR) to approximately 10%. However, on-site optimization of CBR values varied, resulting in a specified CBR of 7%. Specifically, the CBR value obtained for jute geotextiles was approximately 6%.

In a study by Goudazri et al. (2014), the effectiveness of various types of reinforcements in enhancing the bearing capacity of two-layered soil sections was investigated using the CBR test series. The soil sections, classified under the United Soil Classification System (USCS) as SP and GW, consisted of a weak subgrade layer (10 cm thick) and a base course layer of compacted aggregate materials (10 cm thick). The aggregate layer was compacted to a relative density (Dr) of 95% at an (OMC) of 6.5%. Two types of geo-composites (Type A and B), geotextiles, and geogrid were employed as reinforcements at the interface between the soil and aggregate layers, as illustrated in Figure 4. Due to the length required for soaking CBR testing, a modified CBR template was utilized, as the standard template proved inadequate for the study. CBR values corresponding to penetrations of 2.5 mm and 5 mm were analysed to assess stress-settlement behaviour in the samples. The results indicated an increase in CBR values of 21% and 24.5%, respectively, in the presence of geo-composite Type A and geogrid reinforcements.



(a) **(b)**

Fig. 5. Geosynthetics used in the experiments: (a) Geo-composite type A (b) Geo-composite type B (https://www.makeinindiatrade.com)

According to M. Rama Krishna et al. (2015), experiments were conducted where geo-grid, geotextile, and geo-composite materials were incorporated into poorly graded sand at various proportions within soil layers. (CBR) and shear parameters were utilized to assess different combinations of subgrade thickness. The geotechnical properties of poorly graded sand, encompassing Atterberg limits, grain size distribution, compaction characteristics, and CBR values, were comprehensively evaluated and reported. This study aimed to investigate the enhancement of soil strength through the addition of geosynthetic materials to achieve maximum CBR values.

The findings indicated that the inclusion of geogrid in the top layer of sandy soil resulted in a 143% increase in CBR value, while the integration of geo-composite in the same layer produced a 103.6% higher CBR value, as reported in the study.

Tafti et al. (2016) conducted Proctor and CBR tests on sandy soils (SA and SB) with different grading, as well as on clayey soils (CA and CB) reinforced with varying fiber contents. Additionally, UCS, direct shear, and Brazilian tensile tests were performed on the clayey soils. The optimal fiber content for both sandy and clayey soils, across the analyzed grading, was found to be 1%. Moreover, the results suggested that a fiber content of 1.5% provided the best outcomes, indicating that grading did not significantly influence the optimum fiber content for either soil type.

Furthermore, the addition of fibers to clayey soils resulted in approximately a 40% increase in UCS, adhesion, internal friction angle, and CBR values for soil CA, and a 35% increase for soil CB, highlighting a more pronounced beneficial effect on clayey soils. For sandy soils (SA & SB), CBR values increased by 26% and 18%, respectively. Additionally, incorporating recycled tire fibers was found to enhance energy absorption and ductility across all tested soils.

Hazirbaba (2018) investigated the efficacy of geo-fiber reinforcement in poorly graded sand using fibrillated polypropylene geo-fiber samples at dosage rates of 0.2%, 0.5%, and 0.8%. Direct shear box and (CBR) tests were conducted under both submerged and non-submerged conditions. The study evaluated peak friction angle, residual friction angle, and shear stress deformation responses to assess variations in shear strength properties. Results from numerous direct shear tests demonstrated a significant enhancement in shear strength with appropriate geo-fiber dosage. The addition of geo-fibers also influenced the CBR behavior of unreinforced soils, showing increased values correlating with greater penetration depth (Hazirbaba, 2018).

Al-Neami (2018) proposed an innovative approach for enhancing sandy soil by incorporating discarded tire chips as an alternative stabilizing agent. Geotechnical examinations of composite specimens comprising soil and tire chips supported the feasibility of this method. Addition of tire chips improved the shear strength, cohesion, and friction angle of the treated sand. The lower unit weight of tire chips contributed to reduced specific gravity, maximum dry density, and optimal moisture content of the composite material. CBR tests indicated that sand stabilized with tire chips exhibited approximately 1.6 times higher CBR values compared to pure sand, highlighting enhanced load-bearing capacity due to improved physical interactions between sand particles and tire chips (Al-Neami, 2018).

Chenari et al. (2018) investigated the behavior of sandy soil modified with expanded polystyrene (EPS) particles through various laboratory tests including the Modified Proctor (MSP) test, Unconfined Compression Strength (UCS) test, (CBR) test, and Direct Shear test. The study explored the properties of sand-EPS blends with different binders. Their findings indicated that increasing the EPS content by 0.1% resulted in a 10% reduction in the mixture's density, enhancing ductility rather than brittleness. Moreover, the addition of EPS beads led to decreased compressive strength, CBR value, and shear strength characteristics, contrasting with the effects observed with cement and fly ash concentrations.

Mehrpazhouh et al. (2019) analyzed the behavior of unreinforced and reinforced sand using nonwoven geotextile under repeated CBR loading tests involving unloading and reloading cycles. The study examined variables such as geotextile reinforcement layer depth, number of layers, compaction ratios of soil layers above and below the reinforcement, and sand bed compaction ratio. Geotextile layers were applied with thickness ratios of 0.3, 0.6, and 0.9 for upper layers and consistently at 0.3 for lower layers. Soil compaction ratios ranged from 85% to 97% for both the upper layer and the sand bed, simulating dense and medium-dense conditions, respectively. The CBR loading tests were conducted with target loads ranging from 100 to 400 kg. Results demonstrated that introducing a single layer of reinforcement with an upper thickness ratio of 0.3 and compacting the soil above to 97% compaction significantly reduced CBR piston penetration across all load levels. Optimal performance was observed with two reinforcement layers sandwiched between densely compacted soil layers at 97% compaction, with upper and lower thickness ratios of 0.3, achieving the lowest penetration depths.

Farah et al. (2019) investigated the use of recycled empty plastic water bottles as reinforcement materials to enhance the mechanical properties of sandy soil through laboratory experiments. The study involved testing natural and reinforced sands at 30% and 60% relative density, incorporating varying percentages (0%, 0.5%, 0.75%, and 1.0% by dry weight of sand) of waste plastic. Shear strength was evaluated using Direct Shear Box tests, while (CBR) tests were employed to assess penetration resistance. The findings indicated that the addition of waste plastic significantly improved both shear strength and CBR values of the reinforced sands. Optimal enhancement was observed with 0.75% waste plastic content, resulting in a minimum 9% increase in shear strength and penetration resistance compared to natural soils at similar densities.

Jain et al. (2020) explored the use of marble dust (MD) as a stabilizing agent for subgrade soils. Two soil types, sandalwood soil (SS) and black cotton soil (BCS), were treated with varying concentrations (0-100%) of MD, and their subgrade properties were evaluated using the (CBR) test under moist and dry conditions. The study revealed that while lower concentrations (up to 25% MD) had minimal impact or slightly negative effects on CBR values for SS, BCS showed substantial improvement, especially at 60% MD concentration. Comparison between SS and BCS highlighted BCS as more responsive to MD, meeting Indian Road Conference standards for subgrade preparation under both wet and dry conditions. Additionally, physical-chemical parameters such as pH and electrical conductivity were analyzed to understand the soil-MD interactions.

Tao et al. (2021) investigated the use of Polyurethane Foam Adhesive (PFA) to stabilize soil composition and enhance its mechanical properties. Triaxial consolidation, drainage experiments, and CBR tests were conducted on stabilized calcareous sands with varying PFA contents to assess stress-strain behavior, peak shear stress, and shear strength index. The study emphasized the significant influence of particle gradation on the mechanical response of stabilized calcareous sands, with each subclass requiring specific PFA content for optimal performance.

Negi et al. (2021) examined the reinforcement of soil using geotextiles and its impact on subgrade strength through (CBR) tests. Sandy and clayey subgrade soils were reinforced with woven and non-woven geotextiles in single, double, and triple layers to evaluate the effects of geotextile type, placement, and layering configuration. The results demonstrated that woven geotextiles significantly increased CBR values, outperforming non-woven counterparts in enhancing subgrade performance. Finite-element method analysis corroborated experimental findings, validating the efficacy of woven geotextiles in improving subgrade strength.

Farah et al. (2019) conducted laboratory experiments to explore the utilization of recycled empty plastic water bottles as reinforcement materials aimed at enhancing the mechanical properties of sandy soil. The study involved testing natural and reinforced sands at 30% and 60% relative density, incorporating varying percentages (0%, 0.5%, 0.75%, and 1.0% by dry weight of sand) of waste plastic. Direct Shear Box tests were employed to assess shear strength, while (CBR) tests were utilized to evaluate penetration resistance. Their findings indicated a significant improvement in both shear strength and CBR values of the reinforced sands upon the addition of waste plastic. Optimal enhancement was observed with a 0.75% waste plastic content, resulting in a minimum 9% increase in shear strength and penetration resistance compared to natural soils at equivalent densities.

Jain et al. (2020) investigated the efficacy of marble dust (MD) as a stabilizing agent for subgrade soils, focusing on sandalwood soil (SS) and black cotton soil (BCS). Different concentrations (0-100%) of MD were applied to these soils, and their subgrade properties were evaluated using the (CBR) test under varying moisture conditions. The study revealed that lower concentrations (up to 25% MD) minimally impacted or slightly decreased CBR values for SS, whereas BCS exhibited substantial improvement, particularly at 60% MD concentration. Comparison between SS and BCS highlighted BCS's greater responsiveness to MD, meeting Indian Road Conference standards for subgrade preparation under both wet and dry conditions. Additionally, physical-chemical parameters such as pH and electrical conductivity were analyzed to elucidate soil-MD interactions.

Tao et al. (2021) investigated the application of Polyurethane Foam Adhesive (PFA) for stabilizing soil composition and enhancing its mechanical properties. Triaxial consolidation, drainage experiments, and CBR tests were conducted on stabilized calcareous sands with varying PFA contents to assess stress-strain behavior, peak shear stress, and shear strength index. The study underscored the critical influence of particle gradation on the mechanical response of stabilized calcareous sands, with each gradation necessitating specific PFA content for optimal performance.

Negi et al. (2021) examined the reinforcement of soil using geotextiles and its impact on subgrade strength through (CBR) tests. Sandy and clayey subgrade soils were reinforced with woven and non-woven geotextiles in single, double, and triple layers to evaluate the effects of geotextile type, placement, and layering configuration. The results demonstrated that woven geotextiles significantly increased CBR values, surpassing non-woven counterparts in enhancing subgrade performance. Finite-element method analysis supported experimental findings, validating the effectiveness of woven geotextiles in improving subgrade strength.

Table 2 - Summary of improving the soil by synthetic fibers

Research & year	Material used in the improvement	Improvement ratio
Naeini, S. A. et al (2008)	geotextiles were positioned beneath the first layer	CBR increase of up to 112%
Choudhary, A. K. et al (2010)	4% HDPE strips	CBR increase of up to 209%
Hazirbaba, K. et al (2010)	0.5% geo-fiber content	CBR increase of up to 167%
Dhule, S. B. at al (2011)	Unsoaked murum and 3% geogrid	CBR increase of up to 106%
Homauoni, Z. J. et al (2011)	3% poly (methyl methacrylate) or 3% polyvinyl	CBR increase of up to 125%
Chegenizadeh, A. et al (2012)	3% plastic fiber with 10 mm fiber length	CBR increase of up to 226%
Dasgupta, T. et al (2014)	15% Saw Dust	CBR increase of up to 135%
Goudazri, S. A. et al (2014)	Geo-composite type A and geogrid	CBR increase of up to 121%
Krishna, M. R. et al (2015)	, the geogrid at layer 1 in sandy soil	CBR increase of up to 143%
Tafti, M. F. et al (2016)	At 1.5% fiber content	CBR increase of up to 183%
Hazirbaba, K. (2018)	At non submerged condition and 0.8% geo-fiber content	CBR increase of up to 225%
Al-Neami, M. A. (2018)	At 8% tire chips content	CBR increase of up to 160%
Chenari, R. J. at al (2018)	At 12% fly ash content	CBR increase of up to 140%
Farah, R. E. at al (2019)	At 60% relative density and 0.75% plastic waste reinforced sand	CBR increase of up to 11%
Tao, G. at al (2021)	At 7.5% PFA for Natural Graded Calcareous Sands	CBR increase of up to 307%
Negi, M. S. at al (2021)	For sandy soil, a single layer of woven geotextile put at height H/2 from the top provided	CBR increase of up to 140%
Abdi-Goudarzi, S. et al (2022)	Geogrid	CBR increase of up to 145%

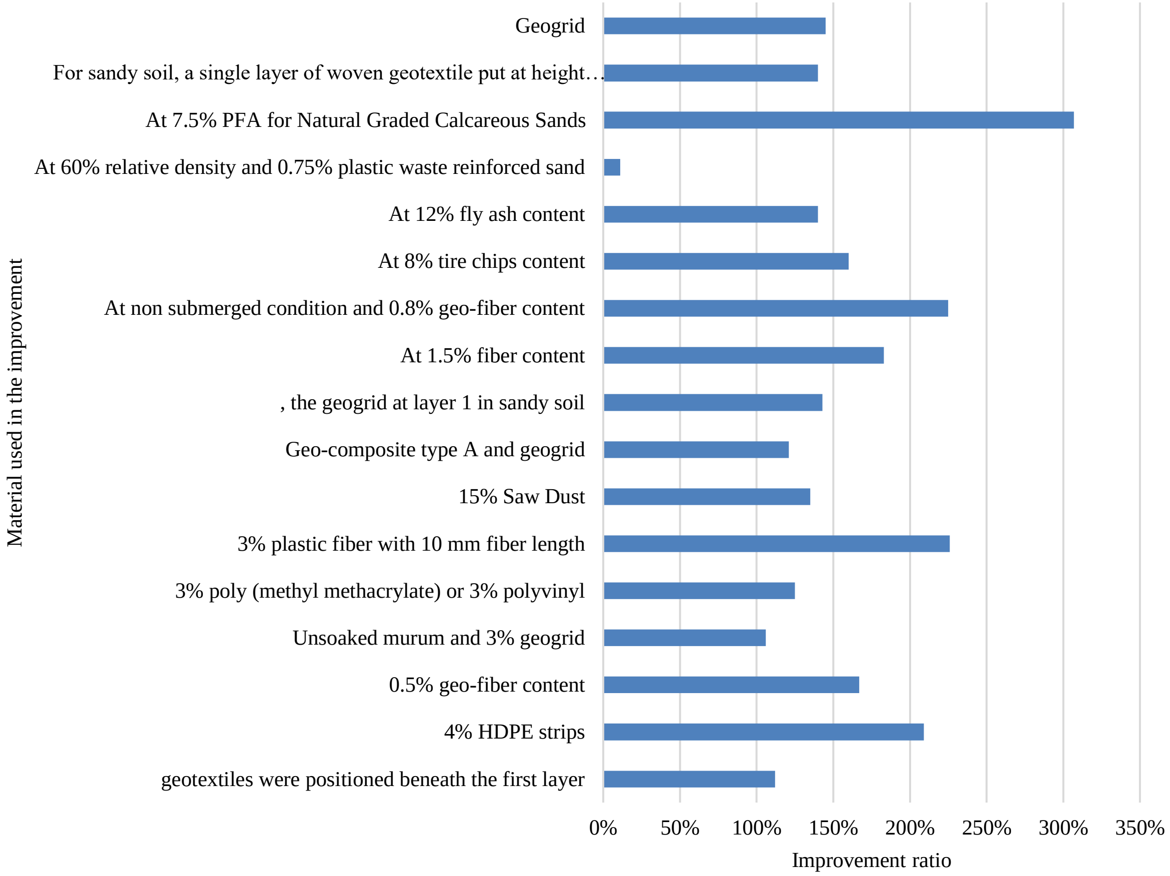


Fig. 6 Improvement ratio of improving the soil by synthetic fibers

3.3. Improving by mixture powders

Soil improvement involves the application of specific substances aimed at enhancing the physical and chemical properties of soil. One method of soil improvement includes incorporating powders such as lime, gypsum, sewage sludge ash, or rock dust into the soil. The quantities of these powders added vary depending on the specific soil requirements (Razouki et al., 2007; Baghini et al., 2015; Lopez-Querol et al., 2017; Singh et al., 2017). Experimental studies have shown significant impacts on soil properties through the addition of these powder mixtures (see Table 3).

Razouki et al. (2007) conducted laboratory tests on silty sand with approximately 28% gypsum content, classified as SM according to USCS and A-1-b according to AASHTO. The (CBR) was evaluated under varying compaction efforts using different compaction techniques. Results indicated that higher compaction efforts led to higher initial CBR values, but these values decreased significantly with increased soaking time, especially for samples compacted under lower efforts.

Baghini et al. (2015) investigated the effects of Portland cement and bitumen emulsion additions on road base performance over the long term. Testing included (UCS), flexural strength (FS), wetting and drying (WD), soaked and unsoaked CBR, dynamic creep (DC), and wheel tracking (WT). Their findings demonstrated substantial improvements in strength characteristics when incorporating these additives into the mixtures, particularly notable in reducing water absorption and enhancing deformation properties under dynamic loading conditions.

Lopez-Querol et al. (2017) examined the compaction and bearing capacity enhancement of aeolian sand from Jeddah treated with varying percentages of Portland cement. Their study highlighted improvements in maximum dry density, , and CBR values with increasing cement content. Confinement conditions were also found to significantly influence the results, suggesting improved applicability of stabilized materials in low confinement support applications.

Singh et al. (2017) investigated the use of waste concrete fines as an additive to enhance the CBR value of soil. Their experiments showed that incorporating concrete fines led to improvements in soil CBR values, demonstrating the potential for utilizing waste materials in soil improvement practices.

These studies collectively underscore the efficacy of powder mixtures and additives in enhancing soil properties, providing valuable insights into optimizing soil stabilization techniques for various engineering applications.

Güllü et al. (2018) conducted a factorial experimental study to assess the efficacy of sewage sludge ash (SSA) in subbase construction, employing (CBR) tests on soil-SSA mixtures ranging from 0% to 50% SSA content by weight. The investigation aimed to determine CBR values, energy absorption capacity, and bearing strength parameters. Statistical analysis indicated that SSA additions up to 50% exhibited insignificant variations in performance, whereas significant decreases were observed below 15% SSA dosage (Güllü et al., 2018).

Abbasi et al. (2018) investigated the influence of lime and natural pozzolan concentrations on the geotechnical properties of silty sand soil. They conducted tests using 20 treatments combining varying levels of pozzolan (0%, 5%, 10%, 15%) and lime (0%, 1%, 3%, 5% by weight). Compressive strength was evaluated on cylindrical samples under different curing ages (7, 14, 28 days), revealing that combined lime and pozzolan application enhanced compressive strength significantly more than individual applications (Abbasi et al., 2018).

Shalabi et al. (2019) studied waste cement-treated sand from Al-Ahsa quarries as a potential base course material for construction. They investigated the effects of Portland cement content (0% to 8%) on stiffness, bearing capacity, and strength enhancement. Tests included and CBR evaluations over various curing durations, with microstructural analysis revealing improvements with increasing cement content and curing time (Shalabi et al., 2019).

Norouznejad et al. (2021) explored the impact of zeolite on cement-sand mixtures, examining compaction characteristics and CBR. Their study involved blending sand, cement (2% to 6% by weight of sand), and zeolite (0% to 90% of cement content). Results indicated that zeolite addition increased the (OMC) and decreased the maximum dry density (MDD), with optimal CBR values achieved at up to 30% zeolite content due to pozzolanic and chemical processes (Norouznejad et al., 2021).

Amhadi et al. (2021) investigated the use of industrial sand, Ordinary Portland Cement (OPC), and Fly Ash (FA) as binders to enhance desert sand strength. Their findings highlighted the beneficial effects of these materials on strength, compaction, and bearing capacity characteristics, particularly noting optimal performance with a blend comprising 26% CFA, 62% manufactured desert sand, 5% OPC, and 7% FA (Amhadi et al., 2021).

Table 3 - Summary of improving the soil by a mixture of powders

Research & year	Material used in the improvement	Improvement ratio
Razouki, S. S. et al (2007)	Sand with 28% gypsum content at 70 blows	CBR increase of up to 205%
Baghini, M. S. et al (2015)	4% cement, 3% bitumen for unsoaked conditions	CBR increase of up to 308%
Lopez-Querol, S. et al (2017)	6% Cement content - confined Tests	CBR increase of up to 207%
Singh, L.et al (2017)	waste concrete fines were incorporated in the soil at a 40% ratio	CBR increase of up to 345%
Güllü, H. et al (2018)	at 10% the sludge ash dosage	CBR increase of up to 118%
Abbasi, N. et al (2018)	At 3% lime and 15% pozzolan	CBR increase of up to 1200%
Shalabi, F. I. at al (2019)	After 28-day treatment and 6% cement content	CBR increase of up to 1250%
Norouznejad, G. at al (2021)	zeolite up to 30% of the cement composition	CBR increase of up to 114%
Amhadi, T. S. at al (2021)	26% CFA, 62% NDS, 5% OPC, and 7% FA	CBR increase of up to 375%

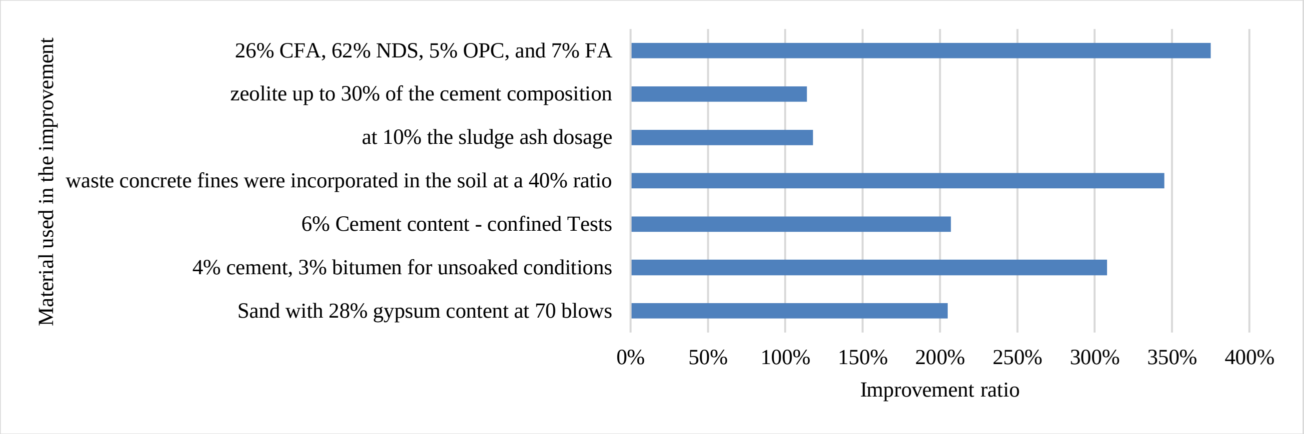


Fig. 7 Improvement ratio for improving the soil by a mixture of powders

4. Conclusions and Future Works

This study focuses on assessment the effectiveness of three techniques for enhancing the (CBR) of granular soil: the use of natural fibers, synthetic fibers, and the addition of powders. More than forty previous research were collected, studied, sorted and compared to draw out the following conclusions:

- The findings indicate that the effectiveness of these improvement methods largely depends on the amount of additives used, whether they are fibers or powders.
- The considered natural fibers included Jute, coir, palm, banana fibers besides the casein and biopolymer. For 1% dose, all of them enhanced the CBR by (200 to 250%) except palm and banana fibers which showed lower efficiencies (≈50%).
- The studied synthetic fibers included geotextiles, HDPE strips, geo-fibers, geogrid, polyvinyl, tire chips and plastic waste fibers. For dose of 3-4%, they improved the CBR by (100 -200%) except the geo-fibers which showed a better efficiency (≈150-250% for 0.5-0.8%)
- The considered mixture powders are gypsum, bitumen, cement, sludge, lime, pozzolan, fly ash, and zeolite. Using a dose of 6-10% enhanced the CBR by (200-300%) except sludge and zeolite which showed lower performance (≈115%).
- Generally, both natural fibers and powders can enhance soil properties by up to 250%, while synthetic fibers achieve an improvement of 150%.
- Moreover, combining different enhancement techniques such as (fly ash with cement) or (lime with pozzolan) can boost overall efficiency up to 300%.
- From an environmental perspective, natural fibers are the most eco-friendly, powders are the least, and synthetic fibers offer the longest durability.

For rather studies, it is recommended to investigate the efficiency of combining two or more fiber types with different mixture powders.

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