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Enhancing Ceramic Body Compositions through Local Resource Utilization in South Qena

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Abstract
Naqada, located in Upper Egypt's South Qena Governorate, possesses a rich pottery heritage extending back to pre-dynastic times in Ancient Egyptian. This research examines the challenges confronting this historically and culturally significant craft, which produces diverse pottery forms for various uses. The craft faces numerous obstacles throughout the production process, from obtaining the raw material and processing to shaping, production, and firing. This study focuses on improving the ceramic body compositions used by Naqada workshops, which currently utilise Nile silt and Hamer stone. The research aims to optimise body preparation methods and adjust the proportions of raw materials and additives. Key objectives include enhancing plasticity for forming through the throwing wheel, improving body smoothness for product quality improvement, especially in cookware, and increasing fired product hardness at low temperatures around 800°C. Critically, the research prioritises maximising the use of locally available materials and respecting existing workshop conditions and capabilities to ensure practical and sustainable improvements for this vital craft.

Keywords
Naqada Pottery; Ceramic Bodies; Nile Silt; Hammer Stone; Additives

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Introduction:
Pottery is one of the oldest crafts and a key part of human history. It shows us how societies lived, their traditions, and their creativity over thousands of years, helping shape who they became. In ancient times, people mainly used pottery for food, drinks, and storage. Pottery in Naqada, Qena Governorate, started in ancient Egypt. Early pottery, from the Stone Age (before the pharaohs), was simple and not fired. Over time, the craft developed and spread, becoming a valued tradition passed down through families. People in Upper Egypt still make pottery today, keeping this tradition alive.The Egyptian government and local artisans have recently worked to revitalize Naqada's pottery craft through numerous support projects aimed at skill development. These efforts focus on improving product quality and boosting local demand, ultimately aiming to positively impact the craft by raising the quality of pottery and increasing sales. [Gamal Abdelmonem, M., p.34]

Naqada's ceramic workshops primarily produce functional items such as cooking pots, plates, and cups, along with some lighting and planting units. However, these products generally lack innovation in both form and function, with most workshops creating similar items with limited variation in materials or ceramic body batches.

Therefore, the research investigates improving ceramic body compositions in Naqada, Upper Egypt, using local materials and existing workshop conditions to enhance pottery quality, plasticity, and fired product hardness

Research Problem:
The research addresses the challenges faced by Naqada's pottery workshops in Upper Egypt, including:

- Limited innovation in ceramic body compositions, relying primarily on Nile silt and Hamer stone.
- The need to optimize local materials and traditional methods to improve product quality while preserving cultural heritage.

Research Objectives
- Optimize ceramic body compositions by adjusting proportions of Nile silt, Hamer stone, and additives (e.g., wood ash, ball clay, talc).
- Enhance workability (plasticity for wheel throwing) and product quality (smoothness, color).
- Improve thermal shock resistance for

functional cookware by testing thermal expansion properties.

Research Significance

- Supports the sustainability of Naqada's ancient pottery tradition as a cultural preservation.
- Demonstrates how traditional methods can be enhanced with simple material adjustments.
- Utilizes local resources (e.g., recycled wood ash) to reduce costs and waste promoting environmental sustainability.

Research Methodology:

Experimental Design:

- Experiment different ceramic body batches with varying ratios of local materials (Nile silt, Hamer stone) and additives (wood ash, ball clay, talc).
- Tested plasticity forming through pottery wheel and fired properties of the ceramic body (hardness, color).
- Applied transparent glaze to assess aesthetic and functional improvements.

Testing Procedures:

- Thermal Expansion Analysis: Used a dilatometer to measure CTE (Coefficient of Thermal Expansion) at 100–300°C for cookware suitability.

Theoretical Frame Work:

1- Naqada's ceramic body compositions

Naqada's ceramic body compositions, used since pre-dynastic times, primarily rely on Nile silt and hammer stone. Nile silt itself comprises two main types: marl clay and Nile clay. The suitability of Nile silt for wheel throwing depends on its calcium content, hardness, density, and the type and amount of organic additives. [Khalifa IEA., p. 15]

Hammer clay, found in Naqada, Qena Governorate, is primarily used for making cooking utensils. Its main components are silica oxide and magnesium oxide, with iron oxide impurities present. [Ibrahim Dosoki, p. 138] The chemical composition of Hammer clay is shown in Table 1

Table 1: presents the chemical analysis of Hammer clays [A.A.A. Gouda]

Oxide	Formula
SiO2	44.4
Al2O3	2.84
CaO	5.50
MgO	27.56
K2O	0.01
Na2O	0.4
TiO2	0.21
Fe2O3	5.48
LOI	12.7

Nile silt has several advantageous characteristics for pottery, including a chemical composition rich in silica and alumina, a fine grain size due to its sedimentary origin which facilitates shaping, good post-firing breaking strength, and a distinctive natural red or brown colour. While this naturally abundant material in Naqada is well-suited for pottery, it often requires treatment and the addition of other materials to further enhance its properties for optimal use and shaping. The specific type and number of additives depend on the clay's properties, the chosen manufacturing techniques, and the desired outcome.

Nile silt's relatively low apparent density (1.67 g/cm^3) and low apparent porosity (21.29%) contribute to lightweight pottery products, though potentially at the expense of mechanical strength. A high plasticity index (35.6) and low fluidity limit (47.4) suggest good formability, but also potential stability issues during the drying and firing processes. The moderate total shrinkage (11.50% linear, 34.46% volumetric) lessens the likelihood of cracking, making this material suitable for lightweight products. [Ibrahim Dosoki, p. 138]

2- Production methods in Naqada

2-1 Preparation methods

Naqada's pottery workshops employ traditional production methods. Nile silt is sourced from the banks of the Nile or irrigation canals during cleaning. The ceramic body preparation then involves several stages: First, hammer stone and other raw materials are coarsely sieved to remove debris like gravel and brick. Next, the silt, already plastic, is mixed with water in basins. Some workshops grind the hammer stone before adding it, while others add it directly to the silt basins; the mixture is left until excess water evaporates. The clay is then "fermented" by storing it covered in the basins for a day or more to enhance plasticity. This is followed by treading the clay to further homogenize it. Finally, just before wheel throwing, the clay is hand-mixed to ensure homogeneity and remove air pockets that could lead to cracking during firing. [El-Senussi A., P1]

2-2 Forming method

Naqada's workshops primarily use the throwing wheel, a foot-powered device dating back to 3500 BC China, for shaping. This method requires significant skill to coordinate foot-kicking speed with the hand-shaping of the clay. [Okewu J.]

2-3 Drying and firing

Naqada's pottery products are air-dried in a shaded, draft-free environment, with workers regularly turning them for even drying, a process that takes 2-3 days in summer and 7-10 days in winter. Firing occurs in simple, wood-fueled, cylindrical kilns. The kiln's floor doubles as the firebox roof, and a side opening allows workers to load and unload the stacked pottery as demonstrated in fig. 1, skilled workers arrange the pieces by size, ensuring heat circulation through floor openings. Once loaded, the kiln openings are sealed to retain heat and prevent thermal shock.

Due to the primitive nature of the kilns, firing temperatures in Naqada are variable, typically ranging between 700 and 800°C. The kilns are fueled by organic materials like wood and palm fronds, which are fed into the fire chamber. The firing process lasts approximately 3-4 hours, with additional fuel added to maintain and intensify the flames. Afterward, the kiln is left to cool overnight before being unloaded. [Gamal Abdelmonem, M., p. 52,53]

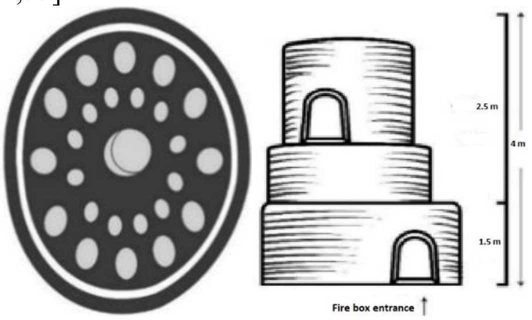


Fig. 1. shows the primitive kilns and firebox roof used in Naqada

3- Materials and Methods (Experimental Part)

This research experimentally aims to improve the ceramic body used in Naqada, focusing on several key properties. The goal is to enhance plasticity for easier wheel throwing and increase smoothness for a better product finish. Additionally, the research seeks to improve the hardness of the fired products at the low kiln temperatures common in Naqada (700-800°C).

Naqada's ceramic body preparation primarily involves soaking Nile silt and Hamer stone in water basins. Two main compositions are used: a 1:1.5 ratio of hammer stone to Nile Silt, and a 2:1 ratio (Hamer stone to silt) when the hammer stone is ground. The increased Hamer stone content in the latter mixture facilitates wheel throwing, as the unground material is difficult to shape and tends to collapse on the wheel. The ceramic body can be further modified by adjusting the proportions of these primary materials or by adding other ingredients.

The experimental part is twofold. First, it explores varying the proportions of existing Naqada raw materials to create new body compositions. Second, it examines the addition of materials like ball clay, talc, and ash in specific proportions to enhance the ceramic body's properties.

3-1 Nile silt, Hamar stone, and wood ash

Naqada pottery production depends on two essential materials: Nile silt clay and fuel sources such as Hamar stone and wood ash. Incorporating wood ash into the clay body serves as a flux, reducing the required firing temperature to match the capabilities of traditional Naqada kilns. This effect stems from the ash's mineral composition, which includes calcium, magnesium, and potassium oxides. Additionally, wood ash helps minimise drying shrinkage and prevents cracking by speeding up the drying process. However, because ash is a non-plastic additive, it increases the clay's water demand during wheel throwing. On the upside, the ash enhances the fired pottery's porosity, improving its thermal shock resistance a critical feature for Naqada's functional cookware. [Net 1]

Four clay batches were prepared with varying ratios of Hamar stone, silt, and ash. Each batch was carefully processed, starting with sieving the dry ingredients through a fine sieve and weighing them according to the proportions shown in Table No. 2 Water was then added, and the mixture was sifted again through an 80-mesh sieve to remove any remaining coarse particles and ensure homogeneity. Finally, all batches were fired at 800°C, approximating the firing temperature used in Naqada workshops.

Fig. 2: The dry materials shown from left to right are Nile Silt, Hamar stone, and ash

All four clay batches exhibited good plasticity during forming. However, the higher Nile Silt content in batch 3 reduced its workability, making it difficult to throw on the wheel. Consequently, batch 4 was developed, using equal parts clay and Hamar stone, supplemented with 10% ash recycled from previous firings. This ash, readily available in Naqada due to the use of wood-fired kilns, was sieved before inclusion to maximize its beneficial effects on the clay body. Batch 4 reduces the Hamar stone-to-clay ratio typical in Naqada, replacing it with ash to improve workability for wheel throwing, and the batches were fired at 800° c which temperatures approximating those of Naqada kilns.

Table 2. shows 4 ceramic body batches

Materials %	Batch 1	Batch 2	Batch 3	Batch 4
Hamer stone	50	75	25	45
Nile Silt	50	25	75	45
Wood Ash	0	0	0	10

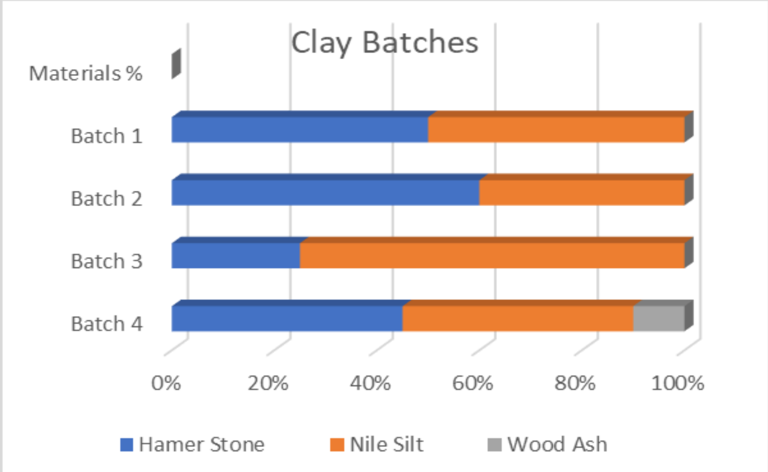


Chart 1 shows 4 ceramic body batches 1 to 4

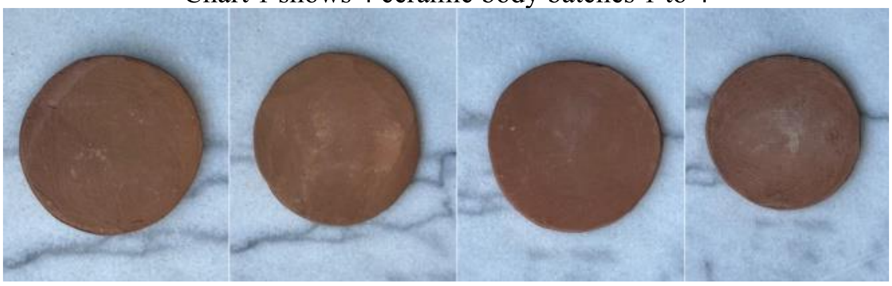


Fig. 3 shows ceramic body batches after firing 800°C arranged from left to right Batch No. 1 to 4

3-2 Addition of ball clay and talc:

The second side of the experimental part work focuses on modifying the Naqada ceramic body through the inclusion of ball clay, talc, and ash. These additions aim to improve thermal shock resistance and whiteness. Batch 5 uses 60% Naqada raw materials and 40% ball clay and talc. Batch 6 will explore a 50/50 ratio.

Ball clays are highly plastic due to their fine-grained, secondary clay composition. This makes them a valuable addition to earthenware bodies, such as the Naqada body, as they enhance plasticity, improve formability on the potter's wheel, and increase green strength without significantly altering the maturation temperature. Additionally, when combined with silt and Hamer stone, ball clays contribute to a whiter body because their iron content is considerably lower compared to that of Nile Silt or Hamer stone. Their unique properties, including fine grain size and low iron ratios, make ball clays required for improving both the workability and aesthetic qualities of ceramic materials.[C.B. Carter p. 19-20, Net 2]

Talc (a hydrated magnesium silicate), the Chemical analysis reveals that talc is a valuable additive for ceramic bodies. The presence of magnesium facilitates melting, reducing the required firing temperature and improving thermal shock resistance. Its low coefficient of thermal expansion and whitening effect further contribute to Naqada ceramic body. [Net 3,4]

Table. 3 shows 2 ceramic body batches (5,6)

Materials %	Batch 5	Batch 6
Hamer stone	30	30
Nile Silt	30	20
Ball Clay	30	30
Talc	10	20

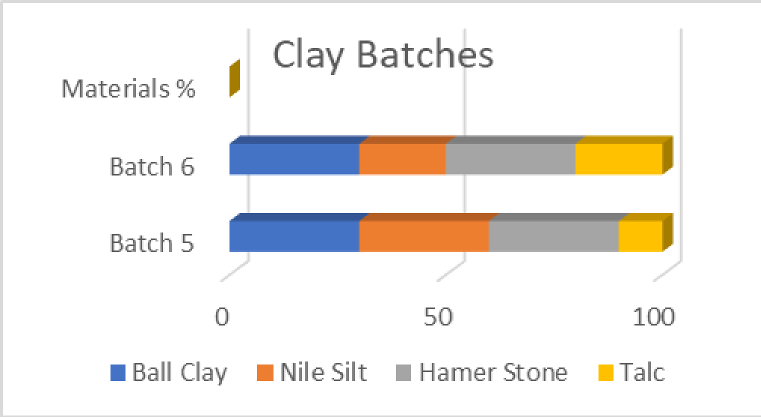


Chart 1 shows 2 ceramic body batches 5 and 6

Batches 5 and 6 were formulated using different proportions of silt and Hamar stone, supplemented with ball clay and talc as specified in Table 3. These mixtures were initially fired at 800°C, as is the case with Naqada firing temperatures. Subsequently, a transparent glaze was applied to the bisque-fired samples, which were then subjected to a second firing at 1000°C. This final firing aimed to achieve optimal ceramic maturity and hardness while evaluating the glaze's influence on both mechanical properties and colour development. Following firing at 800°C, batch 6 was determined to have a higher degree of whiteness than batch 5. Notably, both formulations achieved good plasticity with a soft texture conducive to fine finishing with wheel throwing. Furthermore, batch 6 demonstrated a lighter fired color compared to the standard Naqada batch 2.

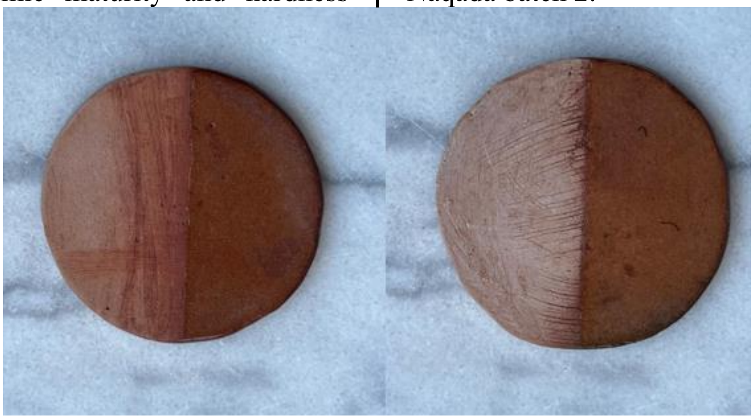


Fig. 4 shows ceramic body batches after firing arranged from left to right Batch No. 5 and 6

Following firing at 1000°C, both before and after glazing, results indicated high iron oxide content in both batches, but batch 6 exhibited higher whiteness after glazing.

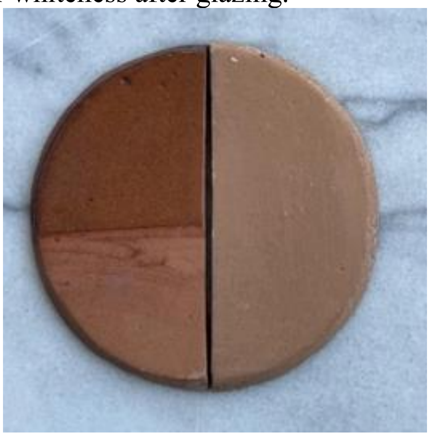


Fig. 5 Batch 6 was fired at two temperatures: 800°C on the right, and 1000°C with a partial transparent glaze on the left.

3-3 Thermal expansion test:

As Thermal expansion testing is critical for ceramic cookware because it directly impacts durability, safety, and performance during real-world use, ceramics can crack or shatter if subjected to rapid temperature changes moving from a hot stove to cold, so Thermal expansion test could determine how much the samples expands when heated and contracts when cooled and whether the cookware can withstand repeated heating-cooling cycles without cracking. [H. Awaji, S.-M. Choi]

The thermal expansion test was conducted using a dilatometer to precisely measure dimensional changes (ΔL) in the ceramic material as a function of temperature. The sample, dimensions (5 mm in width × 20 mm in length), was heated from room temperature to a final temperature of 300°C at a controlled rate of 8°C/min. This moderate heating rate is standard in dilatometry and thermomechanical analysis (TMA) to avoid thermal shock and ensure accurate ΔL measurements.

The reference standard selected was the Naqada sample. For comparison, two batches were analysed: Sample 1_1 (Batch No. 2), fired at 800°C, and Sample 1_2 (Batch No. 6), fired at 1000°C. Batch No. 6 was chosen due to its superior whiteness and enhanced plasticity, which facilitated smoother wheel-throwing and fine finishing. This comparison highlights the differences in material properties between the two batches.

The thermal expansion test was conducted up to 300°C, representing the maximum cooking temperature. The results were analysed in two stages: first, during heating from 100°C to 200°C, and second, during heating from 200°C to 300°C. This segmentation allowed for a detailed assessment of the material's expansion behaviour across different temperature ranges, the results of first segment as shown in the table.4, and the results of second segment as shown in the table.5.

Table. 4 shows first segment results for thermal expansion test batches (2,6)

Property	Sample 1_1 (800°C)	Sample 1_2 (1000°C)
CTE Range (E-6/K)	5.95–6.06	6.05–6.13
CTE Trend	+1.8% increase	-1.3% decrease
Delta L Growth Rate	0.127 µm/°C	0.131 µm/°C
Thermal Stability	Decreasing with temp	Improving with temp
Material Behavior	Accumulates stress	Dimensionally stable
Recommended Use	Gradual heating	Rapid thermal cycling

Table. 5 shows second segment results for thermal expansion test batches (2,6)

Property	Sample 1_1 (800°C)	Sample 1_2 (1000°C)
CTE Range (E-6/K)	5.996–6.085	6.058–6.414
CTE Trend	Stable (±0.045)	Increasing (+0.356)
Delta L Growth Rate	0.127 µm/°C	0.131 µm/°C
Thermal Stability	Good (flat CTE)	Moderate (rising CTE)
Material Behavior	Stress-resistant	Stress-accumulating
Recommended Use	suitable cookware	Short-term applications

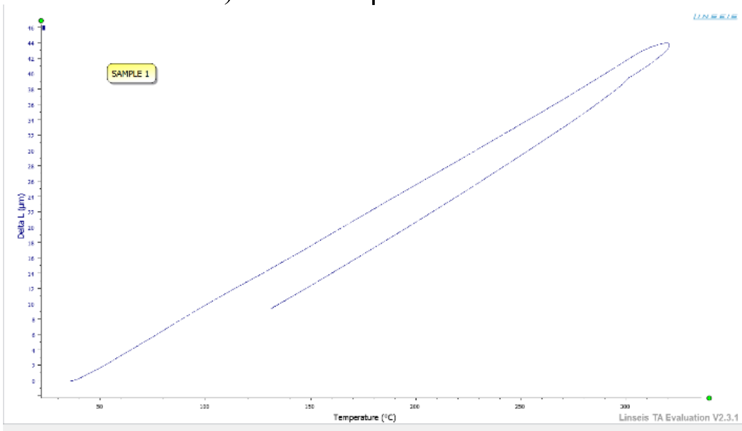
3-4 Thermal Stability & Suitability:

Sample 1_1 (800°C):

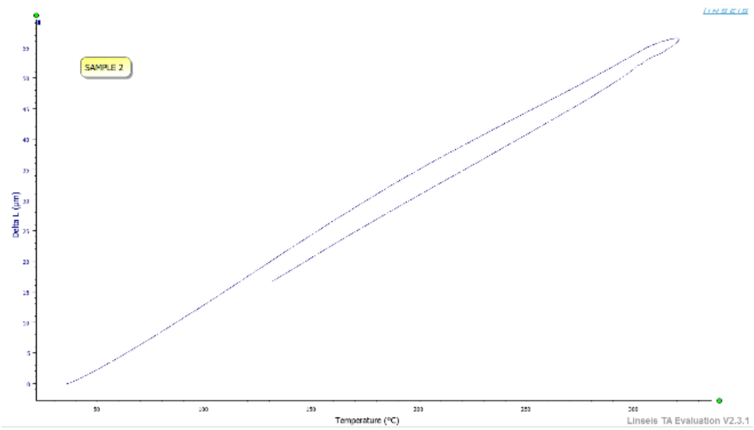
Superior stability in the 200–300°C range, making it ideal for premium cookware requiring long-term durability, best suited for gradual heating applications (e.g., oven-to-table cookware).

Sample 1_2 (1000°C):

Improving stability at 100–200°C, but deteriorates at 200–300°C, limiting its use in high-temperature cooking, better for short-term or rapid thermal cycling but requires optimization for prolonged use.



Plot 1. Thermal Expansion Analysis: Delta L vs. Temperature for Sample 1_1



Plot 2. Thermal Expansion Analysis: Delta L vs. Temperature for Sample 1_2

Table 6: Comparative Thermal Performance of Ceramic Samples for Cookware Applications

Criterion	SAMPLE 1_1 (ΔL vs. Temp)	SAMPLE 1_2 (ΔL vs. Temp)
Thermal Stability	Likely shows CTE (coefficient of thermal expansion) directly. If ΔL rises smoothly with temp, it's stable.	Tracks deformation over time. If ΔL plateaus, it resists creep.
Durability	Reflects immediate response to heat. Sharp spikes = risk of cracking.	Shows long-term stress resistance. Gradual ΔL = better durability.

Results:

Optimization of Ceramic Body Compositions

The experimental batches demonstrated significant improvements in workability, thermal stability, and aesthetic qualities:

Standard Batch 2 (75% Hamer stone, 50% Nile silt):

- Thermal Stability: Exhibited exceptional performance in thermal expansion tests (CTE: 5.95–6.06 × 10^{-6}/K) at 300°C, attributed to the high magnesium oxide content (27.56%) in Hamer clay (Table 1), making it inherently resistant to thermal shock.

Batch 4 (45% Hamer stone, 45% Nile silt, 10% wood ash):

- Plasticity: Achieved optimal workability for wheel throwing, addressing the collapse issue of unground Hamer stone.
- Thermal Shock Resistance: The 10% wood ash reduced drying shrinkage and enhanced porosity, critical for cookware subjected to rapid heating/cooling cycles.
- Firing at 800°C: Matched Naqada's traditional kiln conditions, yielding durable products with minimal cracking.

Batch 6 (30% Hamer stone, 20% Nile silt, 30% ball clay, 20% talc):

- Whiteness: Talc and ball clay reduced iron oxide's reddening effect, producing lighter-colored ceramics (Fig. 4).
- Thermal Expansion: CTE of 6.058–6.414 × 10^{-6}/K at 1000°C (Table 5) showed improved dimensional stability up to 200°C but stress accumulation at higher temperatures (300°C).
- Glazing Potential: Transparent glaze at 1000°C further enhanced surface hardness and whiteness.

Thermal Performance for Cookware Applications

Sample 1_1 (Batch 2, 800°C):

- Stability: Low CTE (5.95–6.06 × 10^{-6}/K) and flat ΔL growth (0.127 µm/°C) (Table 4) made it ideal for gradual heating (e.g., oven-to-table cookware).
- Durability: Good stress resistance (Fig. 1), suitable for long-term use.

Sample 1_2 (Batch 6, 1000°C):

- Short-Term Use: Rising CTE above 200°C (Fig. 2) limited its suitability for high-temperature cooking but worked well for rapid thermal cycling (e.g., stovetop simmering).

Practical Implications for Naqada Artisans

- Batches 2 and 4 demonstrate optimal characteristics for traditional cookware applications, including pots and pans. Their formulation shows excellent compatibility with local kiln conditions and exhibits superior thermal shock resistance, especially batch no 2, attributed to the high magnesium oxide (MgO) content derived from Hamer stone.
- Batch 6 is particularly suitable for decorative and glazed ware applications, including plates, cups, and mugs, where premium whiteness and fine surface finishing are essential requirements. The formulation's thermal properties can be further optimized by adjusting the Hamer stone-to-Nile silt ratio as needed.

From a materials perspective, the incorporation of ball clay and talc offers a cost-efficient solution that aligns well with Naqada workshop capabilities, as these additives can be processed effectively without specialised equipment.

Limitations and Future Work

Kiln Upgrades: Higher firing temperatures (1000°C) improved hardness but are impractical for some workshops. Research into low-temperature fluxes is needed.

Conclusions:

This research optimised ceramic body compositions for Naqada pottery by leveraging local materials and traditional techniques. The study demonstrated that adjusting ratios of Nile silt and Hamer stone, combined with additives, significantly improved product quality. Functional cookware batches (2 and 4) showed excellent thermal shock resistance due to high MgO content, achieving optimal stability (CTE: $5.95\text{-}6.06\times10^{-6}$/K), and Batch 4's 10% wood ash enhancing workability while maintaining durability. For decorative ware, Batch 6 (30% Hamer stone, 20% silt, 30% ball clay, 20% talc) delivered whiteness and finishing, making it ideal for glazed tableware.

The study considered Naqada's workshop conditions, using cost-effective materials like recycled wood ash, widely available additives, materials and firing temperature in traditional kilns 800 ° C needed for traditional cookware - all achievable within existing kiln capabilities.

The research empowers artisans to meet contemporary market demands while preserving cultural identity.

Recommendation

- Future work should explore low-temperature fluxes and raise kilns' capabilities to further expand possibilities, ensuring this ancient craft continues to thrive in modern times.
- The recommendations balance tradition and innovation, ensuring practicality for artisans to try new materials while improving product quality and marketability. By adopting optimized compositions and minor process adjustments, Naqada's pottery can remain sustainable and competitive in market.

Acknowledgments

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