Mechanical and Fresh-State Performance of M40 Concrete Paver Blocks Incorporating Nylon Fibre, Fly Ash and Rice Husk Ash for Medium-Traffic Pavements

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Abstract — Interlocking concrete paver blocks are widely used for pedestrian and light-to-medium vehicular pavements, but their cement content carries a high environmental cost. This study investigates M40-grade, 80 mm thick, I-shaped paver blocks (200 × 160 mm in plan) made with nylon fibre, fly ash (FA) and rice husk ash (RHA). In the first phase, nylon fibre was added at 0.1–0.5% by weight of cement to identify the optimum dosage. In the second phase the optimum dosage (0.3%) was held constant while ordinary Portland cement (OPC) was replaced by 10, 20 and 30% FA or RHA. Slump, apparent and corrected compressive strength (IS 15658:2021) and flexural strength were measured at 7, 14 and 28 days. The 0.3% fibre mix gave the highest strength among the fibre-only mixes (44.26 N/mm² at 28 days, +4.8% over the control value of 42.24 N/mm²), whereas dosages of 0.1, 0.2, 0.4 and 0.5% fell below the control. With 0.3% fibre, 20% FA gave 44.89 N/mm² (+6.3%) and 10% RHA gave 48.70 N/mm² (+15.3%; corrected strength 57.5 N/mm²); 30% replacement of either material reduced 28-day strength below the control. Flexural strength followed the same ranking, reaching 5.09 N/mm² (20% FA) and 5.31 N/mm² (10% RHA) against 4.94 N/mm² for the control. Slump decreased with fibre (83 mm to 71 mm at 0.5%) and with RHA (down to 58 mm at 30%) but increased with FA (up to 110 mm). The mean corrected 28-day strength of every mix exceeded the 40 N/mm² requirement of M40 grade. The results indicate that 20% FA or 10% RHA combined with 0.3% nylon fibre allows a 10–20% reduction in OPC without loss of strength. Abrasion resistance, water absorption and long-term durability were not evaluated and must be verified before field use.

Keywords: Concrete Paver Blocks; Nylon Fibre; Fly Ash; Rice Husk Ash; Compressive Strength; Flexural Strength; Sustainable Construction; M40 Concrete

I. Introduction

Concrete block paving (CBP) is used for roads, parking areas, industrial yards and pedestrian walkways because of its structural efficiency, ease of installation and repairability, and the load-spreading action of the interlocking blocks and jointing sand [1]. The surface performance of the blocks depends strongly on their strength and abrasion resistance, which are governed by mix composition and compaction [2]. In India, precast paving blocks are specified by IS 15658:2021 [10], which grades blocks by compressive strength and relates grade to traffic category; M40 blocks of 80 mm thickness are designated for medium-traffic use.

Cement production is energy-intensive and contributes a significant share of anthropogenic carbon dioxide emissions, so partial replacement of cement with industrial and agricultural by-products is attractive. Fly ash, a by-product of coal-fired power stations, improves the workability of fresh concrete through its spherical particle shape and contributes to later-age strength through pozzolanic reaction [4, 5]. Rice husk ash, obtained by controlled combustion of rice husk, is rich in amorphous silica and is a highly reactive pozzolan, although its fineness and porous structure raise water demand [3, 4].

Synthetic fibres are added to concrete to control plastic shrinkage and micro cracking and to improve post-cracking behaviour [6]. Several studies have examined paver blocks containing fibres or fly ash. Singh and Sahu [7] studied M40, 80 mm blocks with 0.1–0.5% nylon fibre and then 15, 20 and 25% fly ash, and reported an optimum at 0.3% fibre and 20% fly ash. Sachdeva et al. [8] found that fly ash paver mixes of grades M30–M50 with 20–40% replacement met strength requirements, being slightly below the control at 7 and 28 days and slightly above it at 90 days. Ayyadurai et al. [9] reported gains in compressive and flexural strength of fly-ash paver blocks reinforced with banana fibre. Most of this work treats fibre, fly ash or rice husk ash separately, and little is available on nylon fibre used together with rice husk ash in paver blocks.

The present study therefore examines M40 paver blocks in which a fixed optimum dosage of nylon fibre is combined with fly ash or rice husk ash. The objectives are: (i) to determine the optimum nylon fibre dosage from compressive and flexural strength; (ii) to quantify the effect of 10, 20 and 30% replacement of OPC by FA or RHA, at the optimum fibre dosage, on workability and on strength at 7, 14 and 28 days; and (iii) to assess the mixes against the M40 strength requirement of IS 15658:2021.

II. Materials and Methods

A. Materials

The properties of the materials are summarised in Table 1. OPC of 53 grade conforming to IS 12269 [13] was used. Fly ash was obtained from a commercial processor in Bhopal and conformed to IS 3812 (Part 1):2013 [14]. Rice husk was collected from a farm in Vidisha, Madhya Pradesh, burned under controlled conditions for about 48 hours, cooled naturally for about 12 hours and ground mechanically. Natural river sand and crushed angular stone conforming to IS 383:2016 [12] were used as fine and coarse aggregate. For the fine aggregate, 26% passed the 600 µm sieve, which places the sand in grading Zone I of IS 383. The fineness modulus of the combined aggregate (65:35 coarse to fine) was 5.98. Potable water was used for mixing and curing.

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Material	Description	Specific gravity	Other properties
Cement	OPC 53 grade, IS 12269	3.15	–
Fly ash	Processed pulverised fuel ash, IS 3812 (Part 1)	2.50	–
Rice husk ash	Burned about 48 h, ground	2.35	–
Nylon fibre	Synthetic polyamide fibre	–	Dosage 0.1–0.5% by weight of cement
Fine aggregate	Natural river sand, Zone I	2.56	FM 3.29; water absorption 0.21%; bulking 24%
Coarse aggregate	Crushed angular stone	2.75	FM 7.44; water absorption about 1.0%

Table 1: Properties of materials

B. Block Geometry and Mix Proportions

Blocks were I-shaped, 200 mm long, 160 mm wide and 80 mm thick (aspect ratio 2.5, within the limit of 4 in IS 15658:2021). Mixes were proportioned for M40 using IS 10262 [11] with an assumed standard deviation of 5 N/mm², giving a target mean strength of 48.25 N/mm². The total binder content was held at 430 kg/m³ and the water content at 197 kg/m³ (water/binder ratio 0.458) in all mixes. Nylon fibre was added at 0.1, 0.2, 0.3, 0.4 and 0.5% by weight of cement (mixes FB1–FB5). The optimum dosage, 0.3%, was then kept constant while OPC was replaced by weight with 10, 20 and 30% fly ash (FA10, FA20, FA30) or rice husk ash (RHA10, RHA20, RHA30). Proportions are given in Table 2. The aggregate quantities of the 20% and 30% replacement mixes were slightly lower than those of the 10% mixes, as recorded in the original mix sheets.

Mix	Cement	FA or RHA	Nylon fibre	Water	Coarse agg.	Fine agg.
Control	430	–	–	197	892.33	648.65
FB1 (0.1%)	430	–	0.43	197	892.33	648.65
FB2 (0.2%)	430	–	0.86	197	892.33	648.65
FB3 (0.3%)	430	–	1.29	197	892.33	648.65
FB4 (0.4%)	430	–	1.72	197	892.33	648.65
FB5 (0.5%)	430	–	2.15	197	892.33	648.65
FA10 / RHA10	387	43	1.29	197	892.33	648.65
FA20 / RHA20	344	86	1.29	197	877.27	638.35
FA30 / RHA30	301	129	1.29	197	877.27	638.35

Table 2. Mix proportions (kg/m³)

C. Casting and Curing

The dry constituents were mixed to a uniform colour, the nylon fibre was added gradually to avoid fibre balling, and water was added last. Concrete was placed in 80 mm rubber moulds on a vibrating table and compacted until no air bubbles appeared and a smooth surface was obtained. The blocks were left in the moulds for about 24 hours, demoulded, and cured in potable water for 7, 14 and 28 days. Test specimens for each mix and age were selected according to the sampling procedure of IS 15658:2021.

D. Testing

- Workability: Slump was measured with the standard cone (IS 7320:1974 apparatus [16]), compacting each of three layers with 25 strokes.
- Plan area: Because the block is not rectangular, the plan area was determined by the two methods of IS 15658:2021. Hydrostatic weighing gave 28,589 mm², and the cardboard-template method (template mass 0.020 kg against 0.014 kg for a 200 × 100 mm reference rectangle) gave 28,571 mm². A working plan area of 28,000 mm² was adopted for strength calculation, which is within about 2% of the measured values.
- Compressive strength: Blocks were soaked in water for 24 ± 4 h, capped, and loaded without shock at 15 ± 3 N/mm² per minute until failure. Apparent strength is the maximum load divided by plan area. Corrected strength is the apparent strength multiplied by the factor of 1.18 given in IS 15658:2021 for 80 mm thick arrised or chamfered blocks.
- Flexural strength: Tests followed IS 516 [15] with the modifications of IS 15658:2021: a simple beam with a central load applied at 6 kN/min. Flexural strength was calculated as $F = 3Pl / (2bd^2)$, where P is the maximum load, l the span between supports, b the average width and d the average thickness at the fracture line.

III. Results and Discussion

A. Workability

Slump results are given in Table 3. Nylon fibre reduced slump progressively, from 83 mm for the control to 71 mm at 0.5% fibre (−14.5%), because the fibres increase internal friction and form an interconnected network that restrains flow. Fly ash raised slump to 95, 103 and 110 mm at 10, 20 and 30% replacement (+14.5, +24.1 and +32.5%), consistent with the lubricating effect of its spherical particles. Rice husk ash lowered slump to 72, 65 and 58 mm (−13.3, −21.7 and −30.1%) as a result of its fineness and high-water demand, since the water content was not adjusted. Because the FA and RHA mixes also contain 0.3% fibre (slump 78 mm), the changes relative to FB3 are larger in the case of fly ash (+21.8 to +41.0%) and smaller for RHA (−7.7 to −25.6%).

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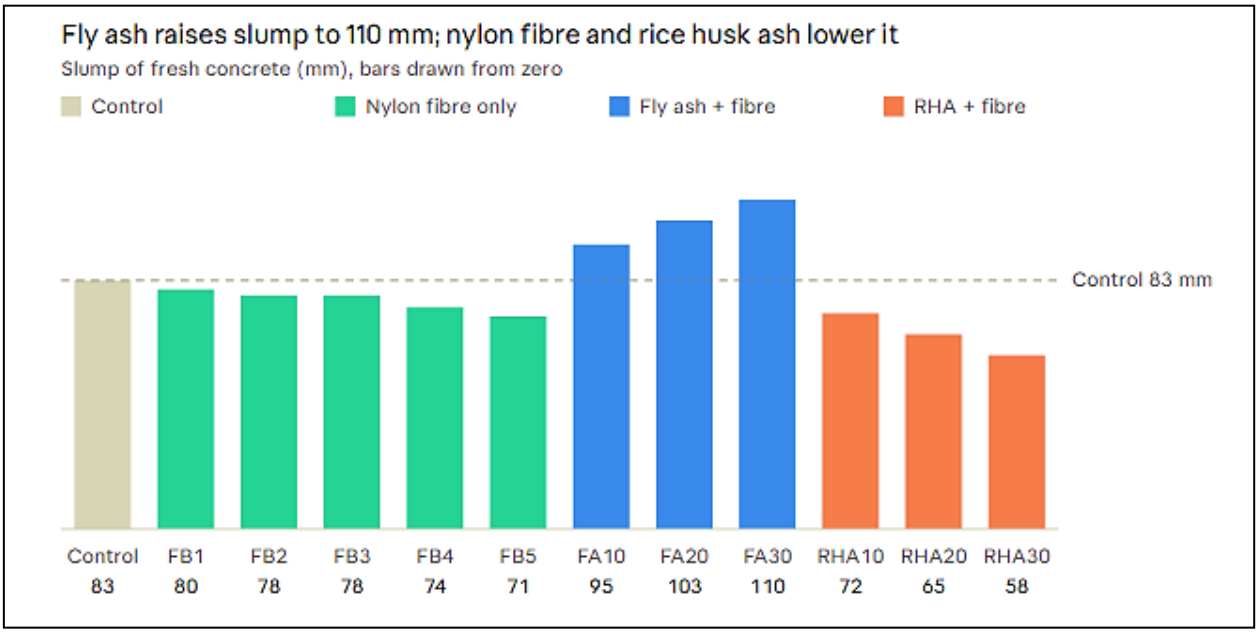


Fig. 1. Slump of fresh concrete by mix. Fly ash raises workability, whereas nylon fibre and rice husk ash reduce it.

Mix	Slump (mm)	Change vs control (%)
Control	83	–
FB1	80	−3.6
FB2	78	−6.0
FB3	78	−6.0
FB4	74	−10.8
FB5	71	−14.5
FA10	95	+14.5
FA20	103	+24.1
FA30	110	+32.5
RHA10	72	−13.3
RHA20	65	−21.7
RHA30	58	−30.1

Table 3: Slump of fresh concrete

B. Compressive strength

Apparent and corrected compressive strengths are given in Table 4. Corrected values are the apparent values multiplied by 1.18.

Mix	7 d	14 d	28 d	7 d corr.	14 d corr.	28 d corr.	28 d change vs control (%)
Control	36.90	39.87	42.24	43.5	47.0	49.8	–
FB1	35.41	36.42	37.44	41.8	43.0	44.2	−11.4
FB2	35.83	37.14	37.85	42.3	43.8	44.7	−10.4
FB3	40.12	42.25	44.26	47.3	49.8	52.2	+4.8
FB4	38.09	39.42	40.21	45.0	46.5	47.4	−4.8
FB5	37.94	39.24	39.90	44.8	46.3	47.1	−5.5
FA10	37.64	39.85	40.66	44.4	47.0	48.0	−3.7
FA20	39.78	41.25	44.89	46.9	48.7	53.0	+6.3
FA30	37.23	38.13	38.52	43.9	45.0	45.5	−8.8
RHA10	34.60	38.79	48.70	40.8	45.8	57.5	+15.3
RHA20	29.41	34.47	40.95	34.7	40.7	48.3	−3.1
RHA30	27.82	32.05	37.15	32.8	37.8	43.8	−12.1

Table 4: Compressive strength (N/mm²)

1) Effect of nylon fibre: The response to fibre dosage was non-monotonic. Strength rose to a maximum at 0.3% fibre (44.26 N/mm² at 28 days, +4.8%; +8.7% at 7 days) and was lower at both smaller and larger dosages. The two lowest dosages (0.1% and 0.2%) gave strengths about 10–11% below the control at 28 days, and 0.4% and 0.5% gave values about 5% below it. A plausible explanation is that at low dosages the fibres are too few to bridge microcracks while still disturbing the paste-aggregate interface, whereas at high dosages reduced workability, fibre clumping and entrapped air offset the benefit of crack bridging. This interpretation is inferred from the strength and slump trends and was not examined microstructurally. On this basis 0.3% was selected as the optimum dosage, in agreement with the optimum reported for nylon fibre paver blocks in [7], although the strength gain observed here is smaller than the maximum gain reported there.
2) Effect of fly ash: With 0.3% fibre, 20% fly ash gave the best result in the series at every age (39.78, 41.25 and 44.89 N/mm² at 7, 14 and 28 days). The 28-day strength was 6.3% above the control and 1.4% above the fibre-only mix FB3, so 20% of the cement (86 kg/m³) could be replaced without strength loss. Replacement of 10% was slightly below the control at 28 days (−3.7%) and 30% was markedly lower (−8.8%), which is consistent with the dilution of cement and the slow pozzolanic reaction of fly ash at early ages, as also noted in [8].

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3) Effect of rice husk ash: Rice husk ash showed a different age-dependence. RHA10 was below the control at 7 days (−6.2%) and 14 days (−2.7%) but reached 48.70 N/mm² at 28 days, +15.3% over the control and +10.0% over FB3. Between 14 and 28 days its strength increased by about 26%, against about 6% for the control, which is characteristic of a pozzolanic contribution that develops late. Higher replacement levels reduced strength at all ages: RHA20 and RHA30 were 3.1% and 12.1% below the control at 28 days, in line with the lower slump (65 and 58 mm) and the greater difficulty of compaction at fixed water content. The size of the late-age gain of RHA10 is larger than usually reported for 10% replacement, so it should be confirmed on additional specimens (see Section 5).

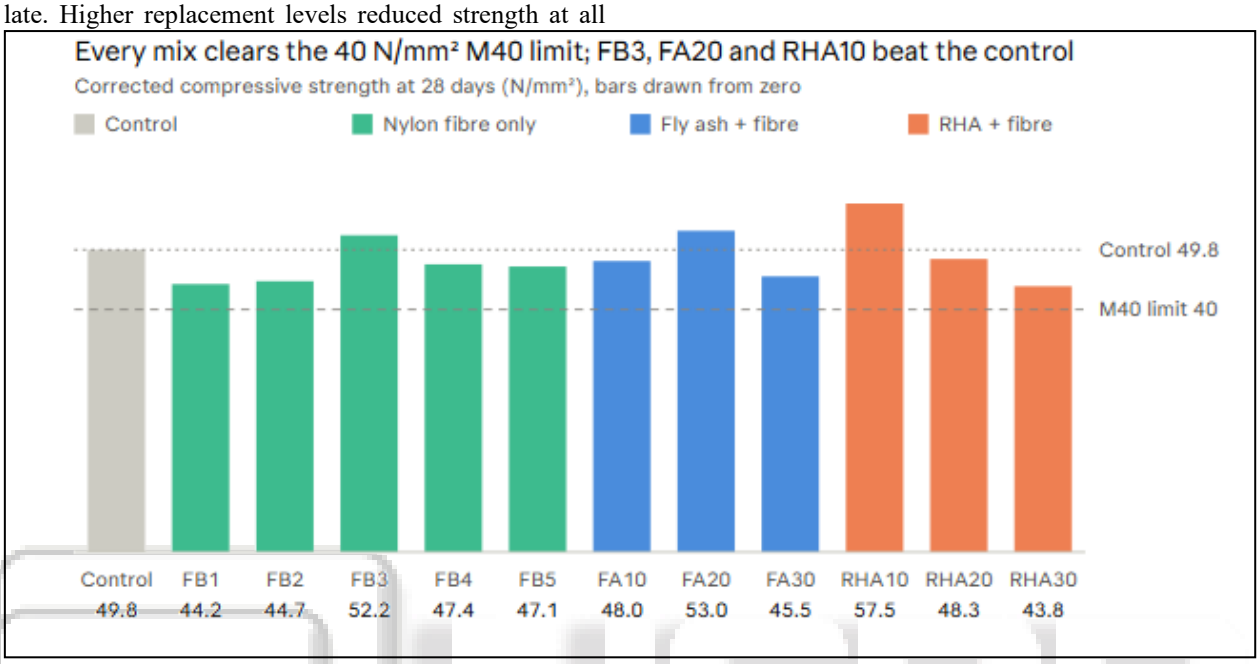


Fig. 2: Corrected 28-day compressive strength of all mixes, shown against the control and the 40 N/mm² strength required for M40 blocks in IS 15658:2021.

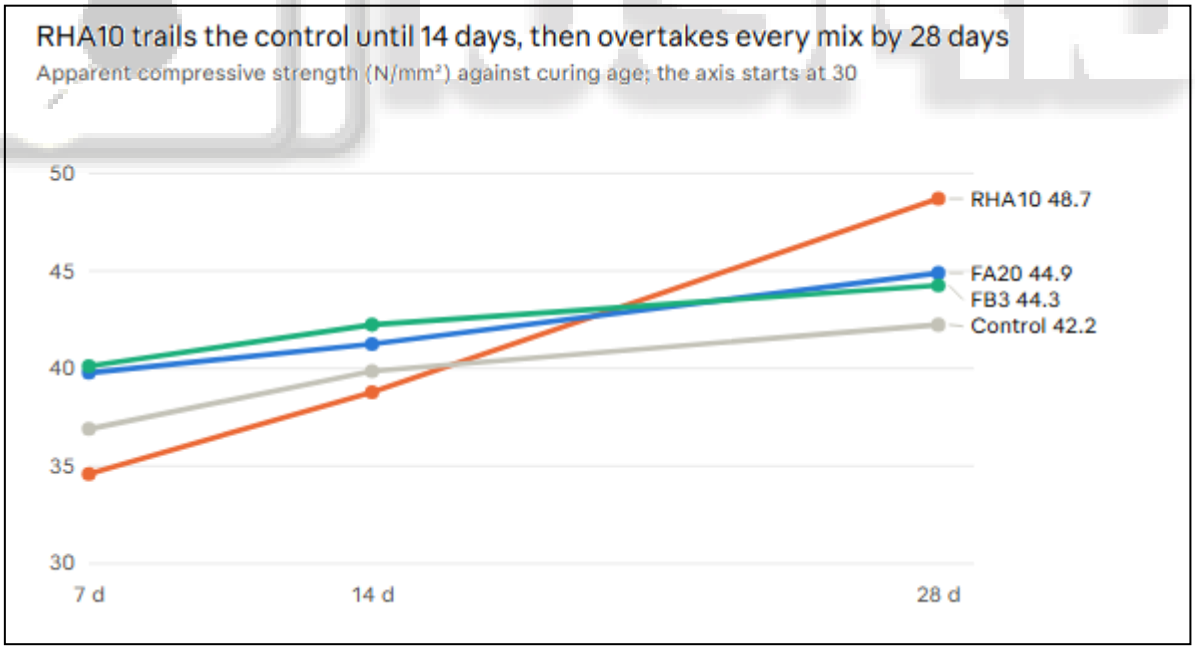


Fig. 3: Compressive strength development of the control and of the best mix in each family (FB3, FA20 and RHA10).

C. Flexural Strength

Flexural strength results are given in Table 5. The trends mirror those of compressive strength. Among fibre-only mixes, 0.3% fibre gave the highest value (5.06 N/mm² at 28 days, +2.4%), while the other dosages were 2.4–5.9% below the control. FA20 gave 5.09 N/mm² (+3.0%) and RHA10 gave 5.31 N/mm² (+7.5%), the highest in the programme; the 30% replacement mixes were 4.5% (FA30) and 6.3% (RHA30) below the control. At 7 days all RHA mixes were below the control, again reflecting the slow reaction of the ash. The improvements in flexural strength are smaller in relative terms than those in compressive strength.

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Mix	7 d	14 d	28 d	28 days change vs control (%)
Control	3.10	4.80	4.94	–
FB1	3.04	4.59	4.65	−5.9
FB2	3.06	4.63	4.68	−5.3
FB3	3.23	4.94	5.06	+2.4
FB4	3.15	4.77	4.82	−2.4
FB5	3.14	4.76	4.80	−2.8
FA10	3.13	4.80	4.85	−1.8
FA20	3.22	4.88	5.09	+3.0
FA30	3.12	4.70	4.72	−4.5
RHA10	3.00	4.74	5.31	+7.5
RHA20	2.77	4.46	4.87	−1.4
RHA30	2.69	4.30	4.63	−6.3

Table 5. Flexural strength (N/mm²)

D. Overall Assessment

Three mixes stand out. FB3 (0.3% nylon fibre, no replacement) is the best fibre-only mix. FA20 gives the best combination of early-age strength, workability (slump 103 mm) and cement saving (20%), and gains 6.3% in compressive strength over the control. RHA10 gives the highest 28-day compressive and flexural strengths (+15.3% and +7.5%) with a 10% cement saving, but with reduced workability and lower early-age strength. The mean corrected 28-day compressive strength of every mix, including the weakest (RHA30, 43.8 N/mm²), exceeded the 40 N/mm² required for M40 blocks. This conclusion rests on mean values only, because individual-specimen minima, which IS 15658:2021 also limits, were not recorded. Suitability for medium-traffic pavements additionally depends on properties that were not measured here, namely abrasion resistance, water absorption, and performance under repeated loading.

IV. Conclusions

1) Among the nylon fibre dosages tested (0.1–0.5% by weight of cement), 0.3% gave the highest compressive and flexural strength at all ages; at 28 days compressive strength was 44.26 N/mm² (+4.8% over the control) and flexural strength 5.06 N/mm² (+2.4%). The other dosages gave lower strength than the control.
2) Nylon fibre reduced slump from 83 mm to 71 mm as dosage increased to 0.5%.
3) With 0.3% fibre, 20% fly ash gave the highest strength of the fly ash mixes at all ages, with 28-day compressive strength of 44.89 N/mm² (+6.3% over the control, +1.4% over the fibre-only mix) and flexural strength of 5.09 N/mm²; 30% replacement reduced strength below the control. Fly ash increased slump by up to 32.5%.
4) With 0.3% fibre, 10% rice husk ash gave the highest 28-day compressive strength of the programme (48.70 N/mm², +15.3% over the control; corrected 57.5 N/mm²) and flexural strength of 5.31 N/mm² (+7.5%), but lower strength than the control at 7 and 14 days. Rice husk ash reduced slump by up to 30.1% at 30% replacement.
5) The mean corrected 28-day compressive strength of all mixes exceeded 40 N/mm². Combining 0.3% nylon fibre with 20% fly ash or 10% rice husk ash allows 10–20% of the OPC to be replaced with waste-derived material while maintaining or improving strength.

V. Limitations and Future Work

- The number of specimens per mix and age and the scatter of results were not reported, so no statistical significance can be claimed for the differences between mixes, particularly those of a few percent.
- The 28-day gain of RHA10 between 14 and 28 days is unusually large, and the 14-day flexural strengths are close to the 28-day values for most mixes (about 90–99%) while the 7-day values are only about 55–66% of the 28-day values. These results should be confirmed by repeat testing.
- Block plan area was taken as 28,000 mm², about 2% below the measured value; using the measured area would lower all reported strengths by about 2%.
- Abrasion resistance, water absorption, durability and performance under repeated traffic loading were not evaluated, and the mechanisms proposed in Section 3.2 were not verified by microstructural analysis.
- Future work should include these durability tests, SEM and XRD characterisation, tests at 56 and 90 days to capture the later pozzolanic gain, fibre length and diameter as variables, and a life-cycle and cost assessment.

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