# Evaluation of the Effect of Starch as Binder in Sand Casting of Aluminium

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**Abstract**

This study focuses on evaluating the effectiveness of cassava starch as an organic binder in sand preparation for aluminium casting, emphasising its influence on key mould properties, moisture content and green compressive strength and overall casting quality. Silica sand mixtures were prepared with cassava starch at 7.5%, 10%, and 12.5% by weight, molded into cylindrical samples, and tested for moisture content, green compressive strength, hardness, and compressive strength. The results revealed that the moisture content of the samples decreased from 6.3% in the control to 3.9% at 12.5% starch, indicating improved moisture regulation with starch addition. The green compressive strength peaked at 30.6 kN/m² at 10% starch, while hardness reached 12.4 HV and compressive strength attained 35.2 MPa at the same starch level, outperforming the control sample (27 MPa) in mould stability and casting performance. Beyond 10% starch, a slight decline in mechanical strength was observed, attributed to excess binder content leading to reduced compaction and increased gas evolution. The study concludes that cassava starch at approximately 10 wt% provides the optimal balance between mould integrity, strength, and environmental sustainability, establishing it as an effective, eco-friendly binder for improved aluminium casting quality.

**Keywords:** Cassava Starch, Sand Casting, Mould Properties, Aluminium Alloy, Eco-friendly Binder, Compressive Strength

## INTRODUCTION

Sand casting represents one of the most ancient and extensively employed metal-forming processes, with historical origins extending several millennia. The technique entails the pouring of molten metal into a refractory mould fabricated principally from sand, within which a cavity corresponding to the required component geometry has been formed. The enduring popularity of sand casting derives from its exceptional versatility, economic viability, and capacity to produce intricate geometries across a broad spectrum of metals and alloys. It continues to occupy a pivotal position in contemporary manufacturing, particularly within the automotive, aerospace, and construction sectors (Campbell *et al.,* 2003).

Key properties of moulding sands that govern casting performance include refractoriness, permeability, cohesiveness, collapsibility, grain size distribution, and grain morphology. Commonly utilised sands encompass green sand, dry sand, chemically bonded (resin) sand, silica sand, zircon sand, and chromite sand. The principal stages of the sand-casting process comprise pattern fabrication, mould preparation, melting and pouring, solidification and cooling, shakeout, and finishing operations.

Organic binders, derived from natural or synthetic polymeric compounds, are widely adopted in foundry practice and related industries. Compared with inorganic binders, they generally offer superior cohesiveness, controlled thermal degradation (collapsibility), enhanced surface finish, improved workability, and reduced energy demand during processing. Starch, a polysaccharide carbohydrate extracted from sources such as rice, wheat, maize, cassava, and potato, constitutes a prominent class of organic binder. Starches are available in native and modified forms; native starch exhibits limitations, including relatively weak binding capacity and poor resistance to elevated temperature and acidic environments. However, physical or chemical modification can substantially enhance water retention, thermal stability, binding strength, and viscosity, thereby rendering it suitable for demanding applications such as foundry moulding (Atanda *et al.,* 2014; Aurore *et al.,* 2009).

The omission of binders in sand moulding gives rise to critical deficiencies in mould cohesion and mechanical strength. Binder-free sands lack sufficient green strength, rendering moulds susceptible to collapse, erosion, or distortion during handling, clamping, or metal pouring. Such instability frequently results in casting defects, including misruns, sand inclusions, and dimensional inaccuracy.

Cassava starch presents a compelling alternative to conventional clay or synthetic resin binders. As a biodegradable, renewable, and abundantly available natural polymer, it poses minimal health or environmental risk. When appropriately incorporated and gelatinised, cassava starch forms a robust adhesive gel that confers high green and dry strength, improves mould stability, promotes superior surface finish, and exhibits low gas evolution during metal pouring, thereby reducing porosity-related defects. Its adoption also diminishes dependence on synthetic binders, many of which raise ecological and occupational health concerns (Oyetunji, 2013).

The present investigation employs locally sourced cassava starch as an environmentally benign binder for the production of sand moulds and cores intended for aluminium alloy casting from recycled scrap.

The study aims to evaluate the effectiveness of cassava starch as an organic binder in the preparation of silica sand moulds for aluminium casting by preparing moulding sand mixtures containing varying concentrations of cassava starch, casting aluminium alloy components using these mixtures, determining the moisture content and green compressive strength of the moulded specimens, and assessing the hardness and dry compressive strength of the resulting castings.

Through this systematic approach, the research seeks to provide substantive data on binding efficiency, mould mechanical properties, and casting quality, thereby contributing to the development of more sustainable foundry practices.

## MATERIAL AND METHOD

### Materials

The cassava starch employed in this investigation was sourced from a local processing mill in Samaru Village, Kaduna State, Nigeria. Aluminium alloy for casting was procured in scrap form from a local vendor and subsequently melted before pouring.

### Methods

### Preparation of Moulding Sand:

Silica sand was initially screened through an appropriate sieve to eliminate oversize particles, debris, and other impurities, thereby ensuring a uniform grain-size distribution. The cleaned sand was then oven-dried at 110 °C to remove residual moisture.

Batches of dried silica sand weighing 1000 g each were prepared. Cassava starch was added at three levels, 7.5%, 10.0%, and 12.5% by weight of sand, corresponding to Sample 1, Sample 2, and Sample 3, respectively (Plate 1). The starch was introduced gradually and mixed thoroughly with the dry sand using a mechanical mixer to achieve homogeneous binder dispersion.

A predetermined quantity of water (optimised through preliminary trials) was added incrementally while continuous mulling was performed until the mixture attained a cohesive, mouldable consistency indicative of adequate starch gelatinisation and binding activation. Following mixing, each sand–starch composition was allowed to temper for 30 minutes to permit full hydration and activation of the binder (Adebayo *et al.,* 2020). The resulting moulding sands were subsequently used for specimen fabrication and casting trials.

Plate 1: Sample of moulding sand

### Casting

Cylindrical test specimens (50 mm diameter × 50 mm height) were produced using a split aluminium pattern in accordance with standard foundry practice. The previously prepared starch-bonded silica sands (containing 7.5%, 10.0%, and 12.5% cassava starch by weight) were employed for moulding.

Each moulding sand batch was re-mixed briefly to restore workability, then rammed manually into two-part moulding boxes around the pattern using a hand rammer. Compaction was performed in three successive layers to achieve uniform density and to minimise the risk of weak zones. After striking off excess sand, the pattern was carefully withdrawn, and the resulting mould cavities (Plate 2) were inspected for surface defects, tears, or distortion.

To enhance green strength and reduce moisture content before pouring, the assembled moulds were either air-dried for 24 hours under ambient conditions or gently baked at 120–150 °C for 1–2 hours in a laboratory oven, ensuring that the starch binder was not thermally degraded.

Aluminium alloy scrap was melted in a graphite crucible using a pit-type coke furnace. The melt was superheated to 720 ± 20 °C, degassed with commercial flux, and skimmed to remove dross. Molten metal was then poured at approximately 700–720 °C into the prepared moulds through a simple top-gating system designed to promote smooth filling and minimise turbulence.

Castings were allowed to solidify and cool naturally within the moulds under ambient conditions to reduce thermal stresses. After complete cooling (approximately 2 hours), the moulds were knocked out, and the castings recovered. Gates, risers, and adhering sand were removed mechanically. Minor surface imperfections were eliminated by light grinding or polishing where necessary before subsequent mechanical testing and evaluation (Olawale *et al.,* 2020; Ravi, 2005).

Plate 2: Cast samples in binder/sand formulations.

### Characterisation of the Sample

#### Determination of moisture content

A representative sample of 50 g of each freshly prepared moulding sand was accurately weighed using a digital balance with a precision of 0.01 g. The specimen was subsequently placed in a ventilated laboratory oven maintained at 110 ± 5 °C and dried to constant mass for 24 hours to ensure complete removal of moisture. Upon completion of drying, the crucible and specimen were transferred to a desiccator, allowed to cool to room temperature, and then reweighed.

The percentage moisture content was calculated according to Equation 1:

$$\text{Moisture Content (\%)} = \left(\frac{w_1 - w_2}{w_1}\right) \times 100 \qquad (1)$$

where: $W_1$ = weight of moist sand and $w_2$ = weight of dried sand sample

#### Determination of green compressive strength

Standard cylindrical test specimens (50 mm diameter × 50 mm height) were rammed from each starch-bonded sand mixture in the green (undried) state using a standard AFS specimen tube. Immediately after ramming, each specimen was carefully placed on the loading platform of a Ridsdale–Dietert Universal Sand Strength Machine (or equivalent hydraulic sand-testing apparatus).

A steadily increasing compressive load was applied at a uniform rate until the specimen failed by shearing or collapse. The maximum load sustained by the specimen at the point of failure was automatically recorded by the instrument and expressed in kN/m². Three replicates were tested for each binder composition, and the mean green compressive strength was reported (Ibeh *et al.,* 2020).

### Characterisation of the Workpieces

#### Determination of Compressive Strength

Cylindrical cast aluminium alloy specimens were machined to the dimensions specified in ASTM E9-19 (diameter 12.5 mm, length-to-diameter ratio 2:1). Each prepared test piece was positioned centrally between the platens of a universal testing machine (capacity 100 kN). A compressive load was applied at a constant crosshead speed of 1 mm/min until visible barreling, cracking, or catastrophic failure occurred. The maximum load at failure was recorded, and compressive strength was calculated as equation 2:

$$\sigma_c = \frac{F_{max}}{A_o} \qquad (2)$$

where $\sigma_c$ is the compressive strength (MPa), $F_{max}$ is the maximum applied load (N), and $A_0$ is the original cross-sectional area of the specimen (mm²) (ASTM E9-19).

#### Determination of Hardness

Hardness measurements were performed using a bench-type universal hardness tester equipped with a Rockwell indenter. Test specimens were sectioned from the central region of each casting produced with the respective starch-bonded moulds. Surfaces were sequentially ground with 240–1200 grit SiC papers and polished to a 1 µm finish to ensure flatness and remove surface defects.

Rockwell hardness testing was conducted using the HRB scale (1.588 mm diameter steel ball indenter, minor load 10 kgf, major load 100 kgf). A minimum of five indentations were made on each specimen, spaced at least three indentation diameters apart and no closer than 2 mm from the edge. Hardness values were read directly from the instrument dial, and the arithmetic mean and standard deviation were calculated and reported (Ochulor *et al.,* 2019).

## DISCUSSION AND RESULTS

### Determination of Moisture Content

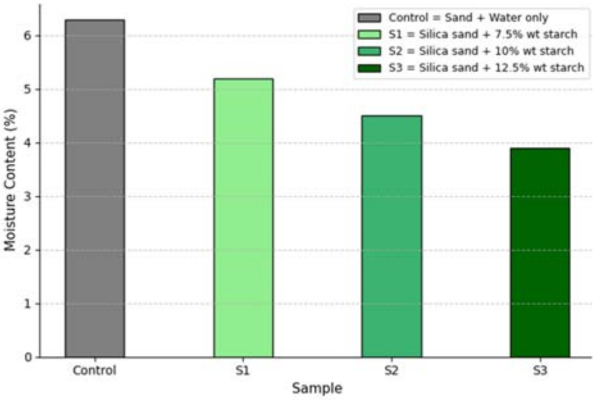

Figure1; Moisture content of sand sample with varying starch composition.

### Moisture Content

Figure 1 illustrates the variation in moisture content of the moulding sand with increasing cassava starch addition. The control sample (0 % starch) recorded the highest moisture content of 6.3 %. Upon incorporation of starch, the moisture content decreased progressively from 5.2 % at 7.5 wt% starch (Sample S1), to 4.3 % at 10.0 wt% starch (Sample S2), and further to 3.9 % at 12.5 wt% starch (Sample S3).

This downward trend is attributed to the hydrophilic nature and gelatinisation behaviour of cassava starch, which absorbs a significant portion of the mixing water and forms a cohesive gel network around sand grains. Higher starch concentrations result in more extensive particle coating, reduced interstitial void volume, and consequently lower retention of free water within the mould. A comparable reduction in moisture content with increasing starch binder has been reported by Ochulor et al. (2019), who noted enhanced water-binding capacity and reduced permeability in cassava starch-bonded sands. All measured values lie within the recommended range of 3–6 % for green sand moulds intended for non-ferrous casting, thereby confirming the suitability of the prepared mixtures for aluminium pouring (Ochulor *et al.,* 2019).

### Green Compressive Strength

Green compressive strength tests were performed on cylindrical specimens rammed from the three starch-bonded sand compositions (S1, S2, and S3) and the binder-free control. The primary objective was to quantify the influence of starch concentration on the wet-state cohesion and load-bearing capacity of the moulding sand, properties that are critical to mould stability during pattern withdrawal, mould assembly, and molten metal pouring. Figure 2 presents the results, which reveal a pronounced optimum in green compressive strength at 10.0 wt% starch addition (Sample S2). The control sample exhibited negligible strength (<5 kN/m²), highlighting the essential role of a binder in developing inter-particle bonding. Strength increased to 27.0 kN/m² at 7.5 wt% starch, reached a maximum of 30.6 kN/m² at 10.0 wt%, and then declined sharply to 17.0 kN/m² at 12.5 wt% starch.

The initial rise reflects improved adhesion provided by gelatinised starch bridges between sand grains. The subsequent fall at higher binder levels is ascribed to excessive starch forming a thick, continuous film that restricts sand-to-sand contact, reduces permeability, and impedes effective compaction. These findings align closely with previous studies on starch-bonded systems, confirming that an optimal binder content of approximately 10 wt% yields maximum green strength while preserving adequate permeability for gas escape during casting (Ochulor *et al.,* 2019; Seidu & Kutelu, 2017).

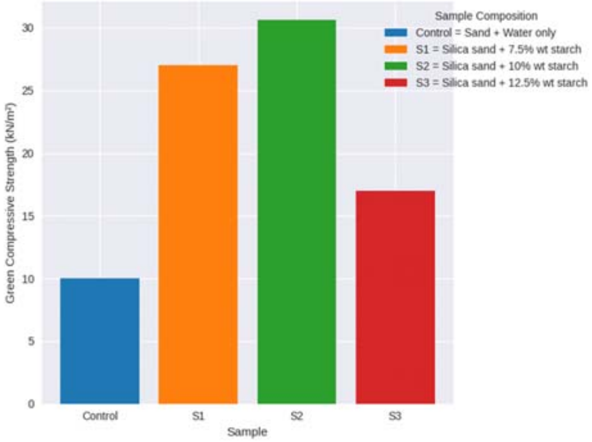

Figure 2: Effect of starch content on the green compressive strength.

Figure 2 illustrates the variation of green compressive strength with cassava starch content. The binder-free control sample exhibited the lowest strength (approximately 10 kN/m²), reflecting the near-absence of cohesion in unbound silica sand. Upon addition of starch, strength increased substantially to 27.0 kN/m² at 7.5 wt% (Sample S1) and reached a maximum of 30.6 kN/m² at 10.0 wt% (Sample S2). This marked enhancement is attributed to the formation of strong adhesive starch gel bridges between sand grains, which provide effective particle-to-particle bonding in the moist state. The observed behaviour is consistent with findings reported by Joshua and Akande (2022).

At 12.5 wt% starch (Sample S3), however, green compressive strength declined sharply to 17.0 kN/m².

This reduction is ascribed to excessive binder coating, which creates a thick, continuous starch films that hinder direct sand–sand contact, reduce effective compaction, and impair gas permeability. The characteristic rise to an optimum followed by a decline at higher binder levels has been widely documented in organic binder systems and aligns closely with the results of Ochulor et al. (2019) and Muhammad and Arogundade (2022). All starch-containing samples achieved green compressive strengths within or above the recommended range of 15–35 kN/m² for green sand moulds used in aluminium casting, confirming their practical suitability.

### Hardness of Cast Aluminium Specimens

Hardness measurements were conducted on aluminium alloy castings produced from moulds prepared with the three starch-bonded sand compositions (S1, S2, and S3) and the control. The objective was to evaluate the influence of binder content and consequent mould rigidity on the microstructure and mechanical properties of the solidified metal.

For each casting, a minimum of five Rockwell B-scale indentations were performed on polished surfaces, and the mean hardness values are presented in Figure 3. Hardness followed a trend similar to that of green compressive strength: the control casting displayed the lowest value (9.8 HV), while hardness increased to 10.9 HV at 7.5 wt% starch (S1), peaked at 12.4 HV at 10.0 wt% starch (S2), and stabilised or slightly decreased at higher binder addition (S3).

The improvement observed at the optimum binder level is attributed to enhanced mould stability and higher compaction pressure during ramming, which minimises metal penetration into sand interstices, reduces surface roughness, and promotes more uniform heat extraction. These factors collectively contribute to a finer dendritic structure and fewer casting defects, thereby elevating hardness. The results corroborate earlier studies indicating that superior mould integrity directly translates into improved mechanical properties of non-ferrous castings (Ochulor *et al.*, 2019; Joshua & Akande, 2022).

Figure 3 demonstrates the influence of cassava starch binder content on the Vickers hardness (HV) of the aluminium alloy castings. The control casting (0 % starch) exhibited the lowest hardness of 9.8 HV, a consequence of inadequate mould cohesion, uneven compaction, and non-uniform heat extraction during solidification, which collectively promote coarse dendritic structures and surface defects.

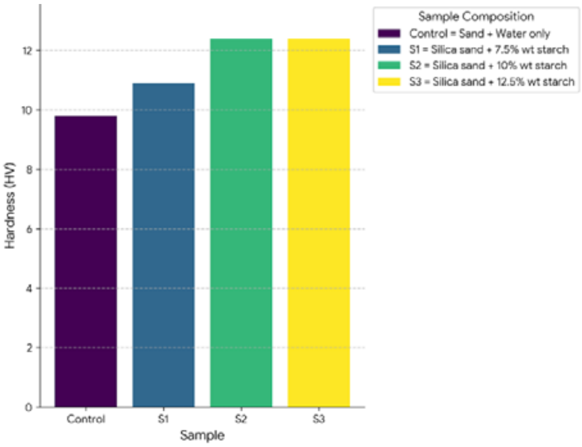

Figure 3: Hardness of Aluminium Alloy Castings for different samples.

Hardness increased progressively with starch addition, reaching 10.9 HV at 7.5 wt% (S1) and a maximum of 12.4 HV at 10.0 wt% (S2). This enhancement is attributed to superior mould rigidity and more effective ramming afforded by the optimally gelatinised starch binder, resulting in smoother mould walls, reduced metal penetration, and more consistent cooling rates—factors that refine microstructure and minimise internal defects. These observations are in close agreement with Ochulor et al. (2019).

At 12.5 wt% starch (S3), hardness plateaued or marginally decreased rather than continuing to rise. The absence of further improvement is attributed to excessive binder, which generates higher volumes of decomposition gases during pouring, resulting in minor porosity and slight degradation of surface and subsurface integrity. This phenomenon has been similarly reported by Ochulor et al. (2019) and Muhammad and Arogundade (2022), who established that the mechanical properties of castings produced in starch-bonded moulds typically peak between 6 and 10 wt% binder, beyond which additional binder yields diminishing or negative returns due to gas entrapment and impaired permeability.

### Compressive Strength of Cast Aluminium Specimens

Compressive strength tests were conducted on machined cylindrical specimens extracted from aluminium alloy castings produced using the control and the three starch-bonded mould formulations (S1, S2, and S3). The primary aim was to quantify the extent to which binder-induced improvements in mould stability and thermal characteristics influence the load-bearing capacity of the solidified metal.

Results are presented in Figure 4. The control casting displayed the lowest compressive strength, whereas strength rose steadily from 34.0 MPa at 7.5 wt% starch (S1) to a peak of 35.2 MPa at 10.0 wt% starch (S2). At 12.5 wt% starch (S3), compressive strength declined to approximately 30 MPa. The optimum observed at 10 wt% reflects the combined benefits of maximum mould rigidity, minimal gas-related porosity, and refined grain structure achieved at this binder level. The reduction beyond the optimum is consistent with the hardness trend and is attributable to increased porosity arising from decomposition of excess starch during metal pouring. These findings reinforce earlier conclusions that cassava starch, when employed at approximately 10 % by weight, delivers castings of superior mechanical performance compared with both binder-free and over-bonded systems (Ochulor *et al.,* 2019; Muhammad & Arogundade, 2022).

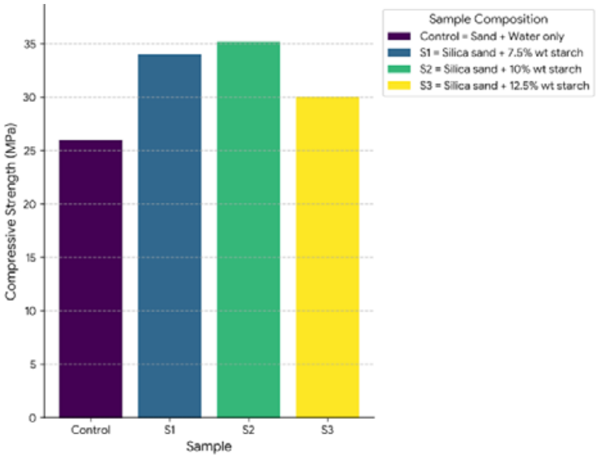

Figure 4 Effect of starch content on the compressed strength of aluminium cast.

Figure 4 illustrates the variation in compressive strength of the aluminium alloy castings as a function of cassava starch binder content. The control casting, produced in a binder-free mould containing only silica sand and water, exhibited the lowest compressive strength owing to poor mould cohesion, inadequate green strength, and pronounced metal penetration, all of which contributed to defective microstructure and reduced load-bearing capacity.

With the introduction of starch, compressive strength increased to 34.0 MPa for Sample S1 (7.5 wt% starch) and reached a maximum of 35.2 MPa for Sample S2 (10.0 wt% starch), corresponding to an improvement of approximately 3.5–4 % relative to the lower binder level and a substantially greater enhancement over the control. This peak performance is ascribed to the superior mould stability, superior surface finish, and more uniform heat extraction afforded by the optimally gelatinised starch binder. These factors promote denser packing, minimise surface and subsurface defects, and facilitate finer dendritic arm spacing during solidification.

At 12.5 wt% starch (Sample S3), compressive strength declined markedly to 30.0 MPa. The reduction is attributed to excessive binder and retained moisture, which generate higher volumes of decomposition gases during pouring, thereby inducing micro-porosity and weakening the casting. This characteristic rise-to-optimum followed by a decline at higher binder concentrations is fully consistent with the observations of Muhammad and Arogundade (2022), who highlighted the critical importance of maintaining an optimal starch-to-sand ratio to avoid deterioration of both mould and casting properties.

The superior performance of starch-bonded moulds is further corroborated by Ochulor *et al.* (2019), who reported that cassava starch systems yielded the highest compressive and shear strengths among several natural binders examined. They attributed the enhancement to strong intermolecular hydrogen bonding in the green state and to the formation of a thin, adherent carbon film upon thermal decomposition of the starch, which further restricts metal penetration and improves surface integrity. The present results, therefore, confirm that cassava starch, when used at approximately 10 wt%, constitutes an effective and sustainable binder for producing aluminium castings of enhanced mechanical performance.

## CONCLUSION

Cassava starch was evaluated as an eco-friendly organic binder for silica sand moulds in aluminium sand casting. Moulding sands containing 7.5%, 10.0%, and 12.5% cassava starch by weight, together with a binder-free control, were prepared and tested. Results revealed that increasing starch content progressively reduced moisture content. Green compressive strength, casting hardness, and compressive strength all reached clear maxima at 10 wt% starch (30.6 kN/m², 12.4 HV, and 35.2 MPa, respectively), significantly outperforming both the control and the other starch levels. Beyond 10 wt%, excess binder impaired permeability and caused a sharp decline in properties. Cassava starch at an optimum concentration of approximately 10% by weight proved to be a highly effective, biodegradable, and renewable binder that enhances mould stability, reduces defects, and improves the mechanical performance of aluminium castings while offering substantial environmental and health benefits over conventional synthetic binders. The study supports the adoption of locally sourced cassava starch as a sustainable alternative in foundry practice.

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