

# Strength Properties Evaluation of Waste Tyre Concrete with Rice Husk Ash as Partial Cement Replacement under Elevated Temperatures

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**Abstract :** This study evaluates the strength properties of sustainable concrete incorporating rice husk ash (RHA) as partial cement replacement and waste tyre (WT) as partial coarse aggregate replacement when exposed to elevated temperatures. RHA and WT, sourced locally from Kaduna, Nigeria, were blended at replacement levels of 0–20 % by weight of cement and coarse aggregate, respectively. Concrete cubes (100 mm × 100 mm × 100 mm) were cast in triplicate for each mix combination and cured in water for 7, 14, 21, and 28 days. Workability decreased progressively with increasing RHA and WT content owing to the higher water demand of RHA and the irregular shape of tyre particles. At ambient temperature, all mixes achieved the target characteristic strength of 20 MPa; the optimum blend of 10 % RHA and 5 % WT delivered a 28-day compressive strength of 31.8 MPa, surpassing the control mix. Exposure to elevated temperatures (718 °C for 15 min and 821 °C for 30 min) caused strength reduction in both normal concrete and the modified matrix. Normal concrete (0 % replacement) exhibited average losses of 14.1 % at 718 °C and 19.7 % at 821 °C, while the optimum mix showed losses of 18.3 % and 34.5 %, respectively, only 4.2 % and 14.8 % greater than the control. These results confirm that 10 % RHA + 5 % WT provides an effective, eco-friendly concrete with acceptable fire resistance, offering significant value to the construction sector through waste valorisation, cost reduction, and environmental sustainability.

**Keywords:** Rice Husk Ash, Waste Tyre Aggregate, Elevated Temperature, Compressive Strength, Sustainable Concrete, Pozzolanic Replacement

## 1. Introduction

Concrete is considered the primary material component of a country's infrastructure due to its high calibre, long service life and economic cost. For carrying out various building activities, the construction sector uses enormous amounts of natural resources, including materials made of calcium and argillaceous (for the manufacturing of cement), sand, coarse aggregate, etc. Concrete's negative impact on the environment when compared to other materials is associated with its high carbon content emission. To improve concrete and make it a more environmentally friendly material attempts are continuously done on its negative effects [1].

Globally, rice paddy production now exceeds 750 million metric tonnes annually, generating approximately 150 million tonnes of rice husk as a by-product that is frequently discarded or openly burned [7]. When calcined under controlled conditions (500–700 °C), this husk yields rice husk ash (RHA) possessing excellent pozzolanic qualities and cement-like fineness [2]. At the same time, the automotive industry produces roughly 2.5 billion new tyres each year, resulting in approximately 1.5 billion end-of-life waste tyres (WT) that demand urgent management [8]. In Nigeria, rapid vehicle growth has intensified tyre accumulation, while traditional reuse pathways have sharply declined. Although some solid wastes such as metals, papers and plastic bottles can be reprocessed with negligible environmental harm, waste rubber tyres remain a persistent disposal challenge [3].

Fire outbreaks in buildings have further heightened concerns about concrete integrity, as post-fire strength often drops dramatically [27]. Partial replacement of cement with pozzolanic materials such as RHA has been shown to improve fire resistance by refining the microstructure and reducing calcium hydroxide content available for deleterious reactions at high temperatures [20].

This research work evaluates the strength properties of waste tyre concrete with RHA. The ash produced from the agricultural waste can be used effectively as a replacement of cement. By adding RHA to concrete, cement is transformed into additional cement-based materials that are environmentally benign. It is possible to classify RHA concrete as “Green” as well as High-Performance Concrete [2]. This might achieve economy, strength requirement and durability of concrete.

## 2. Literature Review

### 2.1 Concrete

Concrete is a widely used construction material known for its durability, versatility, and cost-effectiveness. Concrete in construction can be defined as structural material consisting of a complex, chemically inert particulate substance known as aggregate (usually sand and gravel), bonded together by cement and water [4]. The primary component of concrete is cement, which acts as a binder, holding the aggregates together [5]. The aggregates provide bulk and strength to the concrete mixture. Water is added to initiate the chemical reaction known as hydration, which leads to the hardening of the concrete [6]. Chemical admixtures are often incorporated to enhance specific properties of the concrete, such as workability, strength, and durability.

Concrete exhibits several desirable properties, including high compressive strength, fire resistance, and resistance to weathering and chemical attacks. Its ability to be moulded into various shapes and sizes makes it suitable for constructing different structures, ranging from buildings and bridges to pavements and dams [6]. Concrete is known to be one of the most essential construction materials been used in the construction industry since the existence of the industry and till date, it has become an important construction material in the infrastructure and industrial development today due to its various merits such as; Highly durable, Good mechanical properties, Economical and under proper conditions [6]. Concrete is the most widely used man-made construction material in the world. The performance of a concrete depends to a great extent on the quality of the ingredients like cement, coarse aggregate, fine aggregate with its desired proportioning of mixing. Achieving high strength, workability, durability is the main motive of concrete mix design.

Concrete consists of cement, aggregate (fine and coarse) and water, which must be workable, resistant to freezing, resist chemicals, exhibit low permeability, resist wearing and been economical [6]. Casting of concrete commence when cement and water are been mixed as a paste which coats round all both the fine and coarse aggregate. Concrete normally changes form from a plastic state to a solid state in period of two hours [6]. Hydration cause the concrete to harden, which is a chemical reaction between the water and cement. The demolding take place after the concrete finally set which is usually not less than twenty-four hours inside the mold [6]. Then, curing of the concrete commence. Curing process is crucial in the process of producing a good concrete as the concrete strength increases with the curing age. Quality and proportions of the ingredients and also the curing environment are some of the factors known to influence the compressive strength of a concrete [6]. Concrete is good in compressive strength but virtual without strength in tensile. To cater for this imbalance behavior in the concrete region, reinforcement bar is cast in, to prevent cracking and others failure of the structure [6].

### 2.2 Environmental Impact and Sustainability of Concrete Production

In addition to having a significant impact on concrete’s environmental and social impacts, cement, a crucial component of concrete, has its own effects. The manufacturing and the use of Portland cement is to blame for more than a fifth of the world’s CO<sub>2</sub> emissions. A tonne of structural concrete produces about 410 kg/m<sup>3</sup> of

carbon dioxide when manufactured. One of the major sources of CO<sub>2</sub>, a significant Greenhouse gas, is the cement industry [5]. As a result, there has been growing interest in lowering concrete related carbon emissions by reducing the OPC cement or complimenting the constituent materials with waste or by products. Ogbeide reported that one of the most effective way to reduce CO<sub>2</sub> emission is by partially replacement of cement with supplementary cementations materials [6]. Additionally, the extraction of natural aggregates, such as sand and gravel, depletes non-renewable resources and disrupts ecosystems.

Globally, rice paddy production now exceeds 780 million metric tonnes annually, generating approximately 156 million tonnes of rice husk waste [7]. At the same time, roughly 1.5 billion end-of-life waste tyres are generated worldwide each year, creating a massive disposal burden that pollutes soil, vegetation, and groundwater when landfilled or burned [8]. In Nigeria, increasing vehicle ownership has intensified tyre accumulation while traditional reuse routes such as shoe-making have declined sharply [3].

### 2.3 Supplementary Cementitious Materials (SCMs)

Supplementary cementing materials are generally defined as materials that enhance the properties of concrete through hydraulic or pozzolanic activity or both when used with blend with cement [6]. They are silicate-based materials that react with (consume) the calcium hydroxide generated by hydrating cement to form additional cementitious materials [6]. They are typically used as cement replacement. These materials are generally by-products from other process or natural materials, of which they might be further processed for use in concrete [6]. Concrete paving mixtures made with SCMs and blended cements have many advantages over concrete made with Portland cement alone. Although economic savings are often realized when replacing Portland cement with SCMs, shortage of the most desirable SCMs have developed in some markets in recent years, pushing prices of many SCMs upward [6]. The real economic savings are obtained over the lifecycle, as the enhancements in workability, ultimate strength, and durability often result in improved long-term performance and reduced life cycle costs [1].

### 2.4 Rice Husk Ash (RHA) as a Pozzolanic Material

A unique substance been developed from the agricultural waste known as rice husk ash (RHA) with excellent pozzolanic qualities possessing cement-like fineness, similar to rubber tyre waste has been researched on [2]. Rice husk, sometimes called rice hull, is produced from the outer covering of rice grain when milling rice [32]. Despite its origins as an agro-industrial by-product, R.H. has been successfully proposed as a suitable building material [33]. Rice husk ash is obtained after burning of the rice husk fibre in a control environment (500-700 °C). The ash produced from the agricultural waste can be used effectively as a replacement of cement. By adding RHA to concrete, cement is transformed into additional cement-based materials that are environmentally benign. The strength of the concrete mix is enhanced by RHA concrete resistance to drying shrinkage. With the addition of RHA in concrete the effect of bleeding and segregation are reduced [31]. Higher resistance to assault from chloride and sulphate is a feature of RHA concrete. More hydration products are resulted from the interaction between the calcium oxide and Rice Husk Ashes in the concrete. The calcium hydroxide and rice husk ashes within the concrete react to create additional hydration products. Calcium hydroxide usage will reduce the reactivity of chemicals from the environment [2]. The mass per unit volume is decreased, resulting from RHA's low particular gravity. The use of finer RHA makes the concrete mix denser and gives it greater strength than concrete that contains coarser RHA. RHA concrete is intended to be more tightly packed than controlled mix concrete. It is possible to classify RHA concrete as “Green” as well as High-Performance Concrete [2]. This might achieve economy, strength requirement and durability of concrete.

### 2.5 Waste Tyre (WT) as Coarse Aggregate Replacement

There are still problems in the discarding of much more solid waste among which is waste rubber tyres [3]. Vehicular tyre is a heat set material which has nearly shown impossibility to degrade under normal ambient

conditions. Therefore, it has resulted in growing disposal issues and also polluting soil and vegetation [29]. The use of these tyres as scrap in concrete as construction materials will minimize its impact in the environment and will greatly maximize over dependence on gravel which is natural resources [30].

## 2.6 Performance of RHA and WT Concrete at Elevated Temperatures

Fire outbreaks in buildings have been a major concern in the world today. The integrity of concrete structures is usually questioned due to the fact that after fire outbreak the strength of the concrete reduces considerably [27]. Fire resistance of concrete is the ability of the concrete to withstand fire or to give protection against fire during fire accident which is measured by the compressive strength of the concrete after exposure to a degree of temperature at a specific time [28]. Fire resistance of concrete structure is known to be improved by the partial replacement of cement with pozzolanic material [20]. Structural engineers need to give a proper consideration to safety of the structure and escape time for the end users in case of fire accident [28]. Recent studies confirm that combining RHA with crumb rubber or tyre-derived fibres can maintain acceptable residual strength after exposure to 400-800 °C while simultaneously reducing spalling and mass loss [28].

## 3. Materials and Methods

### 3.1 Materials

Ordinary Portland cement (OPC) grade 42.5N (Dangote) conforming to BS 12 was sourced from the local market at Mando, Kaduna, Nigeria. Locally available river sand served as fine aggregate (FA) and crushed granite chippings of 20 mm maximum nominal size as coarse aggregate (CA); both were obtained from a local supplier at Mando/Airforce roundabout, Kaduna. The river sand passed the 4.75 mm IS sieve and complied with grading zone-II limits of IS 383-1970. Waste tyre (WT) was collected from Panteka market along Nnamdi Azikiwe Expressway, Kaduna, and manually cut into irregular-shaped particles not exceeding 20 mm to replace coarse aggregate. Potable drinking water from the Structures Laboratory, Department of Civil Engineering, Nigerian Defence Academy, Kaduna, meeting BS 8680 (2020) requirements, was used for mixing and curing all specimens. Rice husk was obtained from a small-scale rice-processing mill at Kakuri, Kaduna. The husk was burned under controlled temperature (500-700 °C) in an available incinerator, then ground and sieved through a 75 µm standard sieve to produce rice husk ash (RHA).

The oxide composition of RHA and OPC was determined by X-ray fluorescence (XRF) analysis in accordance with [9]; the results are presented in section 4.

### 3.2 Mix Proportions and Specimen Preparation

Concrete cubes measuring 100 mm × 100 mm × 100 mm were prepared in accordance with [16]. The percentage replacements of coarse aggregate with waste tyre (WT) were 0, 5, 10, 15 and 20 % by weight. Rice husk ash (RHA) replaced cement at the same levels (0, 5, 10, 15 and 20 % by weight). All mixes were designed to achieve a target characteristic compressive strength of 20 MPa.

### 3.3 Testing Procedures

Workability of fresh concrete was assessed using the slump test [14] and compacting factor test [15]. Consistency, initial and final setting times of the cement-RHA pastes were determined according to [13]. Compressive strength was tested at 7, 14, 21 and 28 days of water curing per [16]. For elevated-temperature exposure, 28-day cured cubes were placed in a muffle furnace and heated at 718 °C for 15 min or 821 °C for 30 min, after which residual compressive strength was immediately determined to evaluate thermal resistivity. Aggregate crushing value of the coarse aggregate (including WT blends) was evaluated per [12], and fineness modulus per [11].

## 4. Results and Discussion

### 4.1 Chemical Properties of Binders

The oxide compositions of rice husk ash (RHA) and ordinary Portland cement (OPC) determined by X-ray fluorescence are presented in Table 1.

Table 1: Oxide composition of RHA and OPC binders

Oxides	RHA (%)	CEMENT (%)
SiO <sub>2</sub>	67.26	20.171
Al <sub>2</sub> O <sub>3</sub>	1.93	4.101
Fe <sub>2</sub> O <sub>3</sub>	0.68	3.899
CaO	0.38	63.871
MgO	3.49	2.105
SO <sub>3</sub>	0.63	2.1
Na <sub>2</sub> O	3.75	0.011
K <sub>2</sub> O	3.16	0.938
P <sub>2</sub> O <sub>5</sub>	0.18	0.117
Cl	0.086	0.098
TiO <sub>2</sub>	0.09	0.209
MnO	0.15	0.036
LOI	13.38	2.093

The cement satisfies all [17] limits for CEM II 42.5N (CaO + SiO<sub>2</sub> = 84.042 % ≥ 50 %; CaO/SiO<sub>2</sub> = 3.166 ≥ 2 %; SO<sub>3</sub> = 2.1 % ≤ 3.5 %; MgO = 2.105 % ≤ 5.0 %; Cl = 0.098 % ≤ 0.1 %). For RHA, the combined SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub> + Fe<sub>2</sub>O<sub>3</sub> content reaches 69.9 % (approximately 70 %), exceeding the ≥ 50 % threshold, confirming its classification as Class C pozzolana. This high silica content (67.26 %) underpins RHA's reactivity with calcium hydroxide during hydration, forming additional calcium silicate hydrate (C–S–H) gel that densifies the matrix and enhances long-term strength and durability.

### 4.2 Specific Gravity

Specific gravities of the constituent materials are summarised in Table 2.

Table 2: Specific gravities of concrete materials

Materials	Values
Cement	3.152
RHA	2.22
Fine Aggregate	2.69
Coarse Aggregate	2.92

RHA (2.22) is significantly less dense than OPC (3.152), implying that equal-mass replacements occupy greater volume and increase mix water demand. The fine and coarse aggregates fall comfortably within normal-weight limits [18], ensuring compatibility with the modified binder.

### 4.3 Particle Size Distribution

Dry sieving results for the aggregates are shown in Figure 1.

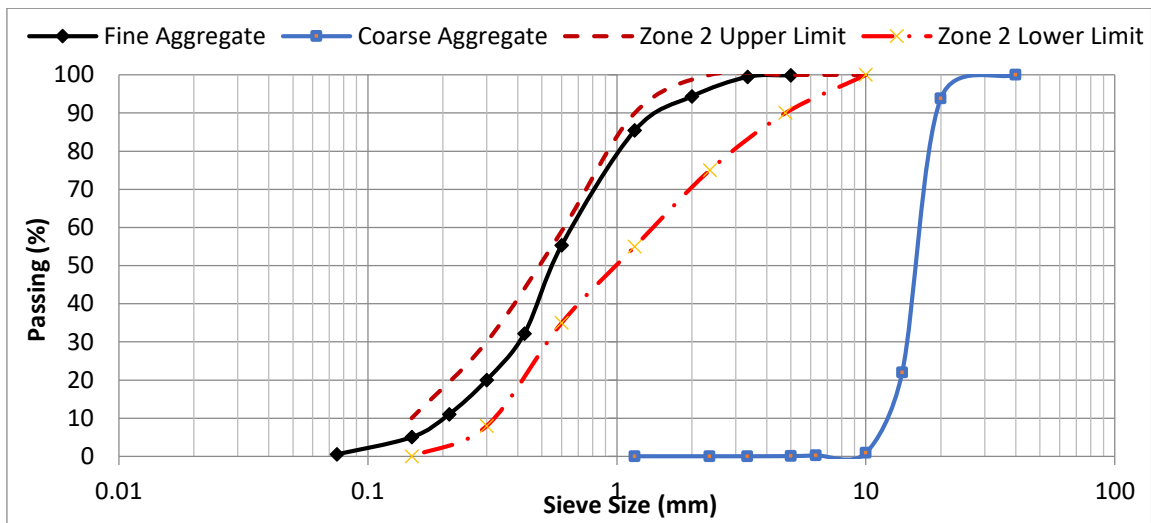


Figure 1: Particle size distribution of fine and coarse aggregates

The fine aggregate exhibits a fineness modulus of 2.57, placing it in Zone II [19]. The coarse aggregate is dominated by 20 mm particles (71.82 % retained on 14 mm sieve), with a fineness modulus of 3.0, confirming its suitability as 20 mm nominal maximum size.

### 4.4 Effects of RHA on Consistency and Setting Times of Cement Paste

Normal consistency and setting times of OPC-RHA pastes are given in Table 3.

Table 3: Normal consistency and setting times of OPC blended with RHA

Replacement of OPC with RHA	Consistency (%)	Initial setting time (mins)	Final setting time (mins)
Cement	28	74	152
5% RHA	30	88	175
10% RHA	33	92	180
15% RHA	36	122	250
20% RHA	39.5	150	315

Consistency rises from 28 % (control) to 39.5 % at 20 % RHA, driven by RHA’s high loss on ignition (13.38 %) and lower specific gravity, which together increase water demand. Initial setting time extends from 74 min to 150 min and final setting time from 152 min to 315 min; both remain within [13] limits ( $\geq 60$  min and  $\leq 600$  min). The progressive delay reflects slower pozzolanic reaction kinetics compared with the rapid hydration of pure OPC [21].

### 4.5 Effects of RHA and WT on Compressive Strength at Ambient Temperature

Compressive strength development at 7, 14, 21 and 28 days is illustrated in Figures 2–5, respectively.

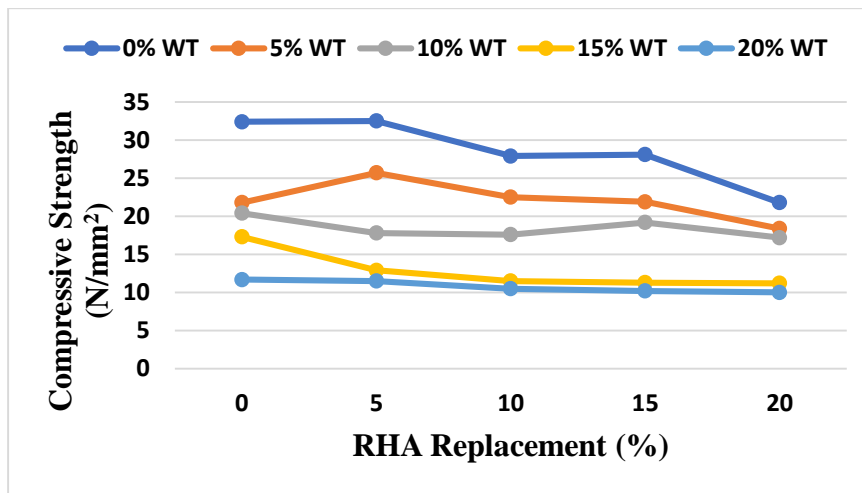


Figure 2: Effect of RHA and WT on compressive strength of the concrete at 7 days

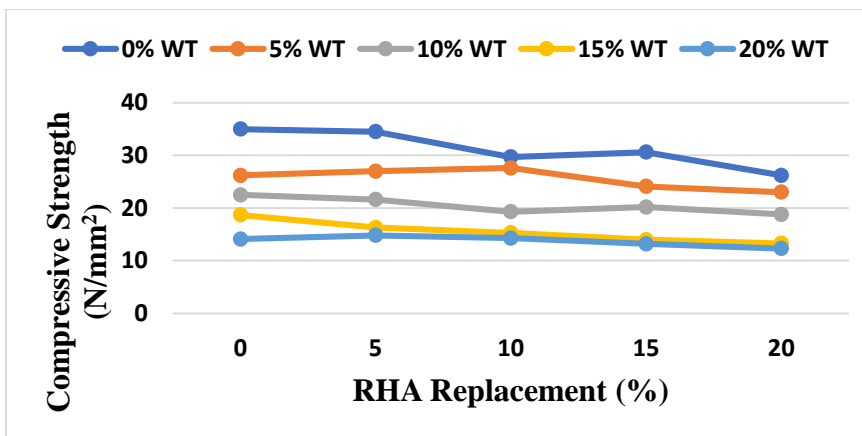


Figure 3: Effect of RHA and WT on compressive strength of the concrete at 14 days

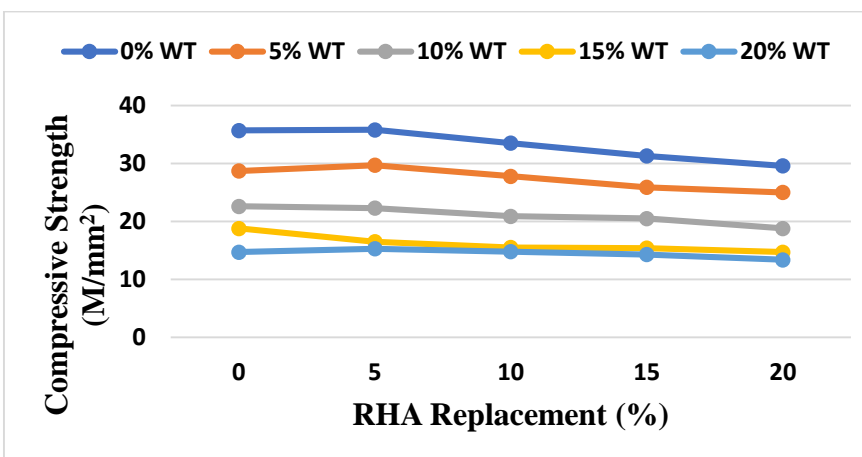


Figure 4: Effect of RHA and WT on compressive strength of the concrete at 21 days

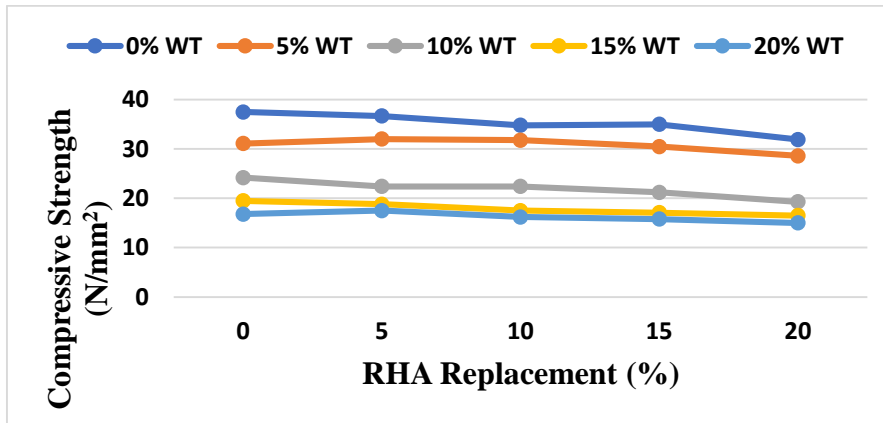


Figure 5: Effect of RHA and WT on compressive strength of the concrete at 28 days

Strength increases with curing age for every mix, confirming that RHA and WT do not disrupt the normal hydration process when used within the studied limits. The control mix (0 % RHA + 0 % WT) attains 37.5 N/mm<sup>2</sup> at 28 days with a density of approximately 2500 kg/m<sup>3</sup>. All mixes meet the 20 MPa target strength; the optimum blend of 10 % RHA + 5 % WT achieves 31.8 N/mm<sup>2</sup> at 28 days - surpassing the control because moderate RHA dosage supplies reactive silica that refines pore structure while 5 % WT maintains adequate aggregate interlock. Higher WT contents ( $\geq 10$  %) cause pronounced strength reduction (up to 50 % at 15 % WT) due to the irregular particle shape, lower stiffness, and entrapped air voids that weaken the interfacial transition zone [22, 23]. Beyond 10 % RHA, excess unreacted ash acts as a filler rather than a binder, further lowering strength.

#### 4.6 Effects of RHA and WT on Residual Compressive Strength after Elevated-Temperature Exposure

Residual compressive strengths of 28-day cubes after exposure to 718 °C for 15 min and 821 °C for 30 min are presented in Figures 6 and 7.

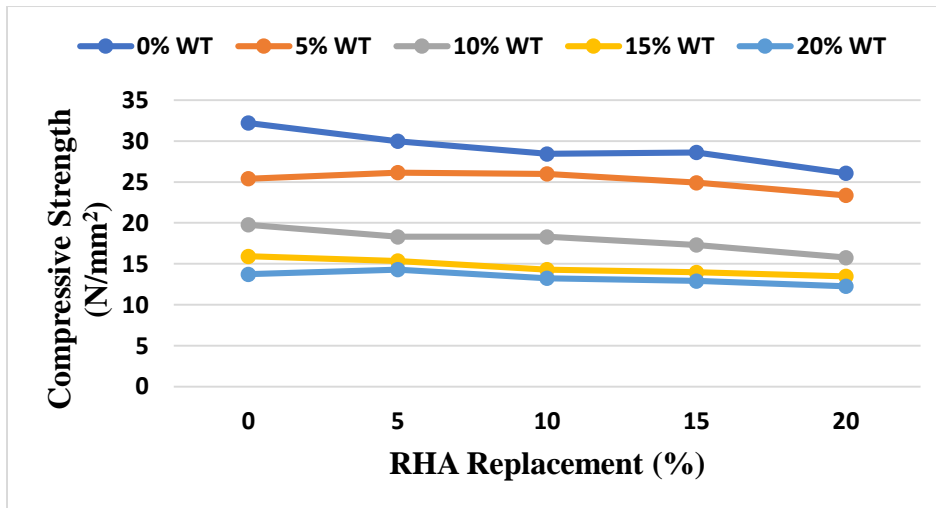


Figure 6: Effect of RHA and WT on compressive strength (burnt cubes at 718 °C for 15 min) of the concrete at 28 days

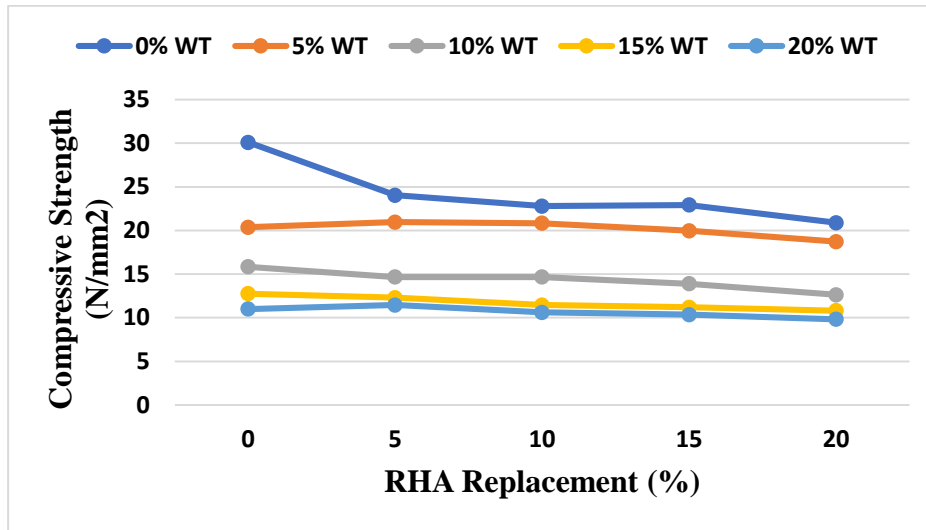


Figure 7: Effect of RHA and WT on compressive strength (burnt cubes at 821 °C for 30 min) of the concrete at 28 days

Elevated temperatures reduce strength in both control and modified concretes, yet the 10 % RHA + 5 % WT mix retains structural integrity better than higher replacement levels. Normal concrete (0 % replacement) loses 14.1 % at 718 °C and 19.7 % at 821 °C. The optimum mix experiences 18.3 % and 34.5 % loss, respectively only 4.2 % and 14.8 % more than the control, demonstrating acceptable thermal resistance. The target 20 MPa is still achieved at 718 °C for all RHA levels with 0–5 % WT and at 821 °C for 0–5 % WT with up to 10 % RHA. Strength decline arises from dehydration of C–S–H gel, decomposition of calcium hydroxide, and thermal cracking; RHA’s pozzolanic products mitigate these effects by lowering free lime and refining porosity [24, 25, 26]. Higher WT fractions exacerbate damage through differential thermal expansion and increased void content. Thus, limiting RHA to 10 % and WT to 5 % optimises both ambient strength and fire performance while valorising abundant local wastes.

## 5. Conclusion

This research has demonstrated the feasibility of utilizing rice husk ash (RHA) and waste tyre (WT) as sustainable alternative materials in concrete production. Compressive strength results showed a consistent increase with curing age for all mixtures, confirming that the inclusion of RHA and WT does not disrupt the normal hydration process when used within optimum limits. The highest compressive strength was obtained from the control mix, while concrete containing 10 % RHA and 5 % WT gives the optimum strength of 31.8 N/mm<sup>2</sup>, higher than the target strength after 28 days. Waste tyre content exhibits a dominant influence, causing a significant reduction in strength compared to rice husk ash through entrapped air voids and weaker interfacial transition zones. However, the reduction in compressive strength with temperature occurred both in the control and the resulting concrete matrix as reported by Nwankwo et al. (2022). The average loss in strength of the control is about 14.1 % at 718 °C and 19.7 % at 821 °C, while for the optimum replacement the resulting concrete gives loss in strength of about 18.3 % at 718 °C and 34.5 % at 821 °C, which is about 4.2 % at 718 °C and 14.8 % at 821 °C more than the normal concrete (0 %). These outcomes establish that 10 % RHA combined with 5 % WT produces a high-performance, fire-resistant concrete that simultaneously valorises abundant local agricultural and automotive wastes, delivering measurable environmental, economic, and structural benefits to the construction sector.

## 6. Recommendations

Based on the findings of this study, rice husk ash should be used as a partial replacement for cement up to a maximum of 10 % by weight, while waste tyre should be limited to 5 % replacement of coarse aggregate to simultaneously achieve the target 20 MPa strength, superior 28-day performance (31.8 N/mm<sup>2</sup>), and acceptable

residual strength after exposure to 718 °C and 821 °C. These limits balance pozzolanic reactivity, workability, and thermal stability while maximising the valorisation of locally abundant agricultural and automotive wastes. Further research is recommended on flexural strength, shear strength, modulus of elasticity, higher-grade concretes (beyond 20 MPa), long-term durability under aggressive chemical and weathering environments, and full-scale structural applications so that these sustainable mixes can be confidently adopted in real-world construction across Nigeria and other developing economies.

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## References

- [1] Muhammad N, Walid AK. Performance of date palm ash as a cementitious material by evaluating strength, durability, and characterization. 2018.
- [2] Sheikh MH, Sachar A. Utilizing rice husk ash and crumb rubber to evaluate the characteristics of concrete. *Int J Innov Res Eng Manag.* 2023;10(4):1-7.
- [3] Nadim AE, Nasser SB. Utilization of waste crumbed rubber tyre as fine concrete aggregate. *Yanbu J Eng Sci.* 2012;4:1-10.
- [4] Britannica Encyclopaedia. Concrete, construction building material [Internet]. 2023 [cited 2026 Apr 15]. Available from: <https://www.britannica.com/technology/concrete-building-material>.
- [5] Panagoda LPSS, Sandeepa RAHT, Perera WAVT, Sandunika DMI, Siriwardhana SMGT, Alwis MKSD, et al. Cement manufacturing process and its environmental impact. *J Res Technol Eng.* 2023;4(3):161-168.
- [6] Ogbeide O. Reducing CO<sub>2</sub> emission in the production of concrete by partial replacement of cement with supplementary cementitious materials. 2012.
- [7] Food and Agriculture Organization of the United Nations. FAO cereal supply and demand brief [Internet]. Rome: FAO; 2026 [cited 2026 Apr 15]. Available from: <https://www.fao.org/worldfoodsituation/csdb/en>.
- [8] Gradeall. Tyre waste environmental impact: global statistics [Internet]. 2026 [cited 2026 Apr 15]. Available from: <https://gradeall.com/tyre-waste-environmental-impact-global-statistics/>.
- [9] ASTM C114. Standard test methods for chemical analysis of hydraulic cement. West Conshohocken, PA: ASTM International; 2018.
- [10] BS EN 196-6. Methods of testing cement – Part 6: Determination of fineness. London: British Standards Institution; 2005.
- [11] BS EN 12620. Aggregates for concrete. London: British Standards Institution; 2013.
- [12] BS EN 1097-2. Tests for mechanical and physical properties of aggregates – Part 2: Methods for the determination of resistance to fragmentation. London: British Standards Institution; 2010.
- [13] BS EN 196-3. Methods of testing cement – Part 3: Determination of setting times and soundness. London: British Standards Institution; 2005.
- [14] BS EN 12350-2. Testing fresh concrete – Part 2: Slump test. London: British Standards Institution; 2009.
- [15] BS EN 12350-4. Testing fresh concrete – Part 4: Degree of compactability. London: British Standards Institution; 2009.
- [16] BS EN 12390-3. Testing hardened concrete – Part 3: Compressive strength of test specimens. London: British Standards Institution; 2002.
- [17] ASTM C618. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. West Conshohocken, PA: ASTM International; 2008.
- [18] BS 812-107. Testing aggregates – Part 107: Method for determination of density. London: British Standards Institution; 1995.

- [19] BS 882. Specification for aggregates from natural sources for concrete. London: British Standards Institution; 1992.
- [20] Wilson UN, Sani JE, Adefila AA, Mohammed IS. Thermal resistance evaluation of raffia palm ash concrete. *J Appl Sci Environ Manag.* 2021;25(2):459-465.
- [21] Ogork EN, Uche OA. Effects of groundnut husk ash (GHA) in cement paste and mortar. *Int J Civ Eng Technol.* 2014;5(10):88-95.
- [22] Kaloush KE, George BW, Zhu H. Properties of crumb rubber concrete. *Transp Res Rec.* 2005;1914(1):8-14.
- [23] Ling GS, Ghataora GS, Su H, Yang J, Dirar S. Properties of concrete prepared with waste tyre rubber particles of uniform and varying sizes. *J Clean Prod.* 2015;91:288-296.
- [24] Nwankwo PO, Wilson UN, Danbuba Z. The fire resistance of concrete made with recycled plastic as partial replacement for coarse aggregate. *Malays J Civ Eng.* 2022;34(2):11-18. DOI: 10.11113/mjce.v34.18309.
- [25] Teja KV, Meena T. Study on temperature resistance concrete. *Int J Civ Eng Technol.* 2018;9(4):1229-1236.
- [26] Prasad PV, Andavan S, Bhaskar R. Rice husk ash as partial replacement material of cement in concrete. *Int J Res Eng Sci Manag.* 2018;1(10):197-201.
- [27] Bamigboye GO, Adigun DO, Oke DA. Effect of elevated temperature on the compressive strength of concrete containing waste tyre rubber. *J Eng Res Rep.* 2019;8(2):1-8.
- [28] Umasabor PC, Okovido JO. Fire resistance of concrete containing rice husk ash. *J Civ Eng Constr Technol.* 2018;9(3):29-36.
- [29] Kumaran GS, Lakshmipathy M, Muthu D. Recycling of waste tyre rubber in concrete – a review. *Int J Civ Eng Technol.* 2008;9(12):1-10.
- [30] Sarah SN, Hameed MS, Alengaram UJ. Use of waste tyre rubber in concrete – a review. *IOP Conf Ser Mater Sci Eng.* 2016;160:012061.
- [31] Jugal P, Vyas A, Patel S. Effect of rice husk ash on properties of concrete. *Int J Eng Res Technol.* 2018;7(3):1-5.
- [32] Bisht K, Kabeer KSA, Kabeer KSA. Utilization of waste materials in concrete production – a review. *Mater Today Proc.* 2020;26:3234-3240.
- [33] Tayeh BA, Alyami MH, Almeshal I, Al-Hadithi AI. Effect of rice husk ash on mechanical properties and durability of concrete: a review. *Case Stud Constr Mater.* 2021;15:e00655.
- [34] Hossain MS, Ahmed S, Rahman MA. Rice production in Bangladesh: a review. *J Agric Food Res.* 2018;3:100-110.
- [35] Steven SS, Olanrewaju OO, Olanrewaju OO. Physical and chemical properties of rice husk. *J Mater Civ Eng.* 2021;33(4):04021012.
- [36] Li Z, Wang X, Li Z. Recent advances in nano-silica modified cement-based materials: a review. *Constr Build Mater.* 2019;228:116804.
- [37] Yang G, Xu J, Yao Z, Han Q. Research on crumb rubber concrete: from a multi-scale review. *J Clean Prod.* 2019;232:116-128.
- [38] Doğruyol M, Ayhan E, Karaşin A. Effect of waste steel fiber use on concrete behavior at high temperature. *Case Stud Constr Mater.* 2024;20:e03051.

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