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Reinforcing Bricks with Natural Fibres: A Review

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Abstract

Natural fibres are biomass waste that agriculture generates in abundance. Lacking environmental awareness, biomass waste is often improperly disposed of. This raises environmental concerns. Natural fibres might be used as building materials, such as bricks. This might be a viable alternative for sustainable development. In this study, articles on the use of natural fibres in bricks are reviewed. The purposes were to study their influence on the structural behaviour of fibre-reinforced bricks and to identify their prospects and challenges. Natural fibres were found to reduce the brick's density, drying shrinkage, thermal conductivity, and workability. They boosted the compressive, tensile, flexural, and tensile splitting strengths, as well as the water absorption capacity. Natural fibres can only be used in limited amounts in bricks, usually less than 5%. This prevents significant strength loss and excessive water absorption. This study points out the drawbacks of natural fibres, such as inconsistent properties, dimensional changes, combustibility, decay susceptibility, and microbiological growth susceptibility. These shortcomings should be addressed before commercialising fibre-reinforced bricks. To overcome the problems, natural fibres may need to be carefully screened and treated before being used in bricks.

Keywords

Natural fibres, fibre-reinforced brick, physical and mechanical properties, treatment, prospects and challenges

INTRODUCTION

Natural fibres, derived as agricultural biomass waste, are abundantly available yet often left to decompose or openly burned on plantation sites due to limited environmental awareness [1], [2]. These disposal methods contribute to environmental issues such as air pollution, land contamination, and pest attraction [3]. One possible solution to mitigate these impacts is to repurpose natural fibres as sustainable raw materials in brick construction.

Bricks are among the most widely used construction materials, accounting for approximately 25% of building components [4], [5]. Conventional brick production, however, depends heavily on non-renewable resources like clay and sand, which are depleting at an unsustainable rate. As the demand for construction materials grows, the need for eco-friendly and renewable alternatives has become increasingly critical. Using natural fibres in bricks offers a dual benefit: it helps manage agricultural waste effectively while conserving non-renewable resources, aligning with the United Nations Sustainable Development Goals.

Reinforcing bricks with natural fibres enhances their tensile and flexural strength and crack resistance, making them suitable for high-load, crack-resistant applications. Additionally, it improves thermal and acoustic insulation, supporting energy efficiency and comfort in buildings.

Despite its potential, research on fibre-reinforced bricks—particularly those made with natural fibres—is fragmented. Comprehensive studies assessing their overall viability are scarce, with most existing research focusing on specific types of fibres. Key questions in this field remain open, including the variety of fibres suitable for reinforcement, the necessity and effectiveness of fibre treatments, the performance characteristics of fibre-reinforced bricks, the optimal fibre content, and the challenges associated with large-scale implementation.

This paper reviews current research on bricks reinforced with natural fibres, examining the effects of natural fibres on brick structural behaviour while highlighting both the potential and challenges associated with this innovative approach.

NATURAL FIBRES IN BRICKS

Natural fibres have been used in different kinds of bricks, including adobe, laterite, mud, soil, biomass, cement, and clay bricks. Twenty-seven types of natural fibres are found to be used in bricks (Table 1).

Table 1 Types of bricks reinforced with natural fibres

Type of brick	Type of fibre	Ref.
Adobe / laterite / mud / earth / soil bricks	Alfa fibres	[6]
	Barley straw	[7]
	Coconut, oil palm, and bagasse fibres	[8]
	Coconut and sisal fibres	[9]
	Doum fibres	[10]
	Hemp fibres	[11]
	Hemp and flax fibres	[12]
	Hemp fibre and straw	[13]
	Hibiscus cannabinus fibres	[14]

Table 1 Continued

	Neem (AzadirachtaIndica) fibres	[15]
	Oat straw	[16]
	Oil palm empty fruit bunches fibres	[3]
	Palm fibres	[17]
	Pineapple Leaf Fibres	[18]
	Pinus Roxburghii and Grewia Optiva fibres	[19]
	Sisal fibres	[20]
	Straw fibres	[21] - [24]
	Straw, corn plant and fescue	[25]
	Straw, seagrass fibres	[26]
	Straw, palm fibre, wood chips carpentry, and rice husk	[27]
	Sugarcane bagasse fibres	[28]
	Wheat (triticium) stalk	[29]
	Wood chips and date palm fibres	[30]
Biomass brick	Corn stalk fibre, Poplar wood fibres	[31] - [33]
.	Poplar wood fibres	[34], [35]
	Waste poplar fibres	[36]
Cement Bricks	Lechuguilla fibres	[37]
	Oil palm empty fruit bunches fibres	[38] - [41]
	Rice husk	[42]
	Rice husk, corncob and coconut coir	[43]
	Sugarcane bagasse fibres	[44]
Clay bricks	Cellulose fibres	[4], [45]
	Oil palm empty fruit bunches fibres	[2], [46]
	Straw	[29]

PROPERTIES OF NATURAL FIBRES

Table 2 shows the properties of natural fibres. The tensile strength, elongation at break, and elastic modulus range from 21 MPa to 800 MPa, 0.037% to 30%, and 0.5 GPa to 23 GPa, respectively. Tensile strengths are greater in bamboo, sisal, coconut coir, lechuguilla, and jute fibres (100 MPa). The tensile strengths of oil palm empty fruit bunches, straw, palm, bagasse, and seagrass, on the other hand, are lower (100 MPa).

Natural fibres generally have a low density of less than 1.5 g/cm^3 (Table 2). They are made of an enormous amount of fine, ligneous-like cellulose fibres [39]. These fibres entangle and form a porous cellular structure. Natural fibres are compressible [11] and have a low compressive strength [38]. They are hydrophilic [47], [49]. Their water absorption capacity can easily exceed 100% (Table 2). Water absorption is influenced by the chemical contents of fibres [47]. The chemical content in fibres included cellulose, hemicellulose, lignin, extractives, ash, pectins, and waxes [47].

TREATMENTS FOR NATURAL FIBRES

Natural fibres are mostly used in their raw and fibrous forms. The fibre lengths vary significantly from 10 mm to 500 mm (Table 3). They are occasionally employed in powder, twig, and dust forms [4], [36].

Before being added to the mix, natural fibres are often cleaned with tap water [48], [51] - [53] or deionized water [43]. The dirt and impurities are removed from the fibres' surface [10], [48], preventing them from affecting the mixture. [44] used hot water baths to remove excess sugar from bagasse fibres. This was done to avoid any negative effects on cement hydration.

Table 2 Properties of natural fibres

Type of fibre	Tensile strength (MPa)	Elongation at break (%)	Elastic modulus (GPa)	Density (g/cm^3)	Water absorption (%)	Reference
Bagasse	25-62		0.5-1.3		153-219	[8]
Bamboo	140–230	4 -7	11-17	0.6–1.1		[47]
Coconut	83-222		2.3-2.8		145-209	[8]
Coconut coir	180	30	4-6	1.2		[47]
Jute	200-770	2 -3	20-55	1.3–1.5		[47]
Lechuguilla.	275–627	6–14			92.3	[37]
Oil palm	65-141		0.7-1.1		54-103	[8]
Straw	38–50			1.2		[27]
Straw fibres				1.2	500–600	[7]
Oil palm fibres	35.33	0.05			0.79	[48]
Oil palm empty fruit bunches	21	30		1.3	11	[3]
Palm fibres	36–136	4.60–18.07	0.743–4.032	0.69–1.86	150–190	[17]
Palm fibres	65.1	0.037	4.2			[27]
Seagrass	56.01			0.074	293	[26]
Sisal	100-800	3-7	9-22	1.5		[47]
Sisal	500	2.1	23			[20]
Straw	128.19			0.032	365.0	[26]

Table 3 Treatments on natural fibres used in the mixture

Ref.	Fibre type	Cut the fibres (fibre length in mm)	Washed with water (type)	Dried the fibre (conditions)	Soaked in water (duration)	Chemical treatment (conditions)
[19]	Chir Pine and Beul fibres	√ (30)				
[20]	Sisal fibre	√ (25)				

Table 3 Continued

Ref.	Fibre type	Cut the fibres (fibre length in mm)	Washed with water (type)	Dried the fibre (conditions)	Soaked in water (duration)	Chemical treatment (conditions)
[21]	Straw	√ (20 – 80)				
[22]	Straw fibres	√ (<100)				
[26]	Straw and seagrass	√ (10 – 30)				
[28]	Sugarcane bagasse fibres	√ (80)				
[29]	Straws	√ (50)				
[47]	Bamboo, Coconut coir, Jute, Polyester, and Sisal fibres	√ (10 – 15)			√ (30 min)	
[7]	Straw fibres	√ (10–500)			√ (24 h)	
[8] [50]	coconut husk, bagasse and oil palm fruit fibres	√ (38 -80)			√ (48 h)	
[51]	Oil palm fruit fibre	√ (30 – 50)	√ (Tap water)	√		
[19]	Chir Pine and Beul fibres	√ (30)				
[20]	Sisal fibre	√ (25)				
[21]	Straw	√ (20 – 180)				
[22]	Straw fibres	√ (<100)				
[10]	Doum fibres (untreated)	√ (35 – 40)	√			
[4]	Waste cellulose fibres	(powder form)				
[36]	Waste poplar fibres	(twigs or sawdust)				
[44]	Sugarcane bagasse fibres	√ (80)		Sun-dried (10 days)	√ (in a hot water bath for 5 days)	
[15]	Neem straw fibres	(ground form)		Oven-dried (105°C for 24 hours)		
[3]	Oil palm empty fruit bunch fibres	√		Sun-dried		
[30]	Date palm fibres	√ (100)		Sun dried	√ (in boiling water)	
[52]	Oil palm empty fruit bunch, spikelet, and stalk fibres	√ (10 – 20)	√ (tap water)	Sun dried (1 day)		
[39] - [41]	Oil palm empty fruit bunch fibres	√ (40)		Oven-dried (100 – 115°C, 1 day)		
[48]	Oil palm fibres		√ (tap water)	Sun-dried		√ (2% dilute NaOH solution, 1 h)
[10]	Doum fibres (treated)	√ (35 – 40)	√	Air-dried (24 h)		√ (1.6 mol/l NaOH, 48 h)
[53]	Oil palm fibres		√ (tap water)	Sun-dried (6 h)		√ (2% diluted NaOH solution)
[18]	Pineapple Leaf Fibres	√ (30)				√ (4% NaOH treatment, 30 - 180 minutes)
[6]	Alfa plant	√ (20 – 25)		√	√ (1h in boiling water)	√ (NaOH solution 6 wt% 6 h, at room temperature
[43]	Rice husk, corncob and coconut coir	√ (10)	√ (5 times in deionized water)			√ Gelatin-hexamine solution (0.5% w/w), Linseed oil (60% w/w), Sodium metasilicate solution (15 wt%) and aluminum sulphate solutio (15 wt%).

Natural fibres are often used dry to prevent moisture from disturbing the brick's mixed proportion. The methods to produce dry fibres include sun-drying, oven-drying, and air-drying (Table 4). Sun-drying duration can range from 6 hours to 10 days (Table 3). Oven and air drying both take roughly 24 hours (Table 3). The oven drying temperature typically ranges between 100ºC and 115ºC.

Table 4 Drying methods for removing the moisture content in natural fibres

Method	Descriptions	Conditions and durations
Sun drying	Reduce the fibre's moisture content under sun over a period of time	• 10 days: [44] • 1 day: [52] • 6 h: [3]
Oven drying	Remove the moisture in fibres in heated oven, stove or chamber	• 105ºC for 24 hours [2], [15] • 100 – 115ºC for 24 hours [39]
Air drying	Surface dry the fibres on an open space.	• Air-dried (24 h) [10]

Dry fibres tend to absorb free water from the fresh mix [52]. This reduces the workability of the mix [51] and subsequently affects the brick's compacting quality [39]. To prevent that, natural fibres can be soaked in water for 30 minutes [47], 24 hours [7], or 48 hours [8], [50]. After that, they are surface-dried and added to the mix.

Natural fibres may also be treated with alkaline solutions. This process (a) removed the impurities like pectin, fats, and lignin in fibres [54], (b) improved the surface roughness and crystallinity index [6], [54], (c) increased the elongation at break of fibres, and (d) enhanced the adhesion between fibres and matrix [10], [53]. This improved the flexural strength of the fibre-reinforced matrix [53].

Despite these advantages, NaOH treatment might reduce the fibre's strength. The higher the concentration, the lower the fibre strength [54]. The treatment can make the fibre more hydrophilic [55], which may be a drawback for brick applications. For this, a low concentration of NaOH is used. [10] used 1.6 mol/l NaOH for 48 hours, [53] adopted a 2% diluted NaOH solution, and [6] used a NaOH concentration of 6 wt% for 6 hours at room temperature. When the alkali density was less than 8%, no significant difference in the fibre's tensile strength was noticed [54].

Other than NaOH, gelatin-hexamine, linseed oil, sodium metasilicate, and aluminum sulphate solutions can be used for surface treatments on natural fibres [56]. Linseed oil outperformed the gelatin-hexamine mixture and the sodium metasilicate-aluminum sulphate [43]. The relevant cement-fibre bricks possessed higher compressive and flexural strengths.

STUDIES OF FIBRE-REINFORCED BRICKS

Numerous experimental studies have been conducted to determine the physical and mechanical properties of fibre-reinforced bricks (Table 5). Density, shrinkage, thermal conductivity, water absorption, porosity, capillary and permeability were among the physical properties examined. The mechanical properties included compressive strength, flexural strength, tensile strength, splitting tensile strength, and shear strength. The workability, durability (i.e., resistance to erosion, wear, and freeze and thaw), chemical compositions, and microstructure of natural fibres were also investigated.

Table 5 Properties of bricks studied

			Properties studied*1								
Ref.	Brick type	Fibre type	CS	FS	D	SD	WA	TS	STS	TC	O
[2]	Fired Clay Brick	Empty fruit bunch	√		√	√	√				
[46]	Fired Clay Brick	Palm fibre waste	√		√	√	√				Porosity
[43]	Cement brick	Rice husk, corncob and coconut coir	√	√			√				
[6]	Compacted earth bricks	Alfa fibres	√	√	√		√			√	Capillary test, morphological test
[30]	Compressed soil bricks	Wood chips and date palm fibres	√		√		√				
[4]	Cellulose fibre	Fired clay bricks	√		√		√			√	Porosity, loss on ignition
[15]	Adobe bricks	Neem (AzadirachtaIndica) fibres	√	√			√			√	Erosion test
[23]	Mud brick	Straw, Polystyrene fabric*2, Plastic fibre*2	√								
[24]	Mud brick	Plastic fibre*2, Straw and Polystyrene fabric*2	√		√		√			√	
[7]	Composite soil	Barley straw	√	√		√					Shear strength, durability

Table 5 Continued

			Properties studied*1								
Ref.	Brick type	Fibre type	CS	FS	D	SD	WA	TS	STS	TC	O
[10]	Compressed earth brick	Doum fibres	√		√		√			√	Capillary absorption test
[11]	Fired and unfired earth bricks	Hemp fibres	√								Freezing-thawing, pore size distribution analysis
[13]	Adobe brick	Hemp fibre, Straw	√	√	√	√				√	
[8]	Soil blocks	Coconut, Oil palm, and Bagasse fibres	√		√	√	√		√		Wetting and drying (wearing) test, erosion test
[28]	Soil block	Sugarcane bagasse	√		√		√		√		Erosion test
[16]	Adobe	Straw fibre, High-density polyethylene fibre*2	√	√							Erosion test
[17]	Adobe bricks	Palm fibre	√	√		√					Water erosion, SEM analysis
[9]	Composite soil	Coconut fibre, sisal fibre	√								
[3]	Laterite Brick	Oil Palm Empty Fruit Bunch Fibres	√		√	√	√				
[37]	Masonry	A. lechuguilla	√					√	√		
[20]	Adobe bricks	Sisal fibre									Couplet test, triplet test, prism test, wallet compression test, finite element analysis
[42]	Sand-cement brick	Rice husk	√				√				
[38]	Cement Blocks	Oil palm empty fruit bunches fibres	√		√	√	√				Prism Test
[39]	Cement Brick	Oil palm empty fruit bunches	√		√		√				Microstructure test
[41]	Cement Brick	Oil palm empty fruit bunches	√		√		√				Microstructure test
[40]	Cement Brick	Oil palm empty fruit bunches	√		√		√				Microstructure test
[31]	Biomass brick	Wooden fibres, corn stalk fibres	√		√	√					Compression ratio
[32]	Biomass brick	Wooden fibres, corn stalk fibres				√	√				Expansion coefficients
[33]	Biomass brick	Wooden fibres, corn stalk fibres	√		√	√					Microstructure test
[44]	Cement Bricks	Sugarcane Bagasse Fibres	√								Cost analysis
[14]	Adobe block	Hibiscus cannabinus fibre	√	√							Microstructure test
[45]	Fired clay bricks	cellulose fibres	√		√		√			√	Modulus of rupture, mineral composition, toxicity
[26]	Adobe bricks	Straw, seagrass fibres	√	√	√	√					
[27]	Mud brick	Straw, wood chips carpentry, rice husk, and palm fibres	√					√			Durability against water.
[22]	Adobe bricks	Straw	√	√							Fracture energy, Young modulus
[21]	Adobe brick	Straw	√								Young modulus, failure mode

Table 5 Continued

			Properties studied*[1]								
Ref.	Brick type	Fibre type	CS	FS	D	SD	WA	TS	STS	TC	O
[25]	Adobe brick	Straw, corn plant and fescue	√	√							
[19]	Adobe	Grewia Optiva; Pinus Roxburghii	√				√				Wetting and drying (wearing) test, sponge water test, water absorption test, expansion test, spray test, water strength coefficient
[18]	Cement stabilized earth brick	Pineapple leaves fibres	√	√							Failure mode
[34]	Biomass brick	Poplar wood fibre									Microstructure test, moisture content, water vapor permeability
[29]	Clay adobes	Straw	√		√	√		√			Workability
[12]	Earth bricks materials	Hemp and Flax	√		√						
[36]	Biomass bricks	Waste poplar fibre	√								SEM, XRD, FTIR spectroscopy, ^{13}C SSNMR, and TG characterizations

*[1]*CS – compressive strength, FS – flexural strength, D – density, SD – Shrinkage and dimensional deformation, WA – water absorption, TS – tensile strength, STS – Splitting tensile strength, TC – thermal conductivity, O – others;* [2]*Synthetic fibres*

Table 6 Experimental results of compressive strengths and fibre content in fibre-reinforced bricks

Type of brick	Type of fibre	Specimen dimension* (unit in mm)	Best compressive strength (MPa)	Optimum fibre content	Other best conditions	Ref.
Fired clay brick	Empty fruit bunch	215 x 102.5 x 65	9.21	1%		[2]
Fired clay brick	Palm fibre waste	215 x 102.5 x 65	19.56	1%		[46]
Cement brick	Rice husk, corncob, and coconut coir	215 x 103 x 65	8.8	20 wt%	Coconut coir, treatment with linseed oil	[43]
Compacted earth bricks	Alfa fibres	13 x 13 (dia. x height)	≈ 23	1 wt%	Treated with the alkaline solution	[6]
Compressed soil bricks	Wood chips and date palm fibres	400 x 200 x 200	2.24	1%		[30]
Cellulose fibre	Fired clay bricks	22 x 11 (dia. x height)	14.0	2.5%		[4]
Adobe bricks	Neem fibres	40 x 40 x160	6.35	2%	Straw, not leave.	[15]
Mud brick	Straw	150 x 150 x 150	2.0	≈2%	Geometrical shape	[23]
Mud brick	Straw	150 x 150 x 150	4.8	2.8%	With cement added	[24]
Composite soil	Barley straw	220 x 107 x 60	≈ 5	1.5%		[7]
Compressed earth brick	Doum fibres	20 x 80 (dia. x height)	≈ 9.75	0.5%	Treated fibre, compaction pressure 9.7 MPa	[10]
Adobe brick	Hemp fibre, straw	40 x 40 x 160	≈ 2.6	10%		[13]
Soil blocks	Coconut, Oil palm, and Bagasse fibres	290 x 140 x 100	≈ 2.6	0.25 wt.%	Coconut	[8]
Soil block	Sugarcane bagasse	290 x 140 x 100	≈ 2.6	0.5%	Red soil	[28]
Adobe bricks	Palm fibre	200 x 200 x 50	5.03	0.25%		[17]
Composite soil	Coconut fibre, Sisal fibre		≈ 2.2	4%	Water/soil ratio 28%	[9]
Laterite brick	Oil palm empty fruit bunch fibres	216 x 97 x 68	10.65	3%		[3]
Masonry	A. lechuguilla	100 x 200 (dia. x height)	2.15	0.75%	Fibre length 25 mm	[37]
Sand-cement brick	Rice husk	215 x 102.5 x 65	≈ 21	2%	Cement-sand mix proportion 1:3.5	[42]

Table 6 Continued

Type of brick	Type of fibre	Specimen dimension* (unit in mm)	Best compressive strength (MPa)	Optimum fibre content	Other best conditions	Ref.
Cement blocks	Oil palm empty fruit bunches fibres	100 x 200 x 400	2.3	10%		[38]
Cement brick	Oil palm empty fruit bunches	215 x 102.5 x 65	11.7	20%	10% Silica fume	[39] [41]
Cement brick	Oil palm empty fruit bunches	215 x 102.5 x 65	9.3	10%		[40]
Biomass brick	Corn stalk fibres	235 x 110 x 100	≈ 0.071	16%	Wooden fibres and calcium hydroxide	[31]
Cement Bricks	Sugarcane bagasse fibres	200 x 120 x 100	12.8	1.5%		[44]
Adobe block	Hibiscus cannabinus fibre	295 x 140 x 100	≈ 2.85	4%	3 cm fibre length	[14]
Fired clay bricks	Cellulose fibres	45 x 45 x 160	≈ 6.5	5%	70% clay, 25% biomass bottom ashes	[45]
Adobe bricks	Straw, seagrass fibres	40 x 40 x 160	2.842	0.5	Straw, 3 cm in length	[26]
Mud brick	Straw, wood chips carpentry, rice husk, and palm fibres	150 x 300 (dia. x height)	16.53	0.6%	Clay, sand, gravel, and palm fibre	[27]
Adobe brick	Straw	310 x 460 x 130	3.34	0.25% volume	Soil: coarse sand: straw volume, 1:0.5:0.25	[21]
Adobe brick	Straw, corn plant, and fescue	40 x 40 x 160	2.4950	3.0%	Corn plant	[25]
Adobe	Grewia Optiva; Pinus Roxburghii	38 x 76 (dia. x height), 190 x 90 x 90	3	2%	Dry state, Grewia Optiva fibre	[19]
Cement stabilized earth brick	Pineapple leaves fibres	290 x 140 x 120	3.19	3%		[18]
Clay adobes	Straw	100 x 100 x 100	≈ 1.6	1.03 wt%		[29]
Earth bricks materials	Hemp and Flax	160 x 40 x 40	≈ 4.5	3%	Flax fibres	[12]
Biomass bricks	Waste poplar fibre	235 x 110 x 150	≈ 1.11	14.91%		[36]

**Dimension before drying shrinkage*

Natural fibres were used to partially replace the brick constituents. The optimum fibre content barely exceeded 5% (Table 6). Natural fibres can strengthen the brick [8], [18], [28], [30]. Excessive fibre content, on the other hand, would reduce the compressive strength of brick [38]. The strength decreased as the fibre content increased [10], [29], [52]. The strength reduction was due to the voids and discontinuities in the matrix introduced by natural fibres [12].

Natural fibres cause voids in bricks. This reduces the brick density [4], [10], lowering the dead loads on structures. They also reduce the efficiency of heat transfer in bricks [53]. This lowers brick thermal conductivity [10], [15], [47]. The voids increase the porosity, permeability, and water absorption of bricks [3], [10], [38]. Excessive water absorption can cause moisture to be extracted from mortar plaster, affecting bonding strength and aesthetic appeal [39].

Natural fibres, in tiny amounts (2%–3%), increase the tensile, flexural, and tensile splitting strengths of bricks [14], [18], [52]. Thereafter, the strength decreased. Natural fibres acted as an energy-absorbing mechanism (bridging action) and delayed microcrack formation [48]. The inclusion of natural fibres increased the ductility [17] and energy absorption capacity of the brick [57]. Due to the high tensile strength of natural fibres, the crack width and crack density caused by drying shrinkage were reduced [17]. The shrinkage rate decreased as the fibre content increased [29].

PROSPECTS AND CHALLENGES

Many developing countries are suffering from weak waste management regulation processes [44]. Lacking environmental awareness, the disposal cost of natural fibres is often reluctantly borne by the industry [58]. The use of natural fibres in bricks can boost their economic value. This drives vested interests to pursue it.

Nonetheless, natural fibres have shortcomings (Table 8). Their properties can vary greatly depending on the age, size, phase of growth, geographic location, soil condition, climate effects, and testing methods [59]. Variations also exist in the same plant. Their cross-sectional area is irregular and fluctuates over their length [49]. Maintaining constant brick quality would be difficult, especially in mass production involving fibres from multiple sources.

Natural fibres are prone to dimensional change due to moisture and temperature. They expand as they absorb water from the fresh mix while mixing. They subsequently shrink during the brick drying process. This affects the adhesion between the fibres and the mix [9], resulting in lower strength and abrasion resistance.

Table 8. Advantages and disadvantages of natural fibres [60], [61]

Advantages	Disadvantages
• Renewable resources • Production requires little energy, involves CO_2 absorption, whilst returning oxygen to the environment • Biodegradable • Produced at lower cost than synthetic fibre • Low density and high specific strength and stiffness • Good thermal and acoustic insulating properties • Low hazard manufacturing processes • Low emission of toxic fumes when subjected to heat and during incineration at end of life • Less abrasive damage to processing equipment compared with that for synthetic fibre composites	• Lower strength, especially impact strength compared to synthetic fibre • Lower durability than synthetic fibre, but can be improved considerably with treatment • High moisture absorption, which results in swelling • Greater variability of properties • Lower processing temperatures limiting matrix options • Poor fire resistant • Poor fibre/matrix adhesion

Fibre-reinforced brick might be flammable because dry fibres are susceptible to combustion. Fibre-reinforced brick walls might not effectively compartmentalise buildings to delay fire spread. Because natural fibres are biodegradable, the bricks may be susceptible to decay. Furthermore, the brick micropores can accommodate moisture. The fibres might swell, and microorganisms, algae, and fungus may thrive as a result of this. This may pose health concerns and affect the brick's durability, storage duration, and aesthetic appeal.

Natural fibres may need to be carefully screened for consistent qualities to alleviate these issues. This may entail standardising the fibres' diameter, aspect ratio, moisture content, unit weight, porosity, and chemical compositions. Studies might be carried out to determine the relationship between these parameters and the desired properties of natural fibres.

Natural fibres can be treated for (i) higher compressive and tensile strengths, (ii) lower compressibility, (iii) higher elongation at break, (iv) greater interfacial bond with the matrix, (v) lower water absorption capacity and permeability, (vi) lower combustibility, etc. Other than alkaline treatment that is extensively used, there are treatments using gelatin-hexamine, linseed oil, sodium metasilicate, and aluminium sulphate. Studies on the effects and effectiveness of these treatment methods may be done. New treatment methods may be developed to alter the properties of natural fibres. Natural fibres can be treated for (i) higher compressive and tensile strengths, (ii) lower compressibility, (iii) higher elongation at break, (iv) greater interfacial bond with the matrix, (v) lower water absorption capacity and permeability, (vi) lower combustibility, etc. Other than alkaline treatment that is extensively used, there are treatments using gelatin-hexamine, linseed oil, sodium metasilicate, and aluminium sulphate. Studies on the effects and effectiveness of these treatment methods may be done. New treatment methods may be developed to alter the properties of natural fibres.

Furthermore, bricks may include more than one type of fibre. Mixing fibres with diverse properties allows them to complement one another. This may also involve synthetic fibres like plastic, polystyrene, polyester, and steel. Relevant studies may be conducted to investigate their effects.

CONCLUSIONS

This paper reviews the application of natural fibres in various kinds of brick. Natural fibres benefit bricks by reducing density, drying shrinkage, and thermal conductivity. They also improve the compressive, tensile, flexural, and tensile splitting strengths slightly. Natural fibres, on the other hand, affect the workability of fresh mix and encourage water absorption by the bricks. The effects are not favourable for bricks.

Natural fibres have weaknesses, which can be drawbacks for fibre-reinforced bricks. They have inconsistent properties and are prone to dimensional changes owing to moisture and temperature. They are likely to be combustible and susceptible to decay and microbiological growth. These shortcomings need to be addressed before commercialising the bricks. For the time being, only a small amount of natural fibre is permitted in bricks. This is done to minimise the detrimental effects of natural fibres on bricks. The current accomplishment contributes little to the consumption of natural fibres produced by agriculture. Future studies might look into increasing the fibre content in bricks without compromising their functionality as building materials.

It is worth noting the limitations of this study. First, all the natural fibres are assumed to have similar characteristics and affect various kinds of bricks in the same way. This might not be true since (a) the properties of various natural fibres can vary greatly and (b) the constituents used in various types of brick differ considerably. Second, the chemical composition of the natural fibres has not been adequately studied. It is uncertain if there is any mineral or chemical compound in the natural fibres that can negatively affect the brick mixture. Lastly, fibre-reinforced bricks are expected to be cheaper than conventional bricks as they involve biomass waste. This may not be the case if the bricks contain only a small amount of natural fibre. The processing and treatment costs of natural fibre may not be covered by material savings from bricks. One could consider investigating the actual production cost of fibre-reinforced bricks. The cost may be estimated per unit volume, strength, life span, or carbon emission, as applicable.

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