Effect of Calcination Temperature on the Fresh and Physical Properties of Locust Bean Pod Ash-Blended Cement Paste and Concrete

[1]Tyogo M., [2]Bala I. M., and [3]Iorshagher, A. S.
[1]Department of Civil Engineering, Joseph Sarwuan Tarka University, Benue State, Nigeria
[2]Department of Civil Engineering, Nasarawa State University, Keffi, Nigeria
[3]Department of Civil Engineering, Federal University Otuoke, Bayelsa State, Nigeria
manassehtyogo@gmail.com

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ORIGINAL RESEARCH

Abstract—The high cost and environmental impact of Portland cement have motivated the use of agricultural pozzolans as partial replacements for clinker. However, their performance depends largely on production conditions, particularly calcination temperature. This study investigated the effect of calcination temperature on the fresh and physical properties of cement paste and concrete containing 5% locust bean pod ash (LBPA) as a partial cement replacement. LBPA was calcined for 2 hours at 400, 500, 600, and 700 °C. The specific gravity and fineness of the materials, together with the standard consistency, initial and final setting times, and soundness of the cement pastes, were determined in accordance with relevant British and ASTM standards. Fresh concrete workability was evaluated using slump and compacting factor tests, and the percentage change in each property relative to the control mix was determined. Incorporating LBPA increased the water demand of the cement paste by 48-59% and prolonged the initial setting time by 67-160%, with both parameters increasing as the calcination temperature rose to 600 °C. Despite the higher water demand, concrete workability improved, with the maximum slump of 25 mm and compacting factor of 0.94 achieved at 600 °C. All blended cement pastes remained sound, exhibiting Le Chatelier expansions below 1.10 mm and meeting standard-setting time requirements. Overall, LBPA calcined at 600 °C produced the most favourable balance of fresh and physical properties, indicating its suitability as an effective supplementary cementitious material.

Keywords— Calcination temperature, Locust bean pod ash, Soundness, Supplementary cementitious materials, Setting time, Workability.

1 INTRODUCTION

The production of Portland cement is energy-intensive and contributes between five and eight per cent of global anthropogenic carbon dioxide emissions, a share that continues to grow with rapid urbanisation in developing economies (Juenger & Siddique, 2015; Gartner & Sui, 2018). Replacing part of the clinker with a supplementary cementitious material is among the most readily available means of reducing both the cost and the embodied carbon of concrete, and where conventional supplements such as fly ash, slag and silica fume are scarce, agro-industrial residues rich in silica and alumina offer a locally sourced alternative that also diverts a waste stream from disposal (Paris et al., 2016; Aprianti, 2017; Raheem & Ikotun, 2020).

Locust bean pod ash, obtained from the empty pods of the African locust bean tree, is an abundant residue across the West African sub-region, produced in large quantities during fruit processing. A number of studies have confirmed that the ash is pozzolanic and can partially replace cement in mortar and concrete, typically at five to fifteen percent (Ndububa & Uloko, 2015; Ikumapayi, 2016; Ojewumi et al., 2017; Olubajo et al., 2020; Kilani et al., 2025). Most of this attention has been directed at hardened strength, yet the practical acceptability of a blended cement depends just as much on its fresh and physical behaviour, because a binder that demands excessive mixing water, sets too quickly or too slowly, or proves unsound is difficult to use on site, whatever its ultimate strength.

The fresh and physical properties of a blended binder are sensitive to the fineness, surface texture and residual carbon content of the ash, all of which are governed by the calcination temperature (Snellings, 2016; Thomas, 2018; Juenger, Snellings and Bernal, 2019; Bonifacio and Archbold, 2022; Qi et al., 2022). A finer, more reactive ash requires more mixing water and tends to retard setting, while incompletely burnt ash may carry unburnt carbon, which increases water demand and impairs workability. Because these effects act in different directions and each varies with temperature, the calcination temperature that yields the best fresh and physical performance cannot be assumed in advance and must be established experimentally (Akpenpuun et al., 2019).

A further consideration is that the change a pozzolan imposes on the fresh state is rarely uniform across properties. The same fine ash that sharply increases water demand may improve the cohesiveness and flow of fresh concrete, so that workability and water demand move in opposite directions; quantifying

Corresponding Author: manassehtyogo@gmail.com
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the magnitude of each change, rather than merely its direction, is therefore necessary to judge whether a given calcination temperature is acceptable in practice. Studies on other agricultural residues confirm that calcination temperature is a first-order variable in this sense rather than a secondary detail. Zaffar et al. (2022) calcined rice husk, wheat straw and cow dung at 300, 600 and 800 °C and found that 600 °C consistently produced the most reactive silica across the three feedstocks, whereas Pantić et al. (2023) showed that the fresh-state performance of corn cob ash mortars depends jointly on calcination-driven fineness and the water-to-binder ratio, so that the two variables cannot be optimised in isolation. Similarly, Adhikary, Ashish and Rudžionis (2022) and Sathiparan, Anburuvel and Selvam (2023) note in their reviews of straw, husk and shell ashes that inconsistent reporting of calcination conditions is a recurring weakness of the agricultural-ash literature, which limits the transferability of conclusions between studies and reinforces the case for treating calcination temperature as an explicit, controlled variable, as done here.

This paper examines how the calcination temperature of locust bean pod ash, varied over 400, 500, 600 and 700 °C, affects the physical properties of the constituent materials and the fresh properties of paste and concrete containing five per cent ash, namely the standard consistency, the initial and final setting times, the soundness, the slump and the compacting factor. In addition to the measured values, the change in each property relative to the control is quantified so that the magnitude of the ash's effect can be compared across properties. The aim is to identify the calcination temperature that yields the most workable, physically sound blended cement, complementing companion studies on the reactivity and hardened strength of the same material.

Investigations of locust bean pod ash as a cement replacement have consistently reported that the ash is pozzolanic, but that its incorporation modifies the binder's fresh state. Ndububa and Uloko (2015) and Ikumapayi (2016) established the pozzolanic character of the ash in concrete and noted the slower early strength typical of pozzolanic blends, an effect attributable to retardation of setting. Ojewumi et al. (2017) characterised the pozzolanic properties of pod waste and highlighted the role of preparation conditions in determining reactivity. More recent work continues to confirm the ash's pozzolanic character across different concrete systems: Isa et al. (2023), reviewing the accumulated literature on locust bean pod ash in concrete and mortar, place the effective replacement range at five to fifteen per cent, consistent with the level examined here, while Ya'u et al. (2025) and Melendrez Llontop et al. (2025) report, respectively, that the ash's incorporation raises fresh-concrete slump at low replacement levels and can be combined with silica fume without loss of mechanical performance, extending the evidence base beyond the mortar- and paste-level studies on which most of the earlier literature rests.

Studies that examined mortar and paste properties more directly have reported increases in water demand and setting time when ash is added. Akpenpuun et al. (2019) found that the mechanical and structural characteristics of locust bean pod ash mortars depended on both the proportion and the processing of the ash, and Olubajo et al. (2020) showed that the strength of locust bean pod ash blends, and by implication the fresh behaviour that precedes it, is optimised only within a limited range of ash content and treatment. Comparable trends have been documented for related agricultural ashes, in which finer, more reactive ashes increase water requirements, lengthen setting times, and improve cohesiveness (Aprianti, 2017; Thomas, 2018; Charitha et al., 2021; Thomas et al., 2021).

Martirena and Monzó (2018) attribute this pattern across vegetable ashes generally to the combined effect of fine particle size and residual organic carbon, both of which are themselves products of the calcination regime, which underscores why the temperature at which an ash is produced, rather than the ash type alone, is central to its fresh-state behaviour.

The influence of calcination or combustion temperature on these properties has been studied for several biomass ashes, but only sparingly for locust bean pod ash. The general finding for agricultural pozzolans is that reactivity, and therefore water demand and setting behaviour, rises with temperature up to a point beyond which the silica crystallises and the effects diminish (Snellings, 2016; Juenger, Snellings and Bernal, 2019; Raheem & Ikotun, 2020). Most existing work on locust bean pod ash, however, fixes the burning condition and varies the replacement level, leaving the systematic effect of calcination temperature on the fresh and physical properties largely unquantified.

The present study addresses that gap by holding the replacement level and dwell time constant, varying only the calcination temperature, and reporting not just the measured fresh and physical properties but also the magnitude of their change relative to a plain control. This provides a clearer basis for selecting a calcination temperature than single-treatment measurements alone.

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2 MATERIALS AND METHODS

2.1 Materials

Ordinary Portland cement of the CEM I type conforming to BS EN 197-1 was used as the reference binder and stored under dry conditions. Locust bean pods were collected as an agricultural waste from rural communities in Benue, Nasarawa and Kaduna States, Nigeria. Sharp, well-graded river sand from the River Benue at Makurdi was used as fine aggregate and crushed granite of 20 mm nominal maximum size as coarse aggregate, both air-dried before use. Potable water conforming to BS EN 1008 was used for mixing and curing.

2.2 Preparation of the ash

The pods were burnt in the open air to remove the bulk of the combustible matter, and the resulting char was calcined in an electric muffle furnace for a fixed dwell time of 2 hours at each of four target temperatures: 400, 500, 600, and 700 °C, to isolate the effect of temperature. After calcination, the ash was cooled, ground to a fine powder, passed through a 75 μm sieve, and stored in airtight containers prior to use.

2.3 Mix proportioning and specimen preparation

Concrete was proportioned by the absolute-volume method for a target 28-day cube strength of 25 N/mm² at a water-to-cement ratio of 0.58. A control mix containing only cement and four blended mixes, each replacing 5% of the cement by mass with one of the calcined ashes, were prepared; for the blends, the ash and cement were weighed proportionally and intimately dry-mixed before the aggregates and water were added. Pastes for the consistency, setting time, and soundness tests were prepared using the same binder combinations.

2.4 Physical-property tests

The specific gravity of the cement, ash, and aggregates was determined in accordance with BS EN 1097-6 and the relevant parts of BS 812, and the fineness of the cement and ash was determined from the residue retained on a 45 μm sieve. The aggregate crushing value, aggregate impact value, and flakiness index of the coarse aggregate were determined in accordance with BS 812. Each physical property was measured on at least three samples, and the mean was reported.

2.5 Fresh-property tests

The standard consistency and the initial and final setting times of the cement–ash pastes were measured with the Vicat apparatus in accordance with BS EN 196-3, and soundness by the Le Chatelier method to the same standard. On the fresh concrete, workability was characterised by the slump test to BS EN 12350-2 and the compacting factor test to BS 1881-103, the two methods providing complementary measures of consistence and compactability.

2.6 Data analysis

To compare the magnitude of the ash's effect across properties that are measured in different units, the change in each fresh property of a blend relative to the control was computed as a percentage, $100\times(X_b - X_c)/X_c$, where X_b and X_c are the blend and control values of the property. This relative change is reported alongside the measured values so that water demand, setting time, and workability can be placed on a common basis and their trends with calcination temperature can be compared directly.

3. RESULTS AND DISCUSSION

3.1. Physical properties of the constituent materials

3.1.1 Materials Properties

The measured physical properties of the constituents are given in Table 1. The specific gravity of the ash (2.94) is close to that of the cement (3.02) and slightly above that of the aggregates, so the 5% replacement makes only a negligible change to the density and the absolute-volume proportioning of the mix. The ash is marginally coarser than the cement, with a 45 μm sieve residue of 0.056, compared with 0.026, consistent with ground biomass ash and fine enough to participate in the binding system while accounting for part of the increased water demand discussed below. The coarse aggregate met the usual mechanical-quality limits; its crushing and impact values (21.5 and 20.5 per cent, respectively) and flakiness index (16.4 per cent) all lie within the ranges specified for structural concrete.

Table 1. Physical properties of the constituent materials

Property	Cement	LBPA	Sand	Granite
Specific gravity	3.02	2.94	2.68	2.70
Fineness (45 μm residue)	0.026	0.056	–	–
Crushing value (%)	–	–	–	21.5
Impact value (%)	–	–	–	20.5
Flakiness index (%)	–	–	–	16.4

Because the specific gravity of the ash is slightly lower than that of the cement it replaces, an equal mass of binder occupies a marginally larger volume, so the five percent blend yields a very slightly greater paste volume and a correspondingly lower fresh density than the control. At this replacement level the change is well within normal batching tolerance and does not require the mix to be re-proportioned, but it would become significant at higher replacement levels and should be allowed for when the ash content is increased.

3.1.2 Standard consistency and water demand

The standard consistency of the pastes is shown in Figure 1. Replacing five percent of the cement with

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ash raised the water demand sharply, from 29 percent for the control to between 43 and 46 percent for the blends, the demand increasing with calcination temperature to a maximum of 46 percent at 600 °C before easing to 43 percent at 700 °C. The higher water requirement reflects the greater fineness and surface area that the ash introduces relative to cement, since finer particles present more surface to be wetted, and is reinforced at the lower calcination temperatures by residual unburnt carbon, which is porous and water-absorbing. The slight reduction at 700 °C is consistent with the particle coarsening and incipient sintering that accompany the highest calcination temperature. Although appreciable, the increase is within the range expected for a five percent biomass-ash replacement and can be moderated with a water-reducing admixture where a lower water demand is required.

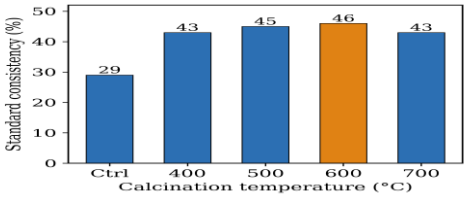

Fig. 1. Standard consistency of the pastes against calcination temperature.

3.1.3 Setting times

The initial and final setting times are shown in Figure 2. Both lengthened substantially relative to the control: the initial set rose from 73 minutes for the control to between 122 and 190 minutes for the blends, and the final set from 193 to between 342 and 397 minutes, each increasing with calcination temperature up to 600 °C and easing marginally at 700 °C. The retardation follows from the partial replacement of rapidly hydrating clinker by a slower-reacting pozzolan, which lowers the early heat of hydration and delays the development of a rigid paste structure, and is reinforced by the higher water demand of the blends. Every paste nevertheless satisfied the BS EN 197-1 requirements for an initial set of at least 45 minutes and a final set within 600 minutes. A moderate extension of the setting time is, in fact, advantageous in the region's hot climate, as it allows more time for transporting, placing, and finishing the concrete before stiffening begins.

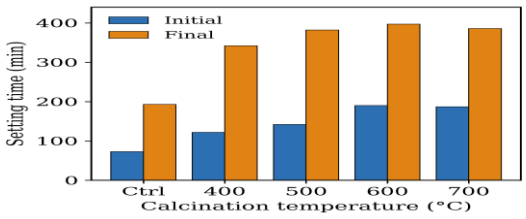

Fig. 2. Initial and final setting times against calcination temperature.

3.1.4 Soundness

The Le Chatelier soundness values are given in Table 2. The expansions were small and uniform, ranging only from 1.04 to 1.10 mm and lying far within the 10 mm limit of BS EN 197-1. The low and stable expansion confirms that the ash introduces no deleterious free lime or magnesia and that the blended binders are volumetrically stable at every calcination temperature. Volumetric stability is a prerequisite for durable concrete, and its retention across the entire temperature range allows the calcination temperature to be selected based on consistency and workability without penalty to soundness.

Table 2. Le Chatelier's soundness of the pastes

Binder	Expansion (mm)	Limit
Control (0%)	1.07	≤ 10 mm
5% @ 400 °C	1.04	≤ 10 mm
5% @ 500 °C	1.07	≤ 10 mm
5% @ 600 °C	1.10	≤ 10 mm
5% @ 700 °C	1.08	≤ 10 mm

3.2 Fresh Properties

3.2.1 Workability of fresh concrete

The slump and compacting factor of the fresh concrete are shown in Figure 3. Despite the higher paste water demand, the workability of the blended concrete equalled or exceeded that of the control: the slump rose from 18 mm for the control to a peak of 25 mm at 600 °C, and the compacting factor from 0.90 to 0.94 at 600 °C, both falling back at 700 °C. The two measures are mutually consistent and indicate that, at 600 °C, fine ash particles improve the cohesiveness and mobility of the fresh mix, acting as a lubricating filler. The 400 °C blend recorded the lowest compacting factor, 0.88, in keeping with the coarser, carbon-bearing character of the low-temperature ash, which hinders particle packing. The improvement at 600 °C is achieved without segregation, so the paste's higher water demand is accommodated by the natural lubricating action of the fine ash rather than by additional free water.

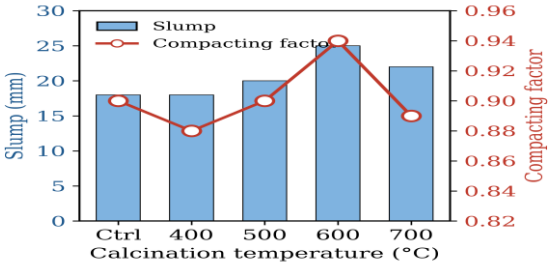

Fig. 3. Slump and compacting factor of the fresh concrete against calcination temperature.

3.2.2 Relative change in the fresh properties

Expressing each fresh property as a percentage change from the control places the three effects on a common basis, as summarised in Table 3 and plotted in Figure 4. The water demand increased by a

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comparatively uniform 48 to 59 percent across the blends, whereas the setting times were far more sensitive to calcination temperature: the initial set increased by only 67 percent for the 400 °C ash but by 160 percent for the 600 °C ash, and the final set by 77 to 106 percent over the same range. The slump, by contrast, changed little at low temperature and rose by 39 percent only at 600 °C. The disparity shows that calcination temperature exerts its strongest leverage on the setting behaviour, a moderate and beneficial leverage on workability, and a relatively flat effect on water demand, which is useful in practice because it means the additional water requirement does not escalate sharply with temperature.

Table 3. Change in the fresh properties of the blends relative to the control (%)

Temp (°C)	Water demand	Initial set	Final set	Slump
400	+48.3	+67.1	+77.2	0.0
500	+55.2	+94.5	+97.9	+11.1
600	+58.6	+160.3	+105.7	+38.9
700	+48.3	+156.2	+100.0	+22.2

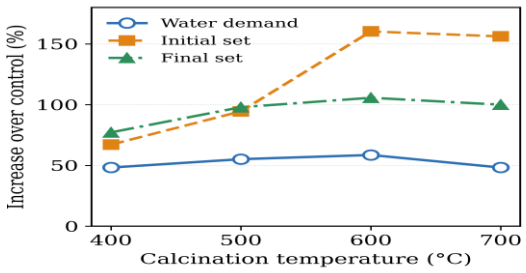

Fig. 4. Percentage increase of water demand and setting times over the control against calcination temperature.

3.2.3 Interrelationship of the fresh properties

The four fresh measurements are not independent but trace a single underlying cause. The same fineness and surface activity that raise water demand also retard setting and, in fresh concrete, improve cohesiveness and flow, so that water demand, setting time, and workability all peak together at 600 °C. This coherence is important for interpretation: the high water demand at 600 °C is not a sign of a poor mix but rather the fresh-state signature of the most surface-active ash, and it is accompanied, rather than penalised, by the best workability and the longest, most controllable setting time. The behaviour at 700 °C, where every property eases back, is the corresponding signature of a coarser, partly sintered ash. Reading the properties together therefore gives a more reliable indication of the optimum than any single property alone.

3.3. Previous studies

The trends observed here are broadly consistent with the wider literature on locust bean pod ash and related agricultural pozzolans, although the comparison should be read with some caution because few of the earlier studies-controlled calcination temperature explicitly. Increases in water demand and setting time on incorporating the ash, and the retention of soundness at low replacement levels, are consistent with the mortar and paste behaviour reported by Akpenpuun et al. (2019) and Olubajo et al. (2020), and the slow setting echoes the slow early strength noted by Ndububa and Uloko (2015) and Ikumapayi (2016); Isa et al. (2023) similarly conclude, from a review of the broader locust bean pod ash literature, that a five to fifteen per cent replacement range consistently produces workable, adequately setting mixes, which agrees with the present findings at the lower end of that range. The improvement in workability with a fine pozzolan, rather than the deterioration that a simple increase in water demand might suggest, is consistent with the filler and lubrication effects observed for other biomass ashes (Aprianti, 2017; Thomas, 2018), and with the slump increase that Ya'u et al. (2025) report for locust bean pod ash concrete at low replacement levels; it is worth noting, however, that not every agricultural ash behaves this way, since Anitha and Senthil Selvan (2024) and Krishnan and Subramanian (2025) both report reduced workability with green gram pod ash and pigeon pea stalk ash respectively, so the lubricating effect identified here should be treated as a property of this particular ash and calcination regime rather than a general rule for agricultural pozzolans. The present results add to that body of work by isolating calcination temperature as an explicit, controlled variable and quantifying the relative sensitivity of each fresh property to it, a treatment that is closer to the controlled calcination studies of Zaffar et al. (2022) and Bonifacio and Archbold (2022) on other agricultural ashes than to most of the single-treatment locust bean pod ash studies published to date, though the present dataset remains limited to one replacement level and one dwell time, a constraint discussed further in Section 3.6.

3.4 Practical implications

For field use, the results suggest, within the fresh- and physical-property scope of this study, that locust bean pod ash calcined at 600 °C can be incorporated at five percent without impairing the fresh quality of the concrete: the mix is more workable than the plain control, remains sound, and sets within standard limits with a useful margin for placing in hot weather. This conclusion is necessarily provisional, since it does not by itself establish suitability for service, which also depends on the hardened strength and durability addressed in the companion studies and in Section 3.6. The chief practical adjustment indicated by the present data is the higher demand for mixing water, which is best met

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with a water-reducing admixture so that the water-to-cement ratio and, hence, the hardened strength are not compromised. Because the ash is a locally abundant agricultural residue, its use in place of a corresponding fraction of cement would also be expected to lower cement demand and the associated embodied carbon of the concrete, a benefit reported for comparable agricultural ashes by Charitha et al. (2021) and Thomas et al. (2021), which may make it attractive for low-rise and rural construction across the producing region, subject to confirmation by the durability testing recommended in Section 5.

In proportioning terms, the additional water indicated by the standard consistency should not simply be added as free water, since that would raise the water-to-cement ratio and depress strength; instead, a normal dosage of a water-reducing or plasticising admixture can restore the target consistency at the design water-to-cement ratio of 0.58. The longer setting time should be seen as an opportunity rather than a defect, as it eases the placement and finishing of larger pours in warm conditions. However, in cooler weather or where rapid form turnaround is needed, the retardation should be checked against the construction programme. Quality control on site can rely on the same slump and compacting factor checks used for plain concrete, with target values set in accordance with Figure 3.

3.5 Overall assessment

Taken together, the fresh and physical results point to 600 °C as the most favourable calcination temperature within the range examined. At this temperature, the ash gave the most workable concrete, with the highest slump and compacting factor, while the paste remained sound and within the setting-time limits; the accompanying rise in water demand is comparatively modest (48–59 per cent across the blends, Table 3), whereas the rise in setting time is substantial, reaching 160 per cent for the initial set at 600 °C. This is a large relative change and should not be understated, but because every blend still satisfied the BS EN 197-1 setting-time limits, the effect is, in this context, an operational benefit rather than a defect. The decline in workability at 700 °C and the poorer packing of the 400 and 500 °C blends place the optimum near 600 °C. These fresh and physical findings are consistent with, and provide a practical complement to, the companion studies on the reactivity and the hardened strength of the same ash, which independently identify 600 °C as favourable; the agreement across three separate property groups strengthens the case for that temperature, though it should be confirmed at other replacement levels before it is generalised.

3.6 Limitations and Further Work

Four limitations should be borne in mind when applying these findings. First, the replacement level was fixed at 5 per cent, and the calcination dwell time at 2 hours, so the interaction between calcination temperature, replacement level, and dwell time, which may shift the optimum, was not explored. Second, the study addressed only the fresh and physical properties; the hardened strength and the reactivity of the same ash are reported in companion studies, and the durability of the blended concrete, including water absorption, sorptivity and resistance to aggressive ions, was outside the present scope yet is decisive for service life. Third, the ash fineness was controlled only by sieving through 75 μm and was not independently varied, although fineness strongly influences both water demand and setting. Fourth, the fresh-property values reported in Section 3.2 are single determinations per mix rather than replicated means with reported variability, unlike the physical-property tests in Section 2.4, which were run in triplicate; the trends across calcination temperature are therefore best read as indicative rather than as differences established to a stated level of statistical confidence, and a replicated fresh-property programme would be needed before the 600 °C optimum could be asserted with the same certainty as the physical-property results. Future work should combine factorial variations in calcination temperature, dwell time, and replacement level with controlled grinding to different finenesses, should replicate the fresh-property determinations to allow a proper statistical treatment, and should add a durability programme to confirm the 600 °C recommendation across a wider range of mixes.

4 CONCLUSION AND RECOMMENDATION

The fresh and physical properties of cement paste and concrete containing 5% locust bean pod ash were examined for ash calcined at 400, 500, 600, and 700 °C. The ash's specific gravity was close to that of cement, so the replacement scarcely altered the mix density. Replacing cement with the ash increased the standard consistency from 29 per cent to as much as 46 per cent, a relative rise of 48 to 59 per cent, and lengthened the initial and final setting times by up to 160 and 106 per cent, respectively, both increasing with calcination temperature up to 600 °C. All pastes remained sound, with Le Chatelier expansions of 1.04 to 1.10 mm, and met the BS EN 197-1 setting-time limits. The workability of the concrete

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improved with the ash, the slump and compacting factor reaching maxima of 25 mm and 0.94 at 600 °C before declining at 700 °C. Quantifying the relative changes showed that calcination temperature has the strongest effect on setting time, a moderate, beneficial effect on workability, and a comparatively weak effect on water demand. Within the scope of the fresh and physical properties examined, and subject to the limitations set out in Section 3.6, calcination at 600 °C gave the most workable and physically sound blended cement at the five per cent replacement level tested; this is a fresh- and physical-property finding and is not, on its own, a claim about long-term structural or durability performance.

On the basis of these findings, the following is recommendations were made. For practical use, locust bean pod ash calcined at 600 °C for 2 hours is recommended for a 5% cement replacement, with a water-reducing or plasticising admixture dosed to offset the higher water demand and keep the water-to-cement ratio at the design value. Site quality control should use the same slump and compacting-factor checks as for plain concrete, with target values set with reference to Figure 3, and should allow for the longer, though standard-compliant, setting time when planning placement and formwork turnaround, particularly in cooler weather.

For research, the 600 °C recommendation should first be confirmed with replicated fresh-property measurements reported with their variability, so that differences between calcination temperatures can be assessed to a stated level of statistical confidence rather than from the single determinations used here. The present factorial design should be extended to other replacement levels and calcination dwell times, and to ashes ground to controlled finenesses, since fineness, dwell time and replacement level all interact with calcination temperature in ways that this study, which fixed the latter two, could not capture. Finally, a durability programme covering water absorption, sorptivity and resistance to aggressive ions is recommended before the 600 °C blend is specified for structures in aggressive service environments, since durability lay outside the scope of the present fresh- and physical-property study.

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