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Evaluating the impact of moisture content on the Foundry performance of Eco-friendly sand from Nyama River Beach for Sustainable Casting Applications

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Abstract
This study evaluates the effect of moisture content on the foundry performance of eco-friendly sand derived from Nyama River Beach for sustainable casting applications. The objective was to determine the suitability of locally sourced sand combined with Edda clay as a binder for environmentally sustainable moulding sand. Grain size distribution was analyzed using a mechanical sieve shaker, showing that more than 70% of the sand particles were retained at key mesh sizes of 0.18 mm, 0.125 mm, and 0.09 mm. The calculated grain fineness number (GFN) of 73.80 indicates an optimal grain distribution suitable for foundry applications. Chemical characterization using X-ray fluorescence (XRF) and X-ray diffraction (XRD) revealed the major oxide compositions as SiO_2 (73.64%), Al_2O_3 (7.98%), and MgO (1.45%), confirming the silica-rich nature of the sand. Foundry performance was evaluated through tests including green compressive strength, green shear strength, dry compressive strength, dry shear strength, compactability, and permeability. The results showed a green compressive strength of 9.50 kN/m² and green shear strength of 236.40 kN/m², indicating good mechanical stability under moist conditions. Compactability and permeability were recorded at 26.10% and 190.09%, respectively, demonstrating adequate moulding and drainage properties. The optimal composition was achieved with 5% Edda clay and 3.85% moisture content, which significantly improved the moulding characteristics of the sand. The findings indicate that Nyama River sand, when properly conditioned with Edda clay, can serve as a sustainable alternative to conventional bentonite-bonded moulding sand, particularly for non-ferrous casting applications, while promoting environmental sustainability and reducing dependence on non-renewable material

Keywords: Eco-friendly sand, Foundry performance, Moisture content, Edda clay, Mechanical properties.

1. Introduction

The foundry industry plays a vital role in manufacturing and industrial production, particularly in the fabrication of metal components used in engineering, automotive, construction, and machinery sectors. One of the most critical materials in metal casting is moulding sand, whose quality directly influences the strength, dimensional accuracy, and surface finish of cast products. Silica sand is widely used in foundry operations because of its desirable properties, including high refractoriness, thermal stability, permeability, and resistance to decomposition at elevated temperatures, making it suitable for moulding and core-making applications (Abdullahi and Katsina, 2018). Foundry operations are generally categorized into ferrous foundries, which produce castings of iron and steel, and non-ferrous foundries, which process metals such as aluminium, copper, zinc, and lead (Opeoluwad and Antonie, 2013). In both cases, the performance of moulding sand largely depends on its physical and chemical characteristics. Key properties that determine the suitability of moulding sand include grain size distribution, clay content, and moisture content. These parameters significantly influence moulding characteristics such as permeability, compactability, green compressive strength, and shear strength, which ultimately determine the quality of the final casting. Among these factors, moisture content plays a particularly critical role, as it controls the bonding strength between sand particles and the binder, thereby affecting mould stability and gas escape during metal pouring.

Several studies have investigated the suitability of natural sand deposits in Nigeria for foundry applications. Katsina et al. (2013) examined beach sands from the Ughelli, Warri, and Ethiope rivers and reported that these sands were suitable for foundry use. However, sand obtained from Lagos beach required further processing to remove coarse particles, highlighting variations in sand quality even among deposits located within similar geographical regions. Similarly, Mathew et al. (2010) evaluated the effect of moisture content on the moulding properties of River Niger sand using Tudun-Wada clay as a binder. Their results indicated that River Niger sand could be effectively utilized as moulding sand, while Tudun-Wada clay served as a viable alternative to conventional bentonite binders. Further investigations by Agbo et al. (2017) examined the influence of moisture content on the moulding properties of sand from River Niger at Onitsha beach. The authors reported that an optimum combination of 3% moisture content and 4% Ukpor clay provided the best moulding performance, suggesting that locally available clays can effectively replace imported bentonite in non-ferrous foundry operations. These findings align with the work of Aramide et al. (2011), who evaluated the effectiveness of different binders, including bentonite and dextrin, on reclaimed foundry sand. Their study demonstrated that recovered Ilaro sand from Ogun State, Nigeria, could be successfully reused in moulding applications with minor modifications.

Despite the abundance of sand resources in many parts of Nigeria, the suitability of these sands for specific foundry applications remains under explored. This study aims to evaluate the impact of moisture content on the foundry performance of eco-friendly sand sourced from the Nyama River Beach, with a focus on sustainable casting applications. In particular, Nyama River Beach sand has received little or no documented evaluation regarding its moulding performance and moisture-dependent properties, creating a significant knowledge gap for its potential utilization in local foundries. The study seeks to establish optimal conditions for the use of Nyama River Beach sand in the foundry industry, due to the growing need for sustainable and locally sourced materials. This study therefore investigates the effect of moisture content on the foundry performance of eco-friendly sand obtained from Nyama River Beach, with particular emphasis on sustainable casting applications. The research examines the grain characteristics, chemical composition, and moulding properties of the sand when combined with locally sourced Edda clay as a binder. By identifying the optimum moisture and binder conditions required for effective mould formation, the study seeks to establish the suitability of Nyama River sand for foundry operations, particularly in non-ferrous metal casting. The study will exploit insights from earlier research on the effects of moisture content and binding materials to propose practical and sustainable solutions for the Nigerian foundry industry.

Furthermore, the study's significance lies in its potential to reduce dependence on imported materials, lower production costs, and promote the use of environmentally friendly alternatives. Through evaluating the impact of moisture content on the foundry performance of sand from the Nyama River Beach, this research contributes to the broader objective of sustainable development in the foundry sector, aligning with global efforts to promote environmentally conscious industrial practices. As noted by Dieter (1966), moulding sand must meet specific mechanical and thermal requirements to produce high-quality metal castings. Consequently, evaluating and optimizing local sand resources such as Nyama River Beach sand will contribute to improving foundry efficiency while promoting sustainable industrial development in Nigeria. Nevertheless, the findings of this study will provide a scientific basis for understanding the relationship between moisture content and the moulding performance of Nyama River sand, thereby supporting the development of cost-effective and environmentally sustainable materials for the Nigerian foundry industry.

2.0 Materials and methods

2.1. Sample Collection and Preparation

This research utilized locally sourced engineering materials from Nigeria, aligning with the goal of promoting sustainable and eco-friendly foundry practices. The primary material, silica sand, was obtained from Nyama River Beach in Enugu South Local Government Area, Enugu State, Nigeria. This sand was chosen for its availability and potential as a sustainable material for foundry applications. The clay binder used in this study was sourced from

Edda in Afikpo Local Government Area, Ebonyi State, Nigeria. The clay serves as a natural binder to improve the cohesiveness of the sand, a critical factor in moulding processes. In general, Sand samples were collected from the Nyama River Beach and transported to the laboratory in sealed containers. Visible impurities such as organic debris, pebbles, and plant materials were removed manually by hand-picking. The sand was subsequently washed with distilled water to remove adhering contaminants and oven-dried at 110 °C for 24 h to eliminate residual moisture. After drying, the samples were cooled to room temperature and stored in air-tight containers prior to analysis.

This study combined chemical characterization and mechanical testing to determine the suitability of the sand for sustainable casting applications in Nigerian foundry industry. The experimental procedures followed recognized foundry testing practices based primarily on American Foundry Society (AFS) standard methods and related ASTM procedures. All measurements were conducted in triplicate (n = 3) and results were expressed as mean ± 0.5 standard deviation to ensure reliability and reproducibility. The study involved several key experimental analyses to determine optimal moisture content and evaluate the foundry properties of the Nyama River Beach Sand. The chemical composition of the sand and binder was analyzed using X-ray fluorescence (XRF) to ascertain their elemental makeup. Mechanical sieve analysis was conducted to determine the particle size distribution of the sand, which plays a crucial role in moulding and casting quality.

To assess the mechanical properties, various tests were performed, including green compression strength, green shear strength, dry compression strength and dry shear strength. These tests provided insights into the sand's performance in its moist and dry states at typically foundry operations. The permeability of sand was also evaluated to measure its ability to allow gases to escape during the casting process and ensuring defect-free castings. Furthermore, Compactability tests were carried out to determine the sand's ability to be compressed into a mould-shape while maintaining sufficient permeability and strength. The combination of chemical and mechanical analyses provided a comprehensive evaluation of the sand's suitability for foundry applications, with a focus on optimizing moisture content to enhance performance in sustainable casting processes.

2.2. Preparation and Determination of Grain size

In preparation for sustainable foundry processes, unwanted materials were first removed from Nyama beach sand through hand-picking. The sand was thoroughly washed, sieved to eliminate coarse substances, and then oven-dried at 110 °C to remove any residual moisture. The particle size distribution of the sand was determined using mechanical sieve analysis following ASTM E11 standard procedures. Approximately 100 g of oven-dried sand was placed on the top sieve of a standard stack of sieves arranged in decreasing mesh size. The sieve stack was mounted on an electric sieve shaker and operated for 35 minutes to ensure proper separation of particles. After sieving, the mass of sand retained on each sieve was measured using a calibrated digital balance. The American Foundry Society Grain Fineness Number (AFS GFN) was calculated using the standard AFS equation based on the percentage of sand retained on each sieve as :

$$AFS\ grain\ fineness\ number = \frac{Product\ of grain\ size}{Amount\ retained\ \%} \quad (1)$$

2.2.1. Preparation of Standard Test Specimens

Standard cylindrical sand test specimens were prepared using a laboratory sand rammer in accordance with AFS moulding sand testing standards. Each specimen had dimensions of approximately 50 mm diameter × 50 mm height (standard AFS specimen size). Controlled quantities of water were added to achieve the desired moisture contents. The mixture was thoroughly blended to ensure uniform moisture distribution before specimen preparation. For each test condition, three replicate specimens (n = 3) were prepared.

2.2.2. Determination of Green Strength

The green strength of Nyama River sand was measured using a universal sand testing machine. A standard test sample, measuring 7 cm in diameter and 7 cm in height, was carefully prepared and positioned in the compression head of the testing machine. Once the sample was properly secured, it was loaded into the machine. As the machine applied increasing pressure, the sample reached its maximum strength and subsequently failed. At this point, the magnetic rider attached to the measuring scale moved to the position corresponding to the peak strength value, which was then recorded. This precise measurement is critical for assessing the sand's ability to withstand mechanical stresses during moulding processes in foundry applications.

2.2.3. Determination of Green Compression Strength

The green compression strength (GCS) of the sand samples was determined using a universal sand strength testing machine equipped with a compression head. Prepared moist specimens were placed centrally in the testing machine. A steadily increasing compressive load was applied until specimen failure occurred. The maximum load at failure was recorded as the green compression strength. Each measurement was repeated three times, and the average value was calculated.

2.2.4. Determination of Green Shear Strength

Green shear strength (GSS) was determined using the same universal sand testing machine fitted with a shear testing head. The standard moist specimen was subjected to an increasing shear force until structural failure occurred. The maximum stress recorded at the point of failure represented the green shear strength of the moulding sand. All tests were performed in triplicate and the mean value was reported.

*2.2.5. Determination of Dry Compression Strength***.**

The dry compression strength (DCS) of the prepared Nyama River sand sample was determined using a universal sand testing machine. A standard sample with dimensions of 7 cm in diameter and 7 cm in height was oven-dried at 110 °C for 20 minutes, then allowed to cool to ambient temperature. After cooling, the sample was secured in the universal sand testing machine, and the compression head was applied to exert a gradually increasing load. As the load increased, the sample eventually failed at its maximum load-bearing capacity. Three replicate measurements were performed for accuracy. This point of failure was recorded as the dry compression strength (DCS), providing crucial data on the sand's structural integrity under dry conditions, which is essential for evaluating its suitability in high-temperature foundry applications.

2.2.6. Determination of Dry shear strength

The dry shear strength of the prepared Nyama River sand sample was determined by first drying a 7 cm diameter x 7 cm height sample in an oven at 110 °C for 15 minutes. After cooling to ambient temperature, the sample was subjected to shear testing. The shear strength was recorded in triplicates and the mean value was reported at the point of failure, providing a key measure of the sand's resistance to shear forces under dry conditions. This value is critical in assessing the sand's suitability for use in foundry moulding, where shear resistance is vital for mould stability.

2.3. Determination of Green Shear Strength

The green shear strength of the Nyama River sand sample was determined using a similar procedure to the green compressive strength test, except that the compression head of the universal sand testing machine was replaced by a shear head. The prepared sample was subjected to an increasing shearing force, and the green shearing strength was recorded at the point of failure in triplicates and the mean value reported. This measurement is essential for evaluating the sample's resistance to shear forces in its green state, thereby providing insights into its stability and suitability for moulding processes in foundry applications.

2.4. Determination of Permeability

The permeability of the moulding sand was evaluated using a standard sand permeability meter. Standard cylindrical specimens were mounted in the permeability testing apparatus, and air was forced through the specimen under controlled pressure. The airflow rate and pressure drop across the specimen were measured using calibrated gauges. The permeability number was calculated according to AFS standard permeability equations. Each test was conducted three times, and the average value was recorded

2.5. Refractoriness

The refractoriness of the sand was evaluated using the pyrometric cone equivalent (PCE) method. The sand was mixed with a small quantity of alkali-free dextrin binder to produce a homogeneous slurry. The mixture was moulded into cone-shaped specimens and dried in an oven at 110 °C. The dried cones were placed in a high-temperature furnace alongside a standard pyrometric cone with known softening temperature. The furnace temperature was gradually increased up to approximately 1000 °C. The temperature at which the sand specimen softened or deformed was recorded and compared with the standard cone to determine the refractoriness of the material.

3.0 Result and Discussion

3.1 Sieve Analysis and Grain Fineness of Nyama River Sand.

Table 1: Mechanical Sieve Analysis of Nyama River Sand Grain fineness number: 7

Aperture sizes (mm)	Sand retained on each sieve (g)	Percentage of sand retained	Multiplier	Product
1.00	8.10	0.84	9	7.56
0.71	11.80	1.22	15	18.30
0.50	43.70	4.51	25	112.75
0.355	98.60	10.18	35	356.30
0.25	50.00	5.16	45	232.20
0.18	335.6	34.66	60	2079.6
0.125	210.10	21.70	81	1757.7
0.09	157.40	16.26	118	1918.68
0.063	53.00	5.47	1.64	897.08
Total	**968.30**	**100**		**7380.17**

The results of the sieve analysis and grain fineness number (GFN) for Nyama River sand are presented in Table 1. According to the American Foundry Men's Society (AFS) standard (1963), sands with an average GFN ranging from 40 to 330 are considered suitable for foundry applications. The Nyama River sand exhibited an average GFN of 74, which falls within this acceptable range, confirming its potential for molding applications. The GFN is a crucial parameter in the foundry industry as it influences the sand's moldability, though the particle size distribution also plays a key role in determining the quality of castings (Rundman, 2009). Uneven particle size distribution can affect the permeability and surface finish of castings, making the GFN a necessary but not sufficient criterion for sand selection.

3.2 *Chemical Composition of Nyama River Sand*

The chemical analysis of Nyama River sand (Table 2) showed that its major components are 73.64 % SiO_2, 7.98 % Al_2O_3, and 1.45 % MgO. The silica content, which is essential for molding sand, compares well with the recommended range of 80-97 % for foundry applications (Jain, 2008). Though slightly below the recommended threshold, the 73.64 % silica content is acceptable for general foundry processes, especially in non-critical applications. The presence of alumina and magnesia also contributes to the sand's refractoriness and strength properties. X-ray diffraction (XRD) analysis identified quartz, sodalite, and muscovite as the predominant minerals in the sand, which further supports its potential use in high-temperature foundry processes (Figure 1).

The XRD pattern (Figure 1) for the Nyama River Beach sand sample (SAND_20221130_084108_G02_S5) indicates the presence of key mineral phases relevant to its potential in foundry applications. Identified minerals include quartz (syn), sodalite, muscovite, chlorite, and albite. Quartz, as the dominant phase, is crucial due to its high thermal stability, essential for withstanding the high temperatures encountered in foundry processes. The presence of chlorite and muscovite could impact the sand's moisture retention, influencing mold strength and collapse behavior during casting. Sodalite and albite, although in smaller quantities, may affect the sand's refractoriness and thermal expansion characteristics. The mixture of these minerals suggests a balance between moisture content and thermal properties, making this sand a potential eco-friendly alternative for sustainable casting. The XRD results support further investigation into the sand's moisture-related performance for optimal foundry use (Gonçalez et al., 2018).

Table 2: Chemical Composition of Nyama River sand

Oxides	Concentration	Peak(cps/mA)	Oxides	Concentration	Peak(cps/mA)
Fe_2O_3	1.3842 %	5232			
NiO	0.00178 %	11			
CuO	0.07551 %	448			
ZnO	0.08288 %	677			
Ga_2O_3	0.000695 %	10	MnO	0.04170 %	189
Lu_2O_3	[0.000018] %	2	Br	0.00027 %	1
Ta_2O_5	0.0059 %	6	Rb_2O	0.00102 %	5
WO_3	0.01373 %	33	Y_2O_3	0.001926 %	2
MgO	1.45 %	2	ZrO_2	0.0420 %	88
Al_2O_3	7.984 %	125	SnO_2	1.222 %	3
SiO_2	73.641 %	5645	PbO	0.01188 %	5
P_2O_5	0.2650 %	63	Bi_2O_3	0.02431 %	0
SO_3	0.0686 %	83	Ag_2O	0.00085 %	2
Cl	0.0391 %	20	Cs_2O	0.00032 %	3
K_2O	0.0746 %	77			
CaO	0.0904 %	140			
TiO_2	0.1714 %	629			
V_2O_5	0.00483 %	21			
Cr_2O_3	0.00226 %	18			

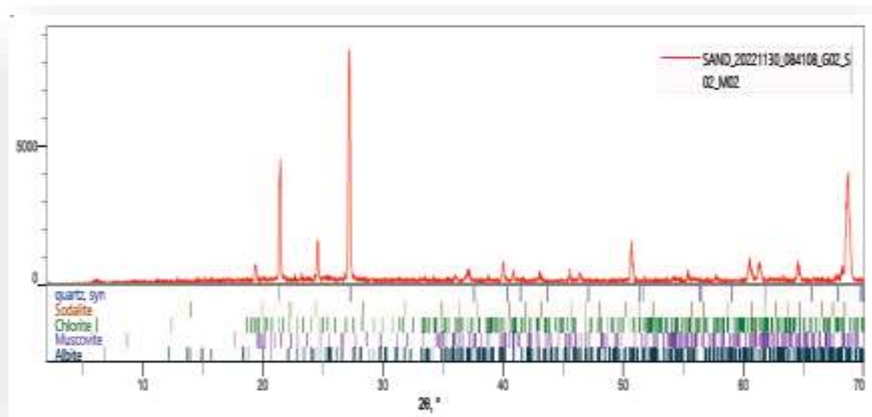

Figure 1: XRD result of Nyama River Sand

3.3 *Green Strength and Dry Compressive Strength*

The foundry properties of Nyama River sand, as presented in Table 3 and Figure 2, demonstrated a direct relationship between moisture content and green strength. The green strength increased from 16.40 kN/m² at 2 % water content to a peak of 29.50 kN/m² at 5 % water content. However, as water content increased beyond this point, the green strength began to decline, reaching 28.20 kN/m² at 6 % water content. This trend aligns with previous studies, such as Ahem and Nuhu (2008), which noted that excessive moisture leads to the weakening of sand molds after reaching a saturation point. The initial increase in strength can be attributed to improved compaction and bonding, while the subsequent decline may result from over saturation, causing the breakdown of sand structure.

Table 3: Foundry properties result of Nyama River sand using 5 % clay content as binder.

Water content (%)	Green Compressive strength (KN/m^2)	Green shear strength (KN/m^2)	Dry compressive strength (KN/m^2)	Dry shear strength (KN/m^2)	Permeability (No)	Moisture content (%)	Compactability
2	16.40	4.20	186.05	62.00	148.24	1.70	14.12
3	23.60	6.25	195.00	67.15	151.00	2.01	20.16
4	26.11	6.40	220.72	73.00	152.54	3.22	22.13
5	29.50	6.45	236.40	77.50	150.09	3.85	26.10
6	28.20	6.43	240.10	81.11	147.65	3.89	25.90

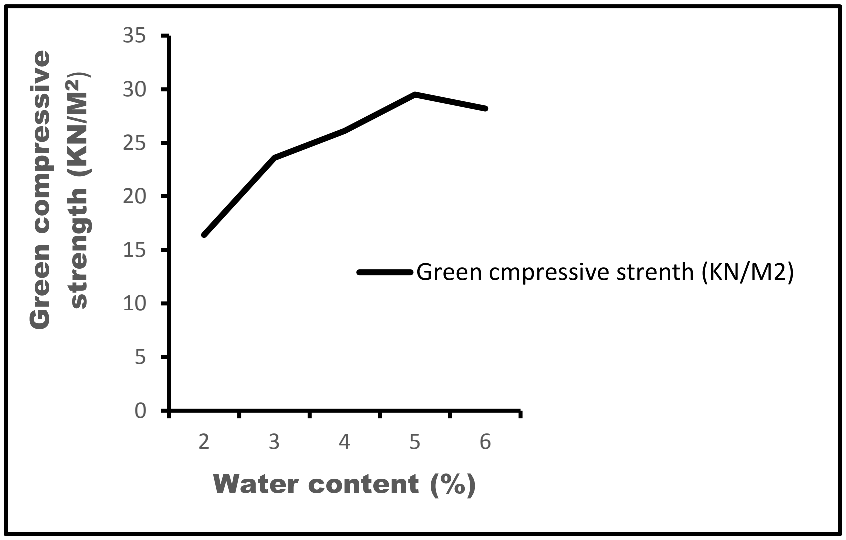

Figure 2: The Effect of water content on the Green Compressive Strength of Nyama River Sand.

The dry compressive strength of the sand followed a similar trend, increasing from 186.05 kN/m² at 2 % water content to 240.10 kN/m² at 6 % water content and 5 % clay content, as shown in Figure 3.

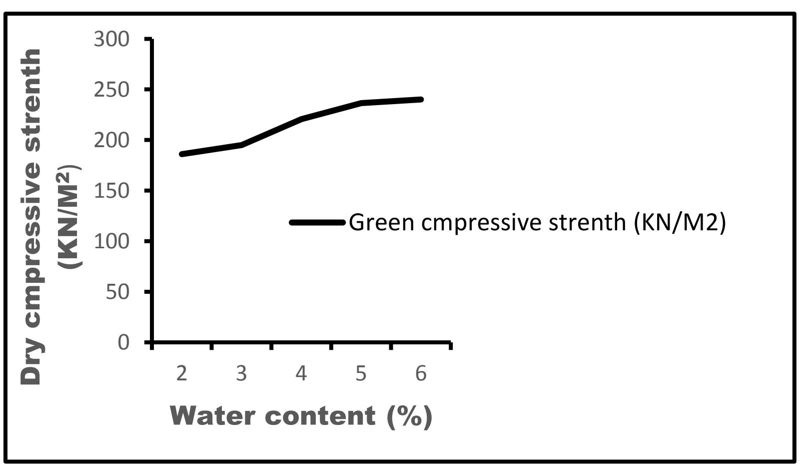

Figure 3: Effect of water content on Dry Compressive Strength of Nyama River Sand.

This suggests that Nyama River sand possesses adequate dry strength for use in casting processes requiring significant mechanical stress tolerance, such as in core making or heavy-duty casting operations (Rundman, 2009).

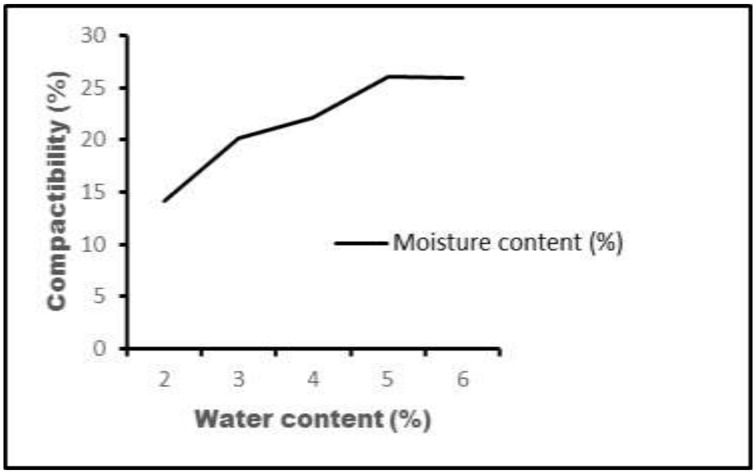

Figure 4: *Water content and Compactability*

Figure 4 illustrates the relationship between water content and Compactability (%) for Nyama River Sand in foundry operations. As water content increases from 2 % to 5 %, there is a steady rise in compactability, peaking at around 26 % at 5 % water content. Compactability reflects the ease with which the sand can be compressed into a mold, which is vital for mold uniformity and structural integrity during metal casting. The upward trend suggests that increasing water content enhances sand particle cohesion, making it easier to compact the sand into a uniform mold structure (Ibhadode, 2001).

However, after reaching 5 % water content, the compactability levels off or slightly declines, indicating that beyond a certain moisture threshold, additional water no longer contributes to further compaction. Excess moisture could lead to over-lubrication of the sand particles, reducing friction and cohesion between them (Weigel, 1927). This can compromise the mold's stability, especially in high-precision casting operations. Optimal compactability is achieved at 4-5 % water content, aligning with previous data on the sand's green strength and permeability. This makes Nyama River Sand suitable for foundry applications where moderate moisture content and efficient mold formation are required, ensuring good mold integrity without sacrificing permeability.

3.5 Permeability and Moisture Content

Permeability is a crucial parameter for ensuring the free escape of gases during casting. The permeability results (Figure 5) show that Nyama River sand's permeability values increased with the addition of water, rising from 148.24 No at 2 % water content to a peak of 152.54 No at 4 % water content.

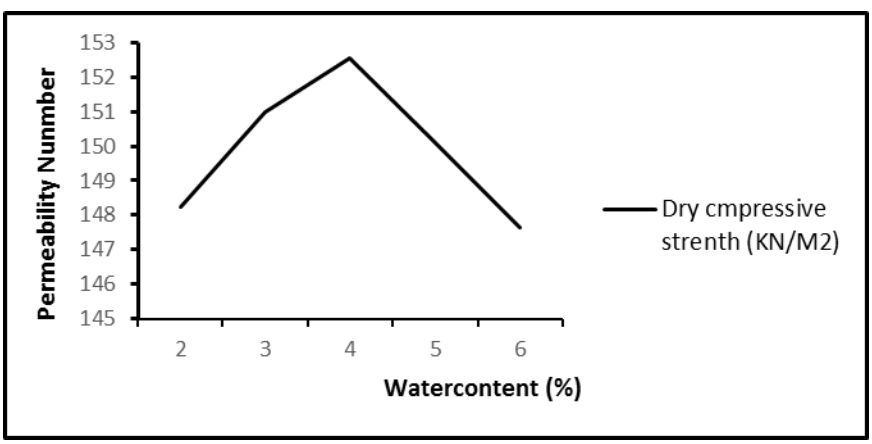

Figure 5: The effect of water content on the Permeability (No) of Nyama River Sand.

Beyond this point, further water additions led to a decrease in permeability, falling to 147.65 No at 6 % water content. This is consistent with the findings of Rundman (2009), which indicated that clay particles expand with increased moisture content, pushing the sand particles apart and initially increasing permeability. However, over saturation causes the sand structure to become too dense, limiting gas flow and reducing permeability.

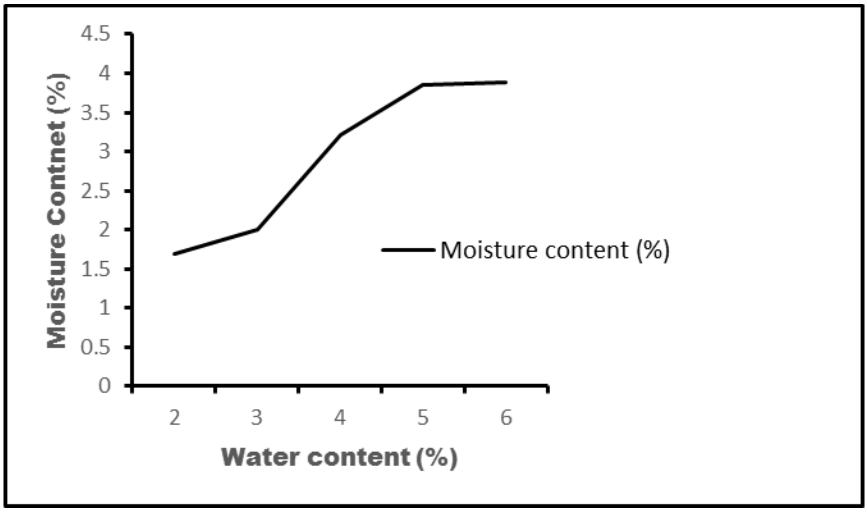

Figure 6: The effect of water content on the Moisture content (%) of Nyama River Sand

Figure 6 highlights the relationship between moisture content and green compressive strength, revealing that moisture content increased steadily with the addition of water. The moisture content rose from 1.7 % at 2 % water content to 3.89 % at 5 % water content, corresponding to an increase in green strength and compactability. This observation is consistent with previous studies by Ahem and Nuhu (2008), who found that initial water additions are absorbed by the binder until saturation is reached, after which any additional water remains as free water, contributing to the observed increase in moisture content.

3.6 Performance Evaluation Nyama River Sand

Table 4: Foundry properties result of Nyama River sand using 5 % clay content as binder

Water content (%)	Green Compressive strength (KN/m^2)	Green shear strength (KN/m^2)	Dry compressive strength (KN/m^2)	Dry shear strength (KN/m^2)	Permeability (No)	Moisture content (%)	Compactability
2	16.40	4.20	186.05	62.00	148.24	1.70	14.12
3	23.60	6.25	195.00	67.15	151.00	2.01	20.16
4	26.11	6.40	220.72	73.00	152.54	3.22	22.13
5	29.50	6.45	236.40	77.50	150.09	3.85	26.10
6	28.20	6.43	240.10	81.11	147.65	3.89	25.90

The performance of Nyama River Sand in foundry operations, as reflected in the tabular results (Table 4) demonstrates how moisture content influences key sand properties. As moisture content increases from 2 % to 6 %, green compressive strength improves significantly, peaking at 5 % moisture (29.50 KN/m²). This trend indicates enhanced mold stability under load, which is critical in casting operations (Ibhadode, 2001). Green shear strength follows a similar pattern, reinforcing the sand's cohesion and plasticity for better mold handling. Dry compressive and shear strengths also increase with higher moisture, suggesting improved binding after drying, vital for casting large, heavy molds (Weigel, 1927). Permeability peaks at 5 % (150.09), crucial for gas venting during casting. However, beyond 5 % moisture, permeability declines, likely due to excess water reducing sand grain porosity (Ibhadode, 2001). Thus, Nyama River Sand performs optimally at 4-5 % moisture, balancing strength, permeability, and compactability for efficient foundry operations.

3.7 *Comparison of Nyama River Sand and Similar previous literature works*

Table 5: Chemical Composition of Nyama River sand compared with global samples

Source of sand	S_1O_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	FeO	Remarks
Key sand, New Jersey	91.11	1.040	4.77	0.25	0.18	0.12	0.09	0.14	0.15	Core sand (Weigel, 1927)
Ottawa, Illinois	99.48	0.020	0.16	-	0.11	0.05	-	-	-	Silica sand, (Weigel, 1927)
Richland, New Jersey	86.46	1.040	6.95	0.41	0.16	0.41	0.21	0.58	0.31	Iron and non-ferrous moulding sand
Albany, New York	75.91	3.260	9.44	0.64	1.12	0.664	1.42	2.96	1.86	Naturally bonded moulding sand
Nyama River Sand, Nigeria	73.641	1.384	7.984	0.171	0.090	1.450	-	0.074	-	Present Study

Source: (McLaws 1971)

The Nyama River Sand from Nigeria exhibits a relatively low silica (SiO_2) content (73.641 %) compared to the other samples, such as Ottawa, Illinois (99.48 %) and Key Sand, New Jersey (91.11 %), making it less suitable for high-purity applications like silica-based casting molds. However, its higher alumina (Al_2O_3) content (7.984 %) and moderate iron oxide (Fe_2O_3) levels (1.384 %) suggest better heat resistance and strength, qualities desirable in some foundry applications requiring durability under thermal stress. Compared to Albany sand, which has a higher clay content (evidenced by Al_2O_3 at 9.44 % and K_2O at 2.96 %), Nyama River Sand is less bonded but may have slightly better permeability due to lower clay and impurity content. Nyama River Sand's high MgO content (1.45 %) can enhance refractoriness, making it potentially useful in non-ferrous molding where thermal stability is critical. Therefore, Nyama River Sand may perform well in foundry operations requiring moderate thermal resistance but is less ideal for high-purity applications, (Ibhadode, (2000) and Weigel, (1927).

3.8 Mould Property Ranges

Table 6: Satisfactory mould property ranges for sand castings

Metal	Green compressive strength (KN/m^2)	Dry strength (KN/m^2)	Permeability (No)
Heavy steel	70-85	1000-2000	130-300
Light steel	70-85	400-1000	125-200
Heavy grey iron	70-105	50-800	70-120
Aluminum	50-70	200-550	10-30
Brass and bronze	55-85	200-860	15-40
Light grey iron	50-85	200-550	20-50
Malleable iron	45-55	210-550	20-60
Medium grey iron	70-105	350-800	40-80

Source: (Dietert, 1966)

Table 7 is typically comparing the performance of Nyama River Sand with strategic foundry requirements for various metals highlights its suitability in specific casting applications. Nyama River Sand's green compressive strength ranges from 16.40 KN/m² to 29.50 KN/m², which is significantly lower than the 50-105 KN/m² required for metals like steel, iron, and aluminum (Ibhadode, 2001). This lower strength suggests Nyama River Sand may not provide adequate mold stability for heavy metals such as steel or gray iron, which demand higher compressive strength. However, its dry strength, peaking at 240.10 KN/m², compares favorably with light grey iron (200-550 KN/m²) and aluminum (200-550 KN/m²), making it more suitable for lighter castings. Permeability values (148.24 to 150.09) are within the range required for heavy steel (130-300) but exceed those for metals like aluminum, which require lower permeability (10-30) (Weigel, 1927). This suggests Nyama River Sand is best suited for metals with moderate permeability needs, such as steel and gray iron.

3.9 Practical Implications for Foundry Use

The combination of adequate grain fineness, silica content, mechanical strength, and permeability makes Nyama River sand a viable material for foundry applications in Nigeria. The sand's performance under varying moisture conditions shows that it can be effectively used in molding operations, provided that water content is carefully controlled to avoid over saturation and maintain optimal permeability and strength. Given the sand’s chemical composition and mechanical properties, it is suitable for use in medium-duty casting operations, particularly in rural foundry processes where natural sand sources like Nyama River are often utilized.

Further research could focus on optimizing the clay content to enhance binding strength and exploring the effects of different binders on the sand’s overall performance. Comparisons with other local sand deposits could also provide insight into improving the availability and selection of foundry materials in Nigeria.

4.0. Conclusion

This study evaluated the influence of moisture content on the moulding performance of eco-friendly sand obtained from Nyama River Beach for sustainable foundry applications. The investigation involved chemical characterization, grain size analysis, and evaluation of key moulding properties including green compression strength, green shear strength, dry compression strength, dry shear strength, permeability, and refractoriness. The results show that moisture content significantly influences the mechanical and permeability characteristics of the moulding sand. An increase in moisture content initially improved the green compression and green shear strengths due to enhanced capillary bonding between sand particles and binders. However, beyond an optimum moisture level, the strength values decreased because excess water reduced inter-particle bonding and increased pore blockage. The sieve analysis results of the Nyama River sand deposit revealed an average grain fineness number (GFN) of 74.0, which falls within the acceptable range of 40 to 300 recommended for foundry applications. This indicates that the sand has suitable granularity for general foundry processes. However, the chemical composition analysis showed that while the sand is predominantly silica (73.6 %), it is not pure enough for use in steel and heavy metal foundries, where higher silica content is essential for optimal performance. In terms of moulding properties, the study demonstrated that the optimal mixture for non-ferrous alloy casting could be achieved by blending the sand with 3.85 % moisture content and 5 % Edda clay. This mixture produced superior moulding qualities when compared with standard foundry sands currently in use. The study focused primarily on laboratory-scale testing of moulding sand properties and did not include full-scale casting trials to evaluate surface finish, dimensional accuracy, or defect formation in actual cast products. In addition, the effects of different binder systems and additive materials on the performance of Nyama River sand were not investigated. Future studies are encouraged to focus on conducting pilot-scale casting experiments, evaluating the sand’s performance in real moulding operations, and investigating the effects of binder modification, additive incorporation, and sand conditioning techniques on mould quality. Further research may also explore thermal stability at higher temperatures and long-term recyclability of the sand in repeated casting cycles. This study demonstrates that Nyama River Beach sand has promising potential as a sustainable moulding material for non-ferrous metal casting applications in Nigeria, contributing to the development of cost-effective and environmentally responsible foundry practices. These findings suggest that Nyama River sand, with appropriate conditioning, can serve as a cost-effective and sustainable alternative for non-ferrous foundry applications, enhancing resource efficiency and promoting sustainable foundry practices in the region and Nigeria.

5.0 Recommendation

- Future studies should investigate the combined effects of moisture content and binder additives including clay, and organic binders on the mechanical and thermal performance of Nyama River beach sand to further optimize its suitability for diverse casting conditions.

- Further research is recommended to evaluate the high-temperature behavior and reusability of the sand, including its thermal stability, degradation characteristics, and performance over multiple casting cycles.

- It is also important to explore the scalability and industrial applicability of the sand through pilot-scale casting trials, alongside a comprehensive economic and environmental impact assessment to validate its sustainability for large-scale foundry operations.

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