
INVESTIGATION INTO THE USE OF LOCALLY AVAILABLE MATERIALS FOR THE PRODUCTION OF INVESTMENT CASTING MOULD

Nura Lawal¹, Mahadi Makoyo^{1,*}, Adamu Umar Alhaji¹, Yakubu Shuaibu Ochetengwu²

¹Department of Mechanical Engineering, Bayero University Kano Nigeria

²Department of Mechanical Engineering, NDA Kaduna

Email: nl2100014.pme@buk.edu.ng, makwayo@gmail.com*, adamumar863@gmail.com,
drsoyakubu4real@gmail.com

*Corresponding author: Mahadi Makoyo

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ABSTRACT

Investment casting produces high-quality, dimensionally accurate parts with complex geometries that forging and machining cannot easily achieve, but imported refractories and binders make the process expensive to adopt. This study investigated locally available moulding plaster, cassava flakes, kaolin, Portland cement, and fine sand as substitutes, using beeswax as the pattern material. Particle size, viscosity, flexural strength, and refractoriness were determined. Viscosity reached 710 mPa·s for moulding plaster, 650 mPa·s for cassava flakes, and 613 mPa·s for kaolin, while flexural strength reached 105.60 MPa for moulding plaster, 80.00 MPa for Portland cement, and 52.13 MPa for kaolin. Six trial compositions were evaluated and an optimum blend containing 82% moulding plaster, 5% cassava flakes, 5% cement, 4% kaolin, and 4% fine sand was selected. The fired mould achieved flexural strengths of 159.25, 139.00, and 154.75 MPa for three samples, with an average permeability of 92 AFS. A brass jewellery piece was successfully cast in the finished mould. The findings demonstrate the feasibility of combining locally available materials into a functional investment casting system without imported refractories.

Keywords: investment casting; locally sourced refractories and binders; ceramic shell mould; beeswax; brass casting

1. INTRODUCTION

Investment casting, commonly known as the lost-wax process, is widely used where complex geometry, dimensional accuracy, and surface finish are important. The process has applications in aerospace, defence, power generation, automotive, medical devices, construction, and other manufacturing sectors (Diamond, 1980; Groover, 2010; Soemardi et al., 2016). A global market review has noted that investment casting continues to expand into new sectors precisely because of this combination of accuracy and geometric freedom (Ronald & Richard, 2012). The process depends heavily on the quality and cost of its refractory mould system. Conventional investment casting commonly uses alumina, silica, zircon, mullite, and related refractory materials with binders such as colloidal silica, ethyl silicate, sodium silicate, or fireclay (Beeley & Smart, 1995; Ibadode, 2014; Prasad, 2012). In Nigeria, many of these materials are imported in usable forms, increasing cost and supply-chain constraints for small and medium-scale foundries.

Previous investigations have demonstrated that slurry viscosity, particle size, suspension behaviour, shell strength, permeability, and refractoriness strongly influence investment casting performance (Kline et al., 2010; Shukla & Juneja, 2011; Singh et al., 2012; Zhao et al., 2011). Parallel work on the pattern side of the process has shown that wax type, blending, and injection conditions govern the dimensional stability and surface quality of the pattern that the shell is built around (Bembalge & Karunakar, 2011; Kamboj, 2017; Rezavand & Behraves, 2007; Sandhu & Sharma, 2012; Yadav et al., 2011); the beeswax pattern route adopted here draws on this body of work while relying on a single, low-cost, locally available pattern material rather than blended commercial waxes. On the shell side, alternative refractory systems and additives have been explored to reduce cost or improve high-temperature performance, including graphite-modified permeability control (Kline et al., 2010), fly-ash-modified ceramic shells (Shukla & Juneja, 2011), calcium zirconate systems for reactive alloys

(Klotz et al., 2019), locally sourced shell materials for steel casting in South East Asia (Purwadi et al., 2012), optimized ceramic shell formulations (Dave & Kaila, 2014), high-temperature strength characterization of shell moulds (Kolczyk & Zych, 2011), camphor-based intensification of shell mechanical properties (Tamta & Karunakar, 2014), and statistically rigorous bend-testing protocols for shell characterization (Richards et al., 2016). However, most published systems still rely on imported refractory and binder systems, or on additives that are themselves imported. This creates a practical research gap: whether locally available materials can be characterized, formulated, and combined into a complete working investment casting mould system.

The aim of this study was to investigate the use of locally available materials for producing an investment casting mould. Specifically, the study sought to identify suitable local materials; characterize their relevant physical and mechanical properties; develop a stable slurry; evaluate viscosity, bulk density, suspension percentage, and thixotropy; produce and fire a ceramic shell mould; determine strength, permeability, and refractoriness; and demonstrate the mould by casting a brass component.

2. METHODOLOGY

Materials and Equipment

Moulding plaster, Portland cement (grade 42.5), and kaolin were used as refractory constituents, while fine sand and cassava flakes served as binder-related constituents. Beeswax was used as the pattern material. All materials were sourced commercially within Nigeria. Equipment included a standard sieve set, digital balance, slurry stirrer, Fann Model 35SA viscometer, Ridsdale permeability testing device, vernier caliper, graduated flask, Universal Materials Testing Machine (100 kN capacity), laboratory thermometers, and a flash-fire oven.

Material Characterization

Particle size distribution was determined by sieve analysis using 1000 g samples in accordance with BS 1377: Part 1: 1990. Flexural strength was measured on $100 \times 10 \times 4$ mm specimens by three-point bending at a crosshead speed of 2 mm/min, using three replicates for each material. Flexural stress was calculated as $\sigma_{3pt} = 3PL/(2bd^2)$, where P is the applied load, L is the support span, b is the specimen width, and d is the specimen thickness. Flexural modulus was determined from the same three-point bending test as $E = L^3m/(4bd^3)$, where m is the slope of the initial linear (elastic) region of the load–deflection curve, following the approach outlined for ceramic shell bend testing by Richards et al. (2016); the linear region was fitted over the first 10–20% of the load range before any visible non-linearity or crack initiation.

Viscosity was measured with a Fann rotational viscometer at 100 rpm. Refractoriness was evaluated by heating specimens from room temperature to 800°C at a controlled rate of 10°C/min in a muffle furnace, holding for 30 min at 200°C intervals, and inspecting each specimen for sintering, cracking, spalling, or grain breakdown at each hold point; a specimen was classified as resistant to thermal shock if it showed no visible cracking or spalling up to 600°C and no gross structural breakdown up to 800°C.

Slurry Formulation and Mould Production

Six trial slurry compositions were prepared by varying cement, cassava flakes, fine sand, kaolin, and moulding plaster (Table 1). The sixth composition—82% moulding plaster, 5% cassava flakes, 5% cement, 4% kaolin, and 4% fine sand—was selected because it produced a stable and workable slurry. Bulk density, suspension percentage, thixotropy, and viscosity were monitored. Beeswax patterns were assembled on a central sprue and repeatedly dipped into the slurry with 3–4 h of drying between coats. After the required shell thickness was achieved, the mould was dried for 2–3 days, dewaxed, and fired at approximately 500°C. The mould was then used for brass casting.

Table 1: Trial Slurry Compositions Investigated (wt%)

Material	Exp.1 (%)	Exp.2 (%)	Exp.3 (%)	Exp.4 (%)	Exp.5 (%)	Exp.6 (%)
Cement	20	25	30	40	40	5
Cassava flakes	20	20	30	40	30	5
Fine sand	10	20	30	11	10	4
Kaolin	20	15	2.5	2	5	4
Moulding plaster	30	20	7.5	7	15	82
Total	100	100	100	100	100	100

Note. The moulding-plaster values for Exp.1 and Exp.5 have been corrected from the originally recorded 40% and 10% (which produced totals of 110% and 95%, respectively) to 30% and 15%, so that every trial composition sums to 100 wt%.



Figure 1: Beeswax Pattern Tree and Completed Investment Casting Mould Prior to Firing.

3. RESULTS AND DISCUSSION

Particle Size Distribution

Table 2 summarizes the sieve retention of the four raw materials on a 1000 g sample basis. Almost all of the kaolin and moulding plaster passed through to the pan, confirming that both were very fine powders, with 986.64 g and 999.54 g respectively retained in the pan fraction. Cassava flakes and fine sand were retained mainly on the coarser sieves from 600 μm to 2.0 mm. Figure 2 presents the same data as the percentage of each material's mass retained at each sieve size, and is directly consistent with Table 2: the plaster and kaolin bars are concentrated almost entirely in the pan fraction, while the cassava-flake and sand bars are distributed across the coarser sieve sizes. The finer and more evenly graded plaster and kaolin particles favour stable packing and suspension in the slurry, whereas the broader particle-size distributions of cassava flakes and fine sand contribute different flow and packing characteristics.

Table 2: Sieve Analysis of the Raw Mould Materials (1000 g Samples)

Sieve Size	Cassava Flakes (g)	Fine Sand (g)	Kaolin (g)	Moulding Plaster (g)
2.0 mm	64.00	38.60	0.27	0
1.18 mm	169.70	520.50	0.58	0
600 µm	481.60	230.02	0.83	0
425 µm	212.02	97.80	0.92	0
212 µm	54.60	41.40	1.04	0
150 µm	9.03	25.70	1.87	0.1
63 µm	0	20.60	2.80	0.13
Pan	0	16.90	986.64	999.54

Figure 2: Particle Size Distribution of Mould Materials (Sieve Retention, 1,000 g Samples)

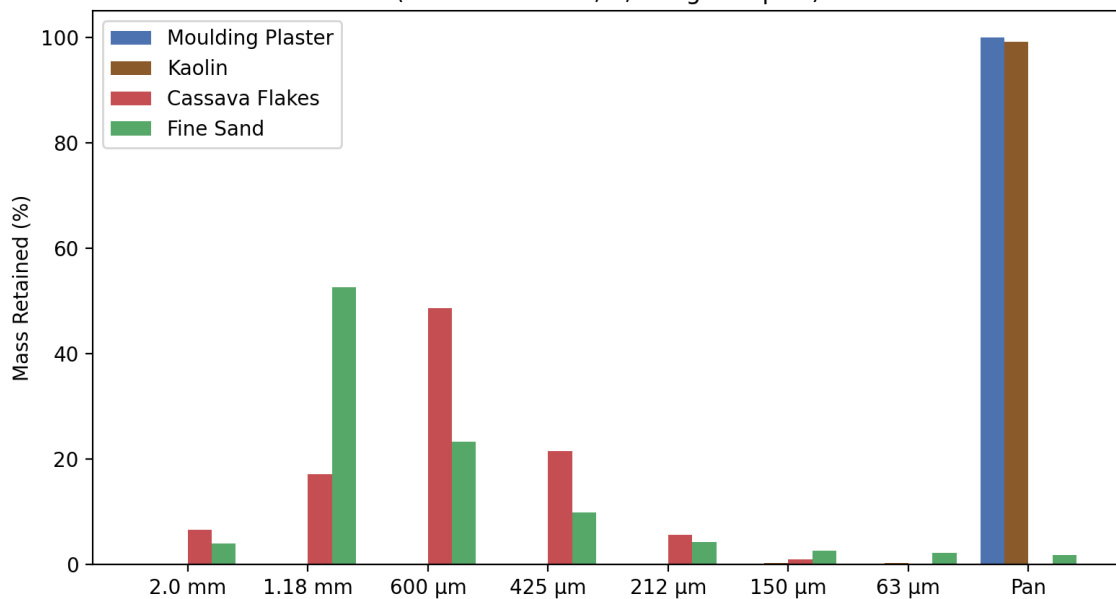


Figure 2: Particle Size Distribution of Mould Materials (regenerated from Table 2 sieve-retention data).

Flexural Strength of Raw Mould Materials

Moulding plaster had the highest average flexural strength, 105.60 MPa, based on replicate values of 100.80, 120.60, and 96.00 MPa. Portland cement averaged 80.00 MPa, with replicate values of 96.00, 96.00, and 48.00 MPa, while kaolin averaged 52.13 MPa from 48.00, 52.80, and 57.60 MPa. The higher strength of moulding plaster supported its dominant proportion in the final slurry.

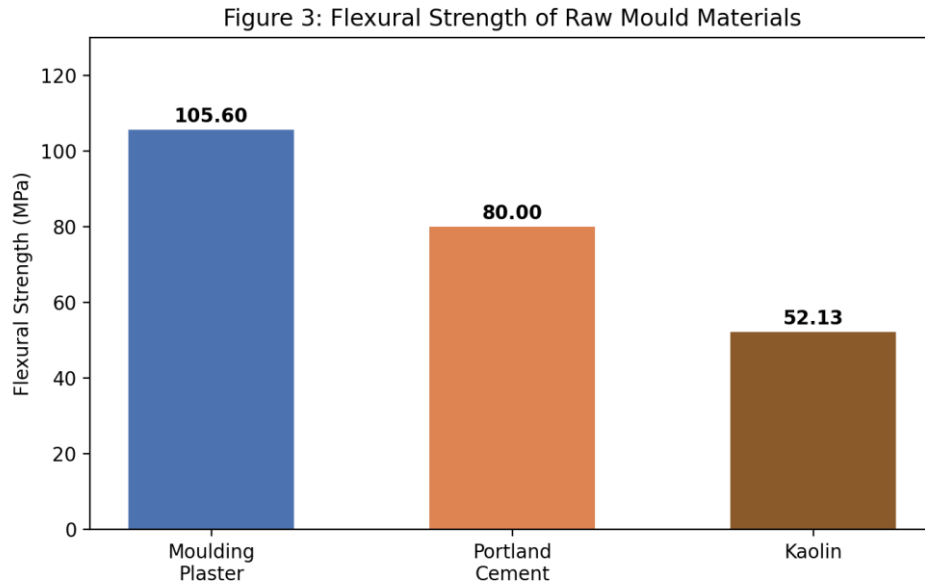


Figure 3: Flexural Strength of Raw Mould Materials.

Slurry Viscosity

Viscosity increased with refractory-to-binder ratio. At the highest ratio tested, moulding plaster reached 710 mPa·s, cassava flakes 650 mPa·s, and kaolin 613 mPa·s. The final combined slurry reached 890 mPa·s, which was within the workable range used for shell building. The combined-slurry curve tracks the moulding-plaster curve closely up to a ratio of 2.4 because plaster is the dominant constituent (82% of the final blend) and therefore governs the rheology of the mixture through most of the tested range; the sharper rise to 890 mPa·s at a ratio of 2.6 reflects the onset of particle-packing saturation, where the finer plaster and kaolin particles begin to interlock and restrict flow once the refractory fraction approaches its maximum practical loading. The relatively high viscosity of the final blend was favourable for maintaining a coherent coating on the beeswax pattern during repeated dipping.

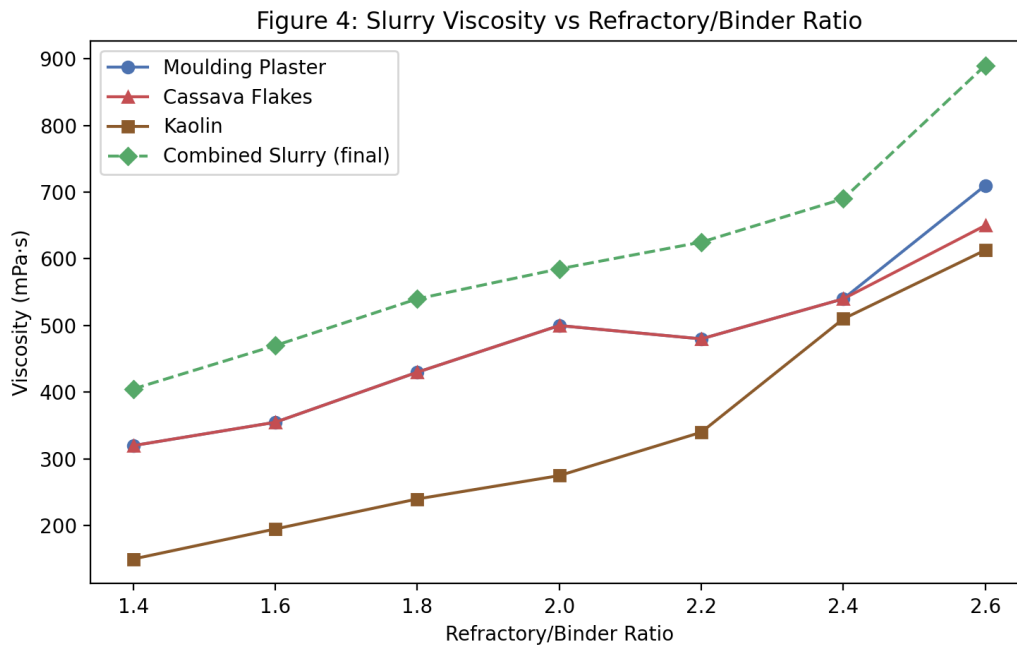


Figure 4: Slurry Viscosity versus Refractory/Binder Ratio and Final Combined Slurry.

Bulk Density, Suspension and Thixotropy

The individual slurry densities were 3.17 g/cm³ for moulding plaster, 3.02 g/cm³ for cassava flakes, and 2.52 g/cm³ for kaolin (Table 3). After 14 hours, moulding plaster retained approximately 43% of its solids in suspension compared with 15% for cassava flakes and 3% for kaolin. All three slurries exhibited viscosity decay under continued shearing, indicating thixotropic behaviour. Moulding plaster had the highest reported thixotropic rate of 4.0, followed by cassava flakes at 3.0 and kaolin at 0.5.

Table 3: Bulk Density of Individual Material Slurries

Material	Slurry Density (g/cm ³)
Moulding Plaster	3.17
Cassava Flakes	3.02
Kaolin	2.52

Figure 5: Thixotropic Behaviour of the Slurries

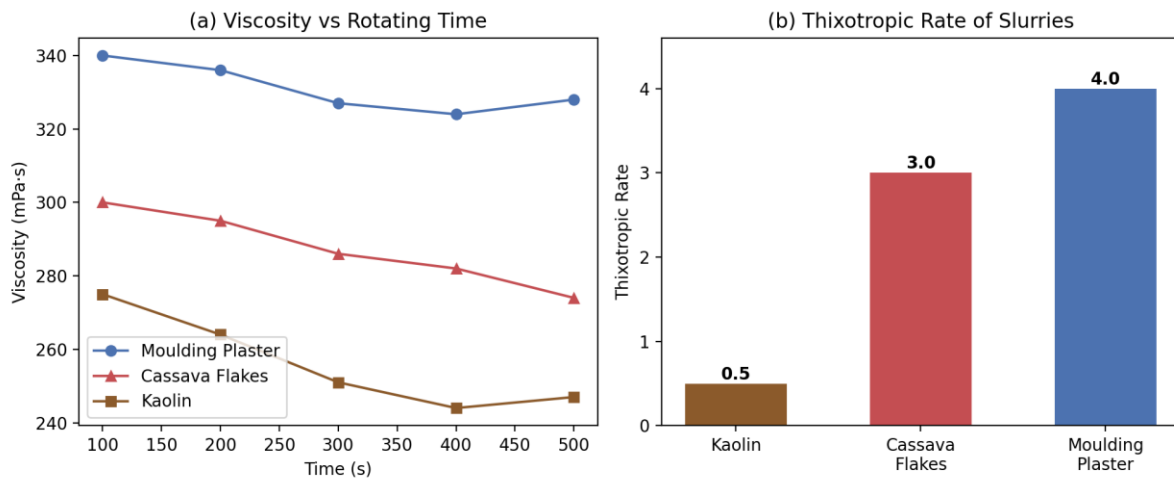


Figure 5: Thixotropic Behaviour of the Slurries: (a) Viscosity vs Rotating Time; (b) Thixotropic Rate.

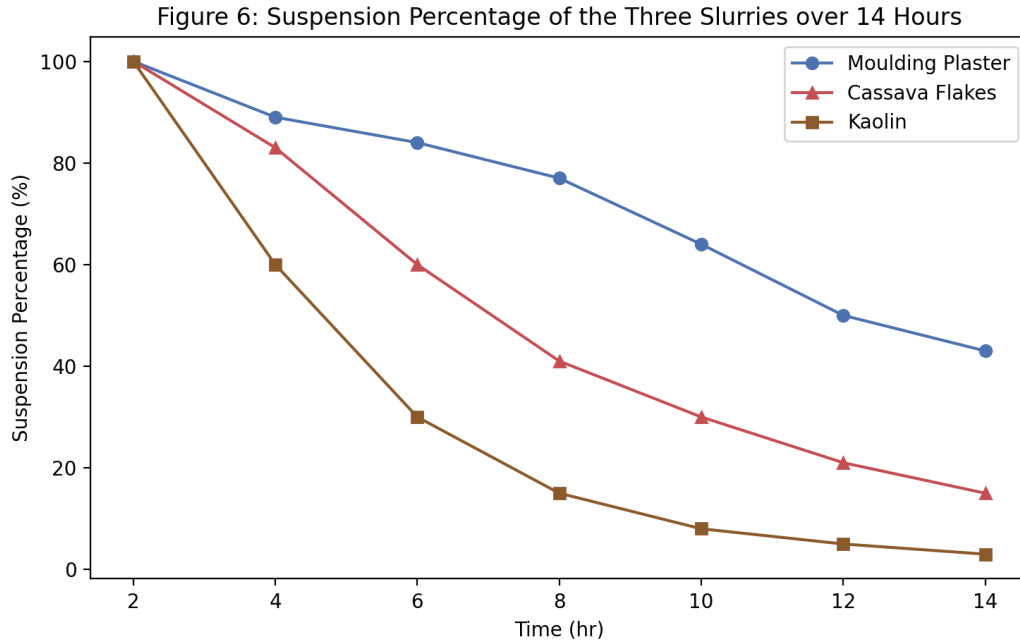


Figure 6: Suspension Percentage of the Three Slurries over 14 Hours.

Refractoriness

Moulding plaster showed the best resistance to sudden temperature change among the three refractories tested, showing no visible cracking or spalling up to 600°C and no gross structural breakdown up to 800°C, and also resisted molten metal and hot gases satisfactorily. Portland cement was mechanically robust but less resistant to thermal shock, developing visible surface cracking at the 400–600°C hold. This complementary behaviour supported the use of plaster as the major refractory with a smaller cement addition to provide mechanical robustness.

Fired Mould Strength, Permeability and Casting Trial

The fired mould produced flexural strengths of 159.25 MPa for sample X, 139.00 MPa for sample Y, and 154.75 MPa for sample Z (Table 4). The corresponding flexural moduli, calculated from the slope of the elastic region of each load–deflection curve (Section 2.2), were 4.37, 4.92, and 6.80 GPa. Permeability was measured on samples taken after each dip coat rather than on the finished shell alone; Figure 8 shows that permeability rose progressively from approximately 70 AFS at the first coat to 112 AFS at the seventh and final coat, giving an overall average of 92 AFS across the build. The mould was successfully used to produce a brass jewellery casting without cracking or gross defects (Figure 9).

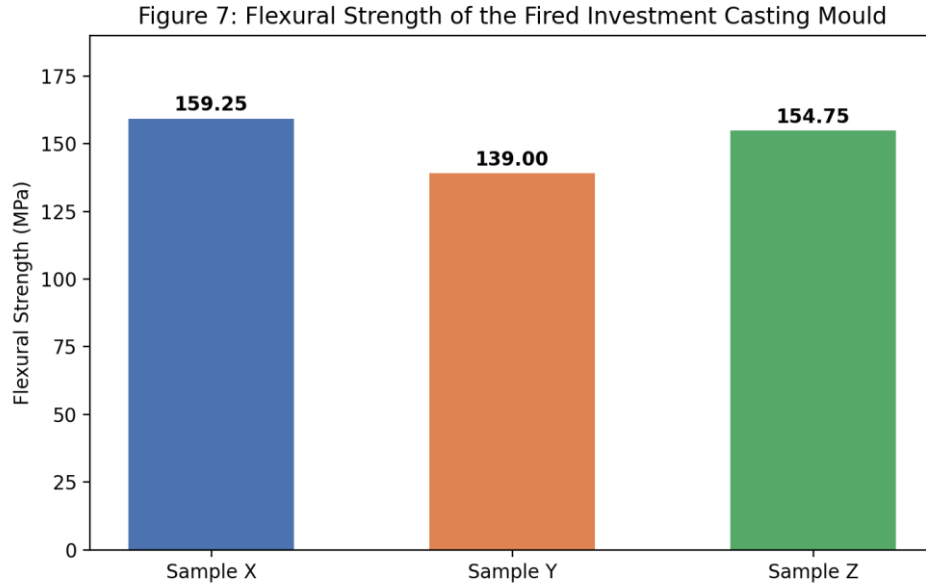


Figure 7: Flexural Strength of the Fired Investment Casting Mould.

Table 4: Flexural Strength and Flexural Modulus of the Fired Investment Casting Mould

Sample	Average Flexural Strength (MPa)	Average Flexural Modulus (GPa)
X	159.25	4.37
Y	139.00	4.92
Z	154.75	6.80

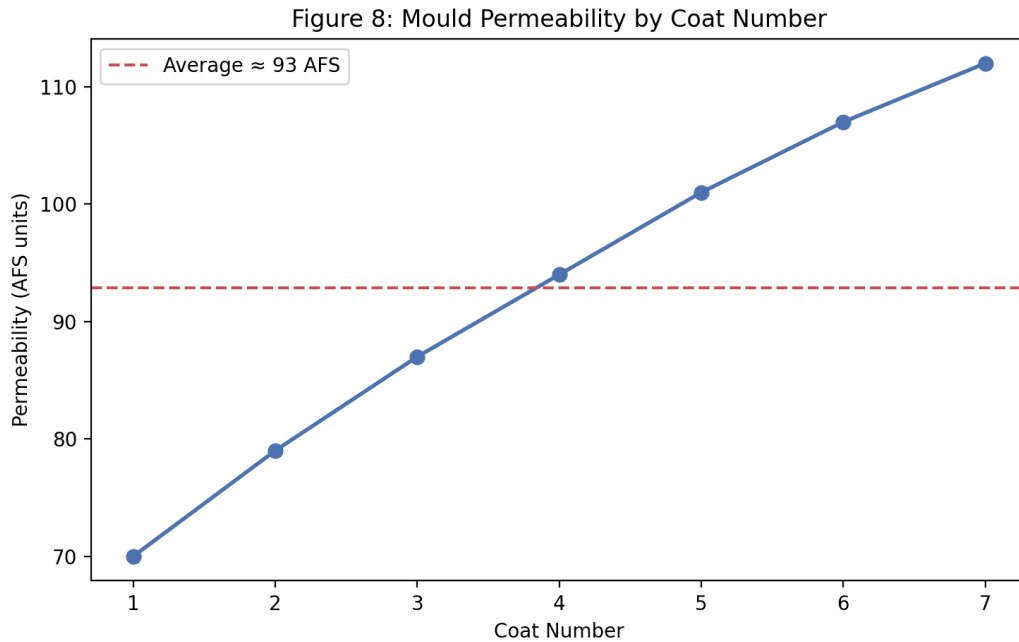


Figure 8: Mould Permeability by Coat Number, Increasing from ~70 AFS (Coat 1) to 112 AFS (Coat 7); Average ≈ 92 AFS.



Figure 9: Brass Jewellery Casting Produced from the Investment Casting Mould.

Discussion

The results indicate that moulding plaster was the most influential constituent in achieving a workable local slurry. Its high flexural strength, strong suspension stability, high thixotropic response, fine particle size, and resistance to thermal shock explain why it constituted 82% of the optimum composition. Cassava flakes provided a locally available starch-based constituent whose viscosity and suspension behaviour were intermediate between plaster and kaolin. The fired shell substantially exceeded the strength of the individual raw materials: the strongest fired sample (159.25 MPa, Sample X) represents an increase of approximately 51% over the strongest raw constituent, moulding plaster alone (105.60 MPa), suggesting that layered construction and firing promoted a stronger integrated mould structure than any single raw material could achieve on its own.

The permeability result is important because investment moulds must allow gases generated during pouring and decomposition of the wax pattern to escape. The measured average of 92 AFS, rising from approximately 70 AFS in the earliest coats to 112 AFS in the fully built shell (Figure 8), indicates adequate and progressively improving gas passage through the build. These observations are broadly consistent with previous studies showing that shell permeability and strength depend on material type, particle characteristics, binder behaviour, and number of coats (Kline et al., 2010; Sarek et al., 2009), and align with the statistically grounded bend-testing approach recommended by Richards et al. (2016) for characterizing ceramic shell moulds. The finding also parallels earlier demonstrations that locally available materials can substitute for imported shell systems in other contexts, including local steel-casting shell development (Purwadi et al., 2012) and camphor-modified shell strength improvement (Tamta & Karunakar, 2014), reinforcing that the present approach is consistent with a broader trend toward locally adapted investment casting systems. The principal contribution of the study is the demonstration that a complete investment casting route from material selection and slurry formulation through mould production and actual casting can be implemented using locally available materials.

4. CONCLUSION

The study demonstrated the feasibility of producing an investment casting mould from locally available materials. Moulding plaster, cassava flakes, kaolin, Portland cement, and fine sand were characterized and combined using beeswax as the pattern material. Moulding plaster recorded the highest flexural strength among the raw refractories at 105.60 MPa and showed the best suspension stability and resistance to sudden temperature change. Six trial compositions led to a workable blend containing 82% moulding plaster, 5% cassava flakes, 5% cement, 4% kaolin, and 4% fine sand. The fired shell achieved flexural strengths between 139.00 and 159.25 MPa, with corresponding flexural moduli between 4.37 and 6.80 GPa, and an average permeability of 92 AFS, and successfully produced a brass jewellery casting without major defects. The results support local material substitution for non-ferrous, jewellery-scale investment casting. Further work should investigate repeated casting cycles,

other alloys, larger and more complex patterns, alternative local refractory combinations, and production-scale economic performance.

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