Tentative Study on the Structural Enhancement of Lightweight Interlocking Composite Blocks with Wood Ash and Wheat Agro-Waste

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Abstract – *The construction sector is increasingly called upon to embrace eco-friendly methods, with a focus on diminishing the use of finite resources and lowering greenhouse gas emissions. In response, this paper details the creation of large-volume, lightweight interlocking composite blocks that surpass the size of standard bricks. These blocks are crafted to lock together without the need for cement mortar, which is a staple in traditional building. The materials used include clay, cement, water, and organic fibers. The clay portion is substituted with 30% wood ash, 6% wheat straw, 6% wheat husk, and 28% M53 grade cement. The balance of 30% consists of clay. The paper examines wood ash sourced from industrial and factory waste, highlighting its role in enhancing the block's lightness and in the repurposing of waste. The use of natural fibers like wheat husk and straw is explored for their contribution to the block's reduced weight and structural reinforcement. These repurposed materials serve as a green alternative to traditional components, aiding the industry in achieving its sustainability objectives. The blocks underwent a battery of tests to assess compressive, tensile, and flexural strengths, along with overall endurance, heat resistance, and impermeability to water. The outcomes indicated compressive strength at 18.21 N/mm2, tensile strength at 0.879 N/mm2, and flexural strength at 3.45 N/mm2. This project signifies a significant stride in sustainable building, offering numerous benefits in terms of flexibility and ecological footprint.*

Key Words: Wood Ash, Wheat Straw, Wheat Husk, Lightweight Interlocking composite block, Sustainability.

1.INTRODUCTION

Innovations in eco-friendly building techniques have led to the creation of lightweight interlocking composite blocks. These blocks are engineered to connect seamlessly, boasting a greater volume than traditional bricks. Their unique design forgoes the requirement for cement mortar, commonly employed in standard masonry. This advancement tackles critical ecological issues related to the manufacturing of cement and the degradation of soil. Incorporating additives into brick production not only reduces the need for clay but also improves their physical and mechanical characteristics. The selection of additives is crucial for the construction industry's move towards sustainability. A variety of environmentally friendly materials, such as fly ash, wood ash, and agricultural residues like wheat and rice husks, have been recognized for their potential to improve bricks' thermal insulation, reduce weight, and increase compressive strength. These enhancements depend on the specific proportions of additives used and the brick firing techniques employed [1-9].

In practical and engineering scenarios, focusing on optimizing a single objective often leads to suboptimal outcomes for other objectives. Consequently, it's typical to amalgamate multiple objective functions into one. Crafting an ideal objective function that simultaneously optimizes all objectives is an arduous task. Therefore, for problems with multiple objectives, it's advantageous to establish a satisfactory spectrum of solutions for each goal. Multi-objective evolutionary algorithms are widely used methodologies for developing a set of solutions that are Pareto optimal [10,11]. Currently, the construction industry employs a variety of interlocking dry-stacked blocks and bricks. These are tailored in diverse sizes, shapes, and compositions, reflecting the materials accessible in their place of production and the preferences of the manufacturer. Notable among the array of interlocking blocks are systems like the Mecano, Sparfil, Haener, and Sparlock system [12]. They also introduced Silblock-1 and Silblock-2, composed of cement, sand, and 12 mm aggregate. These blocks are categorized into three-unit types: stretcher, jamb, and corner, averaging dimensions of 400 mm in length, 150 mm in width, and 200 mm in height.

The manufacture of cement is a major environmental concern, contributing to roughly 4-5% of global CO_2 emissions. The ecological footprint of cement production extends beyond carbon emissions, encompassing issues such as water pollution from runoff, urban heat islands, airborne particulate matter, and emissions of hazardous substances like NOx, SO_2, and CO. In the context of residential construction, the use of cement mortar is notably substantial. To illustrate, a standard 1:4 mortar mix requires about 8 bags of cement, each weighing 50 kg (totalling approximately 383 kg), to prepare 1 cubic meter ($1m^3$) of mortar. The procurement of topsoil for the manufacture of bricks contributes to soil erosion and land degradation. The operation of brick kilns involves the extraction of topsoil, which diminishes agricultural productivity and escalates the expenses associated with nutrient replenishment. In regions like the Gangetic plains of India, where fertile alluvial soil is abundant and constitutes 65% of the brick-making material, such practices jeopardize the integrity and fecundity of the soil. Annually, an estimated 340 billion tons of clay are extracted worldwide for brick production [13]. This substantial extraction rate leads to a decrease in natural soil levels, posing an environmental concern. Researchers globally are investigating innovative substitutes for clay in brick composition to address this issue [14,15].

Plant fibers are extensively utilized across various industries, drawing from a plethora of sources. The mid-20th century saw a dramatic surge in synthetic fibers, leading to a decline in the market share for natural fiber industries. To advocate for natural fibers and materials, 2009 was designated as the International Year of Natural Fiber (IYNF), providing substantial support for farmers, agriculture, the environment, and market needs. The composite market in the United States was reported to be between 2.7 and 2.8 billion pounds from 2006 to 2007. With a compound annual growth rate of 3.3%, it is projected to surpass 3.3 billion pounds [16]. There is a growing interest among scientists and engineers to discover new sources of raw materials that offer physical and mechanical properties similar to those of synthetic fibers. Various other parameters to be considered while selecting raw materials are being cheap, being eco-friendly [17], absence of health hazards, high degree of flexibility [18], lower plants age, easy collection, and regional availability which directly influence the suitability of natural fibers [19, 20]. Integrated within the blocks are organic fibers such as wheat straw and husk, selected for their notable tensile strength and endurance. These fibers fortify the composite blocks, lending them enhanced structural integrity.

The blocks are crafted from a blend of composite materials, designed to demonstrate enhanced characteristics including compressive strength, tensile strength, flexural strength, longevity, thermal insulation, and weather resistance. Such attributes render these blocks versatile for diverse building purposes. This innovative method merges the disciplines of material science and civil engineering to forge a ground-breaking construction material. It stands out not just for its efficiency and sustainability, but also for its role in preserving the environment. This breakthrough marks a substantial leap forward in sustainable construction, providing a multitude of advantages including user-friendliness and reduced ecological footprint. It signifies a

1.1 Lightweight Interlocking composite block

Lightweight interlocking blocks (LICBs) have emerged as a sustainable alternative to traditional building materials, leveraging advancements in materials science and a growing environmental consciousness. Developed to address the demand for efficient and eco-friendly construction methods, LICBs are typically crafted from recycled plastics and rubber, showcasing a commitment to sustainability. Their interlocking design eliminates the need for mortar or adhesives during assembly, simplifying construction processes, reducing labor requirements, and streamlining logistics. Additionally, LICBs' lightweight nature facilitates easier transportation, handling, and installation compared to conventional materials, while still offering durability, weather resistance, and insulation properties. Their modular design allows for versatile configurations, making them suitable for a wide range of indoor and outdoor applications. As the demand for sustainable building solutions continues to rise, LICBs are poised to play a pivotal role in shaping the future of construction, offering a perfect blend of innovation, sustainability, and functionality.

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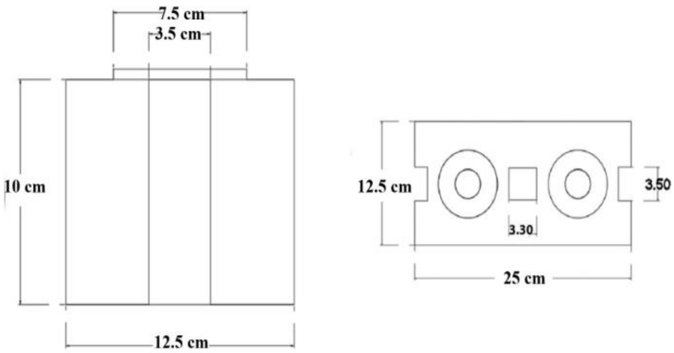

Fig -1: Interlocking Mould Specification

2. MATERIALS AND METHODLOGY

This research explores the creation of interlocking composite blocks (LICBs) as an eco-friendly substitute for traditional clay bricks. Leveraging natural fibers, the study aims to diminish the environmental impact and soil degradation linked with standard brick-making processes.

2.1. Wood Ash

In this study, wood ash serves as a supplementary material to cement. The ash, generated from the combustion of wood in industrial and factory settings, is utilized to partially replace cement in concrete production. The materials employed include OPC 43, 53 Grade, PPC cement, sand, coarse aggregate, and wood ash. The wood ash is incorporated in proportions ranging from 0% to 50%, relative to the cement's weight. A consistent water-cement ratio of 0.45 is maintained across all mixtures. The concrete samples undergo compressive strength and split tensile strength evaluations after 7, 14, and 28 days of curing. Findings indicate that the optimal strength is attained when the concrete contains a wood ash content between 20% and 25%, surpassing the strength of both the standard control concrete and other mix variations.

The chemical analysis of the wood ash, as detailed in Table 1, reveals a significant lime content of approximately 60.55%. Experimental assessments have determined the specific gravity of the ash to be 3.1, with a particle size of 35 micrometers. For the paste to reach the desired standard consistency, about 35% water is necessary, which is achieved when clay is substituted by wood ash at a 20% rate. Exceeding this replacement threshold to more than 20% leads to an increased water demand, rising to 37.5% to maintain the paste's consistency.

Table -1: Wood ash Percentage of Chemical Composition

Ingredient	Value [%]
Cao (Lime)	60.55
K_2O	24.65
SO_3	4.54
MgO	1.82
SiO_2	1.17
Na_20	0.92
Fe_2O_3	0.61

2.2. Wheat Straw and Wheat Husk

The study on interlocking clay bricks incorporated with fibers like wheat straw and wheat husk showed promising results. These bricks exhibited no shrinkage cracks, satisfied the minimum strength criteria set by various mud brick standards, and demonstrated low thermal conductivity along with high insulation capabilities. Wheat straw and husk, which are by-products of agriculture rich in cellulose and lignin, were used in proportions ranging from 1% to 6% by soil weight for each type of fiber. Unlike the control bricks that contained no fibers, the fiber-enriched bricks had a water content of 15% to 18%, compared to 13% in the control.

2.3. Clay

The clay used in this research is sourced specifically from the Puducherry region. Table 2 presents the clay's properties as determined by X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) tests, in line with the material characterization norms NM 01.1.229–2006 (SGG, 1993). The clay is analyzed in its dry, powdered state as per the methodology outlined by Limami et al., 2020a. For the XRD analysis, the powdered sample is placed in the diffractometer's sample mount, and with the aid of an X-Ray tube and divergence slits, the crystalline structure of the clay is identified, adhering to Moroccan standards NM 01.1.333–2006 (IMANOR,2006a), and in compliance with ASTM D5357 (Materials, 2019). This is supported by X-Ray Fluorescence (XRF) test results shown in Table 1, where the silica component (SiO2) constitutes 60.55% of the clay's chemical makeup. The high SiO2 concentration suggests that the clay is well-suited for construction purposes. The clay is composed mainly of Illite and Muscovite, with minor amounts of Calcite and Dolomite. Table 2 confirms the soil's clayey nature, with a substantial Aluminum oxide (Al_2O_3) content of 22.4%. The clay is identified as Illite type due to the Potassium oxide (K_2O) content of 2.53%. Additionally, the Ferric oxide (Fe_2O_3) content influences the red hue of the brick samples, while Calcium oxide (CaO) impacts the structural integrity and susceptibility to cracking.

Table -2: The Properties of clay

Element	Value [%]
SiO_2	64.32
Fe_2O_3	8.51
Al_2O_3	14.89
CaO	1.01
MgO	0.95
SO_3	0.06
Na_2O	2.52
K_2O	0.66
TiO_2	1.35
P_2O_5	0.19
L.O. I	5.54

2.4. Cement

Ordinary Portland Cement (OPC), commonly utilized in a variety of construction projects due to its robustness and optimal setting periods, is the focus of this investigation. Specifically, OPC of grade 53 is employed, known for its high-strength properties that provide resistance against substantial compressive forces and sulphate corrosion. The study utilizes OPC of grade 53, which has a specific gravity of 3.13, serving as the primary binding agent. The cement's chemical makeup was ascertained through X-ray fluorescence (XRF) analysis, with findings detailed in Table 3. The cement's fineness, determined via Blaine's air permeability method, was recorded at 227 m^2/Kg. Its soundness was evaluated using both the Le Chateliers method and Autoclave test, yielding measurements of 10 mm and 0.7%, respectively. The cement's setting duration was gauged with a Vicat apparatus, revealing an initial setting time of 42 minutes and a final setting time of 620 minutes

Table -3: Chemical Composition of Cement of Grade 53

Particulars	Composition [%]
Lime (CaO)	61.86
Silica (SiO_2)	20.08
Iron oxide (Fe_2O_3)	4.63
Alumina ($A1_2O_3$)	5.33
Magnesia (MgO)	0.84
Sulfuric anhydride (SO_3)	2.51
Lime saturation factor (CaO 0.7 SO_3/ 2 .8 SiO_2 + 1.2Al_2O_3 + 0.65 Fe_2O_3)	0.92
Ratio of alumina/iron oxide	1.19
Chloride content	0.0029

2.5. Methodology

The characterization of Wood Ash, Wheat straw and Wheat Husk commenced with a comprehensive examination of its chemical composition with detailed findings summarized in Tables. Particle size analysis was conducted using a range of sieves from 4.75mm to 50 micrometers. After 15 minutes of agitation, the weights of materials retained on each sieve were measured for deeper insight into the material's physical properties. The Physical Properties of the materials are been performed and studied for the contribution to strength and durability of the block. Then the optimum ratio of the mix of the different elements are been considered and compare the strength with the conventional mix casted.

3.Experimental Investigation

The detailed mix proportioning of six different mixes with clay replaced by wood ash at 0, 10, 20, 30, 40 and 50% levels was done and presented in Table 4. Similarly, the detailed mix proportioning of seven different mixes with clay replaced by wheat husk (WH) at 1, 2, 3, 4, 5, 6 and 7% levels and three different mixes with clay replaced by Wheat Straw (WS) at 5, 10 and 15% levels was done and presented in Table 5 and Table 6 respectively. The cement was also replaced with clay with different percentage 0,10,20,30,40% and found that 28% was the optimum. The final mix was prepared with 30% of wood ash, 7% of wheat straw, 6% of wheat husk, and 28% of cement M53 grade as substitutes for clay. The rest 29% was clay. The detailed mix proportioning of the final mix was also presented in final Table. The study covers the fresh properties such as consistency, setting time, soundness test, compressive strength, split tensile strength and flexural strength of the mixes according to IS 4031. Compressive strength, split tensile strength and flexural strength test was carried out with interlocking composite block at the age of 7- and 28-days curing.

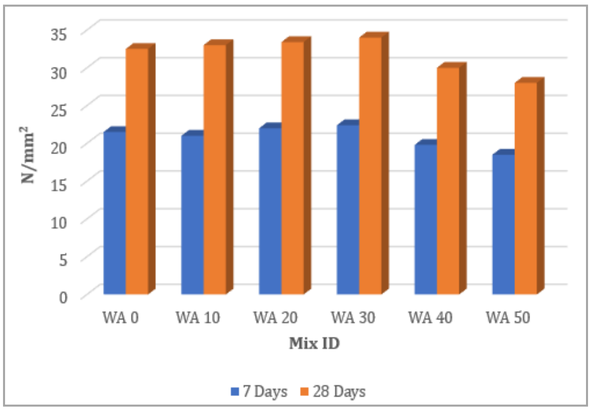

Chart -1: Compression Strength of Wood Ash

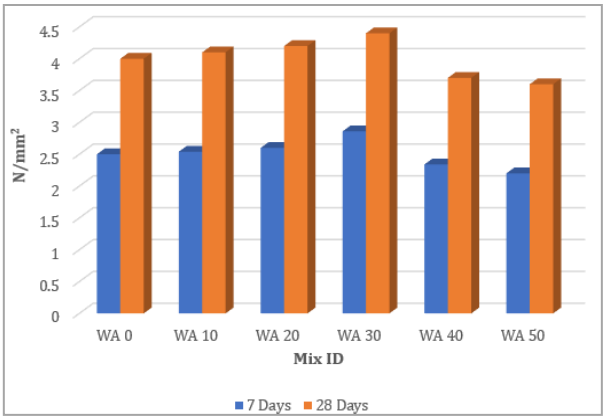

Chart -2: Split Tensile Strength of Wood Ash

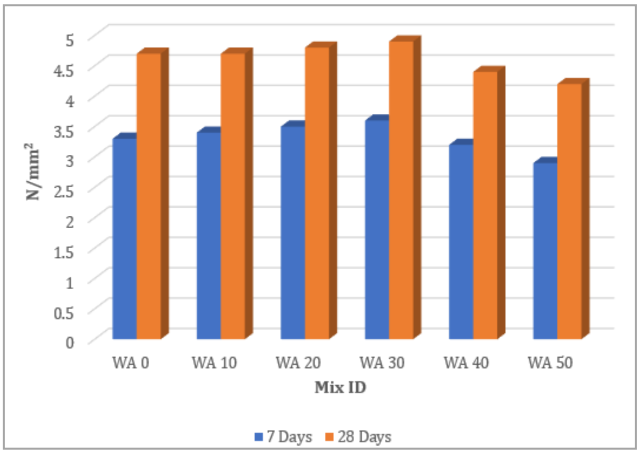

Chart -3: Flexural Strength of Wood Ash

Table -5: Experimental data for Wheat Straw

Wheat Straw (%)	Thermal conductivity (W/mK)	Water Absorption (%)	Compressive Strength (MPa)
WS10	0.43524	5.987	10.67
WS15	0.58548	7.796	8.9
WS15	0.28525	6.943	9.87
WS15	0.21367	7.134	9.32
WS6	0.58132	7.785	12.53
WS6	0.52442	4.98	12.25
WS10	0.49209	6.391	11.31
WS10	0.43621	5.987	10.63

Table -6: Wheat Husk Experimental Analysis

Mix design	Compressive strength (MPa)	Water absorption (%)	Density (kg/m^3)
WH1	6.9	195	3.6
WH2	5.6	210	2.9
WH3	4.89	255	2.5
WH4	4.4	275	2.2
WH5	3.9	305	2.1
WH6	3.2	345	1.8
WH7	7.65	400	4.8

Fig -2: Compression Strength Test on Specimen

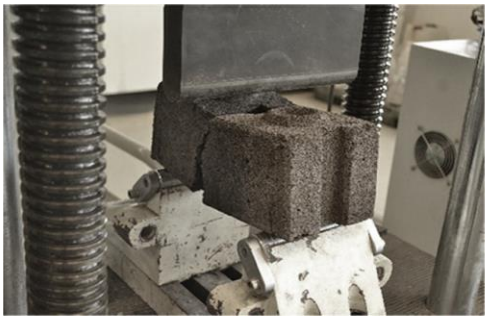

Fig -3: Flexural Strength Test on Specimen

Table -4: Experimental data for Wood Ash

Mix ID	Compressive Strength (N/mm^2)		Split Tensile Strength (N/mm^2)		Flexural Strength (N/mm^2)	
	7 Days	*28 Days*	*7 Days*	*28 Days*	*7 Days*	*28 Days*
WA 0	21.5	32.5	2.5	4	3.3	4.7
WA 10	21	33	2.54	4.1	3.4	4.7
WA 20	22	33.4	2.6	4.2	3.5	4.8
WA 30	22.4	34	2.86	4.4	3.6	4.9
WA 40	19.8	30	2.34	3.7	3.2	4.4
WA 50	18.5	28	2.2	3.6	2.9	4.2

4.RESULT AND DISCUSSION

4.1 Compression Test

The compressive strength test for lightweight interlocking composite blocks (LICBs) evaluates their ability to withstand axial loads. LICBs are placed between steel plates and loaded until failure, following Indian Standard IS 516:1959. LICBs in this study were molded in steel forms and cured for 28 days in water, meeting IS 1077:1992 specifications for common burnt clay building bricks. Evaluating the compressive strength of LICBs is essential to determine their quality and applicability in construction. In this research, around 100 LICB units were tested. The methodology followed the BS EN 772–1 guideline (British Standard Institution, 2011). To guarantee uniform compression, each sample was capped with a steel plate on both sides. Prior to testing, the samples were oven-dried for 24 hours to ensure a consistent mass. The strongest block recorded a compressive strength of 18.21 N/mm^2, achieved through manual compression with a high rate and vibration during the compaction process. This high pressure led to the production of more robust masonry units. The study also found that bricks with deeper grooves were more prone to failure under maximum load due to the increased stress concentration.

4.4. Flexural Strength

The flexural strength test for the lightweight interlocking composite blocks (LICBs) involved evaluating randomly selected samples. These tests were conducted in accordance with ASTM C67 standards, which are specific to the testing of masonry units for structural purposes. The LICB samples were tested in both the bed and flatwise orientations due to their unique interlocking shapes. For the bed direction test, the LICB sample with a dowel was positioned with the dowel facing upwards, while the groove faced downwards. Conversely, for the flatwise direction test, the positions were reversed. A load was applied at the midspan of the LICB, using a steel bearing plate measuring 6.4 mm in thickness and 38.1 mm in width. Flexural strength tests were conducted on lightweight interlocking composite blocks (LICBs) according to ASTM C67 standards. Samples were tested in both bed and flatwise orientations to assess their structural integrity. Load application was performed at midspan using steel bearing plates, allowing for an even distribution of force. Calculations based on maximum load, support distance, and dimensions yielded a maximum recorded flexural strength of 3.45 N/mm^2. Notably, LICBs exhibited higher strength in the bed direction than in the flatwise direction. These findings demonstrate the suitability of LICBs for various construction applications, meeting or surpassing the minimum threshold of 0.25 N/mm^2 for structural efficacy, as recommended by Silva et al. (2015).

4.5. Tensile Strength

The splitting tensile strength test for lightweight interlocking composite blocks (LICBs) examined 100 randomly selected samples in line with ASTM C1006 standards. During testing, 10 mm diameter bearing rods were positioned at the center of the top and bottom surfaces, with loading applied along the bed surface. Results revealed a highest recorded strength of 0.879 N/mm^2, well surpassing the minimum requirement of 0.4 N/mm^2 for masonry tensile strength. LICBs typically failed due to splitting, with cracks forming parallel to the load axis. Notably, the block's shape and compression rate during manufacture significantly influenced tensile strength, underscoring the importance of careful design and production processes for structural integrity.

Table -7: Final Mix ID Compression, Split tensile and Flexural Strength

Mix ID	Compressive Strength	Split Tensile Strength	Flexural Strength
The clay is replaced with 30% of Wood ash, 6% of raw wheat straw, 6% of wheat husk, and 28% cement M53 grade. The remaining 30% is clay.	18.21 N/mm2	0.879 N/mm2	3.45 N/mm2

5. CONCLUSION

This research introduces a novel approach to eco-friendly construction through the development of lightweight interlocking composite blocks (LICBs). These blocks, which are significantly larger than standard bricks, are engineered to connect seamlessly, eliminating the need for cement mortar, which is a fundamental component in traditional brickwork. The LICBs are composed of a mix of clay, cement, water, and organic fibers. In this composition, 30% wood ash, 6% wheat straw, 6% wheat husk, and 28% M53 grade cement were used, with the remaining 30% being clay. The blocks underwent a series of evaluations to assess their performance, including density, weight, durability, strength, abrasion, and impact resistance. The results indicated that the blocks possess a compressive strength of 18.21 N/mm^2, split tensile strength of 0.879 N/mm^2, and flexural strength of 3.45 N/mm^2. The study highlights lightweight interlocking composite blocks (LICBs) as a promising alternative to traditional bricks, offering benefits such as adaptability and reduced environmental impact. LICBs decrease carbon emissions and streamline construction processes while saving costs. Future research includes exploring block shapes, refining mix proportions, and assessing thermoacoustic properties.

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