COMPARATIVE STUDIES OF THE MECHANICAL PROPERTIES OF CORE BINDED BY GUM ARABIC AND COCONUT OIL

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ABSTRACT

The growing demand for sustainable alternatives in foundry applications has led to the exploration of natural binders for green sand in sand casting. This study compares two natural binders, gum Arabic and coconut oil, to assess their impact on the mechanical properties of green sand. The aim was to evaluate their effectiveness in improving core hardness, compression, permeability, collapsibility, and the mechanical properties of cast components. Green sand mixtures were prepared with varying proportions of gum Arabic and coconut oil. The physiochemical properties of the binders were analyzed using ASTM standard procedures. Coconut oil showed a slightly acidic pH of 6.83, while gum Arabic was neutral. Various core tests and mechanical property tests on cast components were conducted. Results revealed that gum Arabic-based sand exhibited superior properties: core hardness of 16.1 BHN, core compression of 0.19 N/mm², permeability of 215 d, and collapsibility of 5.7 s. Castings from gum Arabic had higher hardness (248.7 BHN), tensile strength (120.76 N/mm²), and flexural strength (193.02 N/mm²). In contrast, coconut oil-based sand showed lower mechanical properties, with core hardness of 12.3 BHN, tensile strength of 45.64 N/mm², and flexural strength of 145.52 N/mm². The study concludes that gum Arabic is a more effective and environmentally friendly binder for green sand casting, while coconut oil, though natural, proves less suitable due to weaker mechanical properties. Further research on coconut oil may explore its potential for other applications.

Keywords: Green Sand, Natural Binders, Gum Arabic, Coconut Oil, Mechanical Properties, Sand Casting

1 INTRODUCTION

Sand casting is one of the oldest and most widely used methods for manufacturing metal parts, involving the pouring of molten metal into a mould cavity created by packing sand around a pattern. The pattern's imprint forms the external shape of the casting, and when complex shapes such as undercuts or hollow internal regions are required, sand cores are used to define these features within the mould cavity [1]. Cores are typically supported by core prints or chaplets that hold them in place while allowing molten metal to flow between the core and mould wall. This process is essential for producing intricate designs, with the parting line forming the interface between the cope (upper portion) and drag (lower portion) of the mould [2]. While the basic sand-casting process is simple and cost-effective, various factors such as mould defects, the type of sand, and the binder used can influence the overall quality and mechanical properties of the cast product. The sand binder, which holds the sand grains together, is crucial for ensuring the strength and stability of the mould and cores. Traditional binders, including clay and synthetic resins, are commonly used in industrial casting but often face challenges related to cost, availability, and environmental concerns. Moreover, these binders may not always provide the desired strength or finish required for high-quality castings, leading to imperfections and increased costs in the

production process [3]. In light of these challenges, the use of natural, eco-friendly binders has gained attention in the field of sand casting. Natural substances such as gum arabic and coconut oil are of particular interest due to their low cost, environmental sustainability, and availability. Green sand, which is typically a mixture of silica sand, clay, and water, has been widely employed in casting ferrous and non-ferrous materials due to its versatility and simplicity. However, depending on the binder used, the strength and quality of the sand core can vary significantly [4]. The purpose of this study is to investigate and compare the mechanical properties of binders derived from gum arabic and coconut oil, specifically focusing on their performance in sand casting for the production of a motorcycle engine's connecting rod. While organic binders such as coconut oil and gum arabic have been explored for their potential in improving sand casting processes, their relative effectiveness in terms of bonding strength and casting quality remains inadequately understood. This study seeks to fill this gap by analyzing the physicochemical properties of these binders and evaluating their mechanical performance in sand cores and cast components. The research aims to determine whether these natural binders can offer a more sustainable, cost-effective, and high-performing alternative to conventional binders used in industrial foundries [5]. This research holds significant implications for the foundry industry, particularly in terms of reducing costs and enhancing the mechanical properties of castings while promoting the use of environmentally friendly materials. The findings could contribute to the development of better green sand-casting techniques and add to the growing body of knowledge on the use of natural binders in manufacturing processes.

2 LITERATURE REVIEW

Yaro and Suleiman [6] investigated the use of cassava/guinea corn starch and soybean oil as core binders in the sand casting of aluminum-silicon (Al-Si) alloys. Their results indicated that cassava and cereal starches are reliable binders, with cassava starch exhibiting superior binding ability compared to guinea corn starch. Additionally, soybean oil, a vegetable oil, enhanced the binding properties of both starches. They concluded that cassava/cereal starches and soybean oil are viable alternatives to imported core binders for Al-Si sand castings. Olakanmi and Arome [7] characterized the core-binding properties of fatty-based oils. They found that beniseed and melon oils could replace imported core oils like linseed, corn, and fish oils. Beniseed oil emerged as the most desirable binder due to its superior bulk density, green and baked strength, and faster collapsibility. These properties made it suitable for casting applications of various sizes. Popoola and Fayomi [8] explored gum arabic, molasses, and cassava starch as sand casting binders. Their study demonstrated optimal binder performance at specific concentrations (2–8%) at 200°C for 1.5 hours. Gum arabic provided the best stability and structural strength, while molasses and cassava starch required additives for enhanced mechanical properties. Excess binder content led to poor core strength due to increased gas production. Aponbiede and Shehu [9] evaluated soybean oil and cassava starch as core binders for sand casting. Their findings confirmed that these binders are suitable for producing ferrous and non-ferrous castings. Meanwhile, Shehu and Bhatti [10] examined yam flour (starch) and concluded it displayed good strength but was unsuitable for steel castings due to inadequate mechanical properties. Atanda *et al*. [11] studied the effects of polysaccharide starch extracts on foundry molding sand. They determined that the permeability, compatibility, and dry compressive strength of the sand depend on starch content, with cassava starch outperforming rice and maize starches. Joshua *et al*. [12] compared bentonite, cassava starch, and yam starch as green sand binders. Bentonite showed the best compressive strength, followed by cassava and yam starch. They suggested that Niger River silica sand combined with these binders could improve surface finish and reduce costs. Injor *et al*. [13] evaluated cassava and guinea corn starch as binders. While they enhanced moisture content, surface hardness, crushing strength, and shrinkage, they caused a decrease in the shatter index, permeability, and refractoriness, limiting their use in certain metal castings. Kumaden *et al*. [14] investigated Orihi clay, Jatropha curcas, and Nigella sativa seed oils. They concluded that these materials are effective binders for silica sand casting, with combined use yielding higher strength. Puspitasari and Dika [15] compared bentonite and tapioca flour as binders. Tapioca flour produced higher dry strength, making it a potential substitute for bentonite in sand casting. Similarly, Ochulor *et al*. [16] studied kaolin and cassava starch as binders for thin-wall ductile iron casting. While kaolin outperformed cassava starch in green compression strength and permeability, cassava starch

showed better dry compression strength but was unsuitable for achieving desirable casting microstructures. Sani *et al*. [17] assessed shea butter shell powder, silica flour, corn flour, and marula shell powder as binders on Dukku sand. These binders exhibited high strength and low permeability, making them suitable for molding processes. Madhukumar *et al*. [18] compared various binders, including cement, clay, bentonite, and furnace ash, and found furnace ash to provide the best green compressive strength. Nurul *et al*. [19] investigated organic binders (furan bake and alkaline phenolic ester) and an inorganic binder (sodium silicate) for sand casting. Modified sodium silicate produced castings with superior strength. Cyril *et al*. [20] evaluated acacia gum as a core binder, noting its excellent properties for green sand and superior surface finish, though it is more expensive than other local binders. Arpit and Shailene [21] confirmed that bentonite provided excellent green strength and low permeability. Bartłomiej *et al*. [22] investigated barley malt as a binder. They found it provided good strength, but inadequate amounts caused surface defects in castings. While organic binders such as coconut oil and gum arabic have been investigated for their role in enhancing sand casting processes, the existing body of research lacks comprehensive evaluations of their comparative bonding strength, thermal stability, and casting quality. Previous studies primarily focus on either the chemical composition of these binders or their general feasibility, without systematically assessing their mechanical performance in sand cores and cast components under industrial conditions. Additionally, limited data exist on their long-term durability and sustainability in foundry applications. This study aims to bridge this gap by conducting a detailed physicochemical and mechanical analysis of these natural binders, determining their potential as viable, eco-friendly alternatives to synthetic binders in industrial metal casting.

3 MATERIALS AND METHOD

3.1 Materials

The following materials were used in this research work: Gum Arabic, Silica sand, Coconut oil, Water, Corn flour, Aluminium scrap.

3.2 Equipment

The list of equipment used in this research work are shown in Table 1.

Table 1. List of Equipment and their Specifications

S/N	Equipment name	Specification
1	Digital absolute permeameter	42105B
2	Rammer	BS1377
3	50KN Universal Testing Machine	FS50AT
4	Compression Tester	YES 3000
5	Brinell Hardness Tester	LIC-6003D
6	Digital Weighing Balance,	XY3000MB/XY10K
7	Stainless Steel Sieve Shaker	NL1015X/SPC
8	Handheld XRF Analyzer	x-550
9	Erlenmeyer Flask	100ml
10	Abbey refractometer	20cm x 15cm x 10cm
11	Hydrometer Cylinder	500ml
13	Pyrometer Tube	L 200mm; D 15mm
14	Brookfield Digital Rotational Viscometer	DV2TLV
15	Distillation Flask	100ml

3. 3 Methods

3.3.1 Preparation of Green Sand

Sand samples were procured from Kaduna River, Yakowa Way, Kaduna State. The samples were thoroughly washed and transported to the Structural Laboratory at the Nigeria Defence Academy for drying. A sand sieve vibrator (conforming to ASTM D6913/D6913M-24) [23] was utilized to separate sand particles, collecting fine grains with a particle size of 300 microns. The binders, Gum Arabic and Coconut

Oil, were sourced from local markets in Kaduna State. The additives, corn flour and aluminum dust, were similarly procured from Kaduna, Kaduna State.

3.3.2 Physicochemical Tests for Coconut Oil and Gum Arabic

All physicochemical tests were performed in compliance with ASTM standards at the Chemical Engineering Department, Kaduna State Polytechnic. The following properties were determined:

(i) Saponification Value

The saponification value measures the average molecular weight of fatty acids in the sample. The ASTM D94-07 [24] standard procedure was followed: 2.5 g of the sample was weighed into an Erlenmeyer flask, mixed with 25 ml of 0.5M ethanolic KOH, and refluxed for 60 minutes. The mixture was titrated against 0.5M HCl using phenolphthalein as an indicator until the endpoint (pink to colorless) was achieved. The saponification value (SV) was calculated using equation 1.

$$SV = \frac{56.1\ X\ (B-S)\ X\ N}{W} \quad (1)$$

Where: B = Volume of HCl required by blank (ml); S = Volume of HCl required by sample (ml); N = Molarity of HCl; W = Weight of the sample (g).

(ii) Acid Value

The acid value indicates the degree of freshness or purity of the sample. The procedure followed ASTM D664-18: **Sample Preparation**: 0.5g of the sample was dissolved in 50 ml of neutralized ethyl alcohol, heated, and titrated against 0.1M KOH with phenolphthalein as the indicator. The acid value was calculated as:

$$AV = \frac{A\ X\ M\ X\ 56.1}{W} \quad (2)$$

Where: A = Volume of 0.1M KOH consumed by the sample (ml); M = Molarity of KOH; W = Weight of the sample (g).

(iii) Iodine Value

The iodine value measures the degree of unsaturation of fats and oils. ASTM D5768-02 was employed: The sample was dissolved in 10 ml of carbon tetrachloride and 20 ml of Wijs solution. The mixture was stored in the dark for 30 minutes, then titrated with 0.1M sodium thiosulfate using starch as an indicator. The iodine value (IV) was calculated as:

$$IV = \frac{(B-S)X\ 12.69}{W} \quad (3)$$

Where: B = Blank titre (ml); S = Sample titre (ml); W = Sample weight (g).

(iv) Peroxide Value

The peroxide value quantifies oxygenated compounds in the oil, per ASTM D3707-24: 2 g of the sample and 1 g of powdered potassium iodide were dissolved in a 20:10 solvent mixture of glacial acetic acid and chloroform. The mixture was titrated with 0.01M sodium thiosulfate, with phenolphthalein as the indicator. The peroxide value (PV) was calculated as:

$$PV = \frac{(S-B)X\ 0.01\ X\ 1000}{W} \quad (4)$$

Where: S = Sample titre (ml); B = Blank titre (ml); W = Sample weight (g).

(v) Refractive Index

The refractive index, measured using an Abbe refractometer per ASTM D542, determines the speed of light in the sample. The procedure ensured a controlled temperature of 30°C using circulating water.

(vi) Density

The density was determined according to ASTM D129-12b. A hydrometer cylinder and calibrated hydrometer were used to measure the density at 15°C.

(vii) Viscosity

The viscosity was measured using a Brookfield Digital Rotational Viscometer per ASTM D445. Samples were heated in an oil bath, and the dynamic viscosity was recorded at various temperatures.

3.3.3 Proximate Analysis of Gum Arabic

(i) Density: Density was determined using the water displacement method.

$$\rho = \frac{m_c}{V_w} \tag{5}$$

Where: ρ = Density (g/cm³); m_c = Mass of the sample (g); v_w = Volume of water displaced (cm³).

(ii) Moisture Content (MC): Moisture content was determined per ASTM D3137 by drying samples at 105°C under nitrogen purge.

(iii) Ash Content (AC): Ash content, representing the total mineral content, was measured according to ASTM D2584 by heating samples to 730°C.

(iv) Nitrogen Content: Nitrogen was determined using the Kjeldahl titrimetric method (ASTM D4629).

(v) Protein and Carbohydrate Content: Protein was calculated as:

$$\text{Protein} = \%\ \text{Nitrogen X } 6.25 \tag{6}$$

Carbohydrate content was calculated by difference:

$$Carbohydrate = 100 - (Moisture + Ash + Nitrogen + Protein + Fibre) \tag{7}$$

3.3.4 X-Ray Fluorescence Analysis of Silica Sand

The elemental composition of the silica sand was determined using an X-Ray Fluorescence (XRF) analyzer, following the ASTM C579-01 standard. A 10 g sample of silica sand was prepared, and the relationship between the X-ray intensity and the concentration of the elements was analyzed to confirm the silica sand's purity and composition.

3.3.5 Production of Cores

The prepared silica sand was washed, dried, and sieved to achieve uniform granularity. For core preparation, 300 g of gum Arabic was pounded into smaller particles using a sack bag and a 3 kg wooden pestle for ease of dissolution. The crushed gum Arabic was dissolved in 600 ml of hot water at 100°C, requiring approximately three hours for complete dissolution.

3.3.6 Formulation of Cores

The cores were formulated in accordance with Table 2. The composition and mixing ratios of the materials used are summarized below:

Table 2. Formulation of Sand Cores

Material	Core A	Core B
Silica Sand	85% (1 kg)	85% (1 kg)
Gum Arabic	3% (50 ml)	-
Coconut Oil	-	3% (50 ml)
Water	5% (60 ml)	5% (60 ml)
Corn Flour	7% (0.1 kg)	7% (0.1 kg)

For each batch, 1 kg of silica sand was weighed, and the binders and additives were incorporated as per the formulations provided. A 40 ml tempering water was added, and the mixture was thoroughly homogenized for 15 minutes. Six square iron mold patterns measuring 75 mm x 75 mm were used for core molding. The molds were filled in two stages, producing four sand cores per binder type. The sand cores with coconut oil and gum Arabic as binders are shown in Plates 1 and 2, respectively.

Plate 1. Sand Cores with Coconut Oil as a Binder

Plate 2. Square Sand Core with Gum Arabic as Binder

3.3.7 Casting of Motorcycle Connecting Rods

The green sand molds were prepared as per Table 2, ensuring uniform distribution of the sand, binders, water, and additive. A wooden rectangular pattern measuring 30 cm x 20 cm was utilized for sand casting.

Pattern Preparation: A pre-purchased connecting rod was placed on the prepared green sand to create the casting pattern. Aluminum dust was sprinkled over the surface to facilitate easy separation and reduce surface friction.

Mold Assembly: The second part of the wooden mold pattern was placed to complete the cavity for the casting. After ensuring proper compaction, the mold was carefully separated to remove the connecting rod pattern, leaving the cavity.

Aluminum Melting: 2 kg of aluminum was melted in a furnace, maintaining the molten state at a temperature of 660°C, in adherence to ASTM E155 standards.

Casting Process: The molten aluminum was poured into the prepared molds. Cooling time was set for 10 minutes to allow for solidification.

Core Removal and Repeat Casting: The molds were disassembled, and the solidified aluminum parts were extracted. The process was repeated for rods designated for tensile and flexural testing.

Observation of Binder Performance: For molds using gum Arabic as a binder, gas and smoke escaped within approximately 4 minutes during casting. For molds using coconut oil as a binder, the escape of gas and smoke occurred after 11 minutes, indicating differences in binder performance.

Post-Casting Tests: The cast samples were subjected to various mechanical and thermal tests, including hardness, tensile strength, flexural strength, heat transfer, and thermal conductivity, to evaluate the material properties and core efficacy.

3.3.8 Determination of Mechanical Strength of Sand Cores

The mechanical properties of the sand cores were assessed through a series of tests, including hardness, compression, permeability, collapsibility, tensile, and flexural strength. The methodologies and results are subsequently discussed below:

Core Hardness Test: The Brinell hardness testing method was utilized to determine the hardness of the sand cores, as this method is suitable for polymeric and granular materials. Following ISO 6506, a spherical tungsten carbide indenter was used with a defined ball diameter and test force ranging between 1 kgf and 3000 kgf. The indenter left a measurable indentation, and the force applied was converted to an electric signal, amplified, and displayed. This process was repeated three times for each sample to ensure consistency.

Core Compression Test: The compression strength of the green sand cores was tested using a Digital Compression Testing Machine (YS 3000), adhering to ASTM C365 standards. Three sand cores of 75 mm height with different binders were weighed before testing. The machine was manually adjusted to create an 80 mm gap between the base and the load to accommodate the cores. Each sample was placed in the gap, and the machine was switched on to apply compressive force. The compression load was recorded from the digital display. The process was repeated twice for each sample, and the average value was noted.

Permeability Test for Sand Core: The permeability of the sand cores was determined using a Digital Absolute Permeameter in compliance with American Foundry Men Society (1989) standards. The green sand cores were attached to the permeameter, and the pressure difference was observed as gas flowed through the cores. The permeability number (*Pn*) was calculated using the formula:

$$Pn = \frac{VH}{PRT} \tag{8}$$

where Pn = Permeability number, V = Volume of air passing through the core, H = Height of the specimen (mm), P = Pressure difference (Pa), R = Area of the specimen (mm^2), T = Time (s). The test was conducted in duplicate, and the average value was reported.

Collapsibility Test: The collapsibility of the sand cores was evaluated following ASTM D5333 standards. The cores were dried in sunlight for 5 days. A 30 kg ceramic material was placed over each core, and the time taken for the core to collapse was measured using a stopwatch.

Core Hardness Test for Connecting Rod Samples: The Brinell hardness test, as outlined in ISO 6506, was performed on the connecting rod samples. A spherical tungsten carbide indenter was pressed into the rods with forces ranging between 1 kgf and 3000 kgf. The Brinell Hardness (HB) was calculated similarly to the core samples. The process was repeated three times for each sample to ensure accuracy.

Tensile Stress Test for Connecting Rod Samples: The tensile strength of the connecting rod samples was evaluated in accordance with ASTM D3039-14. Samples were prepared in a dumbbell shape with dimensions 200 mm x 10 mm x 20 mm. **Test Procedure:** A 50 kN Testometric Universal Testing Machine FS 50 AT was used for the test at the Metallurgy Laboratory, University of Ilorin. Each sample was mounted individually, and a test speed of 2 mm/min was applied until failure occurred. The Ultimate Tensile Strength (UTS) was recorded for each sample, and the test was repeated for different sieve sizes and constituent ratios.

Flexural Test for Connecting Rod Samples: A three-point flexural test was conducted using a Universal Material Testing Machine with a capacity of 100 kN, adhering to ASTM D700 standards. Test Parameters: Support span: 80 mm. Sample width and thickness: Measured using a Vernier caliper. Load was applied gradually on each sample using a hydraulic lever until failure occurred. The load at deformation and the corresponding deflection (DDD) were recorded. The flexural strength (σf) and flexural modulus (E) were calculated using the formulas:

$$\sigma f = \frac{3PL}{2bd^2} \tag{9}$$

$$E = \frac{L^3 m}{4bd^3} \tag{10}$$

Where; σf = Flexural strength (N/mm^2), E = Flexural modulus (N/mm^2), P = Load at the given point in the load-deflection curve (N), L = Support span (mm), b = Sample width (mm), d = Sample

thickness (mm), m = Gradient of the initial straight-line portion of the load-deflection curve (N/mm). The connecting rods cast from gum Arabic as binder and coconut oil as binder are shown in Plates 3 and 4, respectively.

Plate 3. Cast Connecting Rods with Gum Arabic as Binder

Plate 4. Cast Connecting Rods with Coconut Oil as Binder

3 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Result of the Physicochemical Properties of the Coconut Oil

The physicochemical properties of Coconut oil are presented in Table 3.

Table 3. Physicochemical Properties of Coconut Oil

S/N	Parameters	Unit	Coconut Oil	Standard (ASTM)
1	PH	-	6.3	7-8
2	Density	Mg/ml	0.8987	0.91
3	Specific Gravity	-	0.93	0.924-0.955
4	Refractive Index	-	1.484	1.448-1.450
5	Viscosity	mPas	4.16	1.9-6.0
6	Acid Value (Av)	mg KOH/g Oil	1.26	4
7	Free Fatty Acid (Ffa)		0.63	0.2
8	Iodine Value (Iv)	mg I/g Oil	6.04	4.1-11
9	Saponification Value (Sv)	mg KOH/g Oil	228.44	-
10	Peroxide Value (Pv)	Meq/kg	3.62	0.5-9.0
11	Moisture Content	%	1.09	0.1

4.1.2 Results of the Physicochemical Properties of the Gum Arabic

The physicochemical properties of Gum Arabic are presented in Table 4.

Table 4. Physicochemical Properties of Gum Arabic

S/N	Parameter	Unit	Gum Arabic	Standard (ASTM)
1	Ash Content	%	2.74	2-4
2	Moisture Content	%	13.7	13-15
3	Crude Fiber	%	4.51	4
4	Bulk Density	g/l	0.515	1.35-1.49
5	Nitrogen	%	0.2368	0.26-0.39
6	Protein	%	1.4800	2.2
7	Carbohydrate	%	89.12	-
8	Solubility	%	51.1% Water	43% Water

4.1.3 XRF Analysis Summary of Result of the Silica Sand

The key composition of the XRF analysis of the Silica sand is presented in Table 5a.

Table 5a. Key Composition Analysis

Component	Concentration (wt.%)	Error (±wt.%)
Silica (SiO_2)	95.44	2.195
Calcium Oxide (CaO)	0.31	0.005
Alumina (Al_2O_3)	2.75	0.073
Iron Oxide (Fe_2O_3)	0.42	0.012

The elemental analysis for the XRF summary is given in Table 5b.

Table 5b. Elemental Analysis

Element	Concentration	Error	Method
Silicon (Si)	48.843	±0.960	FP (Fundamental Parameters)
Calcium (Ca)	6.742	±3.4138	FP
Aluminum (Al)	5.065	±0.942	FP
Iron (Fe)	1.873	±0.627	FP

4.1.4 Result of Core Compression Test

The result for the core compression test is given in Table 6.

Table 6. Core Compression Test Result

S/N	Sample	Trial 1	Trial 2	Average
1	Core compression test for coconut oil(N/mm2)	0.1	0.12	0.11
2	Core compression test for gum Arabic(N/mm2)	0.17	0.21	0.19

4.1.5 Result of Core Hardness Test for each Core

The result of the core hardness test for each core is presented in Table 7.

Table 7. Core Hardness Test Result

S/N	Sample	Trial 1	Trial 2	Trial 3	Average
1	Core with Coconut Oil as Binder	12.12	12.42	12.31	12.28333
2	Core with Gum Arabic as Binder	16.33	15.94	15.99	16.08667

4.1.6 Result of Core Permeability Test

The result of the core permeability test is shown in Table 8.

Table 8. Core Permeability Test Result

S/N	Sample	Trial 1	Trial 2	Trial 3	Average
1	Core with Coconut Oil as Binder (BHN)	111	112	94	105
2	Core with Gum Arabic as Binder (BHN)	214	218	213	215

4.1.7 Result of Core Collapsibility Test

The result of the core collapsibility test is presented in Table 9.

Table 9. Core Collapsibility Test result

S/N	Sample	Trial 1	Trial 2	Trial 3	Average
1	Core with Coconut Oil as Binder	18 sec	15sec	16sec	16.3sec
2	Core with Gum Arabic as Binder	5sec	5sec	7sec	5.7sec

4.1.8 Result of the Hardness Test of the Rods

The result for the hardness test of the rods is presented in Table 10.

Table 10. Hardness Test Result of the Rods

S/N	Sample	Trial 1	Trial 2	Trial 3	Average
1	Connecting Rod with Coconut Oil as Binder (BHN)	212.35	211.89	212.50	212.2467
2	Connecting Rod with Gum Arabic as Binder (BHN)	249.33	249.35	247.34	248.6733

4.1.9 Result of the Tensile Test of the Rods

The result of the tensile test for the rods is presented in Table 11.

Table 11. Tensile Test Result of the Rods

Items	Yield strength (N/mm^2)	Ultimate strength (N/mm^2)
Coconut as binder	45.6	75.1
Gum arabic as binder	120.8	120.8

4.1.10 Result of the Flexural Test of the Rods

The result of the flexural test of the rods is presented in Table 12.

Table 12. Flexural Test Result of the Rods

Items	Bending stress at yield	Bending stress at break
Coconut oil as binder	148.95	145.52
Gum Arabic as binder	193.08	193.02

4.2 Discussion of Results

4.2.1 Physicochemical Properties of Coconut Oil

The coconut oil's pH (6.3) indicates mild acidity, slightly below the ASTM standard (7–8), which might affect chemical interactions during binding. Studies by Adeosun *et al*. [25] and Oladipo & Adetunji [26] have reported similar findings, noting that lower pH values can influence the polymerization process in binder applications. While the density (0.8987 Mg/ml) and specific gravity (0.93) are slightly below standard, they align closely with findings by Aluyor *et al*. [27], suggesting suitability for lightweight applications. The refractive index (1.484) exceeds the standard range, possibly pointing to impurities, as observed in the work of Ibrahim *et al*. [28]. The acid value (1.26 mg KOH/g oil) and saponification value (228.44 mg KOH/g oil) suggest good stability and reactivity, making coconut oil viable as a binder [29]. However, the moisture content (1.09%) is above the standard (0.1%), which could compromise durability, consistent with the findings of Olayemi *et al*. [30].

4.2.2 Physicochemical Properties of Gum Arabic

Gum Arabic meets ASTM standards for ash content (2.74%) and moisture content (13.7%), confirming its quality. These values align with those reported by Ibrahim & Musa [31], who found that the moisture content and ash content of gum Arabic make it suitable for binding applications. However, its bulk density (0.515 g/l) is significantly lower than standard values, which may affect compactness in binding applications, as observed in the studies of Ayeni *et al*. [32]. The high carbohydrate content (89.12%) and superior solubility (51.1% in water) make gum Arabic an excellent adhesive [33], while the reduced nitrogen (0.2368%) and protein (1.48%) may slightly limit its binding efficiency compared to expectations [34].

4.2.3 XRF Analysis of Silica Sand

The composition of the sample is dominated by silica (SiO_2) at 95.44 wt.%, which is characteristic of high-purity silica sand. This is consistent with findings by Ibhadode & Oladele [35], who reported similar compositions in silica sands used for industrial applications. The other oxides, such as CaO, Al_2O_3, and

Fe_2O_3, are present in small amounts. These trace oxides are impurities that could affect the sand's utility in industries like glass production, where clarity and purity are crucial [36]. The elemental analysis provides complementary data, confirming the major contribution of silicon (48.843) and smaller contributions from calcium, aluminum, and iron. The FP (Fundamental Parameters) method was used, ensuring a reliable calibration for these measurements [37]. While the silica content is high, the presence of iron oxide (Fe_2O_3), even at 0.42 wt.%, might require further beneficiation for use in optical or solar glass applications, where even trace amounts of iron can impact light transmission [38]. Similarly, the alumina (Al_2O_3) content may benefit industries such as ceramics, but excessive alumina could complicate processes like melting or forming in glass manufacturing [39].

4.2.4 Core Compression Test

Cores with gum Arabic as a binder exhibit higher compressive strength (0.19 N/mm²) than those with coconut oil (0.11 N/mm²), demonstrating gum Arabic's superior load-bearing capacity. This finding aligns with the study by Adedeji & Akinlabi [40], which highlights the effectiveness of gum Arabic in improving the compressive properties of foundry cores.

4.2.5 Core Hardness Test

The average hardness of gum Arabic cores (16.09) is significantly higher than coconut oil cores (12.28). This suggests that gum Arabic produces stronger, more rigid cores, consistent with the findings of Alade *et al*. [41].

4.2.6 Core Permeability Test

Gum Arabic cores show greater permeability (215 BHN) compared to coconut oil cores (105 BHN), indicating better gas flow characteristics. This property is crucial in casting applications requiring effective ventilation [42].

4.2.7 Core Collapsibility Test

Cores with gum Arabic collapse faster (5.7 seconds) than those with coconut oil (16.3 seconds). This highlights gum Arabic's suitability for applications where quick and easy removal of cores is required post-use [43].

4.2.8 Hardness Test of Rods

The connecting rods made with gum Arabic exhibit higher hardness (248.67 BHN) compared to those made with coconut oil (212.25 BHN), indicating better wear resistance and durability [44].

4.2.9 Tensile Test of Rods

Gum Arabic rods display significantly higher tensile strength, with a yield strength of 120.8 N/mm² and ultimate strength of 120.8 N/mm², compared to 45.6 N/mm² and 75.1 N/mm² for coconut oil rods. This establishes gum Arabic as the superior binder for applications requiring high tensile properties [45].

4.2.10 Flexural Test of Rods

Gum Arabic rods exhibit superior bending stress at yield (193.08) and break (193.02) compared to coconut oil rods (148.95 and 145.52, respectively). This demonstrates gum Arabic's ability to withstand higher flexural loads [46]. Overall, gum Arabic consistently outperforms coconut oil as a binder across most mechanical properties, including compressive strength, hardness, tensile strength, and flexural performance. Its superior permeability and faster collapsibility make it ideal for casting applications. However, coconut oil's higher moisture retention and slower collapsibility may suit applications requiring extended structural stability.

5 CONCLUSIONS

This study successfully investigated the comparative mechanical properties of binders produced from coconut oil and gum Arabic for the sand-casting process. The binders were mixed with green sand in various proportions, and the resulting cores were used to cast motorcycle engine connecting rods. The key

findings include: Silica sand, gum Arabic, and coconut oil are locally abundant and readily available for experimental purposes. The physicochemical properties of the binders, evaluated per ASTM standard procedures, revealed that coconut oil is slightly acidic (pH 6.83), whereas gum Arabic contains no acidic components. Gum Arabic predominantly consists of carbohydrates, proteins, nitrogen, ash, fibers, and water, contributing to its superior binding properties. Sand cores produced with gum Arabic exhibited superior performance across mechanical tests, including hardness, compression, permeability, and collapsibility, compared to those with coconut oil. This is attributed to the low iodine value of coconut oil, which limits its binding efficiency. Mechanical tests on the cast connecting rods demonstrated that rods produced with gum Arabic as the binder displayed significantly higher strength, while rods cast with coconut oil had relatively poor strength.

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