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Review on the Use of Natural Fiber in Cellular Lightweight Concrete for Concrete Block Applications

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ABSTRACT

The growing demand for sustainable building materials has driven research into enhancing the mechanical properties of Cellular Lightweight Concrete (CLC) using natural fibers. This systematic review evaluates the effects of fiber type, treatment, size, and volume fraction on the mechanical properties of CLC, with a focus on compliance with SNI 8640-2018 standards for lightweight concrete blocks. The review was conducted using the PRISMA flowchart, analyzing 13 relevant studies from Scopus and Google Scholar. Results indicate that alkali-treated fibers, such as agave and sugarcane bagasse, significantly improve mechanical performance by enhancing fiber-matrix adhesion. Optimal fiber length (15–20 mm) and volume fraction (0.3–0.45%) were identified for effective crack resistance and strength enhancement. Most fiber-reinforced CLC mixtures met the SNI standard, achieving compressive strengths ≥2 MPa and densities within 750–1200 kg/m³. Untreated fibers also showed improvements at low volumes. Further research is recommended to explore locally available fibers (e.g., coconut, pineapple leaf, and water hyacinth) that remain underexplored but hold promise for future research. This study highlights the potential of natural fibers in developing eco-friendly lightweight construction materials while identifying gaps for further investigation.

Keywords : Cellular Lightweight Concrete (CLC), Natural Fiber Reinforcement, Alkali Treatment, Mechanical Properties, Lightweight Concrete Block (SNI 8640-2018)

INTRODUCTION

The need for building materials has grown dramatically as the world's population continues to expand. Materials that are efficient and effective are required to meet this challenge. Although red clay bricks are frequently used in residential construction, high quantities of waste and greenhouse gases in their production can harm the environment. Lightweight concrete blocks, commonly referred to as Cellular Lightweight Concrete (CLC) are an alternative to clay bricks.

Cellular Lightweight Concrete (CLC), also known as Foam Concrete (FC), is a type of concrete that is made by pouring foam that has already been made using a foam generator and then being placed in the mortar that has already been put together (SNI 8640, 2018). This material can be used for floor fills, wall panels, and lightweight concrete blocks (ACI 523.3R-14, 2014). However, CLC's brittleness and tensile strength are its primary weaknesses (Majeed et al., 2024). Utilizing natural fiber is one of the potential solutions due to its local availability, economic viability, and environmental impact.

This study focuses on the main questions: 1) How does natural fiber affect the mechanical characteristics (Compressive and Flexural Strength) of CLC Concrete?; 2) Does natural fiber in CLC meet the lightweight concrete block standard (SNI 8640-2018)?; 3) What are the natural fibers that have been and have the potential to be used or developed?

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The purpose of this study is to review the use of natural fibers in CLC based on experimental studies, analyze their effects on compressive strength and flexural strength and density, and then assess the suitability of the mechanical characteristics of CLC with SNI 8640-2018 on the specifications of lightweight concrete block for wall masonry to identify the potential of new natural fibers that have not been or are rarely studied.

This study is expected to be a scientific reference in the development of environmentally friendly lightweight building materials, as well as opening up opportunities for further research on local Indonesian fibers.

LITERATURE REVIEW

a. Cellular Lightweight Concrete (CLC)

Cellular Lightweight Concrete (CLC) is a type of lightweight concrete formed from a mixture of cement, water, and foaming agents, with or without fine aggregate. CLC is well-known for its low density, which typically ranges between 400 and 1400 kg/m³, as well as its capacity to insulate against heat and sound. CLC is frequently used in floor fillers, wall panels, and lightweight concrete blocks. Despite its many advantages, the main drawback of CLC is its mechanical properties, especially in low tensile and flexural strength. This makes CLC susceptible to cracking and failure under tensile loads, especially in semi-structural applications.

SNI 8640-2018 on lightweight concrete block for wall masonry states that the primary specifications for lightweight bricks are: stable size, hard to crack or shrink due to drying, dry density between 400 and 1400 kg/m³, and average compressive strengths of 2 MPa for non-structural block and 4 MPa for structural block. To satisfy these requirements, CLC concrete's mechanical qualities must be improved.

b. Natural Fiber in CLC

Natural fibers are an environmentally friendly alternative that is increasingly used as reinforcement in concrete, including lightweight concrete such as CLC. These fibers come from plants (leaves, stems, fruits), and have characteristics such as being lightweight, renewable, and widely available in the environment. From several studies, natural fibers function to resist crack propagation, increase ductility, increase flexural and tensile strength, and improve the bond between cement paste particles.

In addition, there are also major challenges in its application such as fiber degradation in an alkaline cement environment, fiber agglomeration at high levels (balling effect), and variations in quality and shape between fiber types. Several studies have shown that Alkali (NaOH) treatment can improve the binding capacity of fibers with the cement matrix and extend the service life of fibers in the mixture.

RESEARCH METHOD

The research method in this study uses a systematic review approach with the aim of finding out about the application of Cellular Lightweight Concrete using natural fibers in the manufacture of lightweight block products. The selection of articles for review was carried out using the PECO approach (Population: Cellular Lightweight Concrete. Exposure: Natural Fiber, Comparison: Application of Natural Fiber, Outcome: Mechanical Properties of CLC Concrete). Articles were selected using the PRISMA Flowchart approach. Article identification used the Scopus database and Google Scholar search engine. In the article search process, Boolean operators (AND and OR) and several relevant filters were applied. In the Scopus database and Google Scholar searches, the following keywords were used: ("Cellular Lightweight Concrete" OR "Foam Concrete") AND ("Natural Fiber" OR "Natural Fiber") AND ("Mechanical Properties" OR "Mechanical Property"). With a search year filter in the range of 2000-2025 and excluding references. In the data search process, only primary research

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is used. The inclusion criteria used are (1) Full Text, (2) Discussing CLC or FC (3) There is the use of natural fibers (4) There is a mechanical property test (5) Does not include review articles or books. Article examination is carried out using the reference manager tool (Mendelay). Furthermore, the author eliminates based on the Title, Abstract, Keywords, and full text to produce the article to be discussed.

RESULTS AND DISCUSSION

Based on the results of the article search using the Scopus database, 129 articles were found and 756 articles were found in the Google Scholar search. The author conducted an initial selection using the Mendelay application and there were 69 duplicate articles. Furthermore, the author eliminated based on the relevance of the title, abstract, and keywords, the author removed 104 articles. Then the author eliminated again specifically based on the inclusion criteria, resulting in 29 articles that will be read in their entirety to find out the entire contents of the text. The author obtained 13 articles that were in accordance with the research objectives and discussed Cellular Lightweight Concrete which uses natural fibers and reviews the mechanical properties in his research.

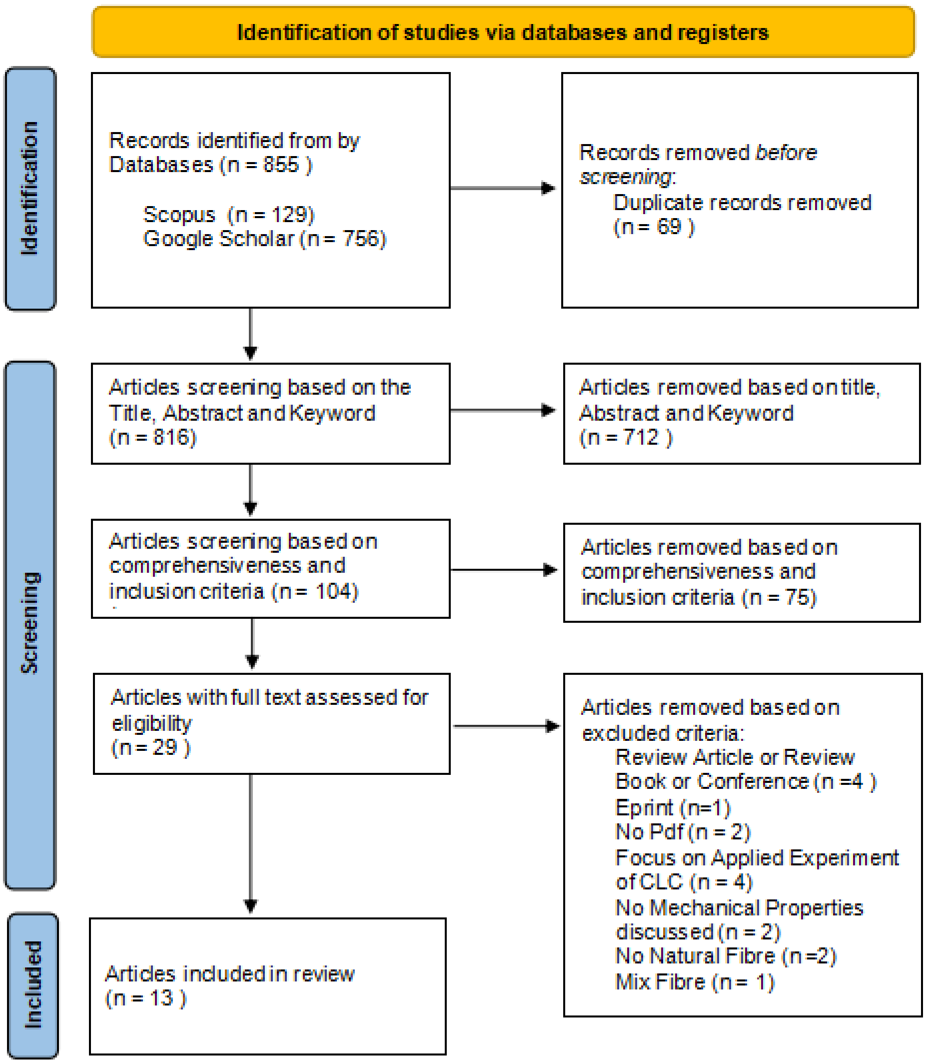

Fig 1. PRISMA Flow Diagram

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a. Summary of Reviewed Articles

The following table presents a summary of 13 articles discussing the effect of natural fibers on Cellular Lightweight Concrete (CLC), including fiber type, treatment, volume fraction, CLC density, and main results on mechanical properties.

Table 1. Summary of Reviewed Articles

Reff	Type of Fiber	Alkali Treated	Other Treated	Size (mm)	Vol.	Max 28d Comp. Strength (MPa)	Max 28d Flex. Strength (MPa)	Design Density (Kg/m3)	Meets SNI Criteria?
(Wang et al., 2024)	Basalt Coir Sisal	0.5% NaOH	N/A	10	0.15-0.45% , of Total Mix	0.65 (0%) 1.77 (0.3%) 1.43 (0.3%)	0.55 (0.45%) 0.49 (0.45%) 0.52 (0.45%)	600	x
(Majeed et al., 2024)	Bamboo Fiber (BF)	N/A	Mech. Refining Process	17	0.1-0.4% of Total Mix	3.59 (0.3%)	1.04 (0.3%)	1000	√
(Majeed et al., 2024)	Agave Cantula Roxb. Fiber (ACRF)	6% NaOH for 24 h, washing using acetic acid, rinse with water, natural sun drying 72 h.	N/A	19	1 - 5% of Total Mix	5.68 (3%)	1.30 (3%)	1060	√
(Mydin, Majeed, et al., 2024)	Agave Fiber (AF)	N/A	N/A	19	1.5 - 7.5% of Total Mix	9.11 (4.5%)	N/A	950	√
(Mydin, Sor, et al., 2024)	Untreated Sugarcane Bagasse Fiber Treated Sugarcane Bagasse Fiber	N/A 4% NaOH for 24 h	Ground Stem, washed and Air Dried 48 h	80-90	1% of Total Mix 1-5% of Total Mix	2.86 (0%) 4.38 (4%)	0.68 (0%) 1.11 (4%)	800	√
(M. Mydin et al., 2023)	Rafia Fiber	N/A	Cleaned and Sun Drying	15-18	2-8% of Total Mix	4.86 (6%)	1.13 (6%)	950	√
(Nesok et al., 2022)	Untreated Banana Fiber	N/A	Sun-dried 72 h, Mechanical Refiner (Grinding Machine) Washed	50	0.35% of Total Mix	1.16 (0.35%)	0.33 (0.35%)	600	x

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	Treated Banana Fiber	6% NaOH for 24 h,	acetic acid and water, Sun-dried 72 h Refiner (Grinding Machine)		0.25-0.55% of Total Mix	1.36 (0.35%)	0.4 (0.35%)		
(Mydin et al., 2022)	Empty Fruit Bunch (EFB)	N/A	Sun Drying	20	0.15-0.6% of Total Mix	1.15 (0.45%) 2.45 (0.45%) 3.59 (0.45%)	0.45 (0.45%) 0.67 (0.45%) 1.02 (0.45%)	550 750 950	x √ √
(Mydin, 2022b)	Coir, Jute, Mesocarp Fiber	N/A	Washing	20	0.45% of Total Mix	1.42 (Mesocarp) 5.15 (Mesocarp) 11.64 (Mesocarp)	0.49 (Mesocarp) 1.59 (Mesocarp) 2.31 (Mesocarp)	700 1100 1500	x √ √
(Mydin, 2022a)	Abaca Fiber	N/A	N/A	20	0.15-0.6% of Total Mix	1.5 (0.45%)	0.46 (0.45%)	550	x
(Mydin, 2021)	Mesocarp Fiber	N/A	Washing	N/A	0.15-0.6% of Binder	1.44 (0.45%) 5.35 (0.45%)	0.32 (0.45%) 1.19 (0.45%)	600 1200	x √
(Castillo-Lara et al., 2020)	Hanaquen Plant (Agave Fourcroydes Lem)	2% NaOH for 1 h in mechanica l stirrer 550 rpm	Washed, dried oven at 60C for 24 h	19	0.5-1.5 of Binder	1.78 (1.5%)	N/A	700	x
(Sua-iam et al., 2016.)	Palm Fiber	N/A	Washing, Boiling for 3 h, saturated 24 h.	~10	0.5-1.5% of Binder	1.38 (1.5%) 1.65 (1.5%) 2.45 (1.5%)	0.27 (1.5%) 0.81 (1.5%) 0.94 (1.5%)	900 1000 1100	x x √

b. Effect of Fiber Type and Treatment

Alkali-treated fibers like Agave (Majeed et al., 2024) and Bagasse (Mydin, Sor, et al., 2024) outperform untreated fiber. The alkali treatment removes the lignin, waxes, hemicellulose, and pectin making the surface of the fiber rougher which improves mechanical interlocking with the cement matrix (Mydin, Sor, et al., 2024). Natural fiber without treatment still shows improvements at low volume fractions (≤ 0.45%) like Empty Fruit Bunch, Mesocarp, and Abaca Fiber.

NaOH treatment significantly improved fiber performance. Treated Sugarcane Bagasse Fiber (4% NaOH) achieved 4.38 MPa compared to 2.86 MPa untreated. Moreover, Treated Banana Fiber (6% NaOH) reached 1.36 MPa compared to 1.16 MPa unreated.

Other treatments such as mechanical refining (e.g., for Bamboo Fiber) and washing/ drying (e.g., for Rafia Fiber) enhanced fiber-matrix bonding, contributing to higher flexural strength.

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c. Size and Volume Fraction

Fiber lengths of 15 - 20 mm show a reasonably best choice in CLC mixture. This can lead to crack bridging and matrix reinforcement (Majeed et al., 2024; Mydin, Sor, et al., 2024). Bagasse fiber shows good results in using the length of fiber ranging from 80-90 mm in its mixture.

For volume fraction, optimum values range from 0.3% to 0.45% of the total mix (e.g., Bamboo, Bagasse, Jute, Mesocarp, Empty Fruit Bunch) in order to meet SNI requirements for lightweight concrete block. Exceptionally Agave Fiber achieved peak strength at 4.5% volume, suggesting fiber-specific optimal thresholds.

d. Compliance with SNI 8640-2018

Most fiber CLC mixtures achieved compressive strength ≥ 2 MPa and density within 750-1200 kg/m3, making them suitable for lightweight concrete block applications.

CONCLUSION

This systematic review highlights the significant influence of fiber type, treatment, size, and volume fraction on the mechanical properties of natural fiber-reinforced composites, particularly in relation to compliance with SNI 8640-2018 standards. Natural fiber addition to CLC significantly enhances compressive and flexural strength. The optimal fiber volume ranges between 0.3%-0.45%. Alkali treatment improves fiber-matrix adhesion and mechanical performance. Fiber sizes between 15-20 mm are ideal for dispersion and performance. Most of the reviewed mixes meet SNI 8640-2018 for lightweight concrete blocks. These insights underscore the potential of natural fibers in sustainable construction, provided proper treatment and mix design are employed. For further study, locally available fibers such as coconut, pineapple leaf, water hyacinth, and banana remain underexplored and highly promising.

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