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A Comprehensive Review Sustainable Use of Coconut Shell and Coir Fiber in Concrete

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Abstract: Construction material sustainability has become a major focus in recent years because it works to decrease environmental effects while optimizing resource utilization. The field of concrete technology now uses agricultural waste materials including coconut fiber and coconut shell as promising alternatives. The review examines how coconut fiber and coconut shell serve as concrete components for reinforcement and partial substitution. The natural lignocellulosic material coconut fiber enhances concrete properties by increasing tensile strength and ductility and impact resistance. Coconut shell functions as a lightweight coarse aggregate that decreases concrete density while promoting sustainable construction practices. Experimental research shows that concrete becomes more durable and resistant to cracks and develops better flexural strength when coconut-based materials are incorporated into its composition. The review examines mix design aspects together with mechanical properties and water absorption and long-term performance while discussing challenges and possible solutions. The research unites knowledge about coconut fiber and shell applications to create sustainable concrete solutions that deliver cost-effective high-performance results for sustainable construction.
Keywords: Coconut Shell Aggregate, Coir Fiber Reinforcement, Sustainable Concrete, Agricultural Waste Utilization, Natural Fiber Composites, Eco-friendly Construction Materials, Mechanical Properties of Concrete.

I. INTRODUCTION

Concrete represents the dominant construction material across the world because it offers versatility alongside durability and strength. The manufacturing of conventional concrete relies on non-renewable substances including cement together with sand and gravel but this process generates substantial carbon dioxide emissions. Scientists and engineers are dedicated to discovering sustainable construction solutions because they need to resolve environmental and economic problems without degrading performance. The use of agricultural waste materials in concrete mixtures represents a promising alternative solution.

The agricultural byproducts of coconut fiber and coconut shell show exceptional promise because they exist abundantly at affordable prices and possess beneficial mechanical properties. Tropical nations including India, the Philippines, Indonesia and Sri Lanka have large coconut cultivation areas. The processing of coconuts produces discarded byproducts including husk (fiber) and shell which are not used efficiently. The use of agricultural waste materials in concrete construction reduces environmental pollution while adding value to agricultural waste to achieve sustainable benefits and performance improvements.

Coconut fiber known as coir originates from the exterior part of the coconut husk. The material contains biodegradable properties with tension strength and high lignin content which makes it strong and durable. The addition of coconut fibers to concrete creates natural reinforcement that prevents shrinkage cracks while strengthening tensile and flexural properties and improving impact tolerance. The fibers function best in non-structural applications including pavements, footpaths and precast panels.

The dense and tough nature of coconut shell makes it suitable as a complete or partial substitute for coarse aggregates in construction. The coconut shell aggregate presents a rough surface texture with strong bonding properties to cement paste which enables its use in lightweight concrete applications. Using coconut shell aggregate in concrete reduces the total weight of concrete structures which leads to reduced structural expenses and lower transportation costs.

The review evaluates the mechanical and physical properties as well as durability characteristics of concrete which incorporates coconut fiber and coconut shell separately or together. The research evaluates the correct mix ratios alongside workability issues and water absorption problems and reviews treatment approaches that improve performance. The paper provides an extensive review of how coconut fiber and shell integrate into modern concrete construction for sustainable infrastructure development while discussing their benefits and constraints.

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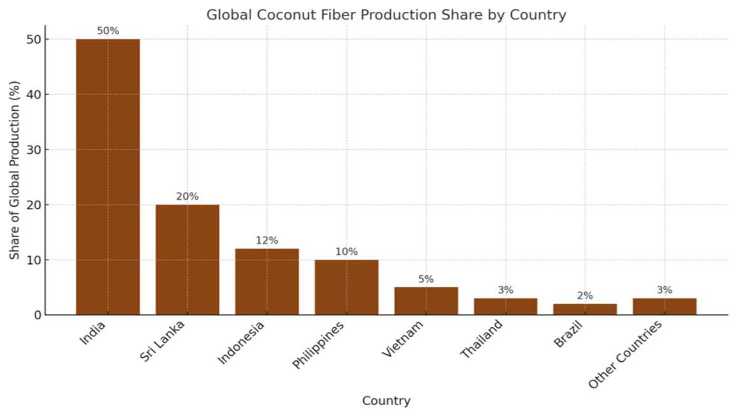
	Approx. % of Global Coconut Fiber Production	Remarks
India	45–50%	World's largest producer and exporter of coir
Sri Lanka	15–20%	Major exporter, especially of brown and white coir
Indonesia	10–12%	Large coconut producer, moderate coir use
Philippines	8–10%	Produces more coconut but less coir
Vietnam	3–5%	Growing market for coir processing
Thailand	2–3%	Smaller but increasing production
Brazil	1–2%	Small-scale coir industry
Other Countries	2–5%	Includes Malaysia, Mexico, Tanzania, etc.



II. BACKGROUND

A. *Coconut Fiber*

The outer husk of coconuts produces natural fiber known as coir which people extract to obtain coconut fiber. The material exists as a strong yet coarse substance which breaks down naturally and serves multiple purposes in construction and agriculture and household applications. The addition of coir to concrete materials improves both its strength and its ability to resist cracking. The material serves multiple purposes including erosion control mats and ropes and brushes and agricultural growing medium applications. The fiber exists as an environmentally friendly renewable resource which tropical nations produce in substantial amounts.

Chemical Composition of Coconut Fiber

Component	Percentage (%)
Cellulose	32–43
Hemicellulose	0.15–0.25
Lignin	40–45
Pectin	3–4
Water-Soluble	5–6
Ash	0.2–0.6

B. *Coconut Shell*

The coconut shell represents the outer protective layer which exists between the coconut husk and the coconut meat. The lignocellulosic material shows durability and hardness and resistance to moisture because of its tough nature. The production of activated carbon and charcoal and bio-composites utilizes coconut shell as a material while researchers investigate its potential as an environmentally friendly construction material for lightweight concrete and fillers. The material exists in tropical areas and decomposes naturally. The material exhibits superior thermal and chemical resistance because it contains high lignin levels and low cellulose content. The crushed form of coconut shell serves to decrease concrete weight while providing sustainable building solutions.

Chemical Composition of Coconut Shell

Component	Percentage (%)
Lignin	45–50
Cellulose	23–25
Hemicellulose	18–22
Ash	1–2
Moisture	6–10
Volatile Matter	20–25
Fixed Carbon	60–70

III. LITERATURE REVIEW

The use of agricultural byproducts in concrete production has gained significant interest because of the rising demand for sustainable construction practices. The combination of coconut fiber and coconut shell has gained substantial interest because they show promise to improve concrete properties while decreasing environmental impact**.**

Ali et al. (2012) The natural lignocellulosic fiber called coconut fiber or coir possesses high tensile strength with moderate elongation properties which make it appropriate for concrete reinforcement. demonstrated that concrete benefits from small additions of coconut fiber up to 2% by weight which improves both tensile and flexural strength.

Balaguru and Shah (1992) showed that coir fibers function as micro-reinforcement elements which help decrease shrinkage cracks and improve ductility properties.

Kandasamy and Murugesan (2011) confirmed that concrete specimens containing 1% coconut fiber demonstrated a 10–15% improvement in compressive strength and underwent significant enhancements in toughness properties. The material provides enhanced energy absorption capabilities along with crack arresting properties which make it suitable for non-structural and medium-load applications.

Ramakrishna & Sundararajan (2005).Natural fibers present a significant challenge due to their tendency to absorb large amounts of water which negatively affects concrete workability and long-term structural integrity. Researchers have employed alkali treatments together with surface coatings to decrease water absorption rates and enhance the cement matrix bonding according to

Gunasekaran et al. (2011) The hard and durable coconut shell material has been studied as an alternative to coarse aggregates in concrete production. concrete mixes with crushed coconut shell replacing 50% of coarse aggregates which resulted in lightweight concrete with a 20% lower density. The structural weight reduction and insulation properties make this material suitable for building applications where lower loads and better thermal performance are necessary. The experimental results of this study demonstrated that coconut shell concrete achieved compressive strength values ranging from 17 to 22 MPa based on the specific mix proportions. The compressive strength values of these materials are suitable for building applications such as partition walls and lightweight slabs although they are slightly below those of conventional concrete.

According to Abundifoh et al. (2015) research coconut shell aggregate demonstrates strong cement paste bonding characteristics and its angular shape enhances interlocking between the components. The durability tests revealed acceptable results for water permeability and chemical resistance under moderate exposure conditions. Combined Use and Synergistic Effects:

According to Manoharan et al. (2019) Current research investigates how to combine coconut fiber with coconut shell in concrete construction. The use of 1% fiber together with 30% shell substitution produced concrete that displayed better flexural and impact performance and suitable compressive strength The hybrid concrete mixes showed better performance after cracking along with enhanced energy absorption characteristics which suit their applications in pavements and precast units

Mechanical Properties of Concrete Using Different Fibres

Author (Year)	Fibre	Mix Grade	% Adding	W/C Ratio	Compressive Strength (MPa)	Flexural Strength (MPa)	Tensile Strength (MPa)
A.M. Shende et al. (2012) [59]	Steel	M40	0% 1% 2%	0.35	45.19 52.00 53.33	7.47 8.80 9.47	3.07 3.30 3.92

			3%		56.30	10.40	4.34
Abdul Ghaffar et al. (2014) [60]	Steel	M35	0%	0.40	43.33	6.05	-
			0.5%		42.34	6.03	
			1%		43.67	6.01	
			1.5%		44.50	5.95	
			2%		44.67	6.11	
			2.5%		45.33	6.29	
			3%		46.00	6.21	
			3.5%		45.00	6.53	
			4%		44.67	7.01	
			4.5%		44.33	6.93	
			5%		44.00	6.91	
Satyashiva Prasad Nannuta (2017) [55]	Steel	M30	0%	0.37	31.15	-	2.64
			0.25%		33.34		2.92
			0.5%		36.17		3.30
			0.75%		38.92		3.62
			1.0%		42.06		3.86
			1.25%		49.74		4.10
E. Arunakanthi et al. (2016) [61]	Steel	M20	0%	0.45	22.56	3.73	1.53
			0.5%		24.06	3.90	1.59
			1%		26.00	4.40	1.65
			2%		27.66	4.75	1.96
			3%		28.15	5.20	2.17
T. Saikiran et al. (2016) [62]	Glass	M30	0%	0.45	39.00	6.61	3.77
			5%		47.27	8.07	4.50
			6%		48.00	8.47	4.59
			7%		48.40	7.97	4.33
Mahmoud Mazen Hilles et al. (2019) [63]	Glass	M50	0%	0.37	57.85	6.35	4.12
			0.3%		61.05	7.53	4.77
			0.6%		66.01	8.28	5.53
			0.9%		66.34	8.79	5.84
			1.2%		66.60	9.68	6.73
Divya S. Dharan et al. (2016) [64]	Polypropylene	M30	0%	0.45	38.50	4.34	3.42
			0.5%		42.14	5.21	3.86
			1%		44.61	5.48	3.98
			1.5%		46.00	5.71	4.38
			2%		41.72	4.82	3.66
Archana P. et al. (2017) [65]	Polypropylene	M20	0%	0.45	33.11	5.84	3.52
			0.2%		34.40	6.16	3.69
			0.4%		36.10	6.56	3.80
			0.6%		37.30	6.96	3.85
			0.8%		38.40	7.60	3.90
			1%		36.11	5.80	2.74
			1.2%		33.91	4.16	1.67
Prashant Muley et al. (2015) [66]	Carbon	M40	0%	0.40	50.50	6.10	3.80
			0.25%		54.70	6.90	4.30
			0.5%		56.70	7.90	4.70
			0.75%		62.00	8.30	5.00
			1%		69.90	9.30	5.40

S.M. Deore et al. (2017) [67]	Carbon (with WFS)	M30	0%+0% 30%+0.25% 30%+0.5% 30%+0.75% 30%+1%	0.50	-	7.51 6.45 7.55 9.05 8.65	-
Emmanuel et al. (2019) [68]	OPB Fibre	M35	0% 0.5% 1% 1.5% 2% 3% 4%	0.53	42.88 41.64 40.51 36.29 33.67 34.78 29.14	3.88 3.50 3.68 3.57 3.55 3.95	3.33 3.45 3.37 3.15 3.05 2.89 2.94
Baruah and Talukar (2007) [17]	Coir	M25	0% 0.5% 1% 1.5% 2%	-	21.42 21.70 22.74 25.10 24.35	3.25 3.38 3.68 4.07 4.16	2.88 3.02 3.18 3.37 3.54
Shikha Rajan et al. (2015) [69]	Coir	M30	0% 1% 2% 3%	-	26.77 26.44 26.85 27.46 30.60 30.95 31.14 31.27	-	-
Ajay Kumar et al. (2018) [70]	Coir (with WFS)	M20	0%+0% 0%+3% 20%+0% 20%+3% 30%+0% 30%+3% 40%+0% 40%+3%	0.53	23.21 24.23 24.01 25.41 25.51 26.50 18.50 19.70	3.83 4.08 3.80 4.17 4.00 4.31 4.30 4.72	2.42 2.60 2.92 3.08 3.35 3.50 1.61 1.80

A. Advantages

1) Sustainability and Eco-Friendliness The use of coconut fiber and shell as construction materials helps decrease landfill waste while supporting sustainable building practices. The use of coconut fiber as a building material decreases environmental impact because it replaces traditional non-renewable construction materials.
2) Improved Mechanical Properties The addition of coconut fiber enhances tensile strength and impact resistance and ductility and helps prevent micro-crack formation. The rough texture and angular form of coconut shell enhances bonding properties in construction materials.
3) Lightweight Concrete The weight of coconut shell aggregates is lower than standard construction ma terials which leads to reduced concrete structure weights. The material works best for applications that require low structural loads such as partition walls and pavements and precast blocks.
4) Cost-Effectiveness The availability and affordability of coconut fiber and shell materials are high particularly in areas where coconut production takes place.
5) Thermal and Acoustic Insulation The use of coconut-based concrete provides superior thermal insulation and sound absorption properties which make it appropriate for residential construction.

B. Disadvantages

1) Workability Issues The absorption properties of coconut fiber negatively affect the workability of fresh concrete. The irregular shapes of coconut shell create problems during mix compaction and consistency maintenance.
2) Variable Material Properties The performance of concrete becomes non-uniform because coir natural fibers present varying lengths and thicknesses and strengths.
3) Durability Concerns The untreated coconut fiber material absorbs water which causes swelling and eventual deterioration that shortens its durability. The water absorption rate of coconut shell exceeds conventional aggregates which negatively impacts both water–cement ratio and strength development.
4) Limited Structural Application The compressive strength of concrete containing coconut shell typically falls below the strength of standard concrete. The material does not perform well in heavy-load structural applications such as columns or beams used in high-rise buildings.
5) Need for Surface Treatment The processing time and cost increases because coconut fiber needs alkali treatment or chemical coating to enhance bonding and decrease water absorption is advantage.

IV. CONLUSION

The use of coconut fiber and coconut shell in concrete production creates an opportunity to develop environmentally friendly construction materials that are both affordable and sustainable. The natural tensile strength and crack-bridging properties of coconut fiber improve concrete's flexural strength and impact resistance and ductility. The use of coconut shell as a coarse aggregate substitute in concrete production results in weight reduction and improved thermal insulation properties which make it suitable for lightweight concrete applications.

The challenges of reduced workability and high water absorption and variable material properties can be overcome by using appropriate mix design methods and fiber treatment techniques and chemical admixtures. The combined use of coconut fiber and shell creates an opportunity to enhance concrete performance especially in applications with low structural requirements and light loading conditions.

The use of coconut-based concrete materials helps achieve sustainable construction goals through reduced dependence on traditional aggregates while minimizing agricultural waste and decreasing environmental carbon emissions. Research should advance to study large-scale applications and durability in harsh environments and life cycle assessments to increase their adoption in construction practices.

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