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Performance Evaluation of Sand-Based and Wood-Based Lightweight Concrete Using Alternative Aggregates Compared to Conventional Concrete

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Abstract: *Lightweight concrete is a specialized type of concrete that incorporates lightweight aggregates to reduce its density and improve its thermal and acoustic insulation properties. Due to its reduced weight,lightweight concrete is highly valued in construction applications that require both strength and a reduction in the overall load on structural elements.The demand for sustainable and lightweight construction materials has increased as the building industry seeks alternatives to traditional aggregates that reduce environmental impact and improve performance. This study investigates the independent use of two unconventional materials: dune sand and wood chips, as partial aggregate replacements in lightweight concrete. Each material is evaluated separately to determine its influence on mechanical, physical, and durability characteristics, with the aim of identifying its suitability for eco-efficient construction applications. The performance of lightweight concrete, which typically requires a high cement content to achieve adequate strength, can be improved through the controlled addition of fines and optimization of the water-to-cement ratio. By integrating dune sand, this study aims to enhance workability, mechanical strength, and long-term rheological properties while reducing production costs. Wood chips, derived from renewable and low-density lignocellulosic materials, offer significant environmental advantages, including reduced carbon footprint, valorization of organic waste, and improved thermal insulation properties of the resulting composites. This study investigates the use of dune sand and wood chips as alternative aggregates for the production of lightweight concrete with enhanced environmental and functional performance. Dune sand, abundant in arid regions and characterized by its fine and uniform particle size, offers potential as a sustainable substitute for traditional coastal sands, improving workability and reducing material costs. Wood chips, a renewable and low-density organic by-product, serve as an eco-aggregate capable of significantly lowering the unit weight of concrete while enhancing thermal insulation and contributing to waste valorization. The two materials are examined independently, each presenting distinct technical challenges and potential benefits, particularly in relation to water absorption behavior, the requirements for optimized mix design, and the need to reconcile mechanical performance with targeted density reduction.*

Conventional concrete remains the most widely used construction material due to its high compressive strength, durability, and availability of raw materials. It is typically composed of cement, natural fine and coarse aggregates, and water, resulting in a dense material with a unit weight ranging from 2300 to 2500 kg/m³.Additionally, the extensive use of natural aggregates contributes to resource depletion and environmental concerns. In this study, conventional concrete is used as a reference material to evaluate and compare the performance of alternative sustainable concrete mixes.

Keywords: *Lightweight concrete, dune sand,wood chips,sustainable aggregates, eco-efficient construction, low-density concrete, conventional concrete.*

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I. Introduction

The global construction industry increasingly demands materials that combine structural performance with sustainability and environmental responsibility. Conventional concrete relies heavily on natural river sand and coarse aggregates, the extraction of which has raised concerns about resource depletion, environmental degradation, and escalating material costs. Lightweight concrete achieved by incorporating low-density or fine alternative aggregates emerges as a promising solution that reduces structural dead load, enhances thermal and acoustic insulation, and lowers environmental impact.Among potential substitutes for conventional aggregates, dune or desert sand has attracted attention due to its abundance in arid and semi-arid regions. Several recent studies indicate that, when properly processed or blended, desert sand can partially replace traditional fine aggregates without severely compromising concrete strength and durability.

Replacement of natural sand with dune sand can yield acceptable performance in terms of workability, strength, and durability. However, challenges such as poor grading, fineness modulus, and water absorption behavior must be addressed to maximize the potential of dune sand in concrete.

The current focus in concrete technology is the development of composite materials capable of fulfilling multiple functional requirements. Modern research not only targets mechanical performance but also seeks to enhance thermal, acoustic, and economic properties. Lightweight concrete, in particular, plays a dual role as a structural material and thermal insulator while maintaining adequate strength, making it suitable for applications that require lightness and cost efficiency. These materials are often studied under two main themes: mechanical/thermal or mechanical/acoustic performance. Lightweight concrete is generally characterized by a density below 2000 kg/m³ and thermal conductivity less than 1.0 W/m·°C. Making it an attractive alternative to normal-weight concrete when economical and lightweight solutions are desired.Desert regions offer abundant and renewable natural resources, such as fine-grained dune sand, which is rich in silicon-based chemical and mineralogical components. However, using dune sand in concrete has been associated with challenges, including endogenous and exogenous shrinkage, early cracking, loss of rigidity, and reductions in mechanical resistance. Nevertheless, significant research has explored the use of waste or unconventional materials as partial substitutes for fine aggregates, showing potential improvements in durability and mechanical performance while supporting sustainable concrete production.Given the variability in concrete production and the sensitivity of mechanical and thermal performance to mix composition, precise control of the concrete mix is essential to achieve the desired properties. The substitution of conventional aggregates with unused local materials presents a promising strategy for developing new lightweight concretes and mortars that address technical, economic, and environmental challenges. Similarly, replacing cement with alternative binders can enhance material properties and broaden the functional capabilities of cementitious composites.The use of wood-based materials such as wood chips, sawdust, or wood-waste have been increasingly studied for their potential to create low-density cementitious composites. Incorporating wood waste into concrete or mortar offers environmental advantages: it valorizes organic by products from the timber industry, reduces reliance on virgin mineral aggregates, and can significantly lower the density of building materials while improving thermal insulation. Studies have shown that wood-aggregate concretes generally exhibit reduced density and thermal conductivity, though often with some reductions in mechanical strength and increases in water absorption or porosity compared to conventional concrete.Wood-processing industries generate substantial quantities of waste, prompting growing interest in the valorization of wood chippings as a lightweight aggregate for cementitious composites. Owing to their low cost, local availability, and environmental benefits, wood chippings offer potential for use in construction products requiring thermal insulation, acoustic performance, or fire resistance. While prior studies have examined wood ash as a filler with limited mechanical benefits, research has shown that incorporating wood chippings into cement-based matrices can reduce capillary absorption and significantly improve thermal insulation properties.

1.1. Performance Characteristics and Engineering Behavior of Conventional Concrete

Conventional concrete is a composite construction material composed of Portland cement, natural fine aggregates, coarse aggregates, and water, whose performance is largely governed by the cementitious matrix and aggregate properties.Concrete performance is strongly influenced by its age and exposure environment. While the cement paste continues to harden over time, improving material properties, early-age curing conditions play a critical role in long-term durability. Cyclic variations in temperature and humidity affect the internal structure of concrete due to the presence of a liquid pore phase. Among deterioration mechanisms, corrosion of reinforcing steel is the most prevalent, occurring as the alkaline protection provided by the cement paste gradually diminishes. It typically exhibits a unit weight in the range of 2300–2500 kg/m³ and achieves 28-day compressive strengths between 25 and 40 MPa, depending on the mix design and curing conditions. The mechanical behavior of conventional concrete is characterized by high stiffness, modulus of elasticity between 25-30 GPa, and reliable load-bearing capacity, making it suitable for structural elements including beams, slabs, columns, and foundations.

Despite its excellent compressive performance and durability under standard environmental conditions, conventional concrete demonstrates relatively high thermal conductivity (1.4-1.9 W/m·K) and susceptibility to cracking due to shrinkage and thermal stresses. Moreover, the reliance on natural aggregates raises sustainability concerns, motivating the development of alternative concrete materials. In engineering research, conventional concrete serves as a baseline material, providing a standardized reference to evaluate the mechanical, thermal, and durability performance of emerging lightweight and sustainable concrete composites.

1.2. Evolution of Lightweight Concrete in Modern Construction

Lightweight concrete has progressed from a specialized material to a central component in modern sustainable construction. Its appeal lies in its key attributes reduced density, low thermal conductivity, and decreased structural dead load which collectively enable the design of thinner, lighter, and more energy-efficient building systems without compromising essential structural performance. Typically, Lightweight concrete exhibits a density below 2000 kg/m³ and thermal conductivity less than 1 W/m·°C, characteristics that position it as a hybrid material offering both mechanical and functional advantages. Growing sustainability demands have further accelerated the shift toward alternative aggregates that help mitigate the environmental impacts linked to conventional river sand extraction, including biodiversity loss, soil degradation, and riverbed erosion. Consequently, non-traditional materials such as dune sand and lignocellulosic biomass residues (e.g., wood chips) are attracting increased research and industrial interest. These resources not only reduce reliance on depleting natural aggregates but also support circular-economy strategies by promoting the use of abundant or waste-derived materials in construction.Modern lightweight concrete technology has expanded beyond structural applications to include multifunctional roles, where energy efficiency, durability, and eco-friendliness are considered alongside strength. The integration of alternative aggregates supports not only reductions in self-weight and embodied carbon but also the creation of construction materials tailored to specific thermal, acoustic, or structural requirements. Consequently, the evolution of LWC reflects a shift toward more sustainable, resource-conscious construction, where traditional limitations are overcome through innovative use of local and waste-derived materials, fostering the design of resilient, low-carbon, and high-performance infrastructure.

1.3. Use of Recycled Wood Waste as Lightweight Aggregate in Concrete Production

The utilization of recycled wood waste, such as sawdust and wood fiber, as lightweight aggregate in concrete has been widely investigated as a sustainable alternative to conventional materials. Several studies have examined the mechanical, physical, and thermal performance of lightweight concrete produced with varying proportions of wood waste as a partial replacement for conventional aggregates. Experimental results indicate that increasing wood waste content significantly reduces concrete density, achieving values between 1508 and 2122 kg/m³, which corresponds to approximately a 25% reduction in dead load compared to normal-weight concrete. Although compressive, tensile, and flexural strengths tend to decrease with higher wood waste incorporation, the resulting concrete remains suitable for specific applications. Additionally, mixtures with higher wood content exhibit improved workability, enhanced thermal insulation, and superior sound absorption due to increased porosity. Overall, recycled wood waste can be effectively employed in lightweight concrete for non-structural and selected structural applications, offering an environmentally friendly solution that reduces solid waste, conserves natural aggregates, and supports sustainable construction practices.

1.4. Impact of Dune Sand and Pumice on the Properties of Lightweight Concrete

The use of dune sand and pumice in lightweight concrete presents a promising approach to enhance both mechanical and thermal performance while reducing material costs. Dune sand, abundant in desert regions, offers a silicon-rich composition that can partially replace traditional alluvial sand, improving concrete density and overall workability. Pumice, a naturally porous volcanic aggregate, contributes to the reduction of dead weight and enhances the thermal insulating properties of the concrete due to the air-filled pores it contains. By carefully pre-wetting aggregates and optimizing the water-to-cement ratio, the mixture achieves higher compressive strength and improved long-term durability. Experimental tests on cylindrical probes demonstrate that substituting conventional sand with dune sand not only increases compressive strength through better void filling but also improves thermal resistance, making this composite material suitable for sustainable, energy-efficient construction. These findings underline the potential of leveraging local natural resources to develop lightweight concrete that balances structural performance, thermal efficiency, and economic viability.

1.5. Experimental Comparison Study of Normal Concrete and Sand Lightweight Concrete

Materials		Proportions, kg/m3				
		NSC	SLW-25%	SLW-50%	SLW-75%	SLW-100%
1	Cement	511.6	550	565	575	580
2	Water	225.8	220	226	230	232
3	Natural coarse aggregate	905.2	645.5	452	230	-
4	CINEXPAN 0500	-	126.5	129.9	132.3	133.4
5	CINEXPAN 1506	-	99	209.1		492.2
6	Natural fine aggregate	719.8	704	723.5	736	742.4
7	Silica fume	-	55	56.5	57.5	58
8	HRWRA	1.47	2.53	2.6	2.64	2.67
9	w/cm	0.44	0.4	0.4	0.4	0.4

Table 1 - Materials - Proportions , kg/m3

NSC-Normal Strength Concrete
SLW 25%- Sand Lightweight Concrete (25% lightweight aggregate replacement)
SLW 50%- Sand Lightweight Concrete (50% lightweight aggregate replacement)
SLW 75%- Sand Lightweight Concrete (75% lightweight aggregate replacement)
SLW 100%- Sand Lightweight Concrete (100% lightweight aggregate replacement)

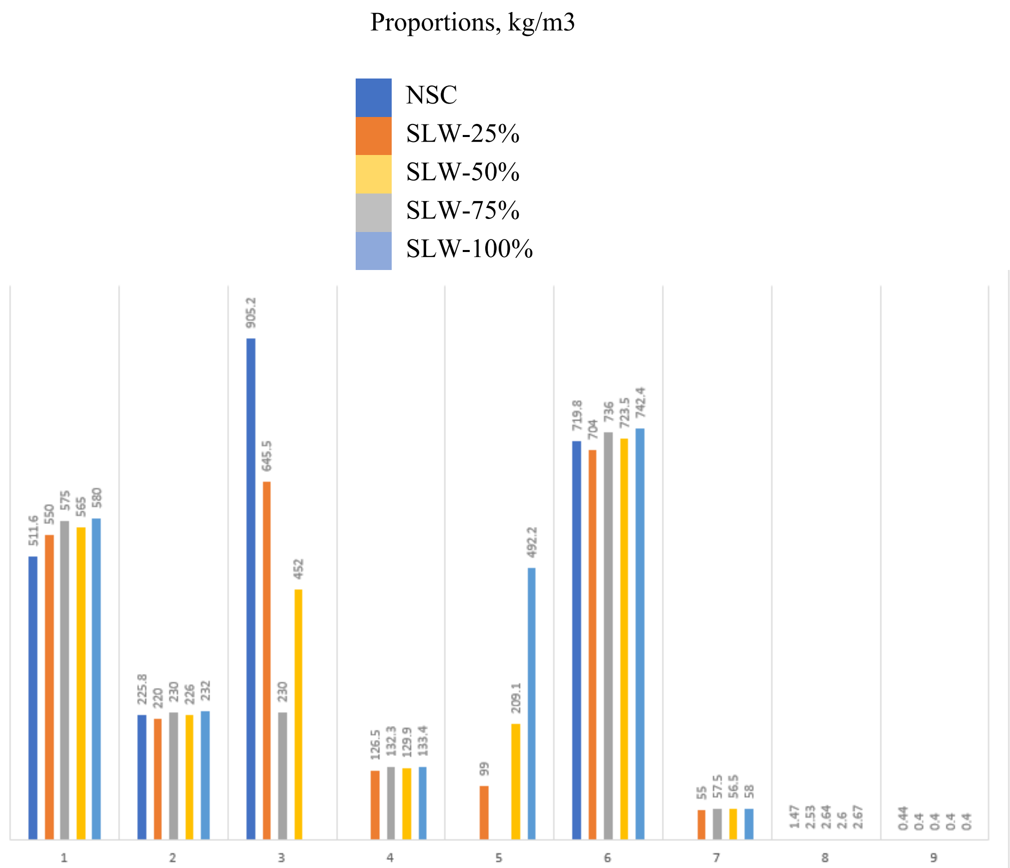

Chart 1 - Materials – NSC, SLW(25%-100%), kg/m3

For the experimental characterization of the interface strength at different concrete ages, five concrete mixtures were defined: one normal-strength concrete (NSC) with normal density and four sand lightweight concretes (SLW). In the SLW mixtures, the conventional coarse aggregate was partially replaced with lightweight aggregate at replacement levels of 25%, 50%, 75%, and 100%, designated as SLW-25%, SLW-50%, SLW-75%, and SLW-100%, respectively.

The mix proportions were designed to produce one normal-strength concrete (NSC) and four sand lightweight concretes (SLW) with increasing levels of lightweight aggregate replacement. As the replacement ratio increased, cement content, silica fume dosage, and HRWRA content were gradually increased, while the natural coarse aggregate content was correspondingly reduced and ultimately eliminated. The water-to-cementitious materials ratio was maintained at approximately 0.40 for all SLW mixtures, enabling a consistent comparison of mechanical performance. These adjustments were implemented to compensate for the higher porosity and water absorption of lightweight aggregates and to ensure adequate workability and matrix quality. Experimental results showed that SLW exhibited a systematic reduction in density relative to NSC, with a corresponding decrease in compressive strength that remained acceptable for structural applications, particularly at moderate replacement levels (25–50%). The use of lightweight aggregates also influenced workability, thermal properties, and potential durability, highlighting additional advantages of SLW beyond weight reduction. Overall, the findings confirm that sand lightweight concrete is a feasible and effective alternative to normal concrete, offering reduced self-weight, potential improvements in thermal performance, and satisfactory mechanical and interface properties. SLW can therefore be considered a practical solution for structural applications where reduced dead load and enhanced performance are desired.

1.6. Innovations and Applications in Lightweight Concrete

Lightweight concrete (LWC) is transforming modern construction by combining reduced structural weight, enhanced thermal insulation, and sustainability. Innovations in engineered lightweight aggregates (LWAs), supplementary cementitious materials (SCMs), fiber reinforcements, geopolymer binders, and nanomaterials have enabled LWC to achieve compressive strengths exceeding 100 MPa while reducing density by up to 30%. Fibers improve flexural strength, fracture toughness, and ductility, whereas hybrid fillers and advanced aggregates optimize microstructure, shrinkage, and durability. Sustainable strategies, including recycled and bio-based aggregates, can lower the embodied carbon footprint by approximately 40%, while alternative binders such as calcium-sulfoaluminate and geopolymers reduce CO_2 emissions and enhance early-age strength and chemical resistance. Thermal performance is further improved through lightweight fillers like expanded polystyrene and aerogels, which can reduce thermal conductivity by up to 50%, supporting energy-efficient building envelopes. Modern high-strength LWC (HSLWC) now enables structural applications previously limited to conventional concrete, including long-span bridges, high-rise prefabricated elements, and offshore structures. Key design strategies including aggregate replacement, controlled air-void generation, hybrid fillers, SCM incorporation, and fiber reinforcement allow engineers to balance density, strength, and durability. Current research on engineered core-shell aggregates, multiscale performance modeling, and circular supply chains is advancing LWC toward net-zero-carbon construction. Consequently, LWC's versatility allows it to meet a wide range of structural, non-structural, and thermal performance requirements, making it a cornerstone material for resilient, low-carbon, and high-performance infrastructure.

II. Conclusion

This study demonstrates the significant potential of sand and wood based aggregates as sustainable alternatives in lightweight concrete, paving the way for eco-efficient, low-density construction materials. Independent evaluation of the two materials clarified their distinct contributions to mechanical, physical, and durability properties, providing a foundation for optimized mix designs tailored to specific functional requirements. Dune sand, with its fine, uniform, silica-rich particles, enhances workability and mechanical strength when partially replacing conventional sand. Its abundance in arid regions reduces reliance on river sand, lowering environmental impact and production costs. Challenges related to shrinkage, water demand, and mix uniformity must be carefully managed to ensure long-term durability. Wood chips, derived from low-density lignocellulosic waste, substantially reduce concrete density while improving thermal insulation and supporting organic waste valorization. Incorporation of wood chips introduces complexities, including high water absorption and potential chemical interactions with cement, which can be mitigated through pre-treatment or optimized mix design. Despite these challenges, wood-chip aggregates offer significant environmental and functional benefits, particularly for non-structural or moderate-load applications.Both aggregates positively influence thermal, workability, and durability properties, demonstrating their potential to produce multifunctional lightweight concretes.

Overall, the findings highlight the dual benefits of environmental sustainability and functional performance: reducing natural aggregate consumption, lowering carbon footprint, enhancing thermal efficiency, and maintaining adequate structural characteristics.Incorporating sand and wood based aggregates into modern concrete represents a circular-economy approach, illustrating that lightweight concrete can be simultaneously eco-friendly and technically efficient. Future research should investigate combined mixes and advanced optimization strategies to fully harness the synergistic benefits of these alternative aggregates in high-performance, multifunctional concrete applications.

References

[1]. M.N Haque, H Al-Khaiat, O Kayali (May 2004) „Strength and durability of lightweight concrete", Available at: https://www.sciencedirect.com/science/article/abs/pii/S0958946502001415

[2]. Minghu Zhang , Xuezhen Zhu , Jinyan Shi , Baoju Liu , Zhihai He, Chaofeng Liang (April 2022) „Utilization of desert sand in the production of sustainable cement-based materials: A critical review", Available at: https://www.sciencedirect.com/science/article/abs/pii/S0950061822006997?utm_source=chatgpt.com

[3]. Pascale Coatanlem , Raoul Jauberthie , Frank Rendell (November 2006) „Lightweight wood chipping concrete durability",Available at: https://www.sciencedirect.com/science/article/abs/pii/S0950061805000814

[4]. „Performance of Conventional Concrete", National Academies of Sciences, Engineering, and Medicine. 1997. Nonconventional Concrete Technologies: Renewal of the Highway Infrastructure. Washington, DC: The National Academies Press.Available at: https://www.nationalacademies.org/read/5560/chapter/3

[5]. Karl-Christian Thienel,Timo Haller,Nancy Beuntner (3 March 2020) „Lightweight Concrete-From Basics to Innovations", Available at: https://www.mdpi.com/1996-1944/13/5/1120

[6]. Dr. Salam Salman Chiad Alharishawi , Haitham Jameel Abd , Suha Rasheed Abass (2020) „EMPLOYMENT OF RECYCLED WOOD WASTE IN LIGHTWEIGHT CONCRETE PRODUCTION", Available at: file:///C:/Users/User/Downloads/Employment_of_recycled_wood_waste_i.pdf

[7]. Chaabane Lynda Amel , El-Hadj Kadri , Yahia Sebaibi , Hamza Soualhi (February 2017) „Dune sand and pumice impact on mechanical and thermal lightweight concrete properties", Available at: https://www.sciencedirect.com/science/article/abs/pii/S0950061816319493

[8]. Patricia Figueiredo, Sergio Luis Garcia, Renato Cossetti, and Afonso Leite (January 2022) „Bond Performance between Normal-Strength Concrete and Sand-Lightweight Concrete", Available at: https://www.researchgate.net/profile/Sergio-Luis-Garcia/publication/357499219_Bond_Performance_between_Normal-Strength_Concrete_and_Sand-Lightweight_Concrete/links/64d4f4dec80b930269045f86/Bond-Performance-between-Normal-Strength-Concrete-and-Sand-Lightweight-Concrete.pdf

[9]. Diptikar Behera, Kuang-Yen Liu, Firmansyah Rachman and Aman Mola Worku (June 2025)„ Innovations and Applications in Lightweight Concrete:Review of Current Practices and Future Directions", Available at: https://www.mdpi.com/2075-5309/15/12/2113