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A REVIEW OF TENSILE PROPERTIES OF NATURAL FIBRES FOR GEOTECHNICAL APPLICATIONS

Natural fibres have recently gained attention as an alternative sustainable material for civil engineering applications due to natural fibres' exceptional performance, including high strength, and their environmental-friendliness and cost-effectiveness. However, there are disadvantages to using natural fibres in extreme environments. Therefore, this paper reviewed the effect of moisture content and temperature on the tensile strength of potential natural fibres for engineering purposes. Furthermore, this paper also critically reviewed the influence of alkaline treatment on natural fibres' tensile strength. This is significant because alkaline treatment enhances surface friction and the fraction of the revealed cellulose on the fibres' surface, resulting in better mechanical interlocking. In conclusion, natural fibres demonstrate their potential for geotechnical applications due to the materials' strong tensile properties after being subjected to treatment processes.

Keywords: Natural fibres; tensile strength; geotechnical applications

1. Introduction

Soil is one of the most critical and elemental media used in construction projects throughout the world [1]. All the loads attained on structures are carried directly to the ground. If the underlying soil is not stable enough to carry transferred loads, failures, such as structure settlement, cracks, and so on, can occur [2,3]. In reinforced soil, soil mass is improved by inserting tensile-resistant reinforcement. If the soil contains discrete elements for improving its qualities by randomly distributing specified-length fibres, it is referred to as fibre-reinforced soil. Soil reinforcement is a method of enhancing soil qualities through chemical or mechanical techniques, with the primary goals of increasing strength and reducing settlement and lateral deformations [4]. Soil reinforcement with fibres is a composite material in which high-tensile-strength fibres are placed within the soil matrix. When the composite is put through shear stresses, the fibres' tensile resistance is mobilised, and tensile resistance from the fibres confers additional strength to the soil [5]. Natural fibres are now widely employed in synthetic fibres, with environmentally benign, biodegradable, and other unique characteristics [6].

Therefore, natural fibres provide the enhancement of mechanical properties in soil. Natural fibres are among agri-

cultural wastes with significant advantages of high strength [7,8], less abrasiveness [9], cost-efficient [7], lightweight [9], biodegradability [10], and being eco-friendly [11]. Natural fibres can be obtained abundantly from many types of plants, such as bamboo [12,13], kenaf [14], sisal [4,15], jute [15], and banana [16]. Waste generation at the global level is expected to increase by 70% in 2050. Nearly eight billion individuals are responsible for generating 2.5 billion tonnes of waste a year. Agricultural waste is one of these types of massively disposed solid waste. Over 90% of waste in developing and low-income nations are thrown in open fields, resulting in major health and environmental implications [17].

However, when a product with natural fibres reaches the end of its life cycle, it is disposed of and composted without affecting the environment. Natural fibres outperform wood fibres in terms of physical and mechanical features; they also have a high cellulose content and crystallinity and lighter weight. These characteristics attract more recognition from industries nowadays [11]. Moisture content, alkaline treatment, temperature, and fibre density have significant impacts on the properties of natural fibres, especially tensile strength, dimensional stability, and swelling behaviour, and hence the study of these factors is important for engineering purposes [18,19].

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2. Potential natural fibres for geotechnical applications

In recent decades, there has been a growing emphasis on utilizing renewable raw resources to create sustainable products in order to reduce the reliance on fossil fuels and to reduce environmental degradation [20]. Due to their abundance in nature, natural fibres have become an effective alternative to current fibres as raw materials. Natural fibres have a lot of potential for geotechnical applications and have gotten a lot of attention lately because of their mechanical strength properties. Based on the literature, TABLE 1 shows the details of the chemical properties of various natural fibres.

TABLE 1
Chemical Properties of Natural Fibres

Type of fibre	Cellulose (%)	Lignin (%)	Hemicellulose (%)	References
Bamboo	73.83	10.15	12.49	[21]
Kenaf	66.47	2.39	9.43	[22]
Sisal	65-68	9.9-14	10-22	[23]
Jute	64.4	11.8	12	[24]
Banana	63-64	5.0	19	[25]
Hemp	70.2-74.4	3.7-5.7	17.9-22.4	[26]
Agave	68.42	4.85	4.85	[26]
Cotton	85-90	7-16	1-3	[27]

Cellulose, hemicellulose, and lignin are the main components of natural fibres' cell walls [26,28] and the chemical properties of natural fibres may be found within certain ranges. Cellulose ranged from 63% to 90% of the entire chemical properties of natural fibres. From the table, banana fibres had the least cellulose of 63%, while cotton fibres had the maximum cellulose of 90%. Lignin ranged from 2.39% to 16%, where the minimum of 2.39% existed in kenaf fibres and the maximum lignin of 16% was observed in cotton fibres. Hemicellulose ranged from 1% to 22.4%. Cotton fibres had the minimum, while hemp had the maximum, of hemicellulose content. Chemical treatments using different chemicals can be used to remove cellulose, hemicellulose, and lignin from natural fibres. As determined by researchers, improvements in stiffness are attributed to the increased cellulose content in fibres and the decrease in composite porosity due to enhanced interface bonding between fibre polymers and matrix polymers [29].

Lignin is an unwanted polymer that requires a lot of energy and chemicals to remove during pulping. Lignin removal will remove celluloses and hydroxyl groups in natural fibres, improving their thermal stability and mechanical properties [30]. According to [31], hemicellulose removal via alkaline treatment resulted in increased viscosity of cellulosic solutions and improved the compactness and tensile strength of the regenerated fibres. The key to hemicellulose removal is removing branched hemicelluloses at lower alkali concentrations to preserve the unbranched hemicelluloses. Additional treatments have also been applied to ensure that natural fibres can be used as a component for geotechnical applications.

Due to its gelation capabilities, cellulose has several possible applications in geotechnical engineering. It can be used to make thickeners and stabilizing agents [32]. Soils with natural cellulose have much higher tensile and flexural strength [33]. In addition, cellulose has been employed to construct open-graded friction course (OGFC) pavement. OGFC comprises single-size coarse aggregates with wide voids, resulting in a high asphalt content, and cellulose helps it perform better by reducing coarse aggregate pop-out and reflective cracking [34]. Lignin is an excellent alternative to traditional stabilizers. Lignin connects soil particles and reduces large pores, generating a stable soil structure [35].

3. Effect of moisture content on tensile strength

The effect of moisture content on the mechanical properties of natural fibres is an important issue when employing natural fibres for geotechnical applications. Due to their hygroscopic nature, bamboo fibres tend to modify their mechanical characteristics depending on the amount of moisture present [36]. From [18], the moisture content has a considerable impact on the mechanical properties of fibres. Hence, their vulnerability to moisture content has limited natural fibres' application as reinforcements due to their chemical composition, which is rich in cellulose, and their hydrophilic nature.

Moisture content causes fibre swelling, which can degrade the mechanical and dimensional properties of composites. The swelling of fibres is attributed to the filling of the gaps between the fibres and the matrix, which is produced by the presence of moisture. However, moisture content may also result in the improvement in the mechanical properties of specific fibres [37]. It was discovered that the key components responsible for significant moisture absorption are cellulose and hemicellulose [38].

The results of natural fibre's tensile strength from moisture studies are shown in TABLE 2. Based on the findings, it can be concluded that moisture content played a substantial role in determining the mechanical properties of most of the fibres. The highest tensile strength was recorded for sisal fibres with 65%

TABLE 2
Effect of Moisture Content on Tensile Strength

Type of fibre	Moisture Content (%)	Tensile Strength (MPa)	Reference
Bamboo	15	232	[39]
	20	231	[39]
Kenaf	65	275	[40]
	90	430	[40]
Sisal	65	680	[40]
	90	250	[40]
Jute	65	430	[40]
	90	563	[40]
Banana	20	525	[40]
	40	540	[40]

moisture content, while the least was at 20% for bamboo fibres. However, the effect of moisture content on tensile strength was not statistically significant. The data may be affected by the different densities, lengths, and ages of the fibres.

4. Effect of alkaline treatment on tensile strength

Alkaline treatment is one of the variables that influence the mechanical properties of fibres. Natural fibres cannot be used in their natural state because of their hydrophilic character, which causes them to absorb water. However, their mechanical properties can be improved using the alkaline treatment [41], which results in surface alteration. An alkaline treatment usually removes lignin, hemicellulose, and other impurities in fibres [42]. Other than that, based on [43], the alkaline treatment considerably adjusts the structure of fibres to release the hydrogen connection, which increases the harshness of the surface of fibres.

The alkaline treatment enhances surface friction and the proportion of revealed cellulose on the fibres' surface, resulting in more excellent mechanical interlocking [44]. Thus, the alkaline treatment creates different mechanical locking sites, improving interfacial bonding and increasing fibre strength [45]. Alkaline treatments of natural fibres using sodium hydroxide (NaOH) were reviewed to validate the treatment's effectiveness in terms of optimal tensile strength.

Bamboo fibres' tensile strength and modulus of elasticity were enhanced after being treated with alkali [46]. This was due to the removal of lignin and hemicellulose via the treatment, which increased the fibres' roughness and effective surface area. It was reported that the tensile strength of alkali-treated bamboo fibres improved compared to that of untreated bamboo fibres [46]. In addition, sisal fibres with the alkaline treatment had the highest tensile strength, with 12% higher tensile strength than that of untreated sisal fibres, which agrees with the finding that the removal of hemicellulose and a portion of lignin increased the interfacial adhesion between the treated fibres and the matrix [47].

Alkaline treatment improved the surface roughness of kenaf fibres and increased mechanical interlocking, which concurs with the findings from a previous study [48]. Alkali-treated jute fibres showed enhanced tensile and flexural strength and did not affect impact and fatigue behaviours [49]. It can be concluded that different treatment procedures of natural fibres affected fibre length, volume percentage, and orientation in different manners [50].

TABLE 3 shows the result of optimal tensile strength with various alkali concentrations for five different fibres. It was discovered that the alkaline treatment of natural fibres is the most extensively applied and the most versatile method to significantly improve tensile strength. However, the concentration of NaOH, treatment periods, and treatment temperature may influence fibre effectiveness in terms of tensile strength.

TABLE 3

Effect of Alkaline Treatment on Tensile Strength

Type of fibre	Alkaline concentration (%)	Tensile Strength (MPa)	Reference
Bamboo	10	368.33	[46]
Sisal	3	55.02	[47]
Kenaf	1	396	[48]
Jute	5	393-800	[49]
Banana	1	443	[50]

5. Conclusion

In summary, kenaf fibres had the minimum lignin content, which was 2.39%, and cotton fibres had the greatest lignin at 16%. On the other hand, cotton fibres had the minimum hemicellulose at 1% to 3% and hemp had the maximum hemicellulose content at 17.9% to 22.4%. Therefore, kenaf fibres had the overall minimum cellulose, lignin, and hemicellulose. Furthermore, based on the effect of moisture content on tensile strength, it can be concluded that sisal fibres had the highest tensile strength at 680 MPa with 65% moisture content, while the least was at 20% for bamboo fibres with tensile strength of 231 MPa. In addition, sisal fibres with alkaline treatment had the highest tensile strength, with 12% higher tensile strength than that of untreated sisal fibres, where the removal of hemicellulose and a portion of the lignin increased the interfacial adhesion between the treated fibres and the matrix.

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