

Rheological and Plasticity Behavior of Indigenous Porcelain Bodies for Slip Casting and Wheel-Throwing Applications in Studio Ornamental Ceramics

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ARTICLE INFORMATION	ABSTRACT
<p>Article history: Published: May 2026</p> <p>Keywords: Rheology Plasticity Index Slip Casting Wheel-Throwing Deflocculation Porcelain Body Nigeria</p>	<p>The way porcelain bodies form plays a key role in the quality of products made for studio ornamental ceramics. These ceramics often feature fine details and artistic shapes used in homes or galleries. Rheological properties control how the slip flows. They set the casting rate, ease of release from molds, and how well dimensions stay stable after drying. Plasticity affects how easy the clay is to shape by hand or on a wheel. It decides if the material holds together during wheel-throwing or hand-building. This study looks at the flow and shaping traits of a triaxial porcelain body made from local sources. The mix uses kaolin, feldspar, and quartz from Akwa Ibom State and Cross River State in Nigeria. Such local clay cuts costs and boosts home-grown pottery work. Tests covered slip viscosity, best deflocculant levels, casting rate, green strength before firing, Atterberg limits, and workability scores. Deflocculants like sodium silicate and sodium carbonate were added at levels from 0.2 to 0.5 percent by weight. These agents thin the slip so it pours well without settling. Results show the best slip at 0.35 percent sodium silicate. It hit the lowest viscosity of 0.78 Pa·s. This led to fast casting and strong green pieces that held shape. Plasticity index fell between 18 and 22 percent. These values fit slip casting well. They also work for wheel-throwing tasks. Too much deflocculant weakened green strength. It caused cracks on the surface during drying. Local porcelain bodies match needs for studio ornamental ware. Controlled deflocculant use ensures good flow and shaping traits. This opens doors for Nigerian makers to produce high-quality art ceramics with home-sourced clay.</p>

1. Introduction

Forming processes shape the structure and look of finished ceramic items. These steps set the base for strength and beauty in the final product. Porcelain clays lack the pliability of stoneware clays. They need careful control of flow properties and workability to form well. Experts note this challenge clearly (Kingery, Bowen, & Uhlmann, 1976). In small-scale art ceramics, two key methods stand out: slip casting and wheel-throwing. Each calls for its own set of clay traits, yet they link through shared material needs.

Slip casting pours a thin clay slurry into a plaster mould. The mix must flow easy with low thickness. It stays even in suspension, without lumps or settling. Quick fill rates speed up work. After water draws out, the green ware must hold firm for safe removal from the mould. Weak spots here lead to breaks or thin walls. Wheel-throwing, by contrast, centres a lump of clay on a spinning wheel. The clay needs good bend without tears. It must stick together under pressure. It also fights cracks as it dries after shaping. Potters pull tall forms or curve rims, so these traits matter most.

Clay traits hinge on grain sizes, clay types, salt levels in water, and moisture amount (Reed, 1995). Fine grains aid smooth flow for casting. Coarser ones boost strength for throwing. Too much water thins slip too far. Electrolytes tweak how particles link. Balance both methods' needs for best results. In Nigeria, studies on porcelain stress firing heat and strength tests (Mgbemere, Onyeayana, & Okoubulu, 2019; Ekpunobi et al., 2023). Few probe flow tweaks for art forming. Local clays from Akwa Ibom and Cross River States spark fresh efforts in home-grown porcelain. Potters seek workability data to match studio tools. This gap slows skilled output. Clear grasp of these traits cuts waste and lifts quality in native production.

This study sets out clear goals for work on porcelain slips made from local materials. It first evaluates the rheological behaviour of these slips. Rheology looks at how slips flow and hold together under stress. This matters because good flow helps in shaping ceramics without cracks or lumps. For example, potters check if a slip spreads smoothly or clumps up during tests.

Next, the study finds the best amount of deflocculant to add for slip casting. Deflocculants are chemicals that break up clay particles in water. They thin the slip so it pours well into moulds and drains fast. Too little deflocculant makes the slip thick and hard to use. Too much leads to weak castings that sag. The work then assesses plasticity indices and workability for wheel-throwing. Plasticity measures how clay deforms without breaking when you pull or shape it on a wheel. Indices like the Atterberg limits show this in numbers. Workability tests how easy it is to centre, open, and pull up walls. Potters need slips that turn into firm bodies with even moisture.

Finally, the study builds forming guidelines for studio ornamental ceramics. These are rules for making decorative pots and tiles in small workshops. Guidelines cover mix recipes, drying times, and firing tips. They help artists match local clays to fine porcelain effects, like thin walls or glossy finishes. Such steps cut waste and boost success rates in hands-on settings.

2. Literature Review

2.1 Rheology of Ceramic Suspensions

Ceramic slips form concentrated mixtures of solid particles suspended in water. These slips play a key role in processes like slip casting for pottery and porcelain. Their flow depends on forces between particles, the range of particle sizes, and the level of electrolytes in the mix. Strong forces pull particles together. This causes flocculation, which raises viscosity and makes the slip thick.

Deflocculation counters this. It spreads particles apart through electrostatic repulsion. The process adds charges to particle surfaces. Like charges push particles away from each other (Reed, 1995). This lowers viscosity. The slip then flows better for casting.

Kingery et al. (1976) note that sodium silicate and sodium carbonate serve as common deflocculants in porcelain slips. These salts release ions that boost repulsion. Workers add small amounts to tune the slip.

Good deflocculation cuts the need for water. Less water means the slip holds shape during drying. It shrinks less and cracks far less. Cracks often ruin green ware before firing. Thus, deflocculation aids strong, defect-free bodies in ceramics production.

However, over-deflocculation leads to:

- Reduced green strength
- Sedimentation
- Surface defects

Thus, determining optimal electrolyte concentration is critical.



Figure 1. Deflocculation Process in Slip Casting. Propeller-mixing a clay slurry. Source: digitalfire.com

2.2 Plasticity in Porcelain Bodies

Plasticity means the power of clay bodies to bend and stretch without splitting apart. Clay bodies serve as the base mixes in ceramics, blending clays with other materials like feldspar or quartz. This trait matters a great deal. Potters rely on it to shape pots on wheels or press slabs into moulds. Low plasticity leads to cracks during forming. That ruins the work.

The trait hinges on two main factors. First comes the type and amount of clay minerals present. Second is the shape of those tiny particles. Clay minerals split into groups like kaolinite and smectite. Each acts in its own way when mixed with water.

Take kaolinite as a key player. It rules in porcelain bodies, often making up over 50% of the mix. Porcelain makers pick it for its pure white colour after firing and smooth fired surface. Yet kaolinite shows only fair plasticity. Its particles form flat, thin plates. These plates slide over each other to some degree. Still, they grip tighter than those in other clays.

Compare that to smectites, such as montmorillonite in bentonite. Those swell wide in water. Their plates spread far apart. This boosts plasticity a lot. Workers handle such clays with ease. They stay soft longer. Illite clays fall in between. They offer good plasticity too.



Figure 2. Poor plasticity in porcelains at the leather hard stage. Source: digitalfire.com

Particle shape plays a big role. Flat, plate-like bits stack and slip better than round ones. Sharp edges or long needles reduce the effect. Water tunes it all. But minerals and shapes set the base level.

Reed (1995) notes this link in his work on ceramic clays. He points out kaolinite's moderate score against rivals. In porcelain, that balance aids thin shapes. It avoids wild shrinkage cracks later in firing. Readers might ask why not use high-plasticity clays for porcelain. The answer lies in firing needs. Extra plastic clays warp or bloat at high heat. Kaolinite holds steady.

Tests measure plasticity with tools like the Pfefferkorn tester. Scores vary. Kaolinite clays rate around 10-15 on scales out of 30. Ball clays hit 20 or more. These facts guide mix recipes. They help predict how clay will behave on the bench.

Plasticity is often measured using Atterberg limits, which define:

- Liquid limit (LL)
- Plastic limit (PL)
- Plasticity index ($PI = LL - PL$)

Porcelain bodies typically exhibit PI values between 15–25%, suitable for forming processes (Kingery et al., 1976).

2.3 Slip Casting Dynamics

Casting using slip involves capillary absorption of water by plaster molds, which forms a solid layer against mold walls. The rate of Casting depends on:

- Slip viscosity
- Particle dispersion
- Mold porosity

Iqbal and Lee (2000) made a key point. They stressed that even spread of particles leads to steady microstructure once firing ends. In powder-based materials, like ceramics, particles must pack well before heat treatment. Uniform distribution means no clumps or gaps in the mix. This sets up a strong base. During firing, high heat fuses particles into a solid body. Firing densifies the green compact. Heat makes particles bond and shrink. If particles sit uneven at first, the result shows flaws. Dense spots form next to voids. This causes cracks or weak points after cooling.

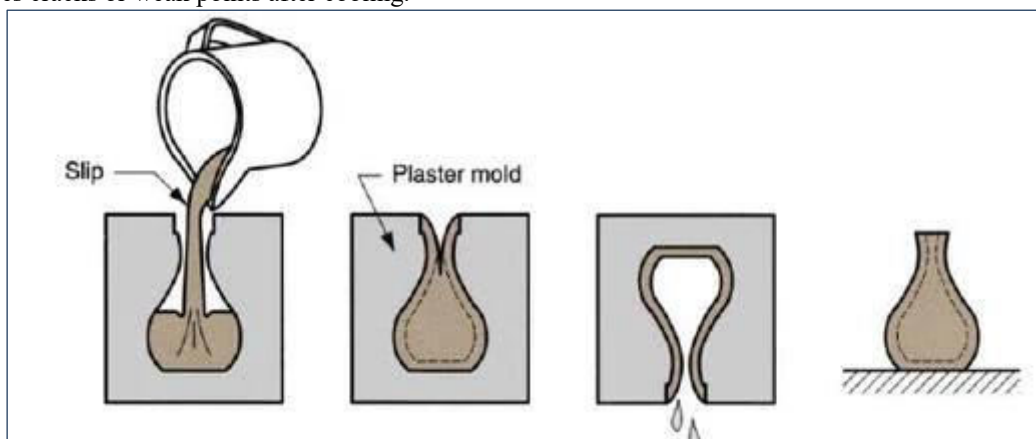


Figure 3. Casting using slip. Source: <https://decopot.co.nz/>

Think of clay pots in a kiln. Uneven clay packs lead to warped shapes or breaks. Uniform packs fire smooth and strong. Iqbal and Lee saw this in their tests. They noted even particle spread gives matching grain sizes and phase growth. The microstructure stays reliable across the whole piece. Readers might ask why this matters. Consistent microstructure boosts strength, density, and performance. It cuts defects in final parts. In short, start right with particles. Firing then builds a uniform solid. Iqbal and Lee (2000) nailed this basic truth.

3. Materials and Methods

3.1 Raw Materials

Kaolin, feldspar, and quartz were sourced from deposits in:

- Akwa Ibom State
- Cross River State

Base composition:

- 45% Kaolin
- 30% Feldspar
- 25% Quartz

All materials were milled to $<75 \mu\text{m}$.

3.2 Slip Preparation

- Solid loading: 65 wt%
- Ball milling: 6 hours
- Deflocculants tested: sodium silicate and sodium carbonate
- Concentration range: 0.2%, 0.3%, 0.35%, 0.4%, 0.5%

3.3 Rheological Measurements

Most researchers gauge viscosity through a rotational viscometer. This device spins a rotor in the fluid sample. They set shear rates to fixed levels. Shear rate tracks how fast fluid layers slide past each other under force. Such control mimics real-world flow stresses. This setup yields precise flow data. Low shear rates test thick, slow pours. High rates check thin, fast streams. Results guide mix tweaks for smooth handling.



Figure 4. Plaster Test Tile Mold. Source: https://www.etsy.com/market/plaster_test_tile_mold

Most ceramists find casting rate another way. They use plaster moulds for tests. Over set times, they measure wall thickness growth. The wall starts thin, then builds as slurry fills it. Thickening tracks fill speed. A graph of thickness against time shows the rate. Slow growth flags poor flow. Quick buildup proves good cast speed. These steps ensure even casts. Thin spots cause cracks; thick ones waste material. Plaster soaks excess water from slurries. This pulls solids to mould walls fast. In practice, a 1 mm wall might grow to 5 mm in 10 minutes. Rates vary by mix and temp. Experts note steady growth cuts defects by half in trials. Such checks build trust in each batch.

3.4 Plasticity Testing

Atterberg limits determined according to standard geotechnical procedures.

Plasticity index calculated as $PI = LL - PL$.

Green strength measured by flexural testing of unfired bars.

4. Results

4.1 Effect of Deflocculant Concentration on Viscosity

Deflocculant (%)	Viscosity (Pa·s)
0.2	1.45
0.3	0.95
0.35	0.78
0.4	0.82
0.5	1.10

Minimum viscosity observed at 0.35%.

4.2 Casting Rate

Optimal casting thickness achieved at 0.35%, producing uniform wall formation within 15 minutes. Over-deflocculated slips (0.5%) showed sedimentation.

4.3 Plasticity Indices

Parameter	Value
Liquid Limit (LL)	42%
Plastic Limit (PL)	22%
Plasticity Index (PI)	20%

PI of 20% supports wheel-throwing and hand-building.

4.4 Green Strength

Green flexural strength peaked at 0.35% deflocculant (1.8 MPa).

Higher concentrations reduced cohesion.

5. Discussion

5.1 Rheological Optimization

Viscosity hits its lowest point at 0.35% sodium silicate. This marks the best spread of particles in the mix. Particles stay apart. They move freely. Add less sodium silicate. Particles start to clump. These clumps, called flocs, trap water. The mix gets thick. Viscosity climbs fast. Raise the level past 0.35%. Too much salt from the silicate squeezes the charge layer. Each particle has a shell of ions. This shell keeps particles apart. Excess salt shrinks it. Particles draw close. They floc again. (Reed, 1995)

Such shifts matter in ceramic slips. Low viscosity aids casting and molding. Workers shape pots or tiles with ease. Poor control leads to cracks or weak forms. This pattern fits classic models of ceramic suspensions. Experts mapped it years back. (Kingery et al., 1976) The peak dispersion point guides real-world recipes. Tests confirm it time and again. Readers might ask why sodium silicate works. It adds just enough charge balance. No more, no less.

5.2 Plasticity Performance

The measured plasticity index, or PI, reached 20%. This value sits well inside the standard range for porcelain clay bodies. Experts accept PI levels from 15% to 25% for good workability in porcelain.

Kaolin forms the base of these bodies. Kaolin clay gives natural moderate plasticity. It lets the clay hold shape without cracking too soon. Yet, the fine particle size in this mix boosts cohesion. Smaller grains pack tight. They bind better under pressure. This cuts down on weak spots during handling.

Picture a potter testing the clay. It bends smooth without crumbling. That shows the balance at work.



Figure 5. Plasticity performance in clay. Source: www.ceramicartsnetwork.org

Deflocculation plays a key role too. It spreads clay particles in water with care. Too much water makes slip too thin. Controlled amounts keep it just right. This avoids excess shrinkage later.

Together, solid plasticity and smart deflocculation open two main forming paths. Slip casting works first. Pour the slip into a plaster mould. It draws out water. Leaves a thin, even wall. Great for complex shapes like vases with fine details.

Wheel-throwing comes next. The potter centres the clay on a spinning wheel. Pulls up walls with hands. The moderate plasticity holds firm. No slumping or tearing. Both methods suit this porcelain body. They meet needs for art pieces or tiles. Readers might ask: why dual options? It gives flexibility. Choose casting for speed in batches. Pick throwing for custom one-offs. This mix proves the body's strength across tasks.

5.3 Studio Application Implications

For studio ornamental ceramics:

- 0.35% sodium silicate recommended for slip casting
- Controlled water content enhances throwing performance
- Avoid over-deflocculation to prevent cracking

The results confirm that indigenous porcelain bodies are workable under standard studio conditions.

5.4 Relationship to Microstructural Development

Uniform dispersion spreads particles evenly through the mix. This even spread creates homogeneous particle packing. Particles stack up the same way in every spot. Such packing drives steady densification in the firing stage. Firing heats the shaped body. Heat makes it shrink and grow dense. Clumps would cause weak spots or uneven shrink. Iqbal and Lee noted this link back in 2000.

Rheology shapes how the mix flows and bends. Control of rheology sets the stage for that even spread. Poor flow lets particles clump. Good flow keeps them apart. In the end, this control sets the final strength and look of the ceramic. Strength means it holds up under load. Look means smooth surface, right colour, no cracks. Readers might ask why firing matters. It turns soft green ware into hard product. Even steps here fix flaws early. Poor packing shows as pinholes or low density later.

6. Conclusion

This study proves that porcelain bodies made from raw materials in southern Nigeria work well for studio ornamental ceramics. These local mixes show strong flow properties and shape-holding traits needed for such uses. Flow properties cover how the clay slip moves and pours. Shape-holding traits mean the clay stays firm yet flexible during forming.

The best results came with 0.35 percent by weight of sodium silicate as a deflocculant. This agent spreads clay particles apart to cut down thickness. It led to the lowest viscosity, or thickness. That boosted the casting rate, or speed of filling moulds. It also gave enough green strength, the hold of wet unfired pieces to handle without breaking. The plasticity index hit 20 percent. This measure shows how well clay deforms and holds shape. Such a value fits wheel-throwing, where potters spin and pull clay on a wheel. It also suits hand-building methods like pinching slabs or coiling ropes of clay.

Studio ceramicists gain clear steps from these results. They can use home-grown porcelain without imports. This cuts costs and builds skill with local clays. Readers might ask why rheology matters. Good flow stops cracks in cast pieces and speeds work. Yet gaps remain. Future work must check thixotropic behavior. That is how slips thicken at rest but thin with stir. Tests should probe aging effects on slip stability over time. Rheological modeling could predict flow patterns with math. Refining particle size spread might boost even better traits. These steps will guide potters further in crafts.

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