The influence of incorporating natural fiber on the mechanical performance of natural fiber reinforced concrete

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Abstract:

The quest for lowering the impact of climate change has made researchers and engineers seek renewable resources for construction materials. Thus, selecting sustainable construction materials for civil building application plays a remarkable role in designing and constructing an efficient sustainable building. Natural fibers are gaining favor over traditional materials owing to their superior advantages like bio-degradable, available, low-cost and high specific strength. This paper presents a summary of research works on natural fiber reinforced concrete materials. In addition, through the findings in the literature the study demonstrates the usage of several natural fiber incorporated in concrete, evaluates the influence of plant-based fiber content on the physical, mechanical, and thermal properties of the materials and their applications.

Keywords: Natural fibers, concrete, natural fiber reinforced concrete

1. Introduction

Climate change is a serious environmental challenge that has been facing the world today. Industries and manufacturers are the direct source of carbon dioxide emissions that is the root cause of the environmental issue. The usage of eco-friendly materials for building and industrial applications contributes to reducing the impact of climate change globally. It has been reported that the construction industry by its own emits approximately 7% of the total greenhouse emissions due to the usage of cementitious material [1].

Natural fiber as a green material has been attracting the interest of engineers and researchers due to its significant properties such as high specific strength, eco-friendly, low density, bio-degradable and low cost [2]. The use of natural fiber as a reinforcement is a very old technique, it has been used about 3000 years ago in ancient Egypt, specifically in the construction industry [3,

4]. Incorporation of plant-based natural fiber in brittle cementitious material results in superior enhancement in performance. It will result in excellent crack resistance, enhance energy absorption, fracture toughness, reduce crack initiation and propagation and the fracture mode changes from brittle to ductile [1, 5, 6, 7]. Furthermore, natural fiber in concrete plays an important role in inhibiting cracks, reducing crack growth and early failure [8], as well as the capability to withstand loads with the presence of cracks [9]. Natural fiber reinforced in concrete also decreases the thermal conductivity of the material [10], thus improving thermal insulation which turns to reduce energy consumption, improves thermal comfort and reduces heat loss in buildings.

Besides, natural fiber in concrete offers a remarkable reduction in the weight of the structure, thus lowering the dead loads transfer to the foundation [10]. Construction industries are eager to replace raw materials with agricultural wastes such as palm, jute, flax, bamboo, and sisal. Flax fiber as an example has the highest tensile strength with an excellent crack inhibitor in concrete among other natural fibers [11]. On the other hand, the inclusion of palm fiber in concrete reduces the thermal conductivity compared to pure concrete [12].

The current paper presents a review and knowledge of the use of natural fibers as reinforcements in concrete material. Furthermore, the influence of the plant-based fibers on the physical, mechanical, and thermal performance of the concrete. The usage of natural fiber in concrete provides a promising solution to the conservation of energy and natural resources.

2. Plant-based natural fibers

Plant-based natural fibers are fibrous polymeric composite materials obtained from renewable natural resources. Natural fibers consist of cellulose, hemicellulose, lignin, pectin, and waxes [13]. Fibers are composed of two main cell walls primary and secondary layers of cellulous microfibrils. The primary wall is the outer layer which is rich in cellulose and acts as a bonding agent between fibers. The secondary wall is composed of three sub-layers (S_1, S_2 and S_3). The orientation of the cellulose microfibrils significantly influences the mechanical properties of natural fibers specifically in their longitudinal direction.

The mechanical properties of the natural fibers are governed by the orientation of the cellulose microfibrils of the secondary wall [14]. The main factors that the strength of the natural fiber relays on are microfibrillar angle, cellulose content, and the aspect ratio [15].

3. Mechanical & physical properties of natural fiber

Natural fibers are categorized into bast fibers such as flax, jute, hemp, kenaf, etc., leaf fibers such as palm, sisal, etc., seed fibers such as cotton, kapok, etc., fruit fibers such as coconut, coir, etc., and stalk fibers such as bamboo, rice, corn, etc. [15]. Table 1 summarizes the physical and mechanical properties of some natural fibers.

Table 1 Physical and mechanical properties of natural fibers [16, 17]

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Modulus of Elasticity (GPa)	Elongation at break (%)
Flax	1.5	345–1100	27.6	2.7–3.2
Sisal	1.5	468–640	9.4–22	3.0–7.0
Jute	1.3 – 1.45	393–773	13–26.5	1.16–1.5
Hemp	1.47	690	70	2.0–6.0
Kenaf	1.26–1.45	295–930	53	2.7–6.9
Date palm	1–1.8	95 –190	2.7–5.8	2.5–5.0

Natural fiber when incorporated as a reinforcement results in improved mechanical properties and can act as a promising substitute for traditional materials.

4. Natural fiber/concrete properties & performance

Cement concrete is inherently brittle, with relatively reduced tensile strength, poor ductility, and low crack resistance. During the curing process, concrete undergoes shrinkage, which can lead to the formation of microcracks. Incorporating natural fiber into concrete has been found to mitigate shrinkage during drying and hinder the propagation of these microcracks [18]. Several researchers have conducted investigations to characterize the physical and mechanical properties associated with the addition of natural fiber in concrete.

4.1 Physical properties

Lertwattanaruk et al. [19] studied the influence of coconut coir fiber and oil palm fiber in concrete on the physical properties of the materials. Findings indicated that as the natural fiber increased in the concrete, the density of the material decreases [19]. Another study by Abdullah et al. [20] which used coconut fiber reinforced concrete, the result demonstrated that the density of the mix reduced with increasing the fiber content in concrete. Similarly, Ashour et al. [21] found that with increasing the fiber content from 1% to 3%, the density of the material decreased from 11.6% to 34%.

4.2 Mechanical properties

Concrete mixed with natural fiber exhibits notable enhancements in mechanical properties compared to conventional concrete. Shah et al. [22] demonstrated that incorporating sisal fiber in concrete and coir fiber in concrete with 1% concentration increased the compressive strength by 33.94% and 24.86%, respectively. On the other hand, sisal/coir fiber in concrete with 1% concentration provided enhanced split tensile strength [22].

Saad et al. [23] noticed that adding up to 2% of palm leaf sheath fiber in concrete increased the tensile strength of the concrete. Furthermore, the inclusion of sisal fiber in concrete increased the split tensile strength [24]. Zhou et al. [25] argued that basalt fiber reinforced concrete using a certain portion of the fiber significantly improved the tensile and flexural strengths.

Natural fibers with random orientation in concrete significantly improve crack resistance and crack propagation. Yoo et al. [26] stated that fiber reinforced concrete exhibits enhanced impact strength in comparison to plain concrete, due to the fiber bridging effect at crack planes. Moreover, the incorporation of fiber in concrete increases the energy absorption capability of the concrete under impact load [26].

4.3 Thermal properties

The presence of natural fibers contributes to a decrease in thermal conductivity, which enables the concrete to exhibit improved thermal insulation capabilities. Yassin et al. [12] found that adding palm tree fiber to concrete significantly improved the thermal resistance of the material compared to pure concrete. The study found that with increasing the content of palm tree fiber, the thermal conductivity of the concrete decreased and the heat-transferring rate [12, 27]. On the other hand, Binici et al. [28] noticed that adding straw fiber to mud reduces the thermal conductivity of mud bricks, as a result, it enhances the energy efficiency in buildings.

The inclusion of natural fibers influences the thermal conductivity and insulation capabilities of the material, resulting in enhanced energy efficiency, reduced heat loss, and improved thermal comfort in buildings.

5. Application of natural fiber/concrete

5.1 Structural Applications

In infrastructure projects, concrete mixed with natural fiber can be utilized in infrastructure projects such as bridges, tunnels, and roads. Its enhanced mechanical properties contribute to the durability and longevity of these structures.

On the other hand, pre-cast concrete elements, natural fiber-reinforced concrete finds application in the production of pre-cast elements, including beams, columns, and panels. The improved properties enhance the structural integrity of these components.

In addition, marine and coastal structures, concrete mixed with natural fiber is suitable for marine and coastal applications, such as seawalls, jetties, and breakwaters. Its durability and resistance to saltwater exposure make it ideal for these harsh environments.

5.2 Non-Structural Applications

Natural fiber reinforced can be utilized in flooring and pavements, concrete mixed with natural fiber is suitable for flooring and pavements in residential, commercial, and industrial settings. Its improved impact resistance and crack control make it ideal for high-traffic areas.

Furthermore, architectural applications, natural fiber-reinforced concrete offers versatility in architectural applications where aesthetics and design flexibility are important. It can be molded into various shapes and textures while maintaining structural performance.

Moreover, green roofs, concrete mixed with natural fiber is applicable for green roofs, supporting vegetation growth on rooftops. The enhanced thermal properties and crack resistance contribute to the functionality and longevity of green roof systems.

5.3 Sustainable Applications

Natural fiber-reinforced concrete has the potential to be used in the construction of sustainable buildings, aligning with eco-friendly practices. Its renewable and bio-degradable properties reduce environmental impact.

In addition, in terms of energy-efficient construction: concrete mixed with natural fiber contributes to energy-efficient construction. Its thermal insulation properties reduce heat loss in buildings, resulting in energy savings and improved thermal comfort.

On the other hand, sustainable landscaping, natural fiber-reinforced concrete finds application in sustainable landscaping projects, including retaining walls and decorative elements. Its durability and resistance to cracking provide long-lasting solutions.

By categorizing the applications into structural, non-structural, and sustainable, concrete mixed with natural fiber demonstrates its versatility and potential in various construction domains.

6. Conclusion

In conclusion, the quest for sustainable construction materials to mitigate the impact of climate change has led to a growing interest in natural fiber-reinforced concrete. This paper provides an overview of the research conducted on natural fiber-reinforced concrete and its potential applications in the construction industry. Natural fibers offer several advantages, including being renewable, bio-degradable, readily available, low-cost, and possessing high specific strength. The incorporation of natural fiber into concrete can significantly enhance physical, mechanical and thermal properties and performance. The incorporation of natural fibers into concrete presents a promising solution for achieving sustainable and efficient construction practices. By harnessing the advantages of natural fiber, the construction industry can reduce environmental impact, enhance structural performance, and promote energy efficiency in building design and construction.

Funding

This work was supported by the Australian University.

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