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Development and Experimental Evaluation of Agave americana Fibre-Reinforced Concrete Bricks: Effect of Fibre Content on Strength, Workability & Moisture

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ABSTRACT

Concrete is strong in compression but brittle and weak in tension, and plant-based fibres are being explored as sustainable supplementary reinforcement for cement-based products. Cement-based bricks reinforced with Agave americana fibres have received comparatively little attention. This study investigated how Agave americana fibre content affects the properties of M20-grade concrete specimens prepared for brick applications. Retted, alkali-treated fibres cut to approximately 40 mm were incorporated at 0%, 0.25%, 0.50%, 0.75% and 1.0%. Specimens were evaluated by compressive strength, slump, moisture absorption, rebound hammer and ultrasonic pulse velocity (UPV) tests. Compressive strength peaked at 26.08 N/mm² with 0.25% fibre, 25.0% above the control (20.86 N/mm²), and declined to 23.75 N/mm² at 1.0%, which remained 13.9% above the control. Slump rose from 150 mm to 162 mm at 0.25% fibre and fell to 102 mm at 1.0%. Moisture absorption increased steadily from 3.00% to 4.44%, and UPV decreased from 4.32 to 3.81 km/s, although all mixes were classified as good quality. Rebound hammer estimates followed the compressive-strength trend. Within the tested range, 0.25% fibre gave the most favourable combination of strength, workability and limited penalties in absorption and UPV. The results derive from a single series of mixes without replicate statistics, and mix proportions, testing age and long-term durability require further confirmation before practical application.

KEYWORDS: *Agave americana fibre; fibre-reinforced concrete; concrete bricks; compressive strength; moisture absorption; non-destructive testing; sustainable construction materials.*

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INTRODUCTION

Concrete masonry units are widely used in civil construction because they are produced from readily available constituents and provide high compressive strength. Like other cement-based materials, however, they are brittle, weak in tension and susceptible to cracking [1]. Steel reinforcement improves the tensile capacity of structural concrete, but corrosion of embedded steel, which follows carbonation and chloride ingress through permeable concrete, is a major cause of deterioration of reinforced concrete structures. These limitations, together with growing concern about the environmental impact of construction materials, have encouraged research on renewable, low-density reinforcement that can be dispersed throughout the matrix. Plant-based fibres are attractive for this purpose because they are renewable, biodegradable and abundant [2]. When well dispersed, fibres can bridge cracks, restrain crack propagation and improve the tensile and flexural behaviour and toughness of cementitious materials [1,2]. Their effectiveness, however, is governed by fibre type, length, content, surface treatment, dispersion, fibre–matrix bonding and curing conditions. Excessive fibre reduces workability [1] and may enlarge and interconnect pores [3], while the alkaline environment of cement can degrade the mechanical resistance of natural fibres [4]. The optimum fibre content therefore has to be established for each fibre–matrix system.

Agave americana is a leaf-fibre-yielding plant. Its fibres are characterised by low density, high tenacity, biodegradability and high moisture absorbency relative to several other leaf fibres, and the plant can be utilised in a range of applications [5]. *Agave* fibres have been used to reinforce mud–lime concrete [4], adobe [6], cement mortar [7], sand–clay–silt blocks [8] and clay earth bricks [9], and a recent systematic review has summarised their effects on concrete properties [10]. Many of these investigations, however, used soil-based or mortar matrices, and comparatively few have examined *Agave americana* fibre in cement-based concrete bricks.

The present work addresses this gap. *Agave americana* fibres were extracted by retting, treated, cut to approximately 40 mm and incorporated into M20-grade concrete at 0%, 0.25%, 0.50%, 0.75% and 1.0%. The objectives were (i) to prepare concrete specimens reinforced with *Agave americana* fibres; (ii) to determine the effect of fibre content on compressive strength, workability, moisture absorption, rebound-hammer-estimated strength and ultrasonic pulse velocity; and (iii) to identify the most promising fibre content among those tested. The contribution of the work is a consistent experimental data set for 40 mm *Agave americana*

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fibres in cement concrete over a dosage range that the literature identifies as promising [10], combining destructive and non-destructive assessment.

LITERATURE REVIEW AND RESEARCH GAP

1. Natural Fibre-Reinforced Cementitious Composites

Anas and Khan [1] reviewed fibre-reinforced concrete and noted that synthetic or natural fibres can improve tensile strength, flexural strength, crack resistance and durability and can reduce shrinkage cracking, whereas excessive fibre lowers workability, so fibre quantity and distribution must be controlled. In foamed concrete, Castillo-Lara et al. [11] incorporated untreated and alkali-treated henequen, another *Agave*-family fibre, at 0.5–1.5% by volume; the fibres improved compressive and tensile properties and prevented sudden brittle tensile failure, with a larger tensile improvement for treated fibres. Wang and Jin [3] studied basalt, coir and sisal fibres at 0.15–0.45% in foamed concrete; coir gave the largest gain, about 42.19% in compressive strength at 0.3%, whereas excess fibre enlarged pores and increased their connectivity.

2. Agave Fibres in Construction Materials

Table 1 summarises studies on *Agave* fibres in construction matrices. Hachem et al. [4] characterised extracted *Agave americana* fibres (crystallinity index about 41.34%, rough surface) and also cautioned that the alkaline cement environment can reduce fibre durability and mechanical resistance. El Oudiani et al. [7] used analysis of variance and design-of-experiments methods to examine fibre length and alkali treatment in *Agave*/mortar composites. Hulle et al. [5] reviewed *Agave americana* fibre as a sustainable reinforcement in hybrid biocomposites. The systematic review of Linares González et al. [10], covering 45 studies published between 2014 and 2025, of which 29 concerned concrete containing *Agave* fibres, identified a commonly promising range of about 0.25–1.0% fibre by volume with lengths close to 25 mm. It stressed, however, that the optimum depends on the material system and processing conditions, and it noted gaps in treatment standardisation, large-scale application and regulation.

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Table 1: Selected Previous Studies on Agave and Related Natural Fibres in Construction Materials.

Ref.	Matrix	Fibre	Dosage and length	Principal reported outcome
[4]	Mud–lime concrete	*Agave americana*	Horizontal orientation	Up to 99% higher flexural and 86% higher compressive resistance
[11]	Foamed concrete	Henequen, untreated and alkali-treated	0.5–1.5%	Improved compressive and tensile properties; larger tensile gain with treated fibre
[3]	Foamed concrete	Basalt, coir, sisal	0.15–0.45%	Coir best (about 42.19% compressive gain at 0.3%); excess fibre enlarged and connected pores
[6]	Adobe	*Agave* bagasse	0.25–1%; 10–25 mm	Compressive strength +33% and flexural strength +7.01% at 1%, 25 mm
[7]	Cement mortar	*Agave americana*	Length and alkali treatment varied	Length and treatment identified as important variables
[8]	Sand–clay–silt blocks	*Agave americana*	0–1% (by sample weight); 25 mm	Compressive +13.39% at 0.25% (about 2.54 MPa); tensile +39.13% at 1%; flexural +14.29% at 0.5%
[9]	Clay earth bricks	*Agave americana*	2–6% by dry soil mass	Compressive strength about 1.26 to 2.45 MPa (about 94%) at 4%; lower thermal conductivity

3. Influence of Fibre Content, Length, Treatment, Bonding and Workability

Favourable results are usually obtained within controlled dosage ranges rather than by continuously increasing fibre content [3,10]. Fibre length governs stress transfer and dispersion: short fibres offer limited crack bridging, whereas very long fibres complicate mixing. Most *Agave* studies cited above used about 25 mm fibres [6,8,10], whereas the present work uses approximately 40 mm. In the study of El Oudiani et al. [7], fibre lengths of 5–50 mm were compared and intermediate lengths of about 25 mm performed best, as summarised in [10]. Alkali treatment modifies the fibre surface and can improve the fibre–matrix bond [7,11], and a strong interface is essential for stress transfer across cracks [4,11]. Finally, fibres

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absorb mixing water and increase internal friction, which lowers the workability of fresh concrete [1].

4. Research Gap

The literature indicates that *Agave* fibres can improve compressive, tensile and flexural behaviour in suitable matrices, but four gaps remain. First, studies have focused mainly on adobe, earth blocks, mortar and other composites, and comparatively few address *Agave americana* in cement-based concrete bricks. Second, dosage and length differ between studies, so no common optimum exists, and 40 mm fibres lie outside the length most often reported. Third, durability of natural fibres in the alkaline cement environment remains a concern [4]. Fourth, the combined relationship among fibre content, workability, strength, absorption and non-destructive response is rarely reported for a single mix series. The present study addresses these gaps for one fibre length and five fibre contents.

MATERIALS AND EXPERIMENTAL METHODOLOGY

1. Materials Used

The constituent materials are listed in Table 2. Ordinary Portland cement (OPC) of 53 grade served as the binder. Natural river sand or manufactured sand was the fine aggregate, crushed angular granite was the coarse aggregate, and potable water was used for mixing and curing. The values in Table 2 are specification values or ranges and not individually measured test results.

T***able 2: Constituent Materials and Specifications.***

Material	Description	Specification listed
Cement	OPC, 53 grade	IS 12269; specific gravity 3.15; initial setting time > 30 min; final setting time < 600 min
Fine aggregate	River sand or M-sand	IS 383 Zone II; specific gravity 2.65; fineness modulus 2.6–2.9; silt content < 5%
Coarse aggregate	Crushed angular granite	Maximum size 6–10 mm; specific gravity 2.70; water absorption < 0.8%

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Water	Potable	IS 456; pH 6.5–7.5
Agave americana fibre	Alkali-treated (NaOH) retted leaf fibre	Length 40 mm; tensile strength 300–700 MPa; density 1.2–1.45 g/cm³

2. Extraction and Treatment of Agave Americana Fibres

Agave americana is a large succulent that forms a rosette of thick, sword-shaped leaves with spiny margins (Plate 1a). Its leaves yield coarse, strong cellulosic fibres whose surface is covered with lignin; after lignin removal the fibres become flexible, smooth and lustrous.

Fibres were separated from the leaves by water retting, in which immersed leaves are softened by microbial degradation of pectin and hemicelluloses so that the fibres can be released (Plate 1b). Retting can take up to about two weeks and must be monitored, because over-retting degrades fibre quality while under-retting leaves gummy residues and makes extraction difficult. The retted fibres were alkali-treated with sodium hydroxide (NaOH) to remove excess lignin and chemical residues and to improve fibre fineness and strength, and were cut to a staple length of approximately 40 mm.



(a) Agave americana plant (rosette of leaves) (b) Extracted leaf fibre (schematic)

Plate 1: Agave Americana: (A) Plant, A Rosette Of Succulent Leaves With Spiny Margins, And (B) Extracted Leaf Fibre, Including Cut Staples of Approximately 40 Mm (Schematic Illustration, Not To Scale).

3. Mix Proportions, Specimen Preparation and Curing

M20-grade concrete was adopted. A control mix without fibre and four fibre mixes were prepared (Table 3). The fibre contents were expressed as volume fractions. The fibres were first dispersed in water; the dry ingredients were mixed uniformly, water was added gradually,

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and the fibre dispersion was then incorporated to obtain uniform distribution. The mix was checked for workability and uniformity before casting, placed in cleaned, oiled moulds in layers, compacted with a vibrator to minimise air voids, and the surface was levelled and finished. All mixes were produced under similar conditions. After making it keept for curing up to 21 days. Compressive-strength specimens were cast in 150 mm × 150 mm × 150 mm moulds, and the reported mean compressive strength of each mix is based on five readings. After initial setting the specimens were demoulded and water-cured, then surface-dried before testing.

Table 3: Mix designations.

Concrete Grade	Fibre content (%)	Fibre length (mm)
M 20	0	–
M 20	0.25	approx. 40
M 20	0.50	approx. 40
M 20	0.75	approx. 40
M 20	1.00	approx. 40

4. Experimental Testing Methods

Five tests were carried out (Table 4). Compressive strength was determined with a universal testing machine under gradually applied load. Slump was measured with the standard cone to assess workability. Moisture absorption was determined by weighing: specimens were immersed in water for 24 h after curing and the mass gain was calculated relative to the initial mass. The rebound hammer test measures the rebound of a spring-driven mass from the concrete surface and gives an index of surface hardness and uniformity from which strength can be estimated indirectly. The UPV test measures the transit time of an ultrasonic pulse through the specimen, with higher velocities generally indicating denser and more uniform concrete and lower velocities indicating voids, cracks or discontinuities.

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Table 4: Tests Conducted And The Standards Cited.

Test	Instrument	Standard cited
Compressive strength	Universal testing machine	ASTM C39
Slump	Slump cone	ASTM C143
Moisture absorption	Weighing after 24 h immersion	ASTM C1585
Rebound hammer	Schmidt rebound hammer	ASTM C805
Ultrasonic pulse velocity	UPV tester	ASTM C597

RESULTS AND DISCUSSION

The measured results are collected in Table 5, and the changes relative to the control calculated with Eq. (4) are given in Table 6. Figures 1–5 show the trend of each property with fibre content. The values are the means reported for each mix.

Table 5: Measured Properties of The Control And Agave Americana Fibre Mixes.

Fibre content (%)	Compressive strength (N/mm²)	Slump (mm)	Moisture absorption (%)	Rebound-estimated strength (MPa)	UPV (km/s)
0	20.86	150	3.00	20.9	4.32
0.25	26.08	162	3.46	24.8	4.25
0.50	25.38	138	3.73	23.8	4.10
0.75	24.65	123	4.17	22.5	3.90
1.00	23.75	102	4.44	21.3	3.81

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Table 6: Percentage Change Relative To The Control, Calculated From Table 5 With Eq. (4).

Fibre content (%)	Compressive strength	Slump	Moisture absorption	Rebound-estimated strength	UPV
0.25	+25.0%	+8.0%	+15.3%	+18.7%	−1.6%
0.50	+21.7%	−8.0%	+24.3%	+13.9%	−5.1%
0.75	+18.2%	−18.0%	+39.0%	+7.7%	−9.7%
1.00	+13.9%	−32.0%	+48.0%	+1.9%	−11.8%

1. Compressive Strength

The control mix had a mean compressive strength of 20.86 N/mm² (Table 5, Fig. 1). Fibre addition increased the strength at every dosage, with a maximum of 26.08 N/mm² at 0.25%, an increase of (26.08 − 20.86)/20.86 × 100 = 25.0%. Strength then declined progressively to 25.38 N/mm² (+21.7%), 24.65 N/mm² (+18.2%) and 23.75 N/mm² (+13.9%) at 0.50%, 0.75% and 1.0% (Table 6). Even at the highest dosage the strength exceeded the control, but it was 8.9% lower than at 0.25%.

These are the measured observations. A plausible explanation for the gain at low dosage is that well-dispersed fibres bridge micro-cracks and redistribute stress, delaying crack coalescence under load [1,11]. At higher dosages, fibre clustering, poorer compaction and larger, better-connected pores of the kind reported by Wang and Jin [3] may offset this benefit. The reduction in slump at higher dosages (Section 4.2) is consistent with harder compaction, but no density, porosity or microstructural data are available to test these mechanisms. The dosage of maximum strength agrees with the 0.25% optimum reported for *Agave americana* in sand–clay–silt blocks [8], with the 0.3% optimum for coir in foamed concrete [3] and with the 0.25–1.0% range summarised in [10]. The magnitude of the gain (+25.0%, against +13.39% in [8]) is not directly comparable because the matrices, fibre lengths and treatments differ. Because only mean values are available, the 2.8% difference between the 0.25% and 0.50% mixes cannot be judged significant.

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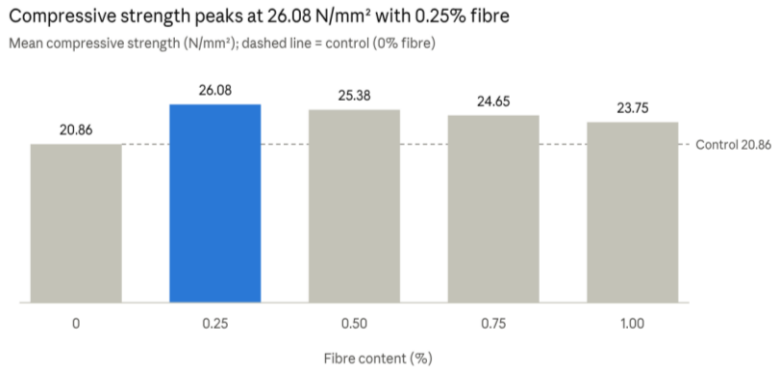


Figure 1: Mean Compressive Strength Of The Control And Agave Americana Fibre Mixes Versus Fibre Content.

2. Workability and slump

Slump was 150 mm for the control and 162 mm (+8.0%) at 0.25% fibre, then fell to 138 mm (−8.0%), 123 mm (−18.0%) and 102 mm (−32.0%) at 0.50%, 0.75% and 1.0% (Table 5, Fig. 2). For example, (10.2 − 15.0)/15.0 × 100 = −32.0%. The steady decrease above 0.25% is consistent with the known tendency of fibres to absorb mixing water and increase internal friction [1]. The small increase at 0.25% is atypical and should be treated cautiously. It is a single 12 mm difference that may lie within the normal variability of the slump test, and it could also arise if the water used to disperse the fibres was not accounted for in the water–cement ratio. It therefore cannot be taken as evidence that fibres improve workability.

Practically, the loss of slump at 0.75–1.0% means that higher dosages would require mix adjustment, such as revised water content or admixtures, if adequate placement and compaction are to be maintained; this was not investigated.

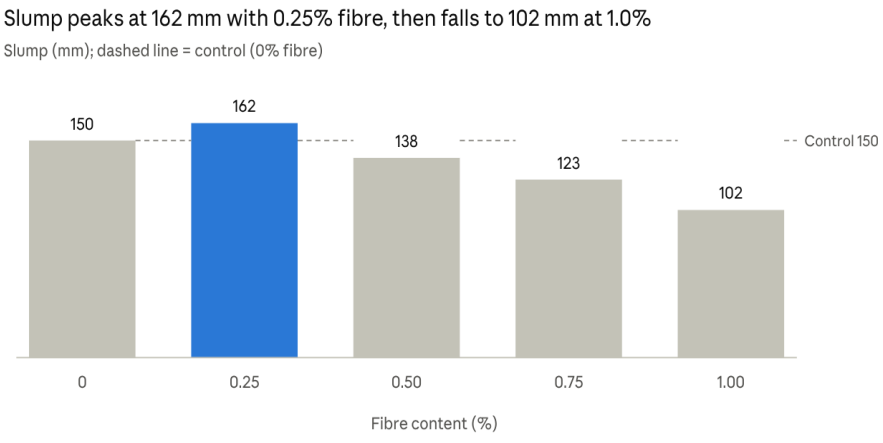


Figure 2: Slump of The Control and Fibre Mixes Versus Fibre Content.

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3. Moisture absorption

Moisture absorption increased steadily with fibre content (Table 5, Fig. 3): from 3.00% (control) to 3.46%, 3.73%, 4.17% and 4.44%, i.e. increases of 0.46, 0.73, 1.17 and 1.44 percentage points, or +15.3%, +24.3%, +39.0% and +48.0% in relative terms (Table 6). Natural fibres are hydrophilic, and additional voids or porous fibre–matrix interfaces would also increase water uptake, which together may explain the trend; no pore-structure measurements are available to confirm this. The result shows that, under the tested conditions, fibre addition did not reduce absorption at any dosage. The absolute values were not compared with acceptance limits for masonry units because the test procedure, specimen age and standard first need to be confirmed (Table 4).

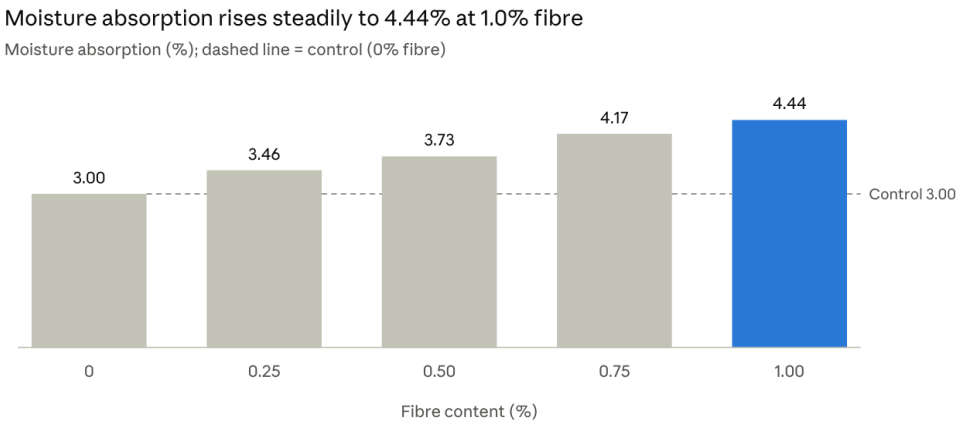


Figure 3: Moisture absorption of the control and fibre mixes versus fibre content.

4. Rebound hammer test

The rebound-hammer-estimated strength was 20.9 MPa for the control and 24.8, 23.8, 22.5 and 21.3 MPa at 0.25%, 0.50%, 0.75% and 1.0% fibre (Table 5, Fig. 4), corresponding to +18.7%, +13.9%, +7.7% and +1.9% (Table 6). The trend therefore resembles that of the direct compressive strength, with a maximum at 0.25% and a gradual decline, and the estimate at 1.0% was only marginally above the control. The estimated values were below the measured compressive strengths for the fibre mixes by 4.9%, 6.2%, 8.7% and 10.3% at 0.25–1.0% fibre, for example $(24.8 - 26.08)/26.08 \times 100 = -4.9\%$, whereas the control estimate differed by only +0.2% (20.9 against 20.86 N/mm²). The rebound hammer measures near-surface hardness and gives an indirect strength estimate through a conversion relation that is not specified here; the results should therefore be read as qualitative corroboration of the trend and not as a substitute for direct strength measurements.

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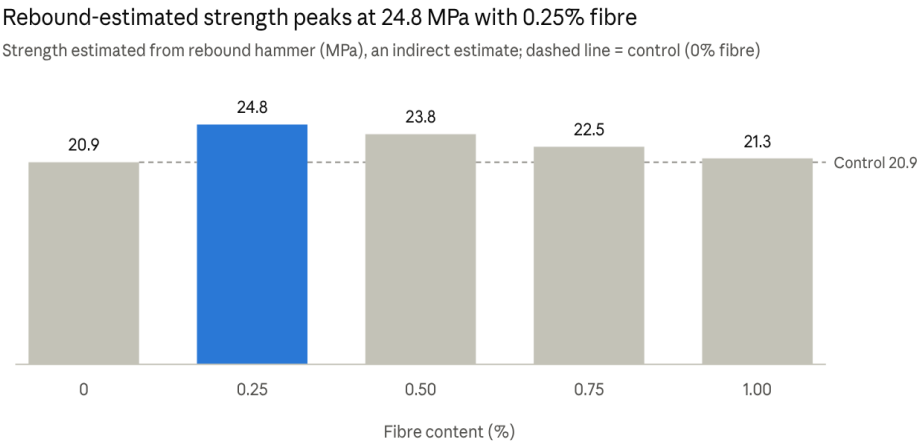


Figure 4: Rebound-Hammer-Estimated Strength of The Control And Fibre Mixes Versus Fibre Content.

5. Ultrasonic pulse velocity

UPV decreased consistently with fibre content: 4.32 km/s for the control and 4.25, 4.10, 3.90 and 3.81 km/s at 0.25–1.0% (Table 5, Fig. 5), i.e. −1.6%, −5.1%, −9.7% and −11.8% (Table 6). Lower velocity is generally associated with additional voids, discontinuities or weaker interfaces, and fibres of lower density and stiffness than the matrix may also lengthen the effective transmission path; the data cannot distinguish between these effects. All mixes were classified as good quality in the report. The decrease in velocity occurred together with an increase in compressive strength at 0.25%, which shows that, for fibre-containing mixes, UPV reflects density and internal continuity rather than strength alone. The reduction in UPV with increasing fibre content suggests decreasing compactness, in line with the reductions in slump and the increases in absorption.

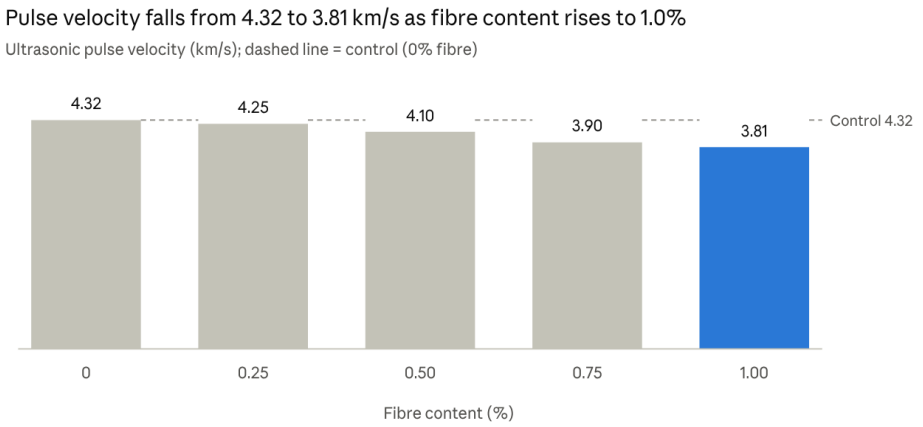


Figure 5: Ultrasonic Pulse Velocity of The Control and Fibre Mixes Versus Fibre Content.

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OVERALL DISCUSSION AND RESEARCH IMPLICATIONS

Strength and workability. Compressive strength and slump followed a similar pattern: both were highest at 0.25% fibre and decreased as the fibre content rose further (Figs. 1 and 2). That the strength gain at 0.25% coincided with the highest slump is consistent with adequate compaction and dispersion at low dosage, whereas the progressive stiffening of the fresh mix at 0.50–1.0% coincides with progressive strength loss. This coincidence does not establish causality: relative to the 0.25% mix, strength fell by only 2.7% at 0.50% while slump fell by 14.8%.

Location of the optimum. Because the maximum occurred at the lowest non-zero dosage and strength fell monotonically beyond it, the true optimum may lie anywhere between about 0% and 0.50%; the 0.25% dosage step is too coarse to resolve it. That low dosages perform best agrees with the pattern reported in [3,8,10].

Moisture absorption. Absorption rose at every dosage, so higher fibre content imposed a monotonic penalty with no compensating gain in the measured properties. Higher absorption may ease the ingress of water and aggressive species and could expose fibres to conditions that degrade natural fibres [4], but durability was not examined and this remains a hypothesis. Even the 0.25% mix, with the smallest increase (+0.46 percentage points), absorbed more water than the control.

Non-destructive tests. The rebound hammer results corroborated the strength trend, including the maximum at 0.25%, but the estimates fell increasingly below the measured strengths as fibre content increased (4.9–10.3%). UPV decreased at every dosage, including 0.25%, where compressive strength was highest. The two methods therefore provide complementary information: the rebound hammer reflects near-surface hardness and approximates strength, whereas UPV reflects internal continuity, and its decline indicates that fibre addition reduced compactness or introduced discontinuities even where compressive strength increased. UPV should not be used to predict strength for these mixes without a dedicated calibration, and the reported good-quality classification should be interpreted only once its criterion is stated.

Trade-offs and promising dosage. Considered together, the 0.25% mix gave the highest compressive strength, slump and rebound-estimated strength, with the smallest penalties in absorption (+15.3%) and UPV (−1.6%) among the fibre mixes. Higher dosages did not

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outperform it in any measured property. Within the tested mixtures and properties, 0.25% is therefore the most promising dosage. This selection is conditional: tensile, flexural, toughness and crack-resistance properties, where higher fibre contents are often expected to be beneficial [1], are not part of the present data set, and a different dosage might be preferred if those properties were prioritised.

Comparison with published studies. The favourable dosage agrees with Valenzuela Inga et al. [8] for *Agave americana* blocks, lies at the lower end of the 0.25–1.0% range summarised in [10], and is close to the 0.3% optimum for coir in foamed concrete [3]. The gain observed here (+25.0%) exceeds that reported in [8] (+13.39%), and strength remained above the control even at 1.0% (+13.9%); however, differences in matrix, fibre length (40 mm against about 25 mm), treatment and test methods preclude direct comparison. The loss of slump with fibre content supports [1]. Unlike the thermal improvement reported for earth bricks [9], no insulation measurements are available here.

Practical significance. The data suggest that a small dosage of treated *Agave americana* fibre can be incorporated into M20-grade concrete without loss of compressive strength or workability, at the cost of somewhat higher absorption and lower pulse velocity. They do not establish structural suitability, durability or commercial viability.

CONCLUSIONS

1. In the tested M20-grade mixes, adding *Agave americana* fibres of approximately 40 mm raised the mean compressive strength above that of the control (20.86 N/mm²) at every dosage: 26.08 N/mm² (+25.0%), 25.38 N/mm² (+21.7%), 24.65 N/mm² (+18.2%) and 23.75 N/mm² (+13.9%) at 0.25%, 0.50%, 0.75% and 1.0%, with the maximum at 0.25%.
2. Slump increased from 150 mm to 162 mm (+8.0%) at 0.25% fibre and then decreased to 138, 123 and 102 mm (−8.0%, −18.0% and −32.0%), showing that dosages above 0.25% progressively reduced workability; the increase at 0.25% requires confirmation.
3. Moisture absorption increased monotonically from 3.00% to 4.44% (+48.0% in relative terms) as the fibre content increased to 1.0%.
4. Rebound-hammer-estimated strength followed the compressive-strength trend, with a maximum of 24.8 MPa at 0.25%, whereas UPV decreased from 4.32 to 3.81 km/s

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(−11.8%), indicating reduced internal compactness or continuity at higher dosages although all mixes were reported as good quality.

5. Among the dosages investigated, 0.25% was the most promising, combining the highest strength and workability with the smallest penalties in absorption and UPV among the fibre mixes. This conclusion applies only to the mixtures and properties examined.
6. The study provides an experimental data set on the effect of 40 mm *Agave americana* fibre content in cement concrete, which can serve as a basis for further work on natural-fibre-reinforced concrete bricks; further validation is needed before practical or structural use.

LIMITATIONS AND FUTURE SCOPE

The findings are limited by the dosage range (0–1.0% in 0.25% steps), a single fibre length and treatment, and the availability of mean values only, with five readings reported for compressive strength and no replicate-level data for the other tests. No durability, tensile, flexural or microstructural data are included, the rebound hammer conversion relation and the UPV classification criterion are not specified, and the mechanisms proposed above are therefore not supported by direct evidence.

Future work should address (i) long-term durability, including fibre degradation in the alkaline pore solution and wetting–drying exposure; (ii) fibre–matrix bonding and optimisation of the NaOH treatment, examined by microscopy and pull-out tests; (iii) standardised absorption, sorptivity and weathering tests; (iv) split tensile and flexural strength, toughness, crack resistance, density and thermal conductivity; (v) statistical validation using adequate replicate specimens and analysis of variance; (vi) finer dosage steps below 0.5% and additional fibre lengths, for example about 25 mm compared with 40 mm; and (vii) cost, availability and life-cycle assessment, together with testing of brick-sized units against relevant masonry-unit standards before field application.

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