Journal of Natural Fibers

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/wjnf20

A Review on Degradation Improvement of Sisal Fiber by Alkali and Pozzolana for Cement Composite Materials

Tsion Amsalu Fode, Yusufu Abeid Chande Jande, Thomas Kivevele & Nima Rahbar

To cite this article: Tsion Amsalu Fode, Yusufu Abeid Chande Jande, Thomas Kivevele & Nima Rahbar (2024) A Review on Degradation Improvement of Sisal Fiber by Alkali and Pozzolana for Cement Composite Materials, Journal of Natural Fibers, 21:1, 2335327, DOI: 10.1080/15440478.2024.2335327

To link to this article: https://doi.org/10.1080/15440478.2024.2335327

JOURNAL OF NATURAL FIBERS
2024, VOL. 21, NO. 1, 2335327
https://doi.org/10.1080/15440478.2024.2335327

A Review on Degradation Improvement of Sisal Fiber by Alkali and Pozzolana for Cement Composite Materials

Tsion Amsalu Fode [a,b,c,d], Yusufu Abeid Chande Jande [a,c], Thomas Kivevele [a,c], and Nima Rahbar[d]

[a]School of Materials, Energy, Water and Environmental Sciences (MEWES), The Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania; [b]Department of Civil Engineering, Wollega University, Nekemte, Ethiopia; [c]Water Infrastructure and Sustainable Energy Futures (WISE-Futures) Centre of Excellence, The Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania; [d]Department of Civil and Environmental Engineering, Worcester Polytechnic Institute, Worcester, Massachusetts, USA

ABSTRACT

Sisal fiber employment in concrete improves its post-crack strength, but sisal fiber degrades due to moisture and cement mineralization. Many researchers used alkaline and pozzolanic techniques to treat sisal fiber in cement composite materials. However, which treatment method is most effectively used to modify sisal fiber for sustainable use in cementing materials has yet to be well known. Therefore, this review highlights the effect of alkaline and pozzolanic materials on sisal fiber treatment. The review of various studies found employment of 1–1.5% of treated sisal fiber by alkaline or pozzolana reduces workability and improves the mechanical properties, especially as many authors found the treatment of sisal fiber by pozzolanic material averagely improves compressive strength and splitting tensile strength of cementing materials by 21.75% and 36.53%, while alkaline treatment 12.83% and 14.92% respectively, compared to control mixture. Besides these, many studies found the treatment of sisal by either alkaline or pozzolana significantly lessens water absorption capacity, improves the thermal resistivity of the fiber, improves fiber adhesion with the matrix, makes rougher microstructure of fiber surface. However, many studies reported alkaline treatment to have drawbacks in the disposal of alkaline chemicals that increase environmental pollution, at high concentrations cause fiber deterioration, and chemical production cost.

摘要

在混凝土中使用Sisal纤维提高了其裂缝后强度，但由于水分和水泥矿化而降解. 许多研究人员使用碱性和火山灰技术处理水泥复合材料中的剑麻纤维. 然而，哪种处理方法最有效地用于改性剑麻纤维，使其可持续地用于胶结材料，目前尚不清楚. 因此，本文着重介绍了碱性和火山灰材料对剑麻纤维处理的影响. 对各种研究的回顾发现，使用1-1.5%的经碱性或火山灰处理的剑麻纤维可降低工作性并提高机械性能，特别是许多作者发现，与对照混合物相比，用火山灰材料处理剑麻纤维平均可提高21.75%和36.53%的胶凝材料抗压强度和劈拉强度，而碱性处理分别可提高12.83%和14.92%. 除此之外，许多研究发现，用碱性或火山灰处理剑麻可以显著降低吸水能力，提高纤维的热阻，提高纤维与基体的附着力，使纤维表面微观结构更加粗糙. 然而，许多研究报告称，碱性处理在处理碱性化学品方面存在缺陷，这会增加环境污染，导致纤维在高浓度下变质，化学品生产成本.

KEYWORDS
Sisal fiber; alkaline; pozzolana; cement composite; degradation; moisture sensitivity

关键词
剑麻纤维; 碱性; 火山灰; 水泥复合材料; 堕落; 湿度敏感性

CONTACT Tsion Amsalu Fode fodet@nm-aist.ac.tz; Yusufu Abeid Chande Jande yusufu.jande@nm-aist.ac.tz School of Materials, Energy, Water and Environmental Science (MEWES), The Nelson Mandela African Institution of Science and Technology, , Arusha, Tanzania

Introduction

Concrete is a highly used building material worldwide; however, it is a brittle material with low strain capacity, tensile strength, fracture toughness, and weak energy absorption. So primarily to mitigate this drawback, reinforcements are crucial in concrete, either steel or synthetic fibers (B. Li et al. 2018; Sadrinejad, Madandoust, and Ranjbar 2018; X. Zhou, Saini, and Kastiukas 2017). Hence, fibers in cement composite materials are important in improving load-carrying capacity, lessening shrinkage cracks, enhancing strength, and protecting the concrete matrix from environmental and possible damages (Aruna 2014; Begum and Islam 2013; Rai and Joshi 2014; Ramasamy 2015; Ramesh 2018; Sekaran, Kumar, and Pitchandi 2015). Besides these, fibers can hold significant stresses and relatively large strain capacity on post-cracking concrete, forming good bonding, and improving strength with cement matrix (Bolat et al. 2014; Gao et al. 2022; Hanif et al. 2017; Jamshaid et al. 2022; Machaka, Basha, and Elkordi 2014a; Naraganti, Pannem, and Putta 2019; P. Zhang et al. 2018).

Furthermore, the employment of fibers in cement composite materials has three effects: i) the ability to improve the tension under the matrix cracks, ii) enhance deformation capacity and toughness, iii) modify the development of cracks by lowering the openings and spacing of cracks (W. Abbass, Khan, and Mourad 2018; de Lima et al. 2022; Latifi, Biricik, and Aghabaglou 2022). Also, fiber employment in concrete improves its post-cracks strength and leads to more ductility of cementing materials due to fibers' ability to transfer tensile stress across the crack points and potentially reduce crack width. However, the reduction of the crack width of concrete depends on the amount and the physical properties of the fiber (Afolayan, Wilson, and Zaphaniah 2019; Mudadu et al. 2018; Wu et al. 2016). Mainly, adding a small volume of fibers improves the tensile strength of concrete, enhances bond strength, lessens permeability, and resists seismic loading and its ductility (Cao et al. 2020; Panchangam 2015b). However, using steel bars or synthetic fibers is expensive, and their production pollutes the environment (X. Zhou, Saini, and Kastiukas 2017). So, employing natural fibers in construction materials enhances strength, is cost-effective, renewable, and reduces carbon impact on the environment (W. Ahmad et al. 2020; Barbuta et al. 2017; dos Santos et al. 2021; Ivanova, Assih, and Dontchev 2020; Krishna et al. 2018; Kundu et al. 2018; Maurya et al. 2015; Shah et al. 2021; Silva et al. 2020; Zakaria et al. 2020).

Natural fibers predominantly have cellulose and others like lignin, hemicellulose, and pectin, in addition to small amounts of ash, wax, and sugars (Abirami and Sangeetha 2022; Benítez-Guerrero et al. 2017; de Lima et al. 2022; S. R. Ferreira et al. 2017; Jeyapragash, Srinivasan, and Sathiyamurthy 2020; Marvila et al. 2021; Naveen et al. 2018). Its cellulose part can increase the mechanical properties of concrete, control crack opening and propagation, and improve tensile strength, ductility, and toughness while allowing high deformation without any loss of integrity (Arshad et al. 2020; Fujiyama, Darwish, and Pereira 2014; Iniya and Nirmalkumar 2021; Izquierdo et al. 2017; Kafodya and Okonta 2018; Machaka, Basha, and ElKordi 2014b; Olivito, Cevallos, and Carrozzini 2014; Shadheer Ahamed, Ravichandran, and Krishnaraja 2021). This improvement in concrete ductility can enhance the seismic resistance of the structures to avoid catastrophic concrete failure (Krishna et al. 2018; Machaka, Basha, and Elkordi 2014a). Also, adding natural fiber to concrete enhances tensile and bending strength, improves ductility, reduces permeability, and highly resists crack occurrence by enhancing concrete's bond strength and toughness (Althoey et al. 2023; Kv 2019; Reis 2012; Thomas and Jose 2021). In addition to these, the employment of natural fiber in cementing materials highly improves flexural strength and shrinkage cracks (Jaradat et al. 2021).

Furthermore, Begum K. and Islam M.A (2013) investigated a comparison of the mechanical strength of natural-reinforced fiber polymer and glass fiber-reinforced composites. The study found that natural fiber-reinforced polymer composite reached equivalent mechanical strength and higher volume fraction than glass fiber. It was also eco-friendly and more cost-effective than synthetic fibers. Natural fibers offer an alternative to synthetic fibers due to their excellent properties like low cost, sustainability, and availability with their environmentally friendly natures (Adekomaya and Majozi 2019; D. P. Ferreira, Cruz, and Fangueiro 2018; Florea and Manea 2019; Helaili, Chafra, and Chevalier

2021; Herrera-Franco, Carrillo, and Li 2020; Jaiswal et al. 2022; Khalid, Al Rashid, et al. 2021; Prabhu et al. 2021; Zwawi 2021).

Among various natural fibers, sisal fiber has multiple benefits in construction materials through property improvement, is environmentally friendly, and is cost-effective (Ali-Boucetta et al. 2021; Asim et al. 2020; Belaadi et al. 2013; D. P. Ferreira, Cruz, and Fangueiro 2018; Martinelli et al. 2023; Thomas and Jose 2022; Yadav et al. 2021; Zakaria et al. 2017; X. Zhou, Saini, and Kastiukas 2017). Sisal fiber is a strong and most extensively cultivated natural fiber, extracted from the Agave-sisalana plant leaf that mainly grows in the tropical and sub-tropical regions of the world (S. R. Ferreira et al. 2014, 2018; Singh et al. 2022), which can grow in stiff soil where typical plants cannot grow and more favor temperature range between 20°C to 28°C with mean annual rainfall 600–1500 mm (Bharath 2017; Chopra and Razahi 2020; S. R. Ferreira et al. 2017; Kv 2019). The sisal fiber accounts for 2% of the world's natural fibers (Chopra and Razahi 2020) and is traditionally used for producing twine dart-boards and rope (S. Ali, Jain, and Singh 2017; P. R. Lima et al. 2014; Sabarish et al. 2020; Sugathan 2017). Sisal fiber is a natural fiber having high strength and modulus, low price, high durability, recycle-ability, low maintenance, and high water absorber (Fiore et al. 2016; Lopes Lima et al. 2017; Thomas and Jose 2021).

The total or partial steel replacement by sisal fiber reinforced concrete credits an economical way to provide an alternative method to safe concrete structures and allow energy-efficient materials, economical, ecological, and upcoming green building technologies (Herrera-Franco, Carrillo, and Li 2020; P. Kumar and Roy 2018; Martínez-Martínez and Corpas-Iglesias 2016; Mukhopadhyay and Srikanta 2008; Tian et al. 2015; Vijayan and Krishnamoorthy 2019; X. Zhou, Saini, and Kastiukas 2017). But highly moisture sensitive and deteriorates by mineralization of cementing minerals. Veigas, Najimi, and Shafei (2022) found that the degradation of sisal fiber in cement concrete is mainly due to calcium hydroxide from cement and moisture sensitivity of its surface. The study did immerse the untreated sisal fiber in calcium hydroxide solution for one week and observed under a scanning microscope the degraded sisal fiber surface, also moisture sensitivity is assessed by wetting and drying for 25 cycles and found cementitious material with untreated sisal fiber lost 50% of flexural strength and while the treated by surface coating is degraded only by 25%. This is mainly due to the untreated sisal fiber absorbs more water into the cement matrix that lessens the interface bond between the fiber and matrix due to swelling of the sisal fiber water absorbed part which consequently much reduces strength compared to the treated sisal fiber under aging conditions. The same finding was found by many researchers studied on ways to reduce sisal fiber degradation primarily by treating alkaline and pozzolanic materials. However, it's not well known which of the two methods is more effective in treating the sisal fiber for its sustainable use in construction materials reinforcement. Therefore, the present review comprehensively reviewed relevant literature on the effect of alkaline and pozzolana sisal fiber treatment methods, especially, the effect of treating either pozzolanic or alkaline on physical properties of concrete such as workability and density, also on mechanical properties such as compressive, splitting tensile, and flexural strength of cement composite materials. Besides these, the present study details reviewed the effects of employing treated sisal fiber by alkaline and pozzolanic materials on the durability of concrete on water absorption, chloride ion migration, and acidic attack in addition to highlighting their effects in the microstructural properties of concrete.

Benefits of sisal fiber employment in cement composite

Sisal fiber has excellent promise in construction applications due to its superior mechanical strengths, fracture energy and durability, low production cost, renewable, less energy absorption, and eco-friendly plant-based raw material (A. S. Filho et al. 2021; Lopes Lima et al. 2017). The incorporation of sisal fiber in concrete composition improves mechanical performance, such as compressive strength and tensile strength (Acosta-Calderon et al. 2022; Beskopylny et al. 2022; A. Filho et al. 2020; Golla and Ranganath 2015; Prakash et al. 2021; Ren et al. 2021; Sabarish et al. 2020; Shah et al. 2021; Yinh et al. 2021), and also the employment of sisal fiber can reduce the number of cracks occurring in concrete by 56–99% (S. Gupta et al. 2021; Okeola, Mwero, and Bello 2021). Besides these, Huang et al. (2020) reported that employing sisal fiber in concrete increases concrete's static and fatigue load resistance. Also, sisal fiber can effectively lessen the corrosion rate of concrete in the marine environment and reduces the shrinkage cracks of the concrete in seawater (Bao et al. 2019). The extent of cracks significantly decreases with the increase in fiber amount in concrete (Asaduzzaman and Islam 2023).

Furthermore, sisal fiber and many natural fibers can reflect excellent secondary structural components with lightweight, improve strength, and ductility, reduce shrinkage cracks, and have low-cost properties (S. D. Gupta et al. 2020; Jo, Chakraborty, and Lee 2015; John and Dharmar 2021; Kundu, Chakraborty, and Chakraborty 2018; Liu et al. 2020; Long and Wang 2021; Machaka, Basha, and Elkordi 2014a; Razmi and Mirsayar 2017; Snoeck, Smetryns, and De Belie 2015; Song et al. 2021). They can be used as additives to enhance the durability and strength of concrete (Jena, Patra, and Mukharjee 2022; Tiwari, Sahu, and Pathak 2020). Mainly, sisal fiber is a substantial replacement for steel bar reinforcement for simple and medium structural elements (Murtiadi and Akmaluddin 2016) and enables renewable, nonhazardous, and biodegradable, which permits the development of more sustainable construction materials (Claramunt et al. 2016; Jariwala and Jain 2019; P. Kumar and Roy 2018; Martel, Salgado, and Silva 2022; Sellami, Merzoud, and Amziane 2013; Song et al. 2021). Besides these, adding different types of natural fibers to concrete improves cement composite materials' electrical resistivity and impact resistance (Afroughsabet and Ozbakkaloglu 2015; Senthilkumar et al. 2021). It strengthens concrete beams by improving load-carrying capacity and mid-span deflection against ultimate load (Hussain and Ali 2019; Yinh et al. 2021).

However, natural fibers can be degraded in cement composite materials due to alkaline hydrolysis and mineralization, leading to a significant problem for their practical utilization in construction work (Zhao et al. 2021). The degradation due to alkaline pore solution in the cement composite matrix seriously lessens the durability and may cause premature failure. Also, natural fibers are highly moisture sensitive, which can cause poor bonding between natural fiber and concrete matrix in the long term (A. Ali et al. 2018; Cruz and Fangueiro 2016; Mármol et al. 2020; Snoeck, Smetryns, and De Belie 2015) and cause shrinkage and swelling that can cause decoupling at interphase. Hence, the debonded interphase and degradation during aging in water leads to reduced mechanical properties of the cement composites (Akash, Venkatesha Gupta, and Sreenivas Rao 2017). Therefore, natural fiber surface modification reduces water absorption from the fiber matrix pore and improves the performance and durability of natural fibers for reinforcement in cement composite materials (Dantas et al. 2019).

Sisal fiber has a cellulose compound responsible for fiber resistance, as shown in Figure 1, which is dominated mainly by the cellulose part. However, hemicellulose and lignin are also part of the sisal fiber composition responsible for the cement materials' low durability, hence can absorb free water or moisture, have high volume content that increases fiber surface area, and have low friction resistance (Marvila et al. 2021; Ren et al. 2021). So lessening the amount of lignin and hemicellulose by removing impurities, waxes, ashes, and sugars, enables the sustainability of sisal fiber in cement composite materials (Marvila et al. 2021).

The sisal fiber degradation in cement composites proceeds slowly from the fiber surface to the inside cell walls. The amorphous protective layers, lignin, and hemicellulose, first deteriorate due to infiltration of alkaline pore solutions in fibers and then proceed to deterioration of cellulose fibrils which causes premature failure of sisal fibers (Wei 2018). Hence, this can limit the application of natural fibers in concrete that degrade in a highly alkaline environment like in the concrete matrix (Veigas, Najimi, and Shafei 2022). Therefore, mitigating the natural fibers degradation in a cement composite matrix has to be a serious issue and to be solved before employing different types of cement composite materials (S. R. Ferreira et al. 2014; Wei and Meyer 2014a). In addressing these challenges, researchers treated natural fibers as used in cement composite materials by alkaline or natural pozzolana (Hari and Mini 2019). Also, treating sisal fiber by mineral addition as a partial replacement of Portland cement and chemical treatment can promote an adequate concrete casting process (P. R. L. Lima et al. 2019).

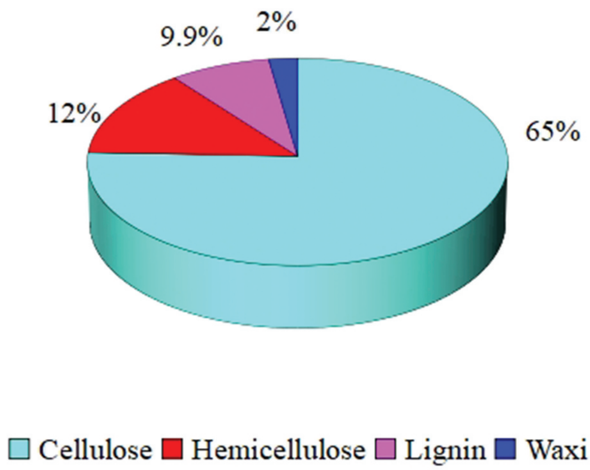

Figure 1. Chemical composition of sisal fiber by Sugathan (2017).

Sisal fiber treatment by alkaline

Natural fibers treated by a chemical process like acetylation, breaching, silane, alkalization, glycidyl methacrylate, and strontium titanate to enhance the degradation resistance and extent of adhesion of the fibers and composite materials improve typically mechanical properties, thermal stability, and water absorption of the natural fibers (Basak, Choudhury, and Pandey 2018; S. Kumar, Tilak, and Dutta 2017; Sellami, Merzoud, and Amziane 2013; Senthilkumar et al. 2018). Most of the time, NaOH is used as an alkaline treatment of natural fibers (R. Ahmad, Hamid, and Osman 2019; Godara and Godara 2019; Jo, Chakraborty, and Kim 2016; Prasad, Gowda, and Velmurugan 2017). Also, sodium bicarbonate ($NaHCO_3$) is currently utilized due to a similar effect on fiber like NaOH and less cost (R. Ahmad, Hamid, and Osman 2019; Benkhelladi, Laouici, and Bouchoucha 2020). The alkaline treatment by Sodium hydroxide solution (NaOH) effectively removes amorphous materials such as hemicellulose, lignin, pectin, and waxes from the outer surface of the sisal fiber. This treatment improves fiber surface roughness and degree of crystallinity (Achour, Ghomari, and Belayachi 2017; Dilfi KF et al. 2018; Gudayu et al. 2022; Huner 2018; Maichin et al. 2020) and lessens the moisture absorbency of hemicellulose and lignin. Sisal fiber alkaline treatment plays a significant role in the improvement of interfacial properties of the fiber by providing better compatibility and modification of interface bonding (Gudayu et al. 2020).

The optimum moisture absorption of the untreated sisal fibers decreases with the surface modification of fibers through chemicals (Kumar, B, and Dutta 2017). Specifically, alkali treatment can avoid some non-cellulose components and impurities (de Azevedo, Marvila, Antunes, et al. 2021; Gupta et al. 2020; Mahjoub et al. 2014; Orue et al. 2015; Shivamurthy et al. 2020; Tenazoa et al. 2021). Also, the treatment can alter the fiber properties on the chemical composition and functional groups between treated and untreated fibers (Amiandamhen, Meincken, and Tyhoda 2018). Partial degradation of the matrix of lignin and hemicellulose leads to a rougher fiber surface, which may improve the contact area and adhesion between the fiber and the cementitious matrix (Castoldi et al. 2022).

Besides these, natural fibers are hydrophilic due to lignin and hemicellulose (A. Abbass, Lourenço, and Oliveira 2019; P. R. L. Lima et al. 2017; Motaung et al. 2017; Sellami, Merzoud, and Amziane 2013). Fiber impurities such as oil and wax can cause debonding and void of the fiber surface, which can lessen the effectiveness of natural fibers (Verma, Singh, and Zafar 2020). Hence, sisal fiber treatment by alkaline gives rise to the breaking down of the cell wall of lignin that exposes the micro fibrillated cellulose, improves hydrophobicity (Gudayu et al. 2020), and enhances the ductility of alkali-treated sisal fiber blended cement composite (S. Kumar, B, and Dutta 2017), which makes sisal fiber cleaner surface (P. R. L. Lima et al. 2017; Motaung et al. 2017).

Alkali treatment of natural fibers increases the existence of the hydroxyl group (OH^-) to form chemical and physical bonds to the polymer chains, hence, in the physical bond of cellulose fiber the hydroxyl group can form hydrogen bonds, whereas cellulose fiber chemical bond of the hydroxyl group can react with alkali NaOH and form – O – Na+ that has potential to bond with cement composite matrix (Verma, Singh, and Zafar 2020). In addition to this, treatment can cause an increase in the crystallinity index of cellulose and surface roughness of the fiber due to the removal of lignin and hemicellulose (Burrola-Núñez et al. 2019; S. R. Ferreira et al. 2015; Razak et al. 2014). This surface roughness of the fiber enhances the bond between cement paste and fibers, increasing concrete's mechanical and durability properties (Ahmad et al. 2022; Akinyemi, Omoniyi, and Onuzulike 2020; Gonzalez-Lopez et al. 2020; Jo, Chakraborty, and Kim 2016; Tian et al. 2015; Zukowski, de Andrade Silva, and Toledo Filho 2018).

Castoldi et al (2022) studied on physical-chemical properties of sisal fibers by alkaline treatment toward cement matrix. The study used 1, 5, and 10% NaOH solution concentrations for chemical, physical, thermal, surface characteristics, and wettability tests. The result of the study shows the enhancement of cellulose proportion with the reduction of sisal fiber hemicellulose and lignin through NaOH treatment. Also, this study found from wettability test results a drop in water uptake of the treated sisal fiber by 5% and 10% of NaOH compared to untreated sisal fiber, and single fiber tensile test result shows NaOH treatment enhanced the tensile strength of the sisal fibers. Besides these, due to alkaline treatment, the study found improved thermal stability, reduced water absorption, improved chemical compositions, and fiber bond with cement matrix observed on the employment of treated sisal fiber.

Furthermore, Hari and Mini (2019) reported that alkali treatment through hydrolysis of the sisal fiber in NaOH can change the fiber color from white to yellowish color (Zwane et al. 2019), which indicates the reaction of the fiber outer surface matrix and the alkaline showing the treatment of the fiber. Also, treating the fibers in NaOH solution enhances the waterproofing layer called the interface layer that increases the ability to limit the water absorption due to the permeability reduction of the internal pores, hence can lessen the capillary flow of internal water (de Azevedo, Marvila, Tayeh, et al. 2021).

Sisal fiber alkali treatment can significantly improve the mechanical properties of cementitious composite materials. However, sometimes composites reinforced with alkali-treated natural fibers reflected matrix cracking, weak fiber pull-out, and fiber breakage at the ends compared to the untreated natural fiber composite. Also, the long soaking time of the natural fibers in alkaline solution treatment can cause a reduction in the mechanical properties, especially tensile strength of the fiber (Ali-Boucetta et al. 2021; Chandrasekar et al. 2017), and similarly, treatment of natural fiber by higher alkaline solution content especially more than 20% NaOH can cause breakage of fiber structure, reduction of fiber area, lessen the amount of cellulose content, consequently can more reduce the tensile strength of the fiber also the cement composite matrix (de Klerk et al. 2020; Musanif and Thomas 2015).

Sisal treatment by pozzolana

The sisal fiber mineralization of the cell wall is the main cause of the degradation mechanism, leading to fiber embrittlement and lessening the strength capacity. Two mineralizations mechanisms of sisal fiber are generally observed. The first is CH^- mineralization, which makes cellulose corrosion mainly from the cement composite matrix, and the other is self-mineralization which may be caused by slight hydrolysis of the fiber part by moisture effect (Mármol et al. 2020; Wei and Meyer 2015). Also, Wei and Meyer (2016) reported mineralization is the main reason for natural fiber degradation in the cement matrix that due to alkali hydrolysis of the natural fiber amorphous part and cement hydration products in the cell wall of fiber, and the study found rice husk ash can mitigate the alkaline deterioration and mineralization effect on sisal fiber.

Consequently, the most promising treatment of sisal fiber is by pozzolanic materials to reduce calcium hydroxide content in the matrix, and the compound highly accelerates the deterioration of the thread. This technique requires the design of the matrix with the blending of Portland cement and amorphous natural pozzolana, which makes a hydration process at which a pozzolanic reaction can cause a reduction of calcium hydroxide contents (Filho, Silva, and Toledo Filho 2013). Also, the treatment method can facilitate the isolation of sisal fiber's various components, such as lignin, pectin, and hemicelluloses, with a change after treatment in the chemical properties of the fibers. Also, Priyadharshini & Ramakrishna (Priyadharshini and Ramakrishna 2018) found the treatment of sisal fiber by pozzolana has changed the color of the fiber from white to grayish, mainly due to the color of most of the calcined pozzolana having a grayish outlook. Behind these, silicon in natural pozzolana is an influential compound that treats natural fibers by actively participating in the mineralization of cementing materials, which causes the deterioration of natural fiber (Jaiswal et al. 2022; Li et al. 2021).

Wei and Meyer (2017) investigated the effect of cement composite materials having metakaolin and montmorillonite on the degradation of natural fiber. The study reported both metakaolin and montmorillonite mitigate fiber deterioration by improving the hydration product and lowering the alkalinity of the cement solution. Their data indicate the successful mitigation of natural fibers degradation due to cement hydration and fiber deterioration by mineralization and alkali hydrolysis of natural fibers.

Castoldi, de Souza, and de Andrade Silva (2019). studied the comparison of mechanical behavior and durability of polypropylene and sisal fiber reinforced concrete. The study designed a way to reduce the alkaline effect degradation of sisal fiber by treating 50% Portland pozzolana which is 30% metakaolin, and 20% fly ash. The study found both fibers increased the ductility of concrete and flexural performance under cyclic and monotonic loading conditions. Also, the treated sisal by pozzolanic materials shows the same level of residual strength compared with polypropylene fiber reinforced concrete, having the same doses of both fibers, which is due to the effectiveness of sisal fiber treatment by pozzolanic materials – the same observation with Barbosa da Silva Junior et al (da Silva Junior, de Souza, and de Andrade Silva 2021), as the treatment of sisal fiber through the substitution of 50% of Portland cement by pozzolana having 40% metakaolin and 10% fly ash has improved the mechanical properties of the fiber in cement composite materials.

Chandrasekaran (2015) studied the effect of micro-silica concrete with sisal fibers on concrete's mechanical and durability properties. The study used silica fume in amounts between 5% to 20% by the mass of the total cementitious material. The results found the immersion of sisal fiber in the silica fume slurry before employing them in the cement-based composites was an effective means of improving the strength of concrete. Hence, the partial substitution of ordinary Portland cement for silica fume was the beneficial approach in obtaining improved durability and deterioration reduction of natural fibers.

Besides these, treating sisal fiber by nanoclay can improve fiber properties, which assist sisal fiber can be used in cement composite materials. Hence, nano clay-treated sisal fibers reinforced with cement composite possess more thermal resistance and less water absorption capacity than untreated sisal fiber (Venkatram et al. 2016). A similar observation was reported by Fidelis et al. (2016). that treating sisal fiber with pozzolana, especially by metakaolin, can consume calcium hydroxide, decreases alkalinity, avoid fiber degradation, and make good bonding between fiber with cement matrix (Fidelis et al. 2016). Therefore, properly treating natural fiber and employing it in construction materials is more economical than synthetic fibers (Dinesh Kumar Raju, Balasubramanian, and Arul Jeya Kumar 2020).

The enhancement in concrete mechanical properties with treated sisal fiber is due to the solid fiber-matrix interfacial bond and a modification of sisal fiber that reduces the hydrophilic nature of the fiber (Mundim et al. 2020; Yadav et al. 2021). Also, More and Subramanian (2022) reported that natural fiber-reinforced concrete treated by pozzolana has many CSH gels compared to conventional concrete, which is used to improve the mechanical properties of cement composite materials (Ahad et al. 2018; Borg et al. 2018; Raggiotti, Positieri, and Oshiro 2018; Trümer et al. 2019; Voit et al. 2020). The sisal fiber's high water absorption capacity creates volume expansion when the fiber is added to the fresh cementitious matrix, and contraction of the matrix dries, which can cause a partial loss of physical contact with the matrix (Ferreira et al. 2015). Hence, untreated natural fiber can show less adhesion between the fiber and concrete matrix due to its high moisture absorption and low wettability, accelerating the degradation of natural fibers in cement composite. Therefore, it is better to improve the hydrophilic risk of the natural fiber by surface modification to improve concrete mechanical properties and enhance concrete matrix inter-facial bond (Ahmad, Hamid, and Osman 2019; Bashiri Rezaie et al. 2021; Srivastav, Behera, and Ray 2007).

Generally, the pozzolanic treatment of sisal fiber improves durability and mechanical properties. However, the use of pozzolanic treatment of sisal fiber blended with high employment of cement by more than 50% can cause the reduction of interface bond strength between the fiber and matrix (Wei and Meyer 2017). Besides these, the reduction of cement mineralization by the reaction of free calcium hydroxide and pozzolana depends on pozzolanic material reactivity property (Wei and Meyer 2016), which some of natural pozzolanic materials such as kaolin and bentonite need activation method since mostly exist as a consolidated form (Rehman et al. 2019).

Sisal fiber treatment on physical properties

Workability

Employing fiber to cement composite materials decreases the flow values compared to the flow of the control mixture (Ahmad et al. 2022; Fadhil and Yaseen 2016; Islam and Ahmed 2018; Priyadharshini and Ramakrishna 2019; Sugathan 2017; Zia and Ali 2017). Especially, employment of sisal fiber in cementing materials significantly reduces workability and in concrete can reduce the workability measured by the slump of concrete (Lima et al. 2018; Rahuman and Yeshika 2015; Shah et al. 2022) and also reduces with an increase in the content of sisal fiber in cement composite (Okeola, Abuodha, and Mwero 2018; Siva Bala and Vaisakh 2018; V 2017). The workability of treated sisal fiber shows a similar trend to that of untreated fibers through reducing the workability of cementing composite materials, and more significantly, workability decreases with increasing the doses of treated fiber to the cement composite, hence can be noted as increasing fiber contents increases cohesion of the composite (Priyadharshini and Ramakrishna 2018). Therefore, most recommended superplasticizers using natural fiber cannot influence the improvement of the strength of cement composite materials due to fiber addition (Anju, Ramamurthy, and Dhamodharan 2016).

Density

The addition of natural fibers to the cement composite materials lightens the composite compared to those without natural fiber, because the substitution of natural fiber takes the concrete places that lightens the cementing matrix, and this is crucial for the manufacturing of lightweight high-rise buildings (Achour, Ghomari, and Belayachi 2017; Barbuta et al. 2017; Ferreira et al. 2018; Khalid, Imran, et al. 2021; Ovalı and Sancak 2022; Vigneshwaran et al. 2020). Also, adding sisal fibers to the cement composite materials can reduce the density compared to the control mixtures (ALmusawi, Hussein, and Shallal 2018). As shown in Figure 2, adding 1% of sisal fiber significantly decreases the cementitious materials' density compared to the control mix, also increasing the content of the sisal fiber more reduces the density compared to the control mixture, which is basically the specific density of sisal fiber is much lower than the cement particles (Barbuta et al. 2017).

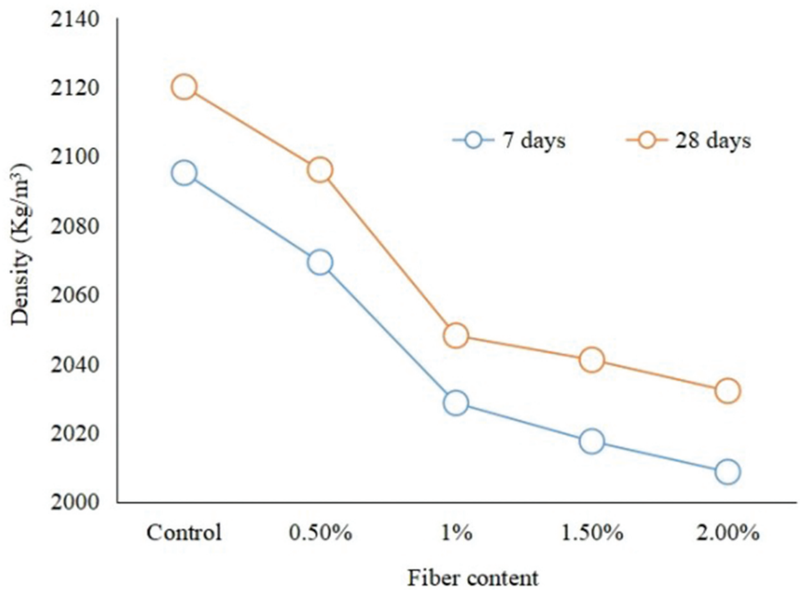

Figure 2. Effect of sisal fibers on the density of concrete by Okeola, Abuodha, and mwero (2018).

Sisal fiber treatment on mechanical properties

Compressive strength

Adding sisal fiber to the concrete can increase compressive strength (Afolayan, Wilson, and Zaphaniah 2019; ALmusawi, Hussein, and Shallal 2018; Rajkumar, Nirmala, and Vivekananthan 2022). Increasing the sisal fiber content improves the compressive strength of concrete (Bao et al. 2019; Bheel et al. 2021). Besides these, as shown in Figure 3 the addition of sisal fiber in concrete enhances the compressive strength, especially, the improvement is significantly observed at 1.5% employment compared to the addition of synthetic fibers steel, carbon, and glass in concrete. This is due to sisal fiber high bonding capacity with concrete matrix than synthetic fibers (More and Subramanian 2022). However, sisal fiber can degrade the initial strength through long term by moisture and mineralization in cement hydration, thus treating sisal fiber is crucial for its sustainable use. Also, as shown in Figure 4, the employment of sisal fiber significantly reduces the occurrence of cracks and defects in the concrete matrix by compressive forces, mainly due to the high tensile strength of sisal fiber that ties the concrete matrix and share the load carrying from the concrete.

Also, treated sisal fiber improves cement composite materials' compressive, tensile, and flexural strength (Abirami and Sangeetha 2022). Alkali treatment of sisal fiber with low concentrations of sodium hydroxide enhances the strength of the fiber and fiber-reinforced cement composite. However, higher concentrations of sodium hydroxide, which means more than 20% solution, significantly reduce the fiber strength (de Klerk et al. 2020). This reduction is mainly because the higher alkaline concentration damages the fiber cellulose matrix responsible for the natural fiber's strength. Treating the sisal fiber with pozzolanic materials like metakaolin and fly ash can improve compressive strength (Neves Junior et al. 2019), and also increases the treated sisal fiber content enhances the compressive strength of the composite materials, which indicates high toughness by increasing the sisal fiber content, which requires high energy to deform (Wei et al. 2018). Also, fiber orientation can be crucial in improving the mechanical properties of fiber-reinforced cement composite materials (Hari and Mini 2019). Also, the microstructure, chemical compositions, and cross-sectional area of natural fiber are other variables that influence the fiber and matrix's strength (Karimah et al. 2021). However, most properties of fiber-reinforced concrete are affected by fiber geometry, orientation,

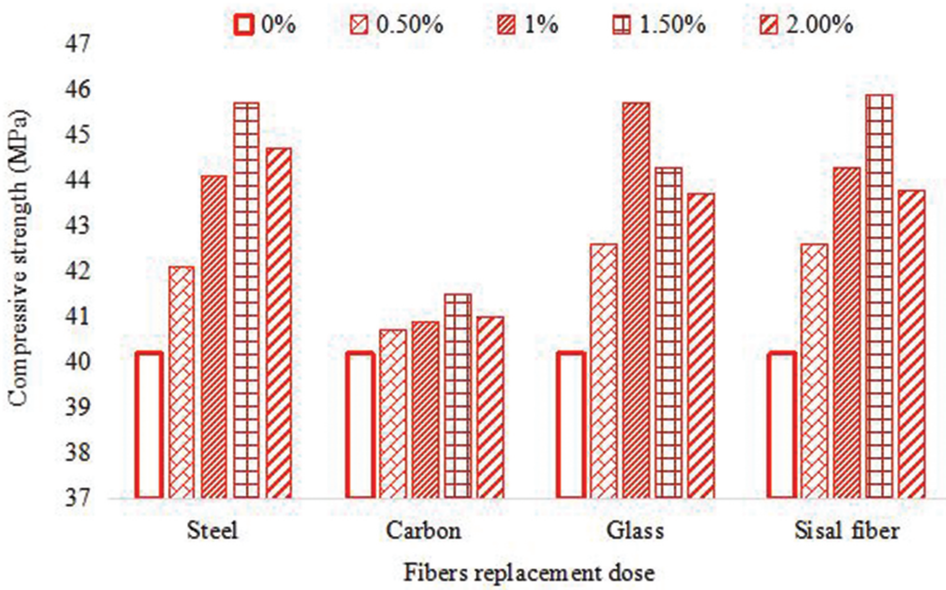

Figure 3. Compressive strength of 28 days concrete blended with different fibers by More and Subramanian (2022).

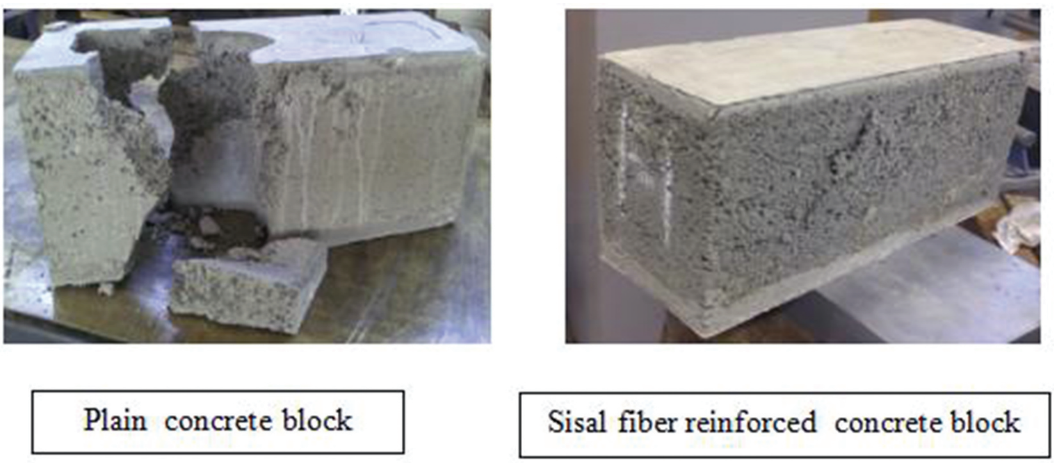

Figure 4. A sample of concrete blocks after compressive strength test by Soto Izquierdo et al (2017) permission Elsevier.

volume, and distribution of fiber (Panchangam 2015b), which can affect most properties of fiber reinforced concrete. Significantly, the homogeneous distribution of natural fiber in cement matrix is vital to improve the mechanical properties of cement mortar (Chakraborty, Kundu, Roy, Adhikari, et al. 2013; Chakraborty, Kundu, Roy, Basak, et al. 2013).

Adding sisal fiber improves cement composite materials' compressive strength, as presented in Table-1. Most studies reported the optimum compressive strength of cementing materials by adding 1–1.5% of sisal fiber to the cementing materials, as illustrated in Figure 5a. However, sisal fiber is moisture sensitive and degrades by mineralization with calcium hydroxide in cement hydration and can lose strength through the long-term ages in the cement composite materials. Thus, sisal fiber treatment with either pozzolanic materials or alkaline can improve sisal fiber degradation, and as shown in Figure 5b, treating sisal fiber with pozzolanic materials improves the compressive strength of

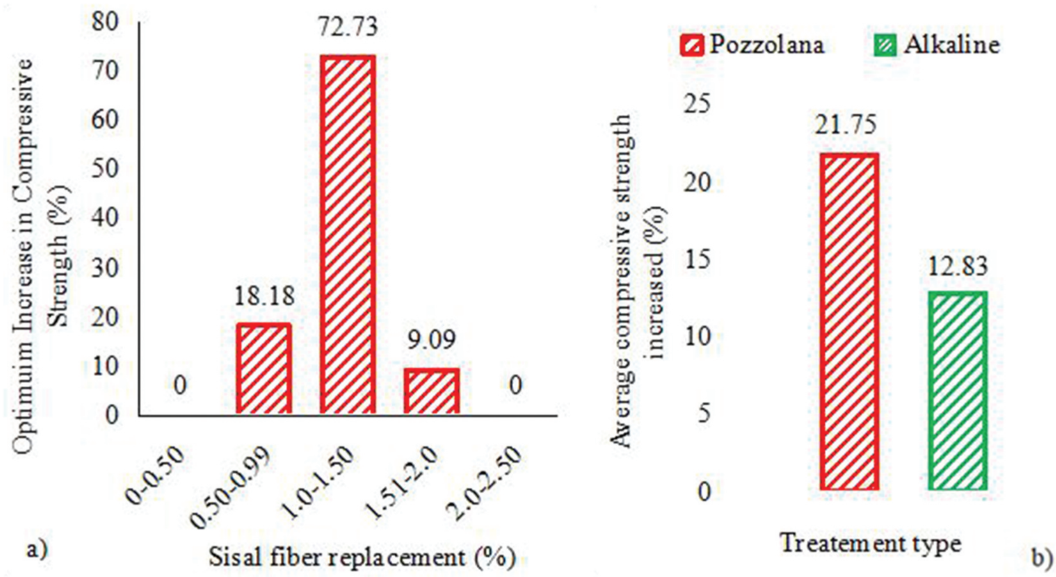

Figure 5. Summary of Table 1 (a) different doses of sisal fiber that give optimum compressive strength and (b) average compressive strength improvement by treated sisal fiber treated with pozzolanic materials and alkaline.

cement composite materials by 21.75% and alkaline treatment by 12.83% compared to the control mixture, this indicates pozzolanic treatment enhances the compressive strength of cement composite materials 69.52% more than alkaline treatment of sisal fiber. This enhancement difference is due to sisal treatment by alkaline which may affect the cellulose part of the fiber, which cannot increase the compressive strength of cement composite materials as much as that of sisal fiber treatment by pozzolanic materials.

Splitting tensile strength

More and Subramanian (2022) found incorporation of sisal fiber in cement composite materials enhance the splitting tensile strength more than the carbon and glass fibers, however, due to its moisture sensitivity the fiber may lose strength. So, surface treatment of natural fibers with alkali can improve the tensile strength of the fiber (Giri et al. 2018; Godara and Godara 2019), especially the treatment of sisal fiber by NaOH solution enhances fiber performance by increasing the tensile strength of the fiber compared to the untreated sisal fiber (Sahu and Gupta 2018; Zhang, Li, and Chen 2017), which is mainly treatment reduces the content of fiber impurities that can make loss of strength. Also, tensile strength increases with increasing fiber contents in the cement composite (Dilfi KF et al. 2018; Kaewkuk, Sutapun, and Jarukumjorn 2013). Besides these, the solution of $NaHCO_3$ can be used to treat sisal fiber, increasing the split tensile strength of the sisal fiber (Benkhelladi, Laouici, and Bouchoucha 2020).

The incorporation of sisal fiber improves the splitting tensile strength of cement composite materials, as presented in Table 2. Also, as shown in Figure 6a, many studies reported the use of sisal fiber dose in the range of 1–1.5% gives optimum split tensile strength of cement composite materials. It has been observed that a minimum quantity doses of sisal fiber cannot significantly change the splitting tensile strength of cement composite materials. However, natural fiber diameter and aspect ratio (length-to-diameter) are other essential parameters affecting the fiber and fiber-reinforced cement composite's tensile strength and mechanical properties (Gudayu et al. 2022).

Table 1. Effect of sisal fiber employment on compressive strength of cement composite materials by different researchers.

W/C	Doses to volume (%)	Optimum CS doses (%)	CS increased (%)	Length (mm)	Treated/ Untreated	Treated by	References
0.38	0,0.50,0.75,1	1	4.04	—	Untreated	—	(Abirami et al. 2020)
0.57	0,0.80,1.40,2	0.80	2.11	6	Untreated	—	[214]
0.45	0,0.5,1,1.5,2,2.5	1.5	14.18	40	Untreated	—	(Voit et al. 2020)
0.40	0,2	2	14.90	12	Untreated	—	(Palanisamy and Ramasamy 2022)
0.20	1,2,3	1	15.50	18	Treated	28% silica fume to the binder	(Beskopylny et al. 2022)
—	0.5,1,1.5,2	1.5	45	12	Treated	Fly ash to the concrete mixture	(Chopra and Razahi 2020)
0.45	0.5,1,1.5,2	1.5	3.5	50	Treated	10% silica fume to the concrete	(P. R. L. Lima et al. 2018)
0.43	0.6, 1.2,1.8	1.2	23	40	Treated	30% Metakaolin to the binder	(Priyadharshini and Ramakrishna 2019)
0.40	0,0.25,0.50, 0.75,1	0.75	18.26	—	Treated	5% Na_2SO_4	(Venkatram et al. 2016)
0.45	0.5,1,1.5,2,2.5	1.5	40.15	—	Untreated	—-	(Panchangam 2015a)
0.42	0.5,1,1.5,2	1	7.39	37.5	Treated	Na_2CO_3	(Abirami and Sangeetha 2022)

Table 2. Effect of sisal fiber employment on split tensile strength of cement composite materials by different researchers.

W/C	Doses to volume (%)	Optimum TS doses (%)	TS increased (%)	Length (mm)	Treated/ Untreated	Treated by	References
0.38	0,0.50,0.75,1	1	12.69	—	Untreated	—	(Abirami et al. 2020)
0.40	0,2	2	37.19	12	Untreated	—	(Palanisamy and Ramasamy 2022)
—	0.5,1,1.5,2	1.5	45	12	Treated	Fly ash to the concrete	(Chopra and Razahi 2020)
0.45	0.5,1,1.5,2	1.5	35.70	50	Treated	10% silica fume to the concrete	(P. R. L. Lima et al. 2018)
0.45	0,1.5	1.5	9.01	40	Untreated	—	(Voit et al. 2020)
0.40	0,0.25,0.5,0.75,1	0.75	17.62	—	Treated	5% Na_2SO_4	(Venkatram et al. 2016)
0.47	0.5,1,1.5,2	1.00	47.23	30	Untreated	—-	(V 2017)
0.45	0.5,1,1.5,2,2.5	1.5	38.89	—	Untreated	—	(Panchangam 2015a)
0.43	0.6,1.2, 1.8	1.2	28.90	40	Treated	30% Metakaolin to the binder	(Priyadharshini and Ramakrishna 2019)
0.50	0,0.5,1, 1.5	1	11.80	30	Untreated	—	(Zia and Ali 2017)
0.42	0.5,1,1.5,2	1	12.23	37.5	Treated	Na_2CO_3	(Abirami and Sangeetha 2022)

Barra et al. (2015) reported accelerated aging tests of treated and untreated sisal. The study found that untreated sisal fiber loses ultimate tensile strength compared to chemically treated sisal fiber. In addition to these, as presented in Figure 6b, sisal fiber treatment enhances the split tensile strength of cementing materials; however, as most of the studies found, treatment by pozzolanic materials improves the split tensile strength of cement composite materials by 144.84% compared to alkaline sisal fiber treatment, which is due to alkaline treatment can lightly damage the matrix of fiber cellulose which required for strength.

Generally, natural fibers carry tensile stresses. Hence, the cement matrix can transfer load among the fibers and enhance the cement composite's long-term durability through fiber coating to improve the adhesion with the cement composite materials matrix (de Carvalho Bello et al. 2019).

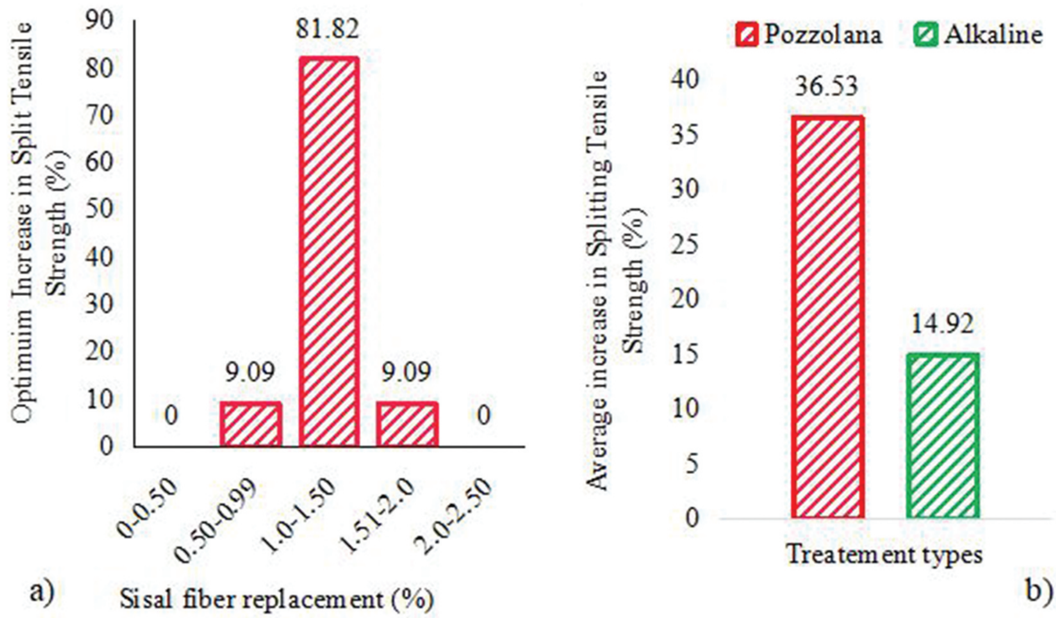

Figure 6. Summary from Table 2, (a) different doses of sisal fiber that give optimum split tensile strength and (b) average split tensile strength improvement by treated sisal fiber through pozzolanic materials and alkaline.

Flexural strength

Employing natural fibers in the cement composite material improves flexural strength compared to the control mixture (Da Fonseca, Rocha, and Cheriaf 2021; Hasan et al. 2023; Lima et al. 2017; Orue, Eceiza, and Arbelaiz 2018; Salih et al. 2019). More and Subramanian (2022) reported employment of sisal fiber in concrete can enhance the flexural strength of concrete compared to the employment of steel, glass, and jute fibers. Also, adding sisal fiber to cement composite material increases ductility with increasing fiber content (Huang and Rodrigue 2022; Panchangam 2015a). Hence as shown in Table 3, adding sisal fiber can significantly improve flexural strength. Especially as many studies reported in Figure 7, adding 1–1.5% of sisal fiber can give optimum flexural strength of cement composite materials compared to the control mixture. Besides these, the employment of treated sisal fiber improves the flexural strength of cementitious material compared to untreated cement composite materials (Agor, Mbadike, and Alaneme 2023; Ramakrishna and Sundararajan 2018). Also, fibers treated through alkali by NaOH improved deformation at the break values (Orue et al. 2015) and

Table 3. Effect of sisal fiber employment on flexural strength of cement composite materials by different researchers.

W/C	Doses to volume (%)	Optimum FS doses (%)	FS increased (%)	Length (mm)	Treated/ Untreated	Treated by	References
0.38	0, 0.50, 0.75, 1	1	3.08	—	Untreated	—	(Abirami et al. 2020)
0.40	0,2	2	84.70	12	Untreated	—	(Palanisamy and Ramasamy 2022)
0.45	0,1.5	1.5	13.79	40	Untreated	—	(Voit et al. 2020)
0.20	1, 2, 3	2	16.70	18	treated	28% silica fume to the binder	(Beskopylny et al. 2022)
0.43	0.6, 1.2,1.8	1.2	44.6	40	treated	30% Metakaolin to the binder	(Priyadharshini and Ramakrishna 2019)
0.45	0.5, 1, 1.5, 2, 2.5	1.5	68.58	—	Untreated	—	(Panchangam 2015a)

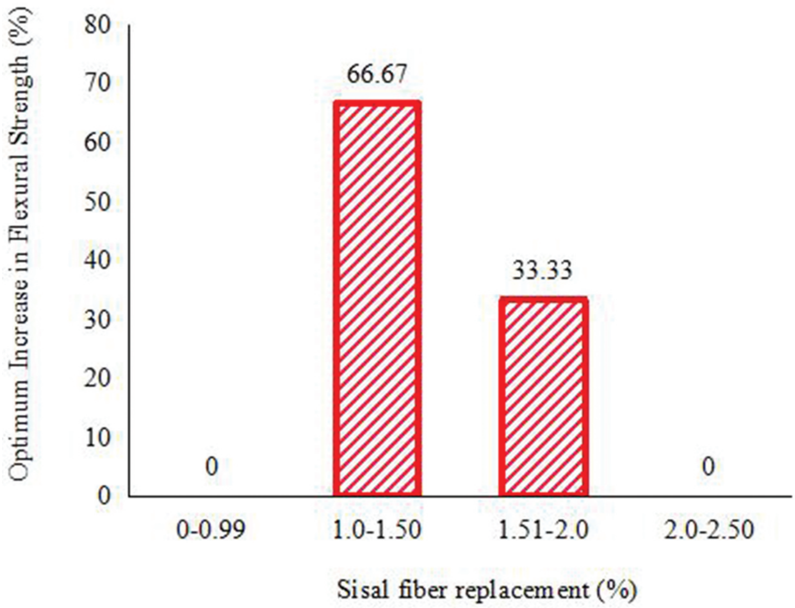

Figure 7. Summary from Table 3, different doses of sisal fiber that give optimum flexural strength.

enhanced cement composite materials' toughness and flexural strength of cement composite materials (Boumaaza, Belaadi, and Bourchak 2021; de Klerk et al. 2020; Godara and Godara 2019; Meenakshi and Krishnamoorthy 2019).

Also, treating sisal fiber with pozzolanas like nanoclay and metakaolin removes the portlandite phase and enhances the content of calcium silicate hydrates. Hence, the interfacial bond between the fiber and cement composite matrix improves the flexural properties of the fiber and cement composite materials. This increase in the interfacial bond indicates that the treatment of sisal fiber by nanoclay and metakaolin effectively enhances the adhesion between the cement matrix and sisal fiber (Wei and Meyer 2014c). Therefore, the flexural strength of cement composites with treated sisal fiber is higher than untreated fiber composites, because alkali treatment of fibers reduce the content of hemicellulose, lignin, and other impurities, from the fiber surface and make improvement in the fiber-matrix bonding and fiber wetting characteristics (Maichin et al. 2020; Raja et al. 2021).

Generally, employing sisal fiber as concrete reinforcement is beneficial for improving the mechanical properties of the concrete matrix (Castoldi, de Souza, and de Andrade Silva 2019). Significantly, sisal fiber enhances the compressive, split tensile, and flexural strength of concrete than some of the synthetic fibers, hence, it can radically reduce the environmental pollution and can make cost effective concrete productions than reinforcing of synthetic fibers.

Sisal fiber treatment on durability

Water absorption

Water absorption of natural fibers is closely related to the dimensional stability of the fiber (Santos et al. 2021), i.e., dimensional variation of natural fiber by the change in moisture condition or water absorption is one of the main reasons that lessen the adhesion between cement composite and fiber (Ferreira et al. 2014). Also, water absorption and moisture present in the concrete effectively react with untreated natural fibers and cause the degradation of the fibers, leading to the occurrence of voids and pores in the concrete matrix, which can directly affect the strength and durability of the concrete (S. Kumar, Tilak, and Dutta 2017; More and Subramanian 2022; Wei and Meyer 2015). Besides these, the hydrophilicity of natural fiber causes water absorption because of the capillary action of the fiber micro-pores (Dilfi KF et al. 2018). Hence, alkali's interfacial modification of natural fibers reflects a significant reduction in water absorption (Kaewkuk, Sutapun, and Jarukumjorn 2013; Ogunbode et al. 2022).

Also, adding pozzolana on the surface of sisal fiber can serve as a medium barrier for water absorption of the fiber. Hence, it can delay the water uptake time by directly reducing water absorption and fiber degradation (Kanny and TP 2013; Mohan and Kanny 2012). This delay in water uptake due to the treatment of sisal fiber reduces the hemicellulose and lignin chemical compounds (Ferreira et al. 2017; Mokaloba and Batane 2014). Therefore, minimizing those compounds improves the fiber's mechanical properties. It increases the crystallinity of the cellulose, the chemical bond of the acetyl group, which can reduce the water absorption of the fiber (Ferreira et al. 2017).

Rapid chloride ion permeability

Incorporating natural fibers in concrete enhances the chloride ion migration in the concrete matrix. That is due to more pores and voids formation in the concrete matrix through the swelling and shrinkage abilities of untreated natural fibers by moisture and water, which allow chloride ion migration in the pores (More and Subramanian 2022). The same observation with Nambiar and Haridharan (Afroz, Patnaikuni, and Venkatesan 2017; Nambiar and Haridharan 2020) as concrete chloride penetration of spacemen with natural fibers is relatively higher compared to the control mixture. However, surface treatment of natural fibers lessens the surface pores of the fiber, which can protect the migration of chloride ions in the cement composite materials. Therefore, using alkaline or pozzolana treated sisal fiber in cement composite materials significantly reduces the chloride ion migration compared to untreated sisal fiber in cementing materials.

Acidic attack and thermal resistance

Natural fibers have higher weight loss to acidic attack than synthetic fibers due to the formation of pores to the degradation of natural fibers in acidic environments (More and Subramanian 2022). However, the surface treatment of natural fibers significantly improves the acidic attack resistance in concrete; mainly due to the surface treatment of the fibers by alkaline or pozzolana which can enhance the interface bond of fibers with matrix, which bound the penetration of acids to the concrete (Wei and Meyer 2014b). Therefore, incorporating treated sisal fiber in cement composite materials improves the acidic attack of cementing materials when using untreated sisal fiber. So as shown in Figure 8, before and after immersion in sulfate solution, sisal fibers employed in cementing material coated by 10% silica have more compressive strength than the control mix, which is mainly due to silica which has the micro-filling capability that fills the pore surface of sisal fiber and cement matrix.

Generally, the use of treated sisal fiber for the reinforcement of cement composite materials significantly increases the durability and mechanical properties of cement composite materials compared to untreated sisal fiber (de Klerk et al. 2020; Padanattil, Jayanarayanan, and Mini 2017).

The treated natural fiber has better thermal resistance than untreated natural fiber (Belayachi, Hoxha, and Ismail 2017; Lahouioui et al. 2020). Significantly, the treatment of sisal fiber by NaOH can reflect improved thermal resistance compared to untreated sisal fiber (Bahja et al. 2021). As presented in Figure 9, alkaline-treated sisal fiber has higher thermal resistance than untreated sisal fibers. The treatment of sisal fiber reduces water absorption and makes a stable material for thermal changes. Also, sisal fiber alkali treatment significantly improves thermal stability, making an excellent inter-facial interface compared to untreated sisal fiber (Gudayu et al. 2022). However, the change in sisal fiber thermal stability characteristics mainly depends on alkali treatment conditions and immersion time (Chandrasekar et al. 2017). Also, using natural pozzolana for natural fibers treatment can significantly reduce mass

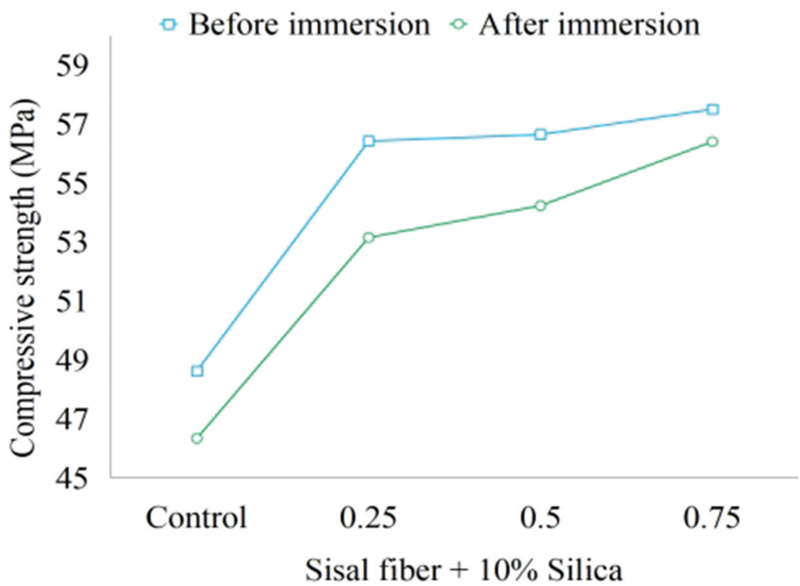

Figure 8. Compressive strength of silica+sisal fiber concrete before and after immersion in sulfate solution by Chandrasekaran (2015).

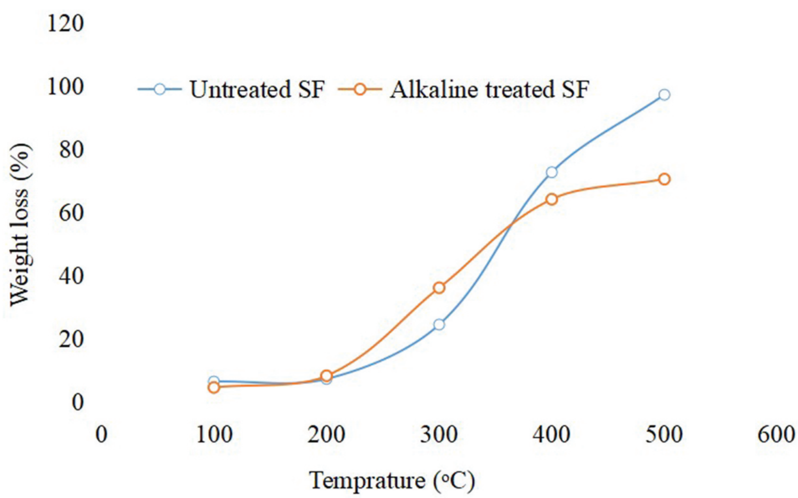

Figure 9. TGA graph of untreated, alkaline treated, and alkaline treated plus coated sisal fiber by Sahu and Gupta (2018).

loss by thermal effect, hence improving the durability of the fiber (da Silva et al. 2017; Jirawattanasomkul et al. 2020) compared with untreated sisal fiber.

Generally, effective treatment of sisal fiber reduces the degradation of the fiber. Specially treated sisal fiber by replacing pozzolanic material in the Portland cement mainly enhances the durability of cement composite material (Wei and Meyer 2015).

Sisal fiber treatment on microstructural property

The microstructure of treated sisal fiber by alkali modification shows enhancement of cellulose exposure that can facilitate the fiber matrix interlocking and improve adhesion characteristics

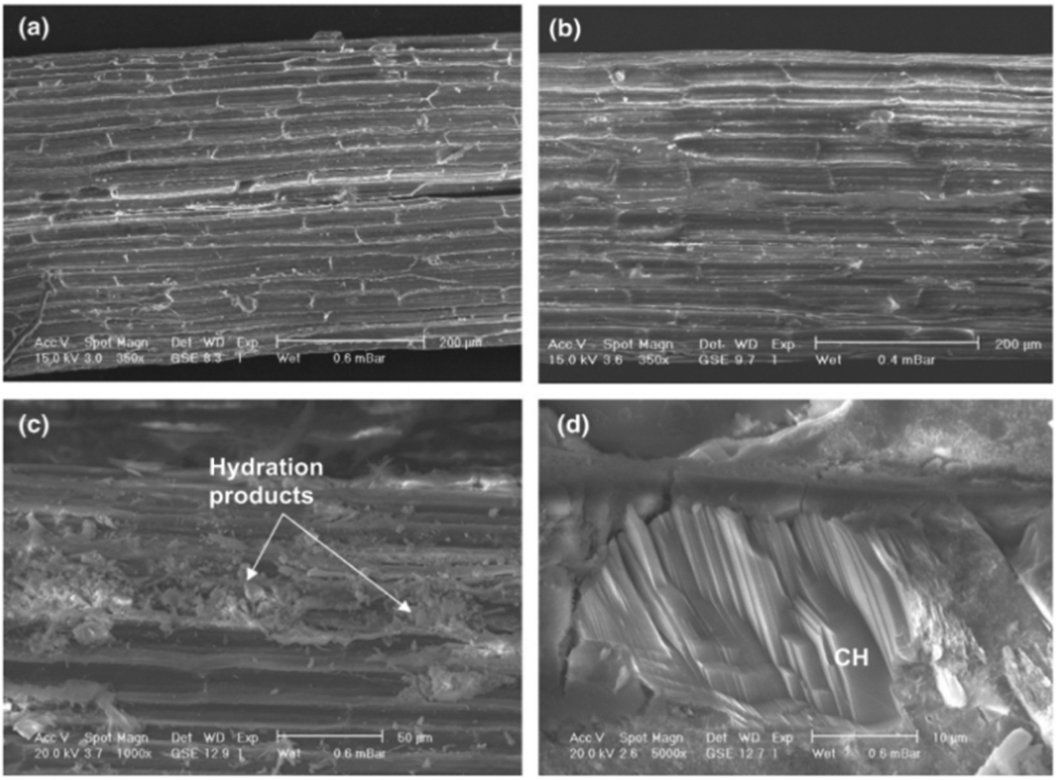

Figure 10. The effect of the wetting and drying cycles on the sisal fiber surface: (a) reference, (b) fiber extracted from a PC–MK matrix after 25 cycles, (c and d) fiber extracted from a PC matrix after 25 cycles by Filho, Silva, and Toledo Filho (2013) permission Elsevier.

compared to untreated sisal fiber (Mokaloba and Batane 2014; Naveen et al. 2018). Micro-structure indicates improved fiber adhesion matrix compared to untreated sisal fiber in cement composite (Orue et al. 2015). Hence, the improved interface enables the load transfer between the fibers and the cement composite materials (Malenab, Ngo, and Promentilla 2017).

As shown in Figure 10(a–d), a high deterioration of the untreated sisal fibers embedded in the Portland cement compared to the ones treated with pozzolana meta-kaolin, indicating the importance of sisal fiber surface treatment. This is mainly due to the surface treatment of natural fiber by pozzolana promoting hydration reduction and improving the overall composite strength by enhancing the fiber matrix's compatibility through strengthening the fiber bond with the matrix (Arsyad 2017; Jo and Chakraborty 2015; Pinto et al. 2013).

Also, Wei and Meyer (2014c) reported the fracture surfaces of macro and micro-analysis of fiber-reinforced cement composite after flexural test shows treatment of sisal fiber by partially substituting pozzolana to Portland cement improves interface bonding between the fiber and the matrix significantly. Additionally, it can be used for preventing sisal fiber from deterioration by the alkaline attack and cement calcium hydroxide mineralization.

Besides these Orue, Eceiza, and Arbelaiz (2018), found the mechanism of untreated sisal fiber pulled out due to poor interfacial adhesion between fibers and cement composite. The study also reported that it was challenging to distinguish the fibers in the microstructure of alkaline-treated sisal fiber used in cement composite materials by pulling them out from the matrix. This further indicates the improvement of the fiber surface bonding with cement composite due to alkaline treatment.

The natural fiber's rougher surface improves the mechanical interlocking adhesion between the fibers and the cement composite matrix (Pinto et al. 2013; F. Zhou, Cheng, and Jiang 2014). Specifically, the

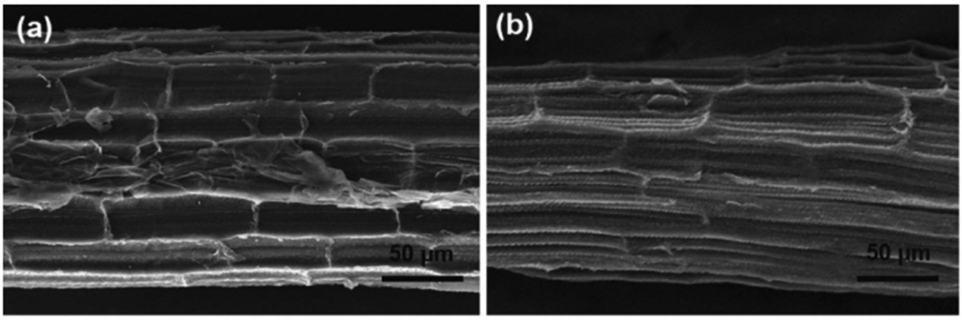

Figure 11. SEM micrographs of (a) untreated, (b) alkali-treated sisal fiber by Z. Zhang et al. (2020) permission Elsevier.

alkali-treated sisal fiber appears to have a more uneven surface than untreated cement composite materials (Motaung et al. 2017). Figures 11a & 11b shows that alkali treatment of sisal fiber have cleared the impurities between the untreated sisal fiber matrix. However, the high-concentration alkaline chemical treatment can damage the fiber's cellulose and hence causes some signs of surface deterioration (Dantas et al. 2019).

Mahjoub et al (2014) reported that the surface morphology of natural fiber treated with alkali shows a clean and rough fiber surface which is crucial for the interfacial bond of natural fiber and cement composite materials. However, the excellent interface depends on fiber length, adhesion, reduction of fiber hydrophilic characteristics, fiber orientation with matrix, and cellulose content (Rocha et al. 2022).

Generally, the surface treatment of natural fiber can improve mechanical, adhesion, and hydrophobic properties between fiber and cement matrix (Ravi et al. 2018). Primarily fiber treatment by alkaline is mainly used. However, this treatment has a drawback on the increased environmental pollution, chemical production cost, and harmful chemical compounds that need careful handling of the fiber treatment (Akinyemi and Adesina 2021; Burrola-Núñez et al. 2019; Koohestani et al. 2019). Also, compared with the chemical treatment, physical treatment offers improved characteristics of the natural fiber composites (Vigneshwaran et al. 2020), and a higher concentration of 20–30% of NaOH causes damage to the fiber structure (de Klerk et al. 2020).

Conclusions

The review of various studies revealed the crucial effect of sisal fiber treatment, either alkaline or pozzolana. Based on a comprehensive review, the following points have been concluded.

- Employment of 1-1.5% amount of sisal fiber treated by alkaline or pozzolana reduces workability and improves the mechanical properties of cement composite materials.
- The treatment of sisal fiber with pozzolanic materials enhances the compressive strength and splitting tensile strength of cementing materials by 69.52% and 144.84%, respectively, compared to sisal fiber treated with alkaline, which is due to the alkaline treatment can damage the cellulose matrix responsible for handling of compressive and tensile strength.
- Using alkaline or pozzolana-treated sisal fiber significantly reduces fiber water absorption capacity. It enhances the thermal resistivity of the fiber, acidic attack, and chloride ion migration resistances compared with the incorporation of untreated sisal fiber in cement composite materials.
- The microstructure of treated sisal fiber, either by alkaline or pozzolana, shows improved fiber adhesion matrix, rougher fiber surface, and less deterioration due to alkaline attack and cement calcium hydroxide mineralization. However, the high concentration of the alkaline solution,

specifically, many studies found more than 20% of alkaline solution causes the deteriorated fiber surface, hence can reduce the mechanical properties and durability of sisal fiber for cement composite.

Generally, from the reviewed studies, the alkaline treatment improves mechanical, hydrophobic, and adhesion properties between fiber and cement matrix compared to the employment of untreated sisal fiber in cement composite materials. However, there is a drawback to the disposal of alkaline chemicals that increase environmental pollution, chemical production cost, and harmful chemical compounds that need careful handling of the fiber treatment.

Future perspective

The present study comprehensively reviewed the treatment of sisal fiber by alkaline treatment mostly NaOH and $NaHCO_3$, also by pozzolanic treatment mainly metakaolin, fly ash, silica fume, and nanoclay. So, other materials classified in alkaline and pozzolana need detail investigation for to be used in sisal fiber degradation treatment for more effective implementation of sisal fiber in any cement composite materials, which is also more seeking profound analysis of chemical composition changes in the fiber due to both treatments. Another consideration is that many researchers focused on using treated sisal fiber by alkaline or pozzolana for plain concrete. However, it is more beneficial to consider concrete structural elements such as beams, columns, slabs, or stairs in composite with steel. This may be done by optimization methods to get a proper mix design of steel versus treated sisal fiber to reduce construction materials' cost and improve concrete performance.

Highlights

- Alkaline and pozzolana treatment methods significantly improves sisal fiber degradation and moisture sensitivity.
- Treatment of sisal fiber by pozzolanic material increases strength than alkaline treatment.
- Higher concentration of alkaline used for sisal fiber treatment can damage cellulose matrix.
- Treated sisal fiber by alkaline or pozzolana have higher adhesion matrix than untreated sisal fiber.

Abbreviations

CS	Compressive Strength
TS	Tensile Strength
FS	Flexural Strength
W/C	Water to Cement

Acknowledgments

The authors are thankful to the Partnership for Applied Sciences, Engineering, and Technology (PASET) - Regional Scholarship and Innovation Fund (RSIF) for the support of this study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Tsion Amsalu Fode http://orcid.org/0000-0002-9186-6517

Yusufu Abeid Chande Jande http://orcid.org/0000-0002-0106-2081
Thomas Kivevele http://orcid.org/0000-0003-4539-6021

References

Abbass, W., M. I. Khan, and S. Mourad. 2018. "Evaluation of Mechanical Properties of Steel Fiber Reinforced Concrete with Different Strengths of Concrete." *Construction and Building Materials* 168:556–569. https://doi.org/10.1016/j.conbuildmat.2018.02.164.

Abbass, A., P. B. Lourenço, and D. V. Oliveira. 2019. "The Use of Natural Fibers in Repairing and Strengthening of Cultural Heritage Buildings." *Materials Today: Proceedings* 31:S321–S328. https://doi.org/10.1016/j.matpr.2020.02.206.

Abirami, R., and S. P. Sangeetha. 2022. "Effect of Surface Modification on the Characteristics of Sisal Fiber Reinforced Concrete Treated with Na2CO3." *Nature Environment & Pollution Technology* 21 (1): 289–295. https://doi.org/10.46488/NEPT.2022.v21i01.034.

Abirami, R., S. P. Sangeetha, K. Nadeemmishab, P. Y. Vaseem, and K. S. Sad. 2020. "Experimental Behaviour of Sisal and Kenaf Fibre Reinforced Concrete." *AIP Conference Proceedings* 2271. https://doi.org/10.1063/5.0024771.

Achour, A., F. Ghomari, and N. Belayachi. 2017. "Properties of Cementitious Mortars Reinforced with Natural Fibers." *Journal of Adhesion Science and Technology* 31 (17): 1938–1962. https://doi.org/10.1080/01694243.2017.1290572.

Acosta-Calderon, S., P. Gordillo-Silva, N. García-Troncoso, D. V. Bompa, and J. Flores-Rada. 2022. "Comparative Evaluation of Sisal and Polypropylene Fiber Reinforced Concrete Properties." *Fibers* 10 (4): 1–18. https://doi.org/10.3390/fib10040031.

Adekomaya, O., and T. Majozi. 2019. "Sustainability of Surface Treatment of Natural Fibre in Composite Formation: Challenges of Environment-Friendly Option." *The International Journal of Advanced Manufacturing Technology* 105 (7–8): 3183–3195. https://doi.org/10.1007/s00170-019-04581-6.

Afolayan, J. O., U. N. Wilson, and B. Zaphaniah. 2019. "Effect of Sisal Fibre on Partially Replaced Cement with Periwinkles Shell Ash (PSA) Concrete." *Journal of Applied Sciences and Environmental Management* 23 (4): 715. https://doi.org/10.4314/jasem.v23i4.22.

Afroughsabet, V., and T. Ozbakkaloglu. 2015. "Mechanical and Durability Properties of High-Strength Concrete Containing Steel and Polypropylene Fibers." *Construction and Building Materials* 94:73–82. https://doi.org/10.1016/j.conbuildmat.2015.06.051.

Afroz, M., I. Patnaikuni, and S. Venkatesan. 2017. "Chemical Durability and Performance of Modified Basalt Fiber in Concrete Medium." *Construction and Building Materials* 154:191–203. https://doi.org/10.1016/j.conbuildmat.2017.07.153.

Agor, C. D., E. M. Mbadike, and G. U. Alaneme. 2023. "Evaluation of Sisal Fiber and Aluminum Waste Concrete Blend for Sustainable Construction Using Adaptive Neuro-Fuzzy Inference System." *Scientific Reports* 13 (1): 2814. https://doi.org/10.1038/s41598-023-30008-0.

Ahad, M. Z., M. Ashraf, R. Kumar, and M. Ullah. 2018. "Thermal, Physico-Chemical, and Mechanical Behaviour of Mass Concrete with Hybrid Blends of Bentonite and Fly Ash." *Materials-MDPI* 12 (1): 60. https://doi.org/10.3390/ma12010060.

Ahmad, J., M. M. Arbili, A. Majdi, F. Althoey, A. F. Deifalla, and C. Rahmawati. 2022. "Performance of Concrete Reinforced with Jute Fibers (Natural Fibers): A Review." *Journal of Engineered Fibers and Fabrics* 17:155892502211218. https://doi.org/10.1177/15589250221121871.

Ahmad, W., S. H. Farooq, M. Usman, M. Khan, A. Ahmad, F. Aslam, R. Alyousef, H. Al Abduljabbar, and M. Sufian. 2020. "Effect of Coconut Fiber Length and Content on Properties of High Strength Concrete." *Materials (Basel)* 13 (5): 1075. https://doi.org/10.3390/ma13051075.

Ahmad, R., R. Hamid, and S. A. Osman. 2019. "Physical and Chemical Modifications of Plant Fibres for Reinforcement in Cementitious Composites." *Advances in Civil Engineering* 2019:1–18. https://doi.org/10.1155/2019/5185806.

Akash, K. G. G., N. S. Venkatesha Gupta, and K. V. Sreenivas Rao. 2017. "A Study on Flammability and Moisture Absorption Behavior of Sisal/Coir Fiber Reinforced Hybrid Composites." *IOP Conference Series: Materials Science & Engineering* 191:012003. https://doi.org/10.1088/1757-899X/191/1/012003.

Akinyemi, B. A., and A. Adesina. 2021. "Utilization of Polymer Chemical Admixtures for Surface Treatment and Modification of Cellulose Fibres in Cement-Based Composites: A Review." *Cellulose* 28 (3): 1241–1266. https://doi.org/10.1007/s10570-020-03627-3.

Akinyemi, A. B., E. T. Omoniyi, and G. Onuzulike. 2020. "Effect of Microwave Assisted Alkali Pretreatment and Other Pretreatment Methods on Some Properties of Bamboo Fibre Reinforced Cement Composites." *Construction and Building Materials* 245:118405. https://doi.org/10.1016/j.conbuildmat.2020.118405.

Ali-Boucetta, T., A. Ayat, W. Laifa, and M. Behim. 2021. "Treatment of Date Palm Fibres Mesh: Influence on the Rheological and Mechanical Properties of Fibre-Cement Composites." *Construction and Building Materials* 273:121056. https://doi.org/10.1016/j.conbuildmat.2020.121056.

Ali, S., N. Jain, and V. K. Singh. 2017. "Review on Mechanical Properties of Sisal Fibre Reinforced Composites." *Proceedings of AETSD* 1:1–3.

Ali, A., K. Shaker, Y. Nawab, M. Jabbar, T. Hussain, J. Militky, and V. Baheti. 2018. "Hydrophobic Treatment of Natural Fibers and Their Composites—A Review." *Journal of Industrial Textiles* 47 (8): 2153–2183. https://doi.org/10.1177/1528083716654468.

ALmusawi, A. M., T. S. Hussein, and M. A. Shallal. 2018. "Effect of Temperature and Sisal Fiber Content on the Properties of Plaster of Paris." *International Journal of Engineering and Technology* 7 (4.20): 205. https://doi.org/10.14419/ijet.v7i4.20.25927.

Althoey, F., O. Zaid, A. Majdi, F. Alsharari, S. Alsulamy, and M. M. Arbili. 2023. "Effect of Fly Ash and Waste Glass Powder As a Fractional Substitute on the Performance of Natural Fibers Reinforced Concrete." *Ain Shams Engineering Journal* 14 (12): 102247. https://doi.org/10.1016/j.asej.2023.102247.

Amiandamhen, S. O., M. Meincken, and L. Tyhoda. 2018. "The Effect of Chemical Treatments of Natural Fibres on the Properties of Phosphate-Bonded Composite Products." *Wood Science and Technology* 52 (3): 653–675. https://doi.org/10.1007/s00226-018-0999-9.

Anju, T. R., K. Ramamurthy, and R. Dhamodharan. 2016. "Surface Modified Microcrystalline Cellulose from Cotton As a Potential Mineral Admixture in Cement Mortar Composite." *Cement and concrete composites* 74:147–153. https://doi.org/10.1016/j.cemconcomp.2016.09.003.

Arshad, S., M. Burhan, S. Muhammad, H. Mehran, K. Jiao, and L. Zhang. 2020. "Efficiency of Supplementary Cementitious Materials and Natural Fiber on Mechanical Performance of Concrete." *Arabian Journal for Science & Engineering* 45 (10): 8577–8589. https://doi.org/10.1007/s13369-020-04769-z.

Arsyad, M. 2017. "Effect of Alkali Treatment on the Coconut Fiber Surface." *ARPN Journal of Engineering Applied Science* 12:1870–1875. https://doi.org/10.1016/j.matpr.2023.03.466.

Aruna, M. 2014. "Mechanical Behaviour of Sisal Fibre Reinforced Cement Composites." *World Academies of Sciences, Engineering* 8:650–653. http://www.waset.org/publications/9997869.

Asaduzzaman, S. M., and G. M. S. Islam. 2023. "Using Jute Fiber to Improve Fresh and Hardened Properties of Concrete." *Journal of Natural Fibers* 20 (2). https://doi.org/10.1080/15440478.2023.2204452.

Asim, M., G. M. Uddin, H. Jamshaid, A. Raza, Z. Ul Rehman, U. Hussain, A. N. Satti, N. Hayat, and S. M. Arafat. 2020. "Comparative Experimental Investigation of Natural Fibers Reinforced Light Weight Concrete As Thermally Efficient Building Materials." *Journal of Building Engineering* 31:101411. https://doi.org/10.1016/j.jobe.2020.101411.

Bahja, B., A. Elouafi, A. Tizliouine, and L. H. Omari. 2021. "Morphological and Structural Analysis of Treated Sisal Fibers and Their Impact on Mechanical Properties in Cementitious Composites." *Journal of Building Engineering* 34:102025. https://doi.org/10.1016/j.jobe.2020.102025.

Bao, H., H. Meng, W. You, and F. Qin. 2019. "Study on the Corrosion Resistance of Sisal Fiber Concrete in Marine Environment." *SN Applied Sciences* 1 (12): 1–6. https://doi.org/10.1007/s42452-019-1551-8.

Barbuta, M., A. A. Serbanoiu, R. Teodorescu, B. Rosca, R. Mitroi, and G. Bejan. 2017. "Characterization of Polymer Concrete with Natural Fibers." *IOP Conference Series: Materials Science & Engineering* 246:012033. https://doi.org/10.1088/1757-899X/246/1/012033.

Barra, B. N., S. F. Santos, P. V. A. Bergo, C. Alves, K. Ghavami, and H. Savastano. 2015. "Residual Sisal Fibers Treated by Methane Cold Plasma Discharge for Potential Application in Cement Based Material." *Industrial Crops and Products* 77:691–702. https://doi.org/10.1016/j.indcrop.2015.07.052.

Basak, R., P. L. Choudhury, and K. M. Pandey. 2018. "Effect of Temperature Variation on Surface Treatment of Short Jute Fiber-Reinforced Epoxy Composites." *Materials Today: Proceedings* 5 (1): 1271–1277. https://doi.org/10.1016/j.matpr.2017.11.211.

Bashiri Rezaie, A., M. Liebscher, M. Ranjbarian, F. Simon, C. Zimmerer, A. Drechsler, R. Frenzel, A. Synytska, and V. Mechtcherine. 2021. "Enhancing the Interfacial Bonding Between PE Fibers and Cementitious Matrices Through Polydopamine Surface Modification." *Composites Part B Engineering* 217:108817. https://doi.org/10.1016/j.compositesb.2021.108817.

Begum, K., and M. A. Islam. 2013. "Natural Fiber As a Substitute to Synthetic Fiber in Polymer Composites: A Review." *Research Journal of Engineering Sciences* 2:46–53.

Belaadi, A., A. Bezazi, M. Bourchak, and F. Scarpa. 2013. "Tensile Static and Fatigue Behaviour of Sisal Fibres." *Materials & Design (1980-2015)* 46:76–83. https://doi.org/10.1016/j.matdes.2012.09.048.

Belayachi, N., D. Hoxha, and B. Ismail. 2017. "Impact of Fiber Treatment on the Fire Reaction and Thermal Assessing the Feasibility of Using the Heat Demand-Outdoor Degradation of Building Insulation Straw Composite Temperature." *Energy Procedia* 139:544–549. https://doi.org/10.1016/j.egypro.2017.11.251.

Benítez-Guerrero, M., L. A. Pérez-Maqueda, R. Artiaga, P. E. Sánchez-Jiménez, and J. Pascual-Cosp. 2017. "Structural and Chemical Characteristics of Sisal Fiber and Its Components: Effect of Washing and Grinding." *Journal of Natural Fibers* 14 (1): 26–39. https://doi.org/10.1080/15440478.2015.1137529.

Benkhelladi, A., H. Laouici, and A. Bouchoucha. 2020. "Tensile and Flexural Properties of Polymer Composites Reinforced by Flax, Jute and Sisal Fibres." *The International Journal, Advanced Manufacturing Technology* 108 (3): 895–916. https://doi.org/10.1007/s00170-020-05427-2.

Beskopylny, A. N., S. A. Stel'makh, E. M. Shcherban', L. R. Mailyan, B. Meskhi, A. A. Shilov, N. Beskopylny, and A. Chernil'nik. 2022. "Enhanced Performance of Concrete Dispersedly Reinforced with Sisal Fibers." *Applied Sciences* 12 (18): 9102. https://doi.org/10.3390/app12189102.

Bharath, P. 2017. "Effect of Fiber Length and Percentage of SISAL on Strength of Concrete." *International Journal of Advanced Research in Science, Engineering and Technology* 4 (9): 4583–4594.

Bheel, N., S. Sohu, P. Awoyera, A. Kumar, S. A. Abbasi, O. B. Olalusi, and M. S. KIRGIZ. 2021. "Effect of Wheat Straw Ash on Fresh and Hardened Concrete Reinforced with Jute Fiber." *Advances in Civil Engineering* 2021:1–11. https://doi.org/10.1155/2021/6659125.

Bolat, H., O. Şimşek, M. Çullu, G. Durmuş, and Ö. Can. 2014. "The Effects of Macro Synthetic Fiber Reinforcement Use on Physical and Mechanical Properties of Concrete." *Composites Part B Engineering* 61:191–198. https://doi.org/10.1016/j.compositesb.2014.01.043.

Borg, R. P., A. M. M. Hamed, R. Edreis, and A. M. Mansor. 2018. "Characterization of Libyan Metakaolin and Its Effects on the Mechanical Properties of Mortar." *IOP Conference Series: Materials Science & Engineering* 442:012005–8. https://doi.org/10.1088/1757-899X/442/1/012005.

Boumaaza, M., A. Belaadi, and M. Bourchak. 2021. "The Effect of Alkaline Treatment on Mechanical Performance of Natural Fibers-Reinforced Plaster: Optimization Using RSM." *Journal of Natural Fibers* 18 (12): 2220–2240. https://doi.org/10.1080/15440478.2020.1724236.

Burrola-Núñez, H., P. J. Herrera-Franco, D. E. Rodríguez-Félix, H. Soto-Valdez, and T. J. Madera-Santana. 2019. "Surface Modification and Performance of Jute Fibers As Reinforcement on Polymer Matrix: An Overview." *Journal of Natural Fibers* 16 (7): 944–960. https://doi.org/10.1080/15440478.2018.1441093.

Cao, S., D. Zheng, E. Yilmaz, Z. Y. Yin, G. L. Xue, and F. D. Yang. 2020. "Strength Development and Microstructure Characteristics of Artificial Concrete Pillar Considering Fiber Type and Content Effects." *Construction and Building Materials* 256:119408. https://doi.org/10.1016/j.conbuildmat.2020.119408.

Castoldi, R. D. S., L. M. S. de Souza, and F. de Andrade Silva. 2019. "Comparative Study on the Mechanical Behavior and Durability of Polypropylene and Sisal Fiber Reinforced Concretes." *Construction and Building Materials* 211:617–628. https://doi.org/10.1016/j.conbuildmat.2019.03.282.

Castoldi, R. D. S., L. M. S. de Souza, F. Souto, M. Liebscher, V. Mechtcherine, and F. de Andrade Silva. 2022. "Effect of Alkali Treatment on Physical–Chemical Properties of Sisal Fibers and Adhesion Towards Cement-Based Matrices." *Construction and Building Materials* 345:128363. https://doi.org/10.1016/j.conbuildmat.2022.128363.

Chakraborty, S., S. P. Kundu, A. Roy, B. Adhikari, and S. B. Majumder. 2013. "Polymer Modified Jute Fibre As Reinforcing Agent Controlling the Physical and Mechanical Characteristics of Cement Mortar." *Construction and Building Materials* 49:214–222. https://doi.org/10.1016/j.conbuildmat.2013.08.025.

Chakraborty, S., S. P. Kundu, A. Roy, R. K. Basak, B. Adhikari, and S. B. Majumder. 2013. "Improvement of the Mechanical Properties of Jute Fibre Reinforced Cement Mortar: A Statistical Approach." *Construction and Building Materials* 38:776–784. https://doi.org/10.1016/j.conbuildmat.2012.09.067.

Chandrasekaran, P. 2015. "Mechanical and Durability Properties of Micro Silica Concrete with Sisal Fibers." *International Journal of Scientific and Engineering Research* 3.

Chandrasekar, M., M. R. Ishak, S. M. Sapuan, Z. Leman, and M. Jawaid. 2017. "A Review on the Characterisation of Natural Fibres and Their Composites After Alkali Treatment and Water Absorption." *Plastics, Rubber & Composites* 46 (3): 119–136. https://doi.org/10.1080/14658011.2017.1298550.

Chopra, A., and M. M. Razahi. 2020. "A Review of Using Sisal Fiber and Coir Fiber as Additives in Stone Matrix Asphalt." *International Research Journal of Engineering and Technology* 7:1692–1697. http://www.irjet.net.

Claramunt, J., L. J. Fernández-Carrasco, H. Ventura, and M. Ardanuy. 2016. "Natural Fiber Nonwoven Reinforced Cement Composites As Sustainable Materials for Building Envelopes." *Construction and Building Materials* 115:230–239. https://doi.org/10.1016/j.conbuildmat.2016.04.044.

Cruz, J., and R. Fangueiro. 2016. "Surface Modification of Natural Fibers: A Review." *Procedia Engineering* 155:285–288. https://doi.org/10.1016/j.proeng.2016.08.030.

Da Fonseca, R. P., J. C. Rocha, and M. Cheriaf. 2021. "Mechanical Properties of Mortars Reinforced with Amazon Rainforest Natural Fibers." *Materials (Basel)* 14 (1): 1–19. https://doi.org/10.3390/ma14010155.

Dantas, L. G., L. A. De Castro Motta, D. Pasquini, and J. G. Vieira. 2019. "Surface Esterification of Sisal Fibres for Use As Reinforcement in Cementitious Matrix." *Materials Research* 22 (4). https://doi.org/10.1590/1980-5373-MR-2018-0585.

da Silva Junior, I. B., L. M. S. de Souza, and F. de Andrade Silva. 2021. "Creep of Pre-Cracked Sisal Fiber Reinforced Cement Based Composites." *Construction and Building Materials* 293:123511. https://doi.org/10.1016/j.conbuildmat.2021.123511.

da Silva, E. J., M. L. Marques, F. G. Velasco, C. Fornari Junior, F. M. Luzardo, and M. M. Tashima. 2017. "A New Treatment for Coconut Fibers to Improve the Properties of Cement-Based Composites – Combined Effect of Natural Latex/Pozzolanic Materials." *Sustainable Materials Technology* 12:44–51. https://doi.org/10.1016/j.susmat.2017.04.003.

de Azevedo, A. R. G., M. T. Marvila, M. L. P. Antunes, E. C. Rangel, and R. Fediuk. 2021. "Technological Perspective for Use the Natural Pineapple Fiber in Mortar to Repair Structures." *Waste and Biomass Valorization* 12 (9): 5131–5145. https://doi.org/10.1007/s12649-021-01374-5.

de Azevedo, A. R. G., M. T. Marvila, B. A. Tayeh, D. Cecchin, A. C. Pereira, and S. N. Monteiro. 2021. "Technological Performance of açaí Natural Fibre Reinforced Cement-Based Mortars." *Journal of Building Engineering* 33:101675. https://doi.org/10.1016/j.jobe.2020.101675.

de Carvalho Bello, C. B., I. Boem, A. Cecchi, N. Gattesco, and D. V. Oliveira. 2019. "Experimental Tests for the Characterization of Sisal Fiber Reinforced Cementitious Matrix for Strengthening Masonry Structures." *Construction and Building Materials* 219:44–55. https://doi.org/10.1016/j.conbuildmat.2019.05.168.

de Klerk, M. D., M. Kayondo, G. M. Moelich, W. I. de Villiers, R. Combrinck, and W. P. Boshoff. 2020. "Durability of Chemically Modified Sisal Fibre in Cement-Based Composites." *Construction and Building Materials* 241:117835. https://doi.org/10.1016/j.conbuildmat.2019.117835.

de Lima, T. E. S., A. R. G. de Azevedo, M. T. Marvila, V. S. Candido, R. Fediuk, and S. N. Monteiro. 2022. "Potential of Using Amazon Natural Fibers to Reinforce Cementitious Composites: A Review." *Polymers (Basel)* 14 (3): 1–20. https://doi.org/10.3390/polym14030647.

Dilfi KF, A., A. Balan, H. Bin, G. Xian, and S. Thomas. 2018. "Effect of Surface Modification of Jute Fiber on the Mechanical Properties and Durability of Jute Fiber-Reinforced Epoxy Composites." *Polymer Composites* 39 (S4): E2519–E2528. https://doi.org/10.1002/pc.24817.

Dinesh Kumar Raju, S., M. Balasubramanian, and A. Arul Jeya Kumar. 2020. "EXPERIMENTALSTUDIES on REPLACEMENT of STEEL STIRRUPS by SISAL FIBER REINFORCED POLYMERS." *IOP Conference Series: Materials Science & Engineering* 912 (6): 062058. https://doi.org/10.1088/1757-899X/912/6/062058.

dos Santos, G. Z. B., D. P. de Oliveira, J. de Almeida Melo Filho, and N. M. da Silva. 2021. "Sustainable Geopolymer Composite Reinforced with Sisal Fiber: Durability to Wetting and Drying Cycles." *Journal of Building Engineering* 43:102568. https://doi.org/10.1016/j.jobe.2021.102568.

Fadhil, S., and M. Yaseen. 2016. "The Effect of Different Accelerated Aging Methods on Properties of Sisal Fiber Reinforced Concrete with and without Metakaolinite." *International Journal of Engineering Trends and Technology* 31 (4): 198–203. https://doi.org/10.14445/22315381/ijett-v31p235.

Ferreira, D. P., J. Cruz, and R. Fangueiro. 2018. "Surface Modification of Natural Fibers in Polymer Composites." In *Green Composites for Automotive Applications*, 3–41. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102177-4.00001-X.

Ferreira, S. R., P. R. L. Lima, F. A. Silva, and R. D. T. Filho. 2014. "Effect of Sisal Fiber Hornification on the Fiber-Matrix Bonding Characteristcs and Bending Behavior of Cement Based Composites." *Key Engineering Materials* 600:421–432. https://doi.org/10.4028/www.scientific.net/KEM.600.421.

Ferreira, S. R., M. Pepe, E. Martinelli, F. de Andrade Silva, and R. D. Toledo Filho. 2018. "Influence of Natural Fibers Characteristics on the Interface Mechanics with Cement Based Matrices." *Composites Part B Engineering* 140:183–196. https://doi.org/10.1016/j.compositesb.2017.12.016.

Ferreira, S. R., F. D. A. Silva, P. R. L. Lima, and R. D. T. Filho. 2015. "Effect of Fiber Treatments on the Sisal Fiber Properties and Fiber–Matrix Bond in Cement Based Systems." *Construction and Building Materials* 101:730–740. https://doi.org/10.1016/j.conbuildmat.2015.10.120.

Ferreira, S. R., F. D. A. Silva, P. R. L. Lima, and R. D. T. Filho. 2017. "Effect of Hornification on the Structure, Tensile Behavior and Fiber Matrix Bond of Sisal, Jute and curauá Fiber Cement Based Composite Systems." *Construction and Building Materials* 139:551–561. https://doi.org/10.1016/j.conbuildmat.2016.10.004.

Fidelis, M. E. A., R. D. Toledo Filho, F. D. A. Silva, V. Mechtcherine, M. Butler, and S. Hempel. 2016. "The Effect of Accelerated Aging on the Interface of Jute Textile Reinforced Concrete." *Cement and Concrete Composites* 74:7–15. https://doi.org/10.1016/j.cemconcomp.2016.09.002.

Filho, A., S. Parveen, S. Rana, R. Vanderlei, and R. Fangueiro. 2020. "Mechanical and Micro-Structural Investigation of Multi-Scale Cementitious Composites Developed Using Sisal Fibres and Microcrystalline Cellulose." *Industrial Crops and Products* 158:112912. https://doi.org/10.1016/j.indcrop.2020.112912.

Filho, A. S., S. Parveen, S. Rana, R. Vanderlei, and R. Fangueiro. 2021. "Micro-Structure and Mechanical Properties of Microcrystalline Cellulose-Sisal Fiber Reinforced Cementitious Composites Developed Using Cetyltrimethylammonium Bromide As the Dispersing Agent." *Cellulose* 28 (3): 1663–1686. https://doi.org/10.1007/s10570-020-03641-5.

Filho, J. D. A. M., F. D. A. Silva, and R. D. Toledo Filho. 2013. "Degradation Kinetics and Aging Mechanisms on Sisal Fiber Cement Composite Systems." *Cement and concrete composites* 40:30–39. https://doi.org/10.1016/j.cemconcomp.2013.04.003.

Fiore, V., T. Scalici, F. Nicoletti, G. Vitale, M. Prestipino, and A. Valenza. 2016. "A New Eco-Friendly Chemical Treatment of Natural Fibres: Effect of Sodium Bicarbonate on Properties of Sisal Fibre and Its Epoxy Composites." *Composites Part B Engineering* 85:150–160. https://doi.org/10.1016/j.compositesb.2015.09.028.

Florea, I., and D. L. Manea. 2019. "Analysis of Thermal Insulation Building Materials Based on Natural Fibers." *Procedia Manufacturing* 32:230–235. https://doi.org/10.1016/j.promfg.2019.02.207.

Fujiyama, R., F. Darwish, and M. V. Pereira. 2014. "Mechanical Characterization of Sisal Reinforced Cement Mortar." *Theoretical and Applied Mechanics Letters* 4 (6): 061002. https://doi.org/10.1063/2.1406102.

Gao, C., Q. Fu, L. Huang, L. Yan, and G. Gu. 2022. "Jute Fiber-Reinforced Polymer Tube-Confined Sisal Fiber-Reinforced Recycled Aggregate Concrete Waste." *Polymers (Basel)* 14 (6): 1260. https://doi.org/10.3390/polym14061260.

Giri, P., V. Jayakumar, V. C. Kumar, and A. Muniappan. 2018. "Investigation of Mechanical Properties of Natural Fiber Composite with & without Fiber Surface Treatments." *International Journal of Mechanical and Production Engineering Research and Development* 8 (4): 785–790. https://doi.org/10.24247/ijmperdaug201881.

Godara, M. S. S., and S. S. Godara. 2019. "Effect of Chemical Modification of Fiber Surface on Natural Fiber Composites: A Review." *Materials Today: Proceedings* 18:3428–3434. https://doi.org/10.1016/j.matpr.2019.07.270.

Golla, R. Y., and R. T. Ranganath. 2015. "Strength of Sisal Fiber Concrete with Fine Construction Waste Aggregate." *International Journal of Research in Engineering and Technology* 4 (14): 5–8. https://doi.org/10.15623/ijret.2015.0414002.

Gonzalez-Lopez, L., J. Claramunt, Y. Lo Hsieh, H. Ventura, and M. Ardanuy. 2020. "Surface Modification of Flax Nonwovens for the Development of Sustainable, High Performance, and Durable Calcium Aluminate Cement Composites." *Composites Part B Engineering* 191:107955. https://doi.org/10.1016/j.compositesb.2020.107955.

Gudayu, A. D., L. Steuernagel, D. Meiners, and R. Gideon. 2020. "Effect of Surface Treatment on Moisture Absorption, Thermal, and Mechanical Properties of Sisal Fiber." *Journal of Industrial Textiles* 51 (2_suppl): 2853S–2873S. https://doi.org/10.1177/1528083720924774.

Gudayu, A. D., L. Steuernagel, D. Meiners, and R. Gideon. 2022. "Effect of Surface Treatment on Moisture Absorption, Thermal, and Mechanical Properties of Sisal Fiber." *Journal of Industrial Textiles* 51 (2_suppl): 2853S–2873S. https://doi.org/10.1177/1528083720924774.

Gupta, S. D., M. S. Aftab, H. M. Zakaria, and C. Karmakar. 2020. "Scope of Improving Mechanical Characteristics of Concrete Using Natural Fiber as a Reinforcing Material." *Malaysian Journal of Civil Engineering* 32 (2). https://doi.org/10.11113/mjce.v32n2.654.

Gupta, U. S., M. Dhamarikar, A. Dharkar, S. Chaturvedi, S. Tiwari, and R. Namdeo. 2020. "Surface Modification of Banana Fiber: A Review." *Materials Today: Proceedings* 43:904–915. https://doi.org/10.1016/j.matpr.2020.07.217.

Gupta, S., T. Islam, M. A. Islam Sohag, S. Salakin, and I. Hossain. 2021. "Experimental Study of Concrete Using Raw Rice Husk As Partial Replacement of Cement with Natural Fiber (Jute Fiber) As Reinforcing Material." *Computational Engineering and Physical Modeling* 4:29–42. http://creativecommons.org/licenses/by/4.0/ .

Hanif, I. M., M. R. Noor Syuhaili, M. F. Hasmori, and S. M. Shahmi. 2017. "Effect of Nylon Fiber on Mechanical Properties of Cement Based Mortar." *IOP Conference Series: Materials Science & Engineering* 271:012080. https://doi.org/10.1088/1757-899X/271/1/012080.

Hari, R., and K. M. Mini. 2019. "Mechanical and Durability Properties of Sisal-Nylon 6 Hybrid Fibre Reinforced High Strength SCC." *Construction and Building Materials* 204:479–491. https://doi.org/10.1016/j.conbuildmat.2019.01.217.

Hasan, R., M. H. R. Sobuz, A. S. M. Akid, M. R. Awall, M. Houda, A. Saha, M. M. Meraz, M. S. Islam, and N. M. Sutan. 2023. "Eco-Friendly Self-Consolidating Concrete Production with Reinforcing Jute Fiber." *Journal of Building Engineering* 63:105519. https://doi.org/10.1016/j.jobe.2022.105519.

Helaili, S., M. Chafra, and Y. Chevalier. 2021. "Alfa natural fiber composite reinforcement for concrete beams." *Civil Engineering and Architecture* 9 (6): 1677–1686. https://doi.org/10.13189/cea.2021.090602.

Herrera-Franco, P. J., J. G. Carrillo, and Q. M. Li. 2020. "Mechanical Properties of Natural Fiber Reinforced Foamed Concrete." *Materials* 13 (14): 1–18. https://doi.org/10.3390/ma13143060.

Huang, J., and D. Rodrigue. 2022. "Stiffness Behavior of Sisal Fiber Reinforced Foam Concrete Under Flexural Loading." *Journal of Natural Fibers* 19 (15): 12251–12267. https://doi.org/10.1080/15440478.2022.2054896.

Huang, J., G. Tian, P. Huang, and Z. Chen. 2020. "Flexural Performance of Sisal Fiber Reinforced Foamed Concrete Under Static and Fatigue Loading." *Materials (Basel)* 13 (14): 3098. https://doi.org/10.3390/ma13143098.

Huner, U. 2018. "Effect of Chemical Surface Treatment on Flax-Reinforced Epoxy Composite." *Journal of Natural Fibers* 15 (6): 808–821. https://doi.org/10.1080/15440478.2017.1369207.

Hussain, T., and M. Ali. 2019. "Improving the Impact Resistance and Dynamic Properties of Jute Fiber Reinforced Concrete for Rebars Design by Considering Tension Zone of FRC." *Construction and Building Materials* 213:592–607. https://doi.org/10.1016/j.conbuildmat.2019.04.036.

Iniya, M., and K. Nirmalkumar. 2021. "A Review on Fiber Reinforced Concrete Using Sisal Fiber." *IOP Conference Series: Materials Science & Engineering* 1055 (1): 012027. https://doi.org/10.1088/1757-899x/1055/1/012027.

Islam, M. S., and S. J. Ahmed. 2018. "Influence of Jute Fiber on Concrete Properties." *Construction and Building Materials* 189:768–776. https://doi.org/10.1016/j.conbuildmat.2018.09.048.

Ivanova, I., J. Assih, and D. Dontchev. 2020. "Application of Natural Fiber Composite Materials in the Strengthening of Reinforced Concrete Structures." *IOP Conference Series: Materials Science & Engineering* 951 (1): 012012. https://doi.org/10.1088/1757-899X/951/1/012012.

Izquierdo, I. S., O. S. Izquierdo, M. A. Ramalho, and A. Taliercio. 2017. "Sisal Fiber Reinforced Hollow Concrete Blocks for Structural Applications: Testing and Modeling." *Construction and Building Materials* 151:98–112. https://doi.org/10.1016/j.conbuildmat.2017.06.072.

Jaiswal, D., G. L. Devnani, G. Rajeshkumar, M. R. Sanjay, and S. Siengchin. 2022. "Review on Extraction, Characterization, Surface Treatment and Thermal Degradation Analysis of New Cellulosic Fibers As Sustainable Reinforcement in Polymer Composites." *Current Research in Green and Sustainable Chemistry* 5:100271. https://doi.org/10.1016/j.crgsc.2022.100271.

Jamshaid, H., R. K. Mishra, A. Raza, U. Hussain, M. L. Rahman, S. Nazari, V. Chandan, M. Muller, and R. Choteborsky. 2022. "Natural Cellulosic Fiber Reinforced Concrete: Influence of Fiber Type and Loading Percentage on Mechanical and Water Absorption Performance." *Materials (Basel)* 15 (3): 874. https://doi.org/10.3390/ma15030874.

Jaradat, O. Z., K. Gadri, B. A. Tayeh, and A. Guettalaa. 2021. "Influence of Sisal Fibres and Rubber Latex on the Engineering Properties of Sand Concrete." *Structural Engineering and Mechanics*, 47–62. Techno press. https://doi.org/10.12989/sem.2021.80.1.047.

Jariwala, H., and P. Jain. 2019. "A Review on Mechanical Behavior of Natural Fiber Reinforced Polymer Composites and Its Applications." *Journal of Reinforced Plastics and Composites* 38 (10): 441–453. https://doi.org/10.1177/0731684419828524.

Jena, B., R. K. Patra, and B. B. Mukharjee. 2022. "Influence of Incorporation of Jute Fibre and Ferrochrome Slag on Properties of Concrete." *Australian Journal of Civil Engineering* 20 (1): 13–30. https://doi.org/10.1080/14488353.2021.1899601.

Jeyapragash, R., V. Srinivasan, and S. Sathiyamurthy. 2020. "Mechanical Properties of Natural Fiber/Particulate Reinforced Epoxy Composites – a Review of the Literature." *Materials Today: Proceedings* 22:1223–1227. https://doi.org/10.1016/j.matpr.2019.12.146.

Jianqiangn, W., and C. Meyer. 2014a. "Degradation Rate of Natural Fiber in Cement Composites Exposed to Various Accelerated Aging Environmentonditions." *Corrosion Science* 88:118–132. https://doi.org/10.1016/j.corsci.2014.07.029.

Jirawattanasomkul, T., S. Likitlersuang, N. Wuttiwannasak, T. Ueda, D. Zhang, and T. Voravutvityaruk. 2020. "Effects of Heat Treatment on Mechanical Properties of Jute Fiber–Reinforced Polymer Composites for Concrete Confinement." *Journal of Materials in Civil Engineering* 32 (12). https://doi.org/10.1061/(asce)mt.1943-5533.0003456.

Jo, B. W., and S. Chakraborty. 2015. "A Mild Alkali Treated Jute Fibre Controlling the Hydration Behaviour of Greener Cement Paste." *Scientific Reports* 5 (1): 1–8. https://doi.org/10.1038/srep07837.

Jo, B. W., S. Chakraborty, and H. Kim. 2016. "Efficacy of Alkali-Treated Jute As Fibre Reinforcement in Enhancing the Mechanical Properties of Cement Mortar." *Materials and Structures* 49 (3): 1093–1104. https://doi.org/10.1617/s11527-015-0560-3.

Jo, B. W., S. Chakraborty, and Y. S. Lee. 2015. "Hydration Study of the Polymer Modified Jute Fibre Reinforced Cement Paste Using Analytical Techniques." *Construction and Building Materials* 101:166–173. https://doi.org/10.1016/j.conbuildmat.2015.10.086.

John, V. J., and B. Dharmar. 2021. "Influence of Basalt Fibers on the Mechanical Behavior of Concrete—A Review." *Structural Concrete* 22 (1): 491–502. https://doi.org/10.1002/suco.201900086.

Kaewkuk, S., W. Sutapun, and K. Jarukumjorn. 2013. "Effects of Interfacial Modification and Fiber Content on Physical Properties of Sisal Fiber/Polypropylene Composites." *Composites Part B Engineering* 45 (1): 544–549. https://doi.org/10.1016/j.compositesb.2012.07.036.

Kafodya, I., and F. Okonta. 2018. "Effects of Natural Fiber Inclusions and Pre-Compression on the Strength Properties of Lime-Fly Ash Stabilised Soil." *Construction and Building Materials* 170:737–746. https://doi.org/10.1016/j.conbuildmat.2018.02.194.

Kanny, K., and M. TP. 2013. "Surface Treatment of Sisal Fiber Composites for Improved Moisture and Fatigue Properties." *Composite Interfaces* 20 (9): 783–797. https://doi.org/10.1080/15685543.2013.819699.

Karimah, A., M. R. Ridho, S. S. Munawar, D. S. Adi, R. D. Ismadi, B. Subiyanto, W. Fatriasari, and A. Fudholi. 2021. "A Review on Natural Fibers for Development of Eco-Friendly Bio-Composite: Characteristics, and Utilizations." *Journal of Materials Research and Technology* 13:2442–2458. https://doi.org/10.1016/j.jmrt.2021.06.014.

Khalid, M. Y., A. Al Rashid, Z. U. Arif, W. Ahmed, H. Arshad, and A. A. Zaidi. 2021. "Natural Fiber Reinforced Composites: Sustainable Materials for Emerging Applications." *Results in Engineering* 11:100263. https://doi.org/10.1016/j.rineng.2021.100263.

Khalid, M. Y., R. Imran, Z. U. Arif, N. Akram, H. Arshad, A. Al Rashid, and F. P. G. Márquez. 2021. "Developments in Chemical Treatments, Manufacturing Techniques and Potential Applications of Natural-Fibers-Based Biodegradable Composites." *Coatings* 11 (3): 1–18. https://doi.org/10.3390/coatings11030293.

Koohestani, B., A. K. Darban, P. Mokhtari, E. Yilmaz, and E. Darezereshki. 2019. "Comparison of Different Natural Fiber Treatments: A Literature Review." *International Journal of Environmental Science and Technology* 16 (1): 629–642. https://doi.org/10.1007/s13762-018-1890-9.

Krishna, N. K., M. Prasanth, R. Gowtham, S. Karthic, and K. M. Mini. 2018. "Enhancement of Properties of Concrete Using Natural Fibers." *Materials Today: Proceedings* 5 (11): 23816–23823. https://doi.org/10.1016/j.matpr.2018.10.173.

Kumar, S., V. T. B, and R. K. Dutta. 2017. "Engineering Properties of Phosphogypsum Composite Reinforced with Treated Sisal Fibers." *Periodica Polytechnica Civil Engineering* 61:554–563. https://doi.org/10.3311/PPci.8183.

Kumar, P., and R. Roy. 2018. "Study and Experimental Investigation of Flow and Flexural Properties of Natural Fiber Reinforced Self Compacting Concrete." *Procedia Computer Science* 125:598–608. https://doi.org/10.1016/j.procs.2017.12.077.

Kumar, S., B. V. Tilak, and R. K. Dutta. 2017. "Engineering Properties of Bentonite-Lime-Phosphogypsum Composite Reinforced with Treated Sisal Fibers." *Periodica Polytechnica Civil Engineering* 61:554–563. https://doi.org/10.3311/PPci.8183.

Kundu, S. P., S. Chakraborty, and S. Chakraborty. 2018. "Effectiveness of the Surface Modified Jute Fibre As Fibre Reinforcement in Controlling the Physical and Mechanical Properties of Concrete Paver Blocks." *Construction and Building Materials* 191:554–563. https://doi.org/10.1016/j.conbuildmat.2018.10.045.

Kundu, S. P., S. Chakraborty, S. B. Majumder, and B. Adhikari. 2018. "Effectiveness of the Mild Alkali and Dilute Polymer Modification in Controlling the Durability of Jute Fibre in Alkaline Cement Medium." *Construction and Building Materials* 174:330–342. https://doi.org/10.1016/j.conbuildmat.2018.04.134.

Kv, S. 2019. "Utilization of Sisal Fiber in Portland." *International Journal of Civil Engineering and Technology* 9. http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=9.

Lahouioui, M., R. Ben Arfi, M. Fois, L. Ibos, and A. Ghorbal. 2020. "Investigation of Fiber Surface Treatment Effect on Thermal, Mechanical and Acoustical Properties of Date Palm Fiber-Reinforced Cementitious Composites." *Waste and Biomass Valorization* 11 (8): 4441–4455. https://doi.org/10.1007/s12649-019-00745-3.

Latifi, M. R., Ö. Biricik, and A. M. Aghabaglou. 2022. "Effect of the Addition of Polypropylene Fiber on Concrete Properties." *Journal of Adhesion Science and Technology* 36 (4): 345–369. https://doi.org/10.1080/01694243.2021.1922221.

Li, Q., L. Ibrahim, W. Zhou, M. Zhang, and Z. Yuan. 2021. "Treatment Methods for Plant Fibers for Use As Reinforcement in Cement-Based Materials." *Cellulose* 28 (9): 5257–5268. https://doi.org/10.1007/s10570-021-03903-w.

Lima, P. R. L., J. A. O. Barros, A. B. Roque, C. M. A. Fontes, and J. M. F. Lima. 2018. "Short Sisal Fiber Reinforced Recycled Concrete Block for One-Way Precast Concrete Slabs." *Construction and Building Materials* 187:620–634. https://doi.org/10.1016/j.conbuildmat.2018.07.184.

Lima, P. R. L., J. A. O. Barros, D. J. Santos, C. M. Fontes, J. M. F. Lima, and R. T. Filho. 2019. "Experimental and Numerical Analysis of Short Sisal Fiber-Cement Composites Produced with Recycled Matrix." *European Journal of Environmental and Civil Engineering* 23 (1): 70–84. https://doi.org/10.1080/19648189.2016.1271357.

Lima, P. R. L., H. M. Santos, G. P. Camilloto, and R. S. Cruz. 2017. "Effect of Surface Biopolymeric Treatment on Sisal Fiber Properties and Fiber-Cement Bond." *Journal of Engineered Fibers and Fabrics* 12 (2): 59–71. https://doi.org/10.1177/155892501701200207.

Lima, P. R., R. J. Santos, S. R. Ferreira, and R. D. Toledo Filho. 2014. "Characterization and Treatment of Sisal Fiber Residues for Cement-Based Composite applicationSotosoto." *Engenharia Agrícola* 34 (5): 812–825. https://doi.org/10.1177/15589250211026940.

Liu, Y., Z. Wang, Z. Fan, and J. Gu. 2020. "Study on Properties of Sisal Fiber Modified Foamed Concrete." *IOP Conference Series: Materials Science & Engineering* 744 (1): 012042. https://doi.org/10.1088/1757-899X/744/1/012042.

Li, B., L. Xu, Y. Shi, Y. Chi, Q. Liu, and C. Li. 2018. "Effects of Fiber Type, Volume Fraction and Aspect Ratio on the Flexural and Acoustic Emission Behaviors of Steel Fiber Reinforced Concrete." *Construction and Building Materials* 181:474–486. https://doi.org/10.1016/j.conbuildmat.2018.06.065.

Long, W., and Y. Wang. 2021. "Effect of Pine Needle Fibre Reinforcement on the Mechanical Properties of Concrete." *Construction and Building Materials* 278:122333. https://doi.org/10.1016/j.conbuildmat.2021.122333.

Lopes Lima, P. R., A. B. Roque, C. M. Ariani Fontes, J. M. Feitosa Lima, and J. A. O. Barros. 2017. "Potentialities of Cement-Based Recycled Materials Reinforced with Sisal Fibers As a Filler Component of Precast Concrete Slabs." https://doi.org/10.1016/B978-0-08-102001-2.00017-6.

Machaka, M. M., H. S. Basha, and A. M. Elkordi. 2014a. "The Effect of Using Fan Palm Natural Fibers on the Mechanical Properties and Durability of Concrete." *International Journal of Materials Science and Engineering* 2. https://doi.org/10.12720/ijmse.2.2.76-80.

Machaka, M. M., H. S. Basha, and A. M. ElKordi. 2014b. "The Effect of Using Fan Palm Natural Fibers on the Mechanical Properties and Durability of Concrete." *International Journal of Materials Science and Engineering*. https://doi.org/10.12720/ijmse.2.2.76-80.

Mahjoub, R., J. M. Yatim, A. R. Mohd Sam, and S. H. Hashemi. 2014. "Tensile Properties of Kenaf Fiber Due to Various Conditions of Chemical Fiber Surface Modifications." *Construction and Building Materials* 55:103–113. https://doi.org/10.1016/j.conbuildmat.2014.01.036.

Maichin, P., T. Suwan, P. Jitsangiam, P. Chindaprasirt, and M. Fan. 2020. "Effect of Self-Treatment Process on Properties of Natural Fiber-Reinforced Geopolymer Composites." *Materials & Manufacturing Processes* 35 (10): 1120–1128. https://doi.org/10.1080/10426914.2020.1767294.

Malenab, R. A. J., J. P. S. Ngo, and M. A. B. Promentilla. 2017. "Chemical Treatment of Waste Abaca for Natural Fiber-Reinforced Geopolymer Composite." *Materials (Basel)* 10 (6): 579. https://doi.org/10.3390/ma10060579.

Mármol, G., A. Ribes, V. Amigó, and H. Savastano. 2020. "Assessment of Sisal Fiber Integrity As a Reinforcing Element in MgO-Based Cement Matrices." *Waste and Biomass Valorization* 11 (6): 3045–3056. https://doi.org/10.1007/s12649-019-00605-0.

Martel, W. D. N. D. R., I. P. Salgado, and F. A. Silva. 2022. "The Influence of Fiber Treatment on the Morphology, Water Absorption Capacity and Mechanical Behavior of Curauá Fibers." *Journal of Natural Fibers* 19 (2): 642–657. https://doi.org/10.1080/15440478.2020.1758863.

Martinelli, F. R. B., F. R. C. Ribeiro, M. T. Marvila, S. N. Monteiro, F. D. C. G. Filho, and A. R. G. de Azevedo. 2023. "A Review of the Use of Coconut Fiber in Cement Composites." *Polymers (Basel)* 15 (5): 1309–1315. https://doi.org/10.3390/polym15051309.

Martínez-Martínez, S., and F. A. Corpas-Iglesias. 2016. "Study of the Mechanical Properties of Concrete with Sisal and Polypropylene Fibers." *Key Engineering Materials* 663:115–123. https://doi.org/10.4028/www.scientific.net/KEM.663.115.

Marvila, M. T., H. A. Rocha, A. R. G. de Azevedo, H. A. Colorado, J. F. Zapata, and C. M. F. Vieira. 2021. "Use of Natural Vegetable Fibers in Cementitious Composites: Concepts and Applications." *Innovative Infrastructure solutions* 6 (3): 1–24. https://doi.org/10.1007/s41062-021-00551-8.

Maurya, H. O., M. K. Gupta, R. K. Srivastava, and H. Singh. 2015. "Study on the Mechanical Properties of Epoxy Composite Using Short Sisal Fibre." *Materials Today: Proceedings* 2 (4–5): 1347–1355. https://doi.org/10.1016/j.matpr.2015.07.053.

Meenakshi, C. M., and A. Krishnamoorthy. 2019. "Study on the Effect of Surface Modification on the Mechanical and Thermal Behaviour of Flax, Sisal and Glass Fiber-Reinforced Epoxy Hybrid Composites." *Journal of Renewable Materials* 7 (2): 153–169. https://doi.org/10.32604/jrm.2019.00046.

Mohan, T. P., and K. Kanny. 2012. "Chemical Treatment of Sisal Fiber Using Alkali and Clay Method." *Composites, Part A, Applied Science and Manufacturing* 43 (11): 1989–1998. https://doi.org/10.1016/j.compositesa.2012.07.012.

Mokaloba, N., and R. Batane. 2014. "The Effects of Mercerization and Acetylation Treatments on the Properties of Sisal Fiber and Its Interfacial Adhesion Characteristics on Polypropylene." *International Journal of Engineering Science and Technology* 6 (4): 83. https://doi.org/10.4314/ijest.v6i4.9.

More, F. M. D. S., and S. S. Subramanian. 2022. "Impact of Fibres on the Mechanical and Durable Behaviour of Fibre-Reinforced Concrete." *Buildings* 12 (9): 1436. https://doi.org/10.3390/buildings12091436.

Motaung, T. E., L. Z. Linganiso, R. Kumar, and R. D. Anandjiwala. 2017. "Agave and Sisal Fibre-Reinforced Polyfurfuryl Alcohol Composites." *Journal of Thermoplastic Composite Materials* 30 (10): 1323–1343. https://doi.org/10.1177/0892705716632858.

Mudadu, A., G. Tiberti, F. Germano, G. A. Plizzari, and A. Morbi. 2018. "The Effect of Fiber Orientation on the Post-Cracking Behavior of Steel Fiber Reinforced Concrete Under Bending and Uniaxial Tensile Tests." *Cement and concrete composites* 93:274–288. https://doi.org/10.1016/j.cemconcomp.2018.07.012.

Mukhopadhyay, S., and R. Srikanta. 2008. "Effect of Ageing of Sisal Fibres on Properties of Sisal – Polypropylene Composites." *Polymer Degradation and Stability* 93 (11): 2048–2051. https://doi.org/10.1016/j.polymdegradstab.2008.02.018.

Mundim, P. B., R. A. R. Ferreira, L. A. C. Motta, M. A. Henrique, and D. Pasquini. 2020. "Study of the Superficial Modification of Sisal Fibres with Lignin, and Its Use As a Reinforcement Agent in Cementitious Composites." *Journal of Renewable Materials* 8 (8): 891–903. https://doi.org/10.32604/jrm.2020.010655.

Murtiadi, S., and A. Akmaluddin. 2016. "Sisal Fiber As Steel Bar Replacement of Lightweight Concrete Under Flexural Loading." *Applied Mechanics & Materials* 845:202–207. https://doi.org/10.4028/www.scientific.net/amm.845.202.

Musanif, I. S., and A. Thomas. 2015. "Effect of Alkali Treatments of Physical and Mechanical Properties of Coir Fiber." *Chemical and Materials Engineering* 3 (2): 23–28. https://doi.org/10.13189/cme.2015.030202.

Nambiar, R. A., and M. K. Haridharan. 2020. "Mechanical and Durability Study of High Performance Concrete with Addition of Natural Fiber (Jute)." *Materials Today: Proceedings* 46:4941–4947. https://doi.org/10.1016/j.matpr.2020.10.339.

Naraganti, S. R., R. M. R. Pannem, and J. Putta. 2019. "Impact Resistance of Hybrid Fibre Reinforced Concrete Containing Sisal Fibres." *Ain Shams Engineering Journal* 10 (2): 297–305. https://doi.org/10.1016/j.asej.2018.12.004.

Naveen, J., M. Jawaid, P. Amuthakkannan, and M. Chandrasekar. 2018. "Mechanical and Physical Properties of Sisal and Hybrid Sisal Fiber-Reinforced Polymer Composites." In *Mechanical Physical Test. Biocomposites, Fibre-Reinforced Composite Hybrid Composite*, 427–440. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102292-4.00021-7.

Neves Junior, A., S. R. Ferreira, R. D. Toledo Filho, E. D. M. R. Fairbairn, and J. Dweck. 2019. "Effect of Early Age Curing Carbonation on the Mechanical Properties and Durability of High Initial Strength Portland Cement and Lime-Pozolan Composites Reinforced with Long Sisal Fibres." *Composites Part B Engineering* 163:351–362. https://doi.org/10.1016/j.compositesb.2018.11.006.

Ogunbode, B. E., B. B. Nyakuma, T. A. Lawal, J. M. Yatim, A. Abdul, and M. I. Ayoosu. 2022. "Morphological, Microstructure, Tensile and Water-Sorption Characteristics of Surface Modified Kenaf Fibre for Sustainable Biocomposite Reinforcement." *Journal of Natural Fibers* 19 (13): 7174–7185. https://doi.org/10.1080/15440478.2021.1944430.

Okeola, A. A., S. O. Abuodha, and J. Mwero. 2018. "Experimental Investigation of the Physical and Mechanical Properties of Sisal Fiber-Reinforced Concrete." *Fibers* 6 (3): 53. https://doi.org/10.3390/fib6030053.

Okeola, A. A., J. Mwero, and A. Bello. 2021. "Behavior of Sisal Fiber-Reinforced Concrete in Exterior Beam-Column Joint Under Monotonic Loading." *Asian Journal of Civil Engineering* 22 (4): 627–636. https://doi.org/10.1007/s42107-020-00336-x.

Olivito, R. S., O. A. Cevallos, and A. Carrozzini. 2014. "Development of Durable Cementitious Composites Using Sisal and Flax Fabrics for Reinforcement of Masonry Structures." *Materials & Design* 57:258–268. https://doi.org/10.1016/j.matdes.2013.11.023.

Orue, A., A. Eceiza, and A. Arbelaiz. 2018. "Pretreatments of Natural Fibers for Polymer Composite Materials." https://doi.org/10.1007/978-3-319-68696-7_3.

Orue, A., A. Jauregi, C. Peña-Rodriguez, J. Labidi, A. Eceiza, and A. Arbelaiz. 2015. "The Effect of Surface Modifications on Sisal Fiber Properties and Sisal/Poly (Lactic Acid) Interface Adhesion." *Composites Part B Engineering* 73:132–138. https://doi.org/10.1016/j.compositesb.2014.12.022.

Ovalı, S., and E. Sancak. 2022. "Investigation of Mechanical Properties of Jute Fiber Reinforced Low Density Polyethylene Composites." *Journal of Natural Fibers* 19 (8): 3109–3126. https://doi.org/10.1080/15440478.2020.1838999.

Padanattil, A., K. Jayanarayanan, and K. M. Mini. 2017. "Novel Hybrid Composites Based on Glass and Sisal Fiber for Retrofitting of Reinforced Concrete Structures." *Construction and Building Materials* 133:146–153. https://doi.org/10.1016/j.conbuildmat.2016.12.045.

Palanisamy, E., and M. Ramasamy. 2022. "Dependency of Sisal and Banana Fiber on Mechanical and Durability Properties of Polypropylene Hybrid Fiber Reinforced Concrete." *Journal of Natural Fibers* 19 (8): 3147–3157. https://doi.org/10.1080/15440478.2020.1840477.

Panchangam, S. C. 2015a. "Experimental Study on Effects of Sisal Fiber Experimental." *International Journal & Magazine of Engineering, Technology, Management* 2:388–394. http://www.ijmetmr.com/.

Panchangam, S. C. 2015b. "Experimental Study on Effects of Sisal Fiber Experimental Study on Effects of Sisal Fiber Reinforced Concrete." *International Journal & Magazine of Engineering, Technology, Management* 2:388–394. http://www.ijmetmr.com.

Pinto, M. A., V. B. Chalivendra, Y. K. Kim, and A. F. Lewis. 2013. "Effect of Surface Treatment and Z-Axis Reinforcement on the Interlaminar Fracture of Jute/Epoxy Laminated Composites." *Engineering Fracture Mechanics* 114:104–114. https://doi.org/10.1016/j.engfracmech.2013.10.015.

Prabhu, L., V. Krishnaraj, S. Sathish, S. Gokulkumar, N. Karthi, L. Rajeshkumar, D. Balaji, N. Vigneshkumar, and K. S. Elango. 2021. "A Review on Natural Fiber Reinforced Hybrid Composites: Chemical Treatments, Manufacturing Methods and Potential Applications." *Materials Today: Proceedings* 45:8080–8085. https://doi.org/10.1016/j.matpr.2021.01.280.

Prakash, R., R. Thenmozhi, S. N. Raman, C. Subramanian, and N. Divyah. 2021. "Mechanical Characterisation of Sustainable Fibre-Reinforced Lightweight Concrete Incorporating Waste Coconut Shell As Coarse Aggregate and Sisal Fibre." *International Journal of Environmental Science and Technology* 18 (6): 1579–1590. https://doi.org/10.1007/s13762-020-02900-z.

Prasad, G. L. E., B. S. K. Gowda, and R. Velmurugan. 2017. "Comparative Study of Impact Strength Characteristics of Treated and Untreated Sisal Polyester Composites." *Procedia Engineering* 173:778–785. https://doi.org/10.1016/j.proeng.2016.12.096.

Priyadharshini, S., and G. Ramakrishna. 2018. "A Novel Approach for the Rheological Behaviour of Polymer Modified Untreated and Treated Sisal Fibre Reinforced Cement Mortar Composites." *Materials Today: Proceedings* 5 (5): 12927–12939. https://doi.org/10.1016/j.matpr.2018.02.278.

Priyadharshini, S., and G. Ramakrishna. 2019. *Flow Characteristics of Polymer-Modified Sisal Fibre-Reinforced Mortar*. Springer Singapore. https://doi.org/10.1007/978-981-13-0362-3_73.

Raggiotti, B. B., M. J. Positieri, and Á. Oshiro. 2018. "Natural Zeolite, a Pozzolan for Structural Concrete." *Procedia Structural Integrity* 11:36–43. https://doi.org/10.1016/j.prostr.2018.11.006.

Rahuman, A., and S. Yeshika. 2015. "Study on Properties of Sisal Fiber Reinforced Concrete with Different Mix Proportions and Different Percentage of Fiber Addition." *International Journal of Research in Engineering and Technology* 4 (03): 474–477. https://doi.org/10.15623/ijret.2015.0403080.

Rai, A., and Y. P. Joshi. 2014. "Applications and Properties of Fibre Reinforced Concrete." *Journal of Engineering Research and Applications* 4:123–131. http://www.ijera.com.

Raja, A. K. A., K. A. V. Geethan, S. S. Kumar, and P. S. Kumar. 2021. "Influence of Mechanical Attributes, Water Absorption, Heat Deflection Features and Characterization of Natural Fibers Reinforced Epoxy Hybrid Composites for an Engineering Application." *Fibers and Polymers* 22 (12): 3444–3455. https://doi.org/10.1007/s12221-021-0222-8.

Rajkumar, R., R. Nirmala, and V. Vivekananthan. 2022. "Mechanical and Durability Characteristics of TiO2and Al2O3Nanoparticles with Sisal Fibers." *Journal of Nanomaterials* 2022:1–6. https://doi.org/10.1155/2022/2813205.

Ramakrishna, G., and T. Sundararajan. 2018. *Long-Term Strength and Durability Evaluation of Sisal Fiber Composites*. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102290-0.00010-6.

Ramasamy, V. 2015. "Effect of Fibers in Concrete Composites." *International Journal of Applied Engineering Research* 10 (1): 419–30.

Ramesh, M. 2018. “Hemp, jute, banana, kenaf, ramie, sisal fibers.” In *Handbook of Properties of Textile and Technical Fibres*, 301–325. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-101272-7.00009-2.

Ravi, M., R. R. Dubey, A. Shome, S. Guha, and C. A. Kumar. 2018. “Effect of Surface Treatment on Natural Fibers Composite.” *IOP Conference Series: Materials Science & Engineering* 376:012053. https://doi.org/10.1088/1757-899X/376/1/012053.

Razak, N. I. A., N. A. Ibrahim, N. Zainuddin, M. Rayung, and W. Z. Saad. 2014. “The Influence of Chemical Surface Modification of Kenaf Fiber Using Hydrogen Peroxide on the Mechanical Properties of Biodegradable Kenaf Fiber/Poly(lactic Acid) Composites.” *Molecules* 19 (3): 2957–2968. https://doi.org/10.3390/molecules19032957.

Razmi, A., and M. M. Mirsayar. 2017. “On the Mixed Mode I/II Fracture Properties of Jute Fiber-Reinforced Concrete.” *Construction and Building Materials* 148:512–520. https://doi.org/10.1016/j.conbuildmat.2017.05.034.

Rehman, S. U., M. Yaqub, M. Noman, B. Ali, M. Nasir, A. Khan, M. Fahad, M. M. Abid, and A. Gul. 2019. “The Influence of Thermo-Mechanical Activation of Bentonite on the Mechanical and Durability Performance of Concrete.” *Applied Sciences* 9 (24): 5549. https://doi.org/10.3390/app9245549.

Reis, J. M. L. 2012. “Sisal Fiber Polymer Mortar Composites: Introductory Fracture Mechanics Approach.” *Construction and Building Materials* 37:177–180. https://doi.org/10.1016/j.conbuildmat.2012.07.088.

Ren, G., B. Yao, H. Huang, and X. Gao. 2021. “Influence of Sisal Fibers on the Mechanical Performance of Ultra-High Performance Concretes.” *Construction and Building Materials* 286:122958. https://doi.org/10.1016/j.conbuildmat.2021.122958.

Rocha, D. L., L. U. D. T. Júnior, M. T. Marvila, E. C. Pereira, D. Souza, and A. R. G. de Azevedo. 2022. “A Review of the Use of Natural Fibers in Cement Composites: Concepts, Applications and Brazilian History.” *Applications and Brazilian History, Polymers (Basel)* 14 (10): 1–22. https://doi.org/10.3390/polym14102043.

Sabarish, K. V., P. Paul, B. Bhuvaneshwari, and J. Jones. 2020. “An Experimental Investigation on Properties of Sisal Fiber Used in the Concrete.” *Materials Today: Proceedings* 22:439–443. https://doi.org/10.1016/j.matpr.2019.07.686.

Sadrinejad, I., R. Madandoust, and M. M. Ranjbar. 2018. “The Mechanical and Durability Properties of Concrete Containing Hybrid Synthetic Fibers.” *Construction and Building Materials* 178:72–82. https://doi.org/10.1016/j.conbuildmat.2018.05.145.

Sahu, P., and M. K. Gupta. 2018. “Mechanical, Thermal and Morphological Properties of Sisal Fibres.” *IOP Conference Series: Materials Science & Engineering* 455 (1): 012014. https://doi.org/10.1088/1757-899X/455/1/012014.

Salih, Y. A., N. N. Sabeeh, M. F. Yass, A. S. Ahmed, and E. S. Khudhurr. 2019. “Concrete Beams Strengthened with Jute Fibers.” *Civil Engineering Journal* 5 (4): 767–776. https://doi.org/10.28991/cej-2019-03091286.

Santos, R. D., S. Thomas, S. R. Ferreira, F. A. Silva, M. Y. Combariza, C. Blanco-Tirado, S. A. Ovalle-Serrano, F. G. Souza Jr, G. E. Oliveira, and R. D. Toledo Filho. 2021. “Molecular Grafting of Nanoparticles Onto Sisal Fibers - Adhesion to Cementitious Matrices and Novel Functionalities.” *Journal of Molecular Structure* 1234:130171. https://doi.org/10.1016/j.molstruc.2021.130171.

Sekaran, A. S. J., K. P. Kumar, and K. Pitchandi. 2015. “Evaluation on Mechanical Properties of Woven Aloevera and Sisal Fibre Hybrid Reinforced Epoxy Composites.” *Bulletin of Materials Science* 38 (5): 1183–1193. https://doi.org/10.1007/s12034-015-0999-4.

Sellami, A., M. Merzoud, and S. Amziane. 2013. “Improvement of Mechanical Properties of Green Concrete by Treatment of the Vegetals Fibers.” *Construction and Building Materials* 47:1117–1124. https://doi.org/10.1016/j.conbuildmat.2013.05.073.

Senthilkumar, K., N. Saba, N. Rajini, M. Chandrasekar, M. Jawaid, S. Siengchin, and O. Y. Alotman. 2018. “Mechanical Properties Evaluation of Sisal Fibre Reinforced Polymer Composites: A Review.” *Construction and Building Materials* 174:713–729. https://doi.org/10.1016/j.conbuildmat.2018.04.143.

Senthilkumar, K., T. Ungtrakul, M. Chandrasekar, T. Senthil Muthu Kumar, N. Rajini, S. Siengchin, H. Pulikkalparambil, J. Parameswaranpillai, and N. Ayrilmis. 2021. “Performance of Sisal/Hemp Bio-Based Epoxy Composites Under Accelerated Weathering.” *Journal of Polymers and the Environment* 29 (2): 624–636. https://doi.org/10.1007/s10924-020-01904-7.

Shadheer Ahamed, M., P. Ravichandran, and A. Krishnaraja. 2021. “Natural Fibers in Concrete – a Review.” *IOP Conference Series: Materials Science & Engineering* 1055 (1): 012038. https://doi.org/10.1088/1757-899x/1055/1/012038.

Shah, I., L. Jing, Z. M. Fei, Y. S. Yuan, M. U. Farooq, and N. Kanjana. 2021. “A Review on Chemical Modification by Using Sodium Hydroxide (NaOH) to Investigate the Mechanical Properties of Sisal, Coir and Hemp Fiber Reinforced Concrete Composites.” *Journal of Natural Fibers* 19 (13): 5133–5151. https://doi.org/10.1080/15440478.2021.1875359.

Shah, I., J. Li, S. Yang, Y. Zhang, and A. Anwar. 2022. “Experimental Investigation on the Mechanical Properties of Natural Fiber Reinforced Concrete.” *Journal of Renewable Materials* 10 (5): 1307–1320. https://doi.org/10.32604/jrm.2022.017513.

Shivamurthy, B., N. Naik, B. H. S. Thimappa, and R. Bhat. 2020. “Mechanical Property Evaluation of Alkali-Treated Jute Fiber Reinforced Bio-Epoxy Composite Materials.” *Materials Today: Proceedings* 28:2116–2120. https://doi.org/10.1016/j.matpr.2020.04.016.

Silva, G., S. Kim, R. Aguilar, and J. Nakamatsu. 2020. "Natural Fibers As Reinforcement Additives for Geopolymers – a Review of Potential Eco-Friendly Applications to the Construction Industry." *Sustainable Materials Technology* 23: e00132. https://doi.org/10.1016/j.susmat.2019.e00132.

Singh, S., M. I. Khairandish, M. M. Razahi, R. Kumar, J. S. Chohan, A. Tiwary, S. Sharma, et al. 2022. "Preference Index of Sustainable Natural Fibers in Stone Matrix Asphalt Mixture Using Waste Marble." *Materials (Basel)* 15 (8): 1–17. https://doi.org/10.3390/ma15082729.

Siva Bala, P., and G. Vaisakh. 2018. "Mechanical Properties of Self Compacting Concrete Containing Crushed Sand and Sisal Fiber." *International Journal of Environmental Science* 13:71–81. http://www.ripublication.com.

Snoeck, D., P. A. Smetryns, and N. De Belie. 2015. "Improved Multiple Cracking and Autogenous Healing in Cementitious Materials by Means of Chemically-Treated Natural Fibres." *Biosystems Engineering* 139:87–99. https://doi.org/10.1016/j.biosystemseng.2015.08.007.

Song, H., J. Liu, K. He, and W. Ahmad. 2021. "A Comprehensive Overview of Jute Fiber Reinforced Cementitious Composites." *Case Studies in Construction Materials* 15:e00724. https://doi.org/10.1016/j.cscm.2021.e00724.

Srivastav, A. K., M. K. Behera, and B. C. Ray. 2007. "Loading Rate Sensitivity of Jute/Glass Hybrid Reinforced Epoxy Composites: Effect of Surface Modifications." *Journal of Reinforced Plastics and Composites* 26 (9): 851–860. https://doi.org/10.1177/0731684407076735.

Sugathan, A. 2017. "Self Compacting Concrete Reinforced with Sisal Fibres." *International Journal of Latest Technology in Engineering, Management & Applied Science* VI:180–187.

Tenazoa, C., H. Savastano, S. Charca, M. Quintana, and E. Flores. 2021. "The Effect of Alkali Treatment on Chemical and Physical Properties of Ichu and Cabuya Fibers." *Journal of Natural Fibers* 18 (7): 923–936. https://doi.org/10.1080/15440478.2019.1675211.

Thomas, B. C., and Y. S. Jose. 2021. "A Study on Characteristics of Sisal Fiber and Its Performance in Fiber Reinforced Concrete." *Materials Today: Proceedings* 51:1238–1242. https://doi.org/10.1016/j.matpr.2021.07.312.

Thomas, B. C., and Y. S. Jose. 2022. "Impact of Sisal Fiber Reinforced Concrete and Its Performance Analysis: A Review Biju." *Evolutionary Intelligence* 15 (2): 865–875. https://doi.org/10.1007/s12065-019-00230-9.

Tian, H., Y. X. Zhang1, C. Yang, and Y. Ding. 2015. "Recent Advances in Experimental Study on Mechanical Behaviour of Natural Fibre Reinforced Cementitious Composites." *Structural Concrete* 1–51. https://doi.org/10.1002/suco.201500177.

Tiwari, S., A. K. Sahu, and R. P. Pathak. 2020. "Mechanical Properties and Durability Study of Jute Fiber Reinforced Concrete." *IOP Conference Series: Materials Science & Engineering* 961 (1): 012009. https://doi.org/10.1088/1757-899X/961/1/012009.

Trümer, A., H. M. Ludwig, M. Schellhorn, and R. Diedel. 2019. "Effect of a Calcined Westerwald Bentonite As Supplementary Cementitious Material on the Long-Term Performance of Concrete." *Applied Clay Science* 168:36–42. https://doi.org/10.1016/j.clay.2018.10.015.

V, R. 2017. "Experimental Studies of Silica Fume and Sisalfibre on Performance of Concrete." *International Journal for Research in Applied Science and Engineering Technology* V (X): 1877–1883. https://doi.org/10.22214/ijraset.2017.10275.

Veigas, M. G., M. Najimi, and B. Shafei. 2022. "Cementitious Composites Made with Natural Fibers: Investigation of Uncoated and Coated Sisal Fibers." *Case Studies in Construction Materials* 16:e00788. https://doi.org/10.1016/j.cscm.2021.e00788.

Venkatram, B., C. Kailasanathan, P. Seenikannan, and S. Paramasamy. 2016. "Study on the Evaluation of Mechanical and Thermal Properties of Natural Sisal Fiber/General Polymer Composites Reinforced with Nanoclay." *International Journal of Polymer Analysis and Characterization* 21 (7): 647–656. https://doi.org/10.1080/1023666X.2016.1194616.

Verma, N., M. K. Singh, and S. Zafar. 2020. "Development of Porous Bio-Nano-Composites Using Microwave Processing." https://doi.org/10.1007/978-3-030-40301-0_10.

Vigneshwaran, S., R. Sundarakannan, K. M. John, R. D. Joel Johnson, K. A. Prasath, S. Ajith, V. Arumugaprabu, and M. Uthayakumar. 2020. "Recent Advancement in the Natural Fiber Polymer Composites: A Comprehensive Review." *Journal of Cleaner Production* 277:124109. https://doi.org/10.1016/j.jclepro.2020.124109.

Vijayan, R., and A. Krishnamoorthy. 2019. "Review on Natural Fiber Reinforced Composites." *Materials Today: Proceedings* 16:897–906. https://doi.org/10.1016/j.matpr.2019.05.175.

Voit, K., O. Zeman, I. Janotka, R. Adamcova, and K. Bergmeister. 2020. "High-Durability Concrete Using Eco-Friendly Slag-Pozzolanic Cements and Recycled Aggregate." *Applied Sciences* 10 (22): 8307–8321. https://doi.org/10.3390/app10228307.

Wei, J. 2018. "Degradation Behavior and Kinetics of Sisal Fiber in Pore Solutions of Sustainable Cementitious Composite Containing Metakaolin." *Polymer Degradation and Stability* 150:1–12. https://doi.org/10.1016/j.polymdegradstab.2018.01.027.

Wei, J., F. Kong, J. Liu, Z. Chen, D. P. Kanungo, X. Lan, C. Jiang, and X. Shi. 2018. "Effect of Sisal Fiber and Polyurethane Admixture on the Strength and Mechanical Behavior of Sand." *Polymers (Basel)* 10 (10): 1–15. https://doi.org/10.3390/polym10101121.

Wei, J., and C. Meyer. 2014b. "Improving Degradation Resistance of Sisal Fiber in Concrete Through Fiber Surface Treatment." *Applied Surface Science* 289:511–523. https://doi.org/10.1016/j.apsusc.2013.11.024.

Wei, J., and C. Meyer. 2014c. "Sisal Fiber-Reinforced Cement Composite with Portland Cement Substitution by a Combination of Metakaolin and Nanoclay." *Journal of Materials Science* 49 (21): 7604–7619. https://doi.org/10.1007/s10853-014-8469-8.

Wei, J., and C. Meyer. 2015. "Degradation Mechanisms of Natural Fiber in the Matrix of Cement Composites." *Cement and Concrete Research* 73:1–16. https://doi.org/10.1016/j.cemconres.2015.02.019.

Wei, J., and C. Meyer. 2016. "Utilization of Rice Husk Ash in Green Natural Fiber-Reinforced Cement Composites: Mitigating Degradation of Sisal Fiber." *Cement and Concrete Research* 81:94–111. https://doi.org/10.1016/j.cemconres.2015.12.001.

Wei, J., and C. Meyer. 2017. "Degradation of Natural Fiber in Ternary Blended Cement Composites Containing Metakaolin and Montmorillonite." *Corrosion Science* 120:42–60. https://doi.org/10.1016/j.corsci.2016.12.004.

Wu, Z., C. Shi, W. He, and L. Wu. 2016. "Effects of Steel Fiber Content and Shape on Mechanical Properties of Ultra High Performance Concrete." *Construction and Building Materials* 103:8–14. https://doi.org/10.1016/j.conbuildmat.2015.11.028.

Yadav, D., G. R. Selokar, A. Agrawal, V. Mishra, and I. A. Khan. 2021. "Effect of Concentration of NaOH Treatment on Mechanical Properties of Epoxy/Sisal Fiber Composites." *IOP Conference Series: Materials Science & Engineering* 1017 (1): 012028. https://doi.org/10.1088/1757-899X/1017/1/012028.

Yinh, S., Q. Hussain, P. Joyklad, P. Chaimahawan, W. Rattanapitikon, S. Limkatanyu, and A. Pimanmas. 2021. "Strengthening Effect of Natural Fiber Reinforced Polymer Composites (NFRP) on Concrete." *Case Studies in Construction Materials* 15:e00653. https://doi.org/10.1016/j.cscm.2021.e00653.

Zakaria, M., M. Ahmed, M. M. Hoque, and S. Islam. 2017. "Scope of Using Jute Fiber for the Reinforcement of Concrete Material." *Textiles and Clothing Sustainability* 2 (1). https://doi.org/10.1186/s40689-016-0022-5.

Zakaria, M., M. Ahmed, M. Hoque, and A. Shaid. 2020. "A Comparative Study of the Mechanical Properties of Jute Fiber and Yarn Reinforced Concrete Composites." *Journal of Natural Fibers* 17 (5): 676–687. https://doi.org/10.1080/15440478.2018.1525465.

Zhang, P., S. Han, S. Ng, and X. H. Wang. 2018. "Fiber-Reinforced Concrete with Application in Civil Engineering." *Advances in Civil Engineering* 2018:1–4. https://doi.org/10.1155/2018/1698905.

Zhang, Z., Y. Li, and C. Chen. 2017. "Synergic Effects of Cellulose Nanocrystals and Alkali on the Mechanical Properties of Sisal Fibers and Their Bonding Properties with Epoxy." *Composites, Part A, Applied Science and Manufacturing* 101:480–489. https://doi.org/10.1016/j.compositesa.2017.06.025.

Zhang, Z., Y. Li, K. Fu, and Q. Li. 2020. "Determination of Interfacial Properties of Cellulose Nanocrystal-Modified Sisal Fibre in Epoxy by Cyclic Single-Fibre Pull-Out." *Composites Science and Technology* 193:108142. https://doi.org/10.1016/j.compscitech.2020.108142.

Zhao, L., S. Zhu, H. Wu, H. Liang, C. Liu, W. Liu, W. Zhou, and Y. Song. 2021. "The Improved Resistance Against the Degradation of Sisal Fibers Under the Environment of Cement Hydration by Surface Coating of Graphene Oxide (GO) Based Membranes." *Construction and Building Materials* 305:124694. https://doi.org/10.1016/j.conbuildmat.2021.124694.

Zhou, F., G. Cheng, and B. Jiang. 2014. "Effect of Silane Treatment on Microstructure of Sisal Fibers." *Applied Surface Science* 292:806–812. https://doi.org/10.1016/j.apsusc.2013.12.054.

Zhou, X., H. Saini, and G. Kastiukas. 2017. "Engineering Properties of Treated Natural Hemp Fiber-Reinforced Concrete." *Frontiers in Built Environment* 3:1–9. https://doi.org/10.3389/fbuil.2017.00033.

Zia, A., and M. Ali. 2017. "Behavior of Fiber Reinforced Concrete for Controlling the Rate of Cracking in Canal-Lining." *Construction and Building Materials* 155:726–739. https://doi.org/10.1016/j.conbuildmat.2017.08.078.

Zukowski, B., F. de Andrade Silva, and R. D. Toledo Filho. 2018. "Design of Strain Hardening Cement-Based Composites with Alkali Treated Natural curauá Fiber." *Cement and Concrete Composites* 89:150–159. https://doi.org/10.1016/j.cemconcomp.2018.03.006.

Zwane, P. E., T. Ndlovu, T. T. Mkhonta, M. T. Masarirambi, and J. M. Thwala. 2019. "Effects of Enzymatic Treatment of Sisal Fibres on Tensile Strength and Morphology." *Scientific African* 6:e00136. https://doi.org/10.1016/j.sciaf.2019.e00136.

Zwawi, M. 2021. "A Review on Natural Fiber Bio-Composites, Surface Modifications and Applications." *Molecules* 26 (2): 404. https://doi.org/10.3390/molecules26020404.