THE USE OF CASHEW NUTS SHELL ASHES AS PARTIAL REPLACEMENT OF CEMENT FOR MAKING NORMAL CONCRETE IN TANZANIA

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ABSTRACT

This study investigates the feasibility of using Tanzanian Cashew Nut Shell Ash (CNSA) as a partial replacement for Portland cement in concrete production. Unlike previous studies that utilized CNSA from India, Brazil, and Nigeria, this research focuses on Tanzanian CNSA, whose chemical composition and properties remain unexplored. Tests, including X-ray fluorescence, compressive strength, flexural strength, water absorption, and ultrasonic pulse velocity, were conducted on concrete samples cured for 7, 28, and 56 days. The results confirm that Tanzanian CNSA meets pozzolanic material standards and its concrete demonstrates promising performance as a construction material, with its suitability varying based on the curing period and cement replacement levels ranging between 5% to 10%. This study highlights CNSA's potential to promote sustainable construction practices while addressing waste management challenges in Tanzania.

Keywords: cashew nut shell ash; CNSA; concrete admixture; durability; flexural strength; x-ray fluorescence; compressive strength; Portland cement; ultrasonic pulse velocity.

INTRODUCTION

Rising global populations and increasing consumption have heightened the demand for food, driving the rapid expansion of agricultural production. This growth has resulted in significant waste generation, with substantial environmental and economic consequences (Duque-Acevedo et al., 2020; Foley et al., 2011; Manjunath et al., 2023). Utilizing agro-waste not only reduces the financial costs of waste disposal but also promotes environmental protection by helping to lower the carbon footprint. (Amran et al., 2021; Gupta et al., 2022).

Cashew production generates millions of tons of wastes globally (Cruz et al., 2024). On average, approximately 3.3 million metric tons of Cashew Nut Shells (CNS) are produced worldwide (Shahbandeh, 2023), and these shells are usually either incinerated or discarded (Ogundiran et al., 2011). When incinerated, Cashew Nut Shell Ash (CNSA) is produced, and often the CNSA is discarded in open landfills (Manjunath et al., 2023).

In recent years, researchers have explored the feasibility of making the CNS disposal process more sustainable and reusing the CNSA in concrete production and soil stabilization (Tantri et al., 2022; Devarajan et al., 2024; Manjunath et al., 2023; Ogundiran et al. 2011; Oyebisi et al., 2022; Oyebisi et al., 2019 and Lima et al. 2010, to mention a few). As discussed by Lima et al. (2010) and Thirumurugan et al. (2018), most nut ashes, including CNSA, are pozzolanic due to their composition of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and other oxides and alkalis. These compounds react with Calcium hydroxide ($Ca(OH)_2$) to produce more Calcium Silicate Hydrates (C–S–H) and Calcium Aluminate Hydrates (C–A–H) which are primarily responsible for strength and durability, thus enhancing concrete durability and resistance to chemical attacks like sulphate exposure (Kasaniya et al., 2021; Lin et al., 2023). Consequently, these ashes hold potential as cementitious additives in concrete mixtures.

Tanzania ranks as the sixth-largest cashew producer globally, contributing approximately 225,000 metric tons annually, which accounts for about 7% of global production (Kamer, 2023). However, the potential of Tanzanian Cashew Nut Shell Ash (CNSA) as a partial replacement for Portland cement remains unexplored. Previous studies on CNSA from Brazil (Lima et al., 2010), India (Thirumurugan et al., 2018), and Nigeria (Oyebisi et al., 2019) indicate that chemical compositions can vary significantly by region as shown in Figure 1. Despite these variations, one key factor supporting CNSA's suitability as a cement admixture is its classification as a suitable pozzolan, meeting the requirement of at least 70% combined silica, aluminium oxide, and iron oxide content (ASTM C618-23e1, ASTM 2022).

Research shows that varying CNSA replacement in concrete offers distinct advantages. A 15% replacement is ideal for structural applications, while a 20% replacement is better suited for non-load-bearing uses. Additionally, up to 25% replacement has been found to reduce water absorption, improve curing, decrease porosity, and enhance overall strength (Cruz et al., 2024; Tantri et al., 2021, 2022; Thirumurugan et al., 2018; Pandi and Ganesan, 2015; Oyebisi et al., 2019).

The management of cashew nut production residues, such as Cashew Nut Shells (CNS) and Cashew Nut Shell Ash (CNSA), poses significant environmental and economic challenges (Cruz et al., 2024). Valorising these agro-wastes, such as utilizing CNSA in construction activities like concrete production, offers a sustainable solution for waste management and environmental conservation, particularly in developing countries like Tanzania.

This research aims to evaluate the feasibility of using Tanzanian CNSA, specifically from the coastal region, which accounts for approximately 61% of the country's cashew production, as a partial replacement for Portland cement in the production of grade 20 concrete. The chemical and physical properties of Tanzanian CNSA remain largely unexplored, making this research essential. The resulting concrete is intended for use in local construction activities where lighter overall structural weight is required, such as lightweight foundations for garages, sheds, workshops, driveways, internal floor slabs, paving, patios, and posts (Dyer, 2017; Limited, 2022).

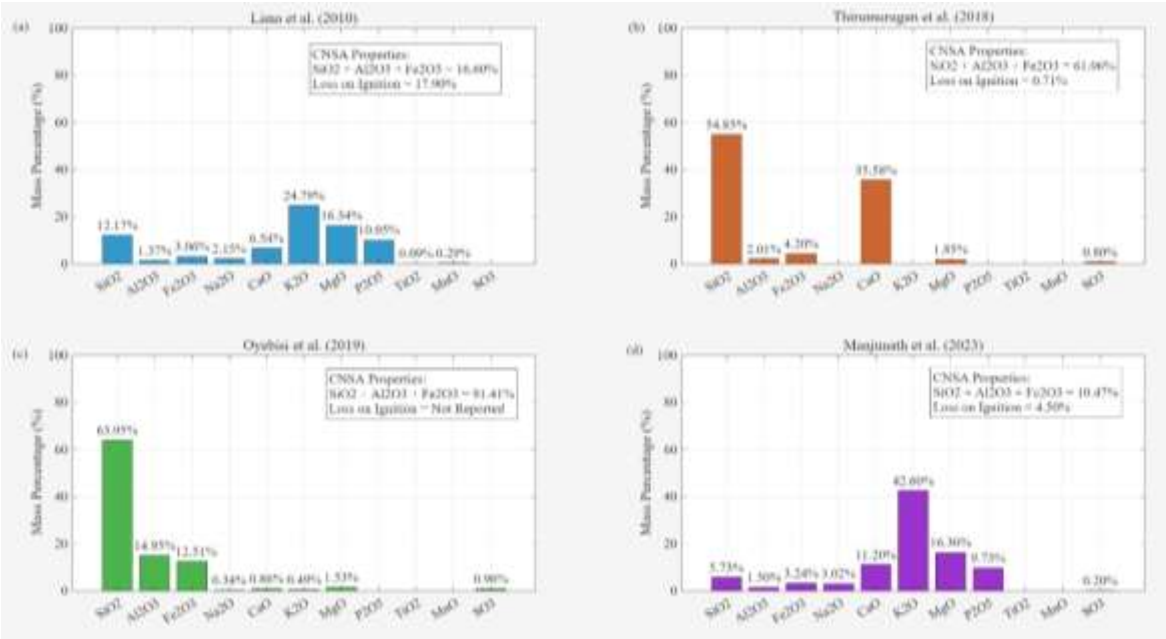

Figure 1: Mass percentage (%) chemical composition of CNSA

METHODOLOGY

Cashew Nut Shells (CNS) were collected from small-scale cashew nut producers located in the Mkuranga region of Tanzania and air dried for three days to remove moisture. Then, the CNS were incinerated at temperatures between 500 to 550ºC (verified with an infrared thermometer). The resulting mixture was sieved using 2 mm and 500-micron standard sieves (ASTM, 2024) to separate the unburnt CNS from the CNSA. The CNSA was further processed by grinding it into a fine powder using a Ball Mill machine. It was then sieved through a 75-micron sieve to obtain finer particles comparable in texture and size to Portland cement.

Figure 2: Fine CNSA after sieving through 75-micron sieve.

Chemical analysis test was conducted on the resultant powder using energy dispersive x-ray fluorescence spectrometer EDX-8000 as shown in Figure 3 and was performed at the Tanzania Bureau of Standards (TBS) laboratory.

Figure 3: Chemical analysis test using x-ray fluorescence spectrometer EDX-8000.

As shown in Figure 6, data from the preliminary analysis were favorable in the sense that XRF suggested that the Tanzanian CNSA contained the minimum required amounts of pozzolanic compounds, with 74.23% $SiO_2 + Al_2O_3 + Fe_2O_3$ which is greater than 70%, as specified by ASTM standards (ASTM C618-23e1, ASTM 2022). This composition validated the potential of CNSA for use in concrete production.

Coarse aggregate, fine aggregate, and sand were selected for this mixture along with the CNSA, and laboratory tests were conducted to determine the CNSA, aggregate and sand physical properties. These physical tests in this study were performed at the University of Dar es salaam's College of Engineering and Technology structural and materials laboratory and ESTIM Construction Company Ltd Materials laboratory.

Density and absorption tests were conducted in accordance with ASTM C127-15 (ASTM 2015). Sieve tests were conducted in accordance with Tanzania Central Laboratory Testing Manual (CML 2009 Test No. 1.7). Specific gravity, fineness (i.e., percent diameter less than the No. 200 sieve), and loss on ignition (LOI) were tested in accordance with ASTM C188-17 (ASTM 2017), ASTM C430-17 (ASTM 2017) and ASTM D7348-21 (ASTM 2021) respectively (Figure 4, Figure 6 and Table 1).

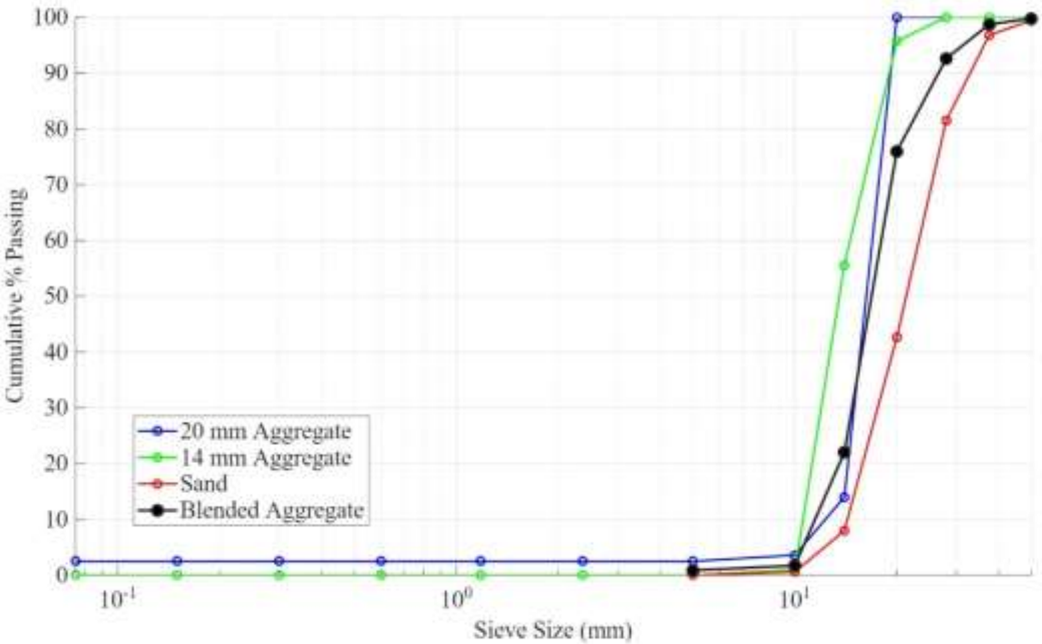

Figure 4: Grading curve for aggregates

Table 1: Physical properties for fine and coarse aggregates used during this study

Material	Absorption	Bulk Density (g/cm^3)	Specific Gravity (g/cm^3)
Sand	0.86%	2.615	2.675
14 mm Coarse Aggregate	1%	2.804	2.885
20 mm Coarse Aggregate	0.70%	2.857	2.915

Table 2: Concrete mix design proportions per m^3 concrete

Batch No.	Mix Designation	Portland Cement (kg)	CNSA (kg)	Water (kg)	20 mm Aggregate (kg)	14 mm Aggregate (kg)	Sand (kg)
1	CNSA00	275	0	155	800	400	800
2	CNSA05	261	14	155	800	400	800
3	CNSA10	248	27	155	800	400	800
4	CNSA20	220	55	155	800	400	800

Then, 4 batches of concrete were mixed using varying ratios between CNSA (0%, 5%, 10% and 20%) and Portland cement following ACI (2022). The type of cement used for this study was Nyati 42.5R Grade Portland Cement. Each batch was tested for slump in accordance with ASTM C143/C143M-20 (ASTM 2020). Concrete mixing was performed using an electric concrete mixer in accordance with ASTM C192/C192M-19 (ASTM 2019). Each batch was used to construct nine 15-cm by 15-cm by 15-cm cubes and four 10-cm by 10-cm by 50-cm beams. The cubes were submerged and allowed to cure for 7, 28, and 56 days while the beams cured for 56 days. Water absorption was tested after curing by comparing the cubes' wet weights and their weights after 24 hours of air drying for each cure period. After curing, the cubes were tested for compressive strength in accordance with CML Test No. 2.13 (CML 2000). Meanwhile, Ultrasonic Pulse Velocity Testing (UPV) was performed in accordance with ASTM C597-22 (ASTM 2022) in a 10-cm interval to assess the specimens' uniformity and relative quality of concrete to indicate the presence of voids and cracks (Prusty and Patro, 2015). Flexural strength was tested on the beams in accordance with ASTM C293/C293M-16 (ASTM 2016) with center-point loading.

Figure 5: (a) Ultrasonic Pulse Velocity Testing (UPV) on the beam (b) Flexural strength test on the beam with centre-point loading.

RESULTS

Results from XRF, UCS, flexural strength, water absorption, and UPV are shown below in Figure 6 and Table 3 through Table 4 respectively. Selected graphical data are presented in Figure 7.

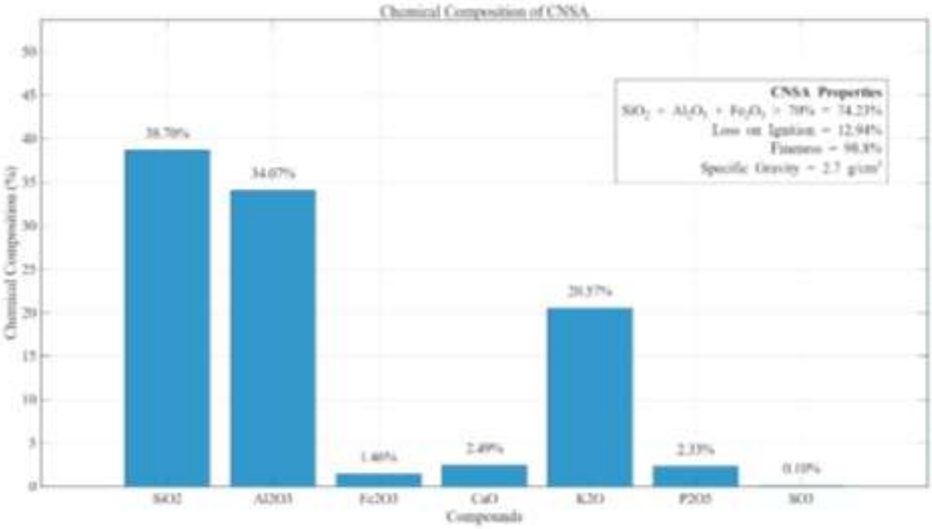

Figure 6: Data from physical tests and chemical composition (XRF) of Tanzanian CNSA

Table 3: Compressive strength for cured specimens

Cement Replacement %	Cement Content (kg)	CNSA Content (kg)	Slump (mm)	Average Density of Specimens (kg/m^3)		
				7 Days	28 Days	56 Days
0	9.35	0	80	2492	2524	2545
5	8.88	0.47	70	2498	2503	2504
10	8.42	0.93	70	2514	2458	2502
20	7.48	1.87	60	2442	2461	2545

Table 4: Flexural strength of concrete cubes at 56 days

CNSA Content	Beam Mass (kg)	Load (kN)	Flexural Strength (MPa)
0%	12.481	7	5.25
5%	12.54	8.8	6.6
10%	12.472	7.4	5.55
20%	12.475	5	3.75

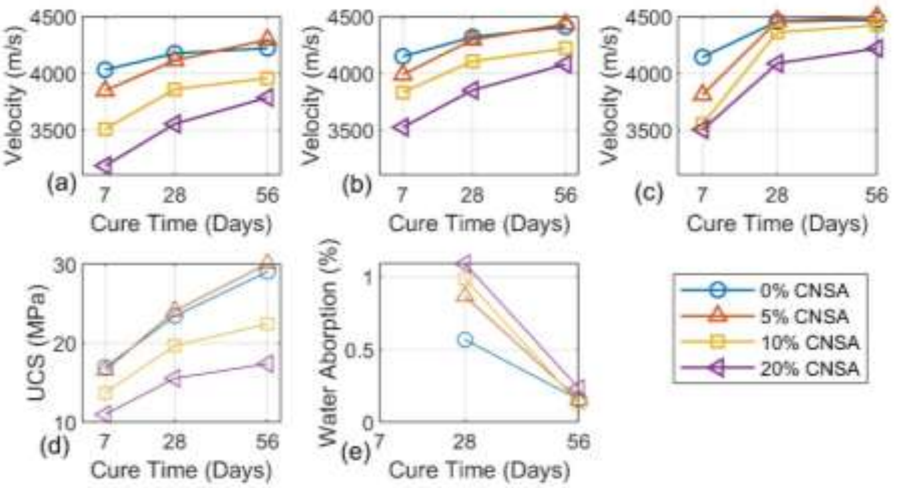

Figure 7: Selected Tanzanian CNSA graphical output showing (a) UPV results at 10 cm; (b) UPV results at 20 cm; (c) UPV results at 30 cm; (d) Compressive strength; and (e) water absorption; all as a function of cure time

DISCUSSION

ASTM C618-23e1 (ASTM 2022) specifies a minimum pozzolan (i.e., SiO_2, Al_2O_3, and Fe_2O_3) requirement for ashes of 70% and a maximum of 4% SO_3. Data in Figure 6 suggested that the Tanzanian CNSA would behave similarly to other pozzolanic ashes in a concrete mix in the sense that sufficient pozzolan and SO_3 criteria were achieved. Results from physical testing showed that the Tanzanian CNSA had a specific gravity of 2.7 g/cm^3; a fineness of 98.8%, and an ignition loss of 12.94%.

The slump test results in table 3 showed a decrease in workability as the percentage of CNSA replacement increased. The mix with 0% CNSA had the highest slump of 80 mm, indicating medium workability, while mixes with 5%, 10%, and 20% CNSA had slumps of 70 mm and

60 mm, respectively, reflecting a reduction in workability. These findings align with those of previous researchers, including Oyebisi et al. (2019) and Pandi et al. (2019), who observed a similar decreasing trend in slump with higher CNSA content. This reduction is likely attributed to the increased presence of mineral compounds which affects setting and hardening of concrete.

Data in Table 4 indicate that the 5% CNSA concrete beam achieved the highest flexural strength, and this was even higher than the flexural strength in the beam with 0% CNSA. The beam with 10% CNSA showed lower flexural strengths than the beam with 5% CNSA, but the flexural strength was still higher than the beam with 0% CNSA. The beam with 20% CNSA was significantly weaker than the control beam. The trend of increase in flexural strength at 5-15% CNSA replacement and decrease in flexural strength beyond 15% CNSA is similar to observations from Oyebisi et. al. (2019). Therefore, concrete with 5-15% CNSA replacement demonstrates slightly better flexural strength than normal Portland cement concrete.

Water absorption (i.e., data in Figure 7(e)) was inversely proportional to CNSA quantity after 28 days in the sense that water absorption was the lowest for the control specimen (i.e., 0% CNSA) and highest in the specimen with 20% CNSA. However, after 56 days, water absorption from the CNSA specimens appeared to converge and approach the water absorption ratio for the 0% CNSA. The specimen with 10% CNSA appeared to have a slightly lower absorption value than 0% CNSA specimen after 56 days of curing. These findings are consistent with Oyebisi et al. (2019) and Pandi et al. (2019), who observed that partially replacing Portland cement with CNSA improved water absorption and sorptivity properties, noting that concrete with 25% CNSA replacement showed lower water absorption and sorptivity compared to conventional concrete.

UPV results (Figure 7(a) through Figure 7(c)) showed that the control specimen had the highest velocity at 7 days and 28 days. But, after 56 days of curing, concrete with 5% CNSA achieved a greater velocity than the control specimen. A higher UPV value is indicative of higher concrete uniformity and quality. According to Kaliyavaradhan & Ling (2019), concrete is classified as good quality when the UPV values fall between 3.5 and 4.5 km/s, and superior quality when the UPV values exceed 4.5 km/s. Thus, results suggest that the 5% CNSA specimen achieved the highest concrete uniformity and quality overall after 56 days and these results were comparable with data from concrete composed of Portland cement only.

Data in Figure 7(d) show that the concrete with 5% CNSA concrete showed a slightly lower 7-day strength than the control specimen (i.e., 0% CNSA), but greater values than the control specimen at 28 and 56 days respectively. The concrete with 10% CNSA showed slow strength development at 7 and 28 days, and achieved its target strength (i.e., greater than 20 MPa) within 56 days. The concrete with 20% CNSA did not achieve its target strength. Results from Oyebisi et. al. (2019), showed that the compressive strength increased with increasing CNSA content from 5 to 15% replacement at all curing ages in comparison to the Portland cement concrete. Contrary to their findings, results of our study showed an increasing trend in compressive strength for 5% CNSA replacement, and a decreasing compressive strength for 10% and 20% CNSA replacement.

CONCLUSION AND RECOMMENDATION

Despite slow early strength development, concrete that utilized 5% Tanzanian CNSA as a replacement for Portland cement achieved the highest compressive strength after 28 days (and 56 days) of curing. These specimens achieved similar water absorption, flexural strength, and UPV results as control specimens. While concrete with 10% CNSA did not achieve target strength after 7 days or 28 days, target strength was achieved after 56 days. The 20% CNSA specimens did not achieve target strength and water absorption was higher than it was in the other specimens. Thus, data suggest that Tanzanian CNSA may be a viable replacement for Portland cement in small (i.e., 10% or less) ratios if sufficient cure time is allowed even though its chemical composition is different from CNSA from previous data obtained from Brazil, India, and Nigeria. Investigators recommend that the concrete produced by Tanzanian CNSA at low CNSA replacement (5% to 10%) can be used for construction activities where the intended structure will experience low to moderate loading such as lightweight foundations for garages, sheds, and workshops, driveways, internal floor slabs, paving, patios, and fence or structural posts. Finally, utilizing CNSA in concrete production will offer a sustainable solution for waste management and environmental conservation in Tanzania. Future research should focus on using Tanzanian CNSA to produce different concrete grades such as (C15, C25, C30 etc.) with a wide range of CNSA replacement. More physical and mechanical tests on the concrete and cement mortar specimens such as split tensile test, setting time and consistency test should be conducted to reveal a better understanding on the effect of Tanzanian CNSA on concrete properties.

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