

Sustainable Concrete Paver Blocks with Unprocessed C&D Waste: Flexural Strength as the Critical Compliance Parameter

Saneesh Nayak^{1*}, Aman Tiwari², and R. K. Agrawal³

¹ MTech. Scholar, Department of Civil Engineering, Faculty of Engineering, VNS Group of Institutions, Bhopal 462044, Madhya Pradesh, India

² Assistant Professor, Department of Civil Engineering, Faculty of Engineering, VNS Group of Institutions, Bhopal 462044, Madhya Pradesh, India

³ Principal, Faculty of Engineering, VNS Group of Institutions, Bhopal 462044, Madhya Pradesh, India

*saneeshnayak14@gmail.com

Abstract. The sustainable production of concrete paver blocks demands simultaneous reduction in Ordinary Portland Cement consumption and natural aggregate extraction. While processed recycled concrete aggregate has been extensively studied, the performance of unprocessed, heterogeneous Construction and Demolition (C&D) waste reflecting Indian sourcing conditions has received limited attention. This paper presents a 2×3 full factorial investigation on M30 grade I-shaped paver blocks incorporating Class F fly ash (0% and 10% of OPC) and directly sourced C&D waste (0%, 15%, 30% of natural coarse aggregate), yielding six mix variants tested at 28 days against the mandatory limits of IS 15658:2006 (First Revision 2021). The mix with 10% fly ash and zero C&D waste attained the highest compressive (40.8 MPa) and flexural (4.68 MPa) strengths. Three mixes failed the 3.30 MPa flexural threshold despite passing compressive, water absorption, and abrasion criteria. The study establishes flexural strength as the sole discriminating compliance criterion under the 2021 revision and identifies practical substitution bounds for Indian non-traffic pedestrian paving.

Keywords: Concrete paver blocks · Construction and demolition waste · Class F fly ash · Flexural strength · IS 15658:2021 · Factorial design.

1 Introduction

The precast concrete paver block dominates non-traffic pedestrian pavement across Indian cities, but its production couples heavy Ordinary Portland Cement (OPC) demand with intensive natural coarse aggregate (NCA) extraction. OPC manufacture alone accounts for approximately 7–8% of global anthropogenic CO₂ emissions [1], while Indian urban areas generate between 112 and 431 million tonnes of Construction and Demolition (C&D) waste annually, much of it disposed in uncontrolled dumpsites [2]. Two decades of research have established the viability of recycled coarse aggregate (RCA) and Class F fly ash as partial substitutes in concrete [3–6]; the pozzolanic reaction of fly ash refines the pore structure [3], while RCA at moderate replacement levels satisfies mechanical requirements [4, 7]. Attri et al. [8] reported that M30 paver blocks with up to 25% RCA comply with IS 15658:2006, and Singh et al. [9] demonstrated similar performance for combined brick-bat and slag mixes.

Three gaps motivate the present investigation. First, the overwhelming majority of published studies use RCA from dedicated recycling plants — crushed, screened, often pre-soaked [7, 10] — whereas the material actually available at Indian paver-block production facilities is heterogeneous unprocessed C&D waste comprising concrete rubble, brick fragments, adhered mortar, and granular debris [2]. Second, the combined effect of fly ash and unprocessed C&D waste across a structured factorial matrix has not been reported under Indian sourcing conditions. Third, the 2021 revision of IS 15658:2006 [11] has elevated flexural strength from optional indicator to mandatory compliance limit (≥ 3.30 MPa for M30) — implications of this change for recycled-material mixes remain unexplored.

The present paper addresses these gaps through a 2×3 full factorial programme on six M30 mixes evaluated against the mandatory IS 15658:2021 envelope. The specific objectives are: (i) to quantify the individual and combined effects of fly ash and unprocessed C&D waste on 28-day compressive strength, flexural strength, water absorption, and dry

abrasion resistance; (ii) to identify the discriminating compliance criterion under the 2021 revision; and (iii) to provide guidance on practicable substitution levels for Indian non-traffic pedestrian paving.

2 Materials and Methods

2.1 Materials

OPC of 43 Grade conforming to IS 8112:2013 (specific gravity 3.15) and Class F fly ash conforming to IS 3812 (Part 1):2003 (specific gravity 2.20) were used as the binder. The fine aggregate was natural river sand from the Narmada Zone II (specific gravity 2.65). NCA was crushed granite of 12 mm nominal maximum size (specific gravity 2.74; water absorption 0.5%). The C&D waste aggregate — the principal novel constituent — was sourced directly from local demolition sites in Bhopal at 20 km transport distance, without washing, separation, or grading. After screening out particles larger than 20 mm and visible organic debris, the measured specific gravity was 2.40 and water absorption 5.0%, consistent with the elevated porosity attributable to adhered mortar and brick fragments [4, 12]. A polycarboxylate ether superplasticizer was used at 0.72–0.80% by binder mass.

2.2 Mix Design and Factorial Matrix

The M30 mix was proportioned per IS 10262:2019. A target mean strength of 38.25 MPa was adopted using a standard deviation of 5.0 MPa. The reference water content was reduced by 15.7% to 172 kg/m³ to reflect the low-workability vibro-compaction regime of paver block production, giving a cement content of 390 kg/m³ at w/c = 0.441. A 2×3 full factorial was applied with fly ash at 0% and 10% of OPC mass and C&D waste at 0%, 15%, and 30% of NCA mass, generating six mix variants designated M30-FA[X]-RCA[Y] (Table 1).

Table 1. Mix proportions per cubic metre of concrete for the six mix variants.

Mix	OPC	FA	Water	Sand	NCA	C&D Agg.	SP
M30-FA0-RCA0	390.0	0.0	172.0	846.0	1027.0	0.0	3.12
M30-FA0-RCA15	390.0	0.0	172.0	846.0	872.9	154.1	3.43
M30-FA0-RCA30	390.0	0.0	172.0	846.0	718.9	308.1	3.74
M30-FA10-RCA0	351.0	39.0	172.0	846.0	1027.0	0.0	2.81
M30-FA10-RCA15	351.0	39.0	172.0	846.0	872.9	154.1	3.12
M30-FA10-RCA30	351.0	39.0	172.0	846.0	718.9	308.1	3.43

All values in kg/m³; SP = superplasticizer.

2.3 Fabrication and Testing

I-shaped steel moulds of 200 × 160 × 60 mm (block volume 0.001920 m³) were used throughout. Specimens were cast in a single lift, compacted on a vibrating table at 50 Hz for 30 s, demoulded after 24 h, and water-cured by immersion at 27 ± 2 °C for 28 days. A finished paver block specimen is shown in Fig. 1. All four hardened-property tests followed the annexures of IS 15658:2021: compressive strength (Annex D, five blocks per mix); flexural strength by three-point bending (Annex G, five blocks per mix); water absorption (Annex C, three blocks per mix); and dry abrasion resistance (Annex E referring to IS 1237, three 71 × 71 mm cut specimens per mix). The mandatory IS 15658:2021 acceptance limits for M30 grade were adopted as compliance benchmarks: average compressive strength ≥ 34.13 MPa; flexural strength ≥ 3.30 MPa; water absorption ≤ 6.0%; dry abrasion loss ≤ 18,000 mm³.



Fig. 1. I-shaped paver block specimen ($200 \times 160 \times 60$ mm) used in the present study.

3 Results and Discussion

3.1 Consolidated Performance and Compliance Matrix

Consolidated 28-day results for all six mixes and IS 15658:2021 compliance status are presented in Table 2.

Table 2. Consolidated 28-day experimental results and IS 15658:2021 compliance status.

Mix	CS ₇ (MPa)	CS ₂₈ (MPa)	FS (MPa)	WA (%)	Abrasion (mm ³)	IS 15658:2021
Limit	—	≥ 34.13	≥ 3.30	≤ 6.0	≤ 18 000	—
M30-FA0-RCA0	25.7	39.5	4.55	3.8	13 200	Compliant
M30-FA0-RCA15	24.2	37.2	4.28	4.1	14 500	Compliant
M30-FA0-RCA30	22.5	34.6	3.20	4.6	16 200	Non-comp. (FS)
M30-FA10-RCA0	25.3	40.8	4.68	3.5	12 600	Compliant
M30-FA10-RCA15	23.9	38.6	3.20	3.9	13 800	Non-comp. (FS)
M30-FA10-RCA30	20.8	33.5	3.00	4.3	15 600	Non-comp. (CS+FS)

CS = compressive strength; FS = flexural strength; WA = water absorption.

3.2 Compressive Strength

The 28-day compressive strength ranged from 33.5 MPa (M30-FA10-RCA30) to 40.8 MPa (M30-FA10-RCA0) (Fig. 2). Within each fly ash series, strength declined monotonically with C&D waste content: 5.8% and 12.4% reductions in the FA0 series and 5.4% and 17.9% reductions in the FA10 series at 15% and 30% C&D replacement. The reduction is consistent with multi-zone interfacial transition zone (ITZ) degradation: adhered mortar phases introduce additional weak ITZ regions with elevated porosity [4, 7, 13]. The fly ash effect reverses with age: 7-day strengths in the FA10 series are marginally lower than FA0 counterparts due to clinker dilution, but by 28 days the FA10-RCA0 strength of 40.8 MPa exceeds the FA0-RCA0 strength of 39.5 MPa by 3.3%, confirming pozzolanic compensation [3, 6]. Only M30-FA10-RCA30 falls below the 34.13 MPa threshold; M30-FA0-RCA30 narrowly passes at 34.6 MPa.

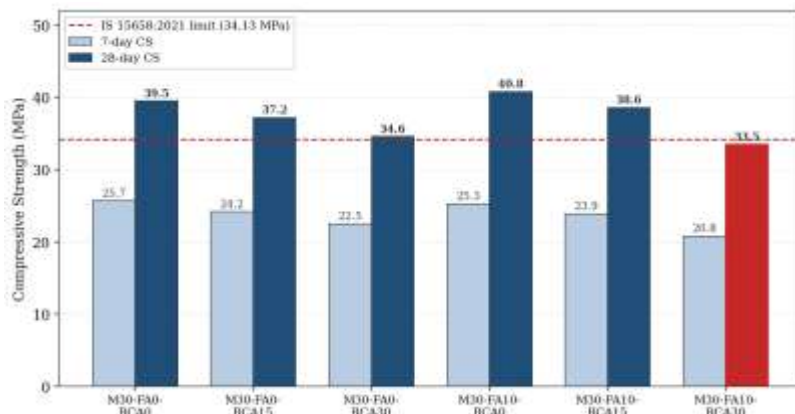


Fig. 2. 7-day and 28-day compressive strength for all six mix variants; dashed line denotes the IS 15658:2021 minimum (34.13 MPa). Red bar denotes non-compliance.

3.3 Flexural Strength: The Discriminating Criterion

Flexural strength is the principal finding (Fig. 3). The FA0 series fell from 4.55 MPa (RCA0) to 4.28 (RCA15) and 3.20 MPa (RCA30) — reductions of 5.9% and 29.7%. The FA10 series achieved the highest value (4.68 MPa at RCA0) but collapsed to 3.20 and 3.00 MPa at 15% and 30% C&D replacement — declines of 31.6% and 35.9%. Only M30-FA0-RCA0, M30-FA0-RCA15, and M30-FA10-RCA0 satisfy the mandatory 3.30 MPa limit. Flexural strength is far more sensitive to C&D waste than compressive strength because flexural failure is tensile and initiates at the weakest plane: the multi-zone ITZ provides the preferred fracture path [13]. The disproportionate flexural penalty in FA10-RCA15 and FA10-RCA30 reflects clinker dilution: reduced primary C-S-H at early ages leaves the ITZ more porous when flexural loading recruits it, before pozzolanic products mature.

A key practical implication is that the 2021 revision of IS 15658 has materially tightened the compliance envelope: under the 2006 version, M30-FA0-RCA30 and M30-FA10-RCA15 would have satisfied all mandatory requirements; under the 2021 revision they do not.

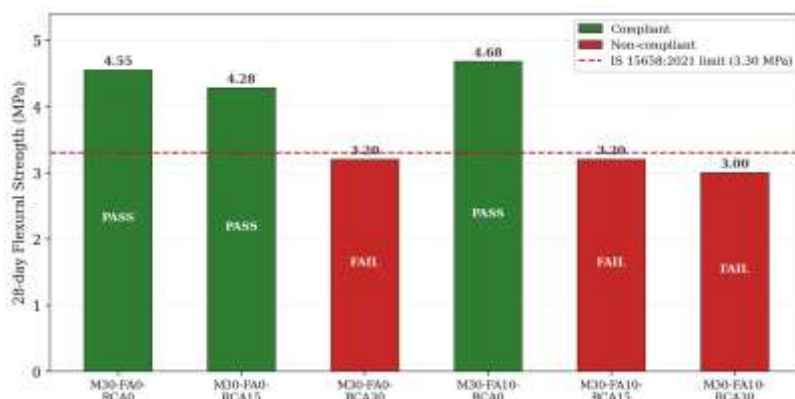


Fig. 3. 28-day flexural strength for all six mix variants; dashed line denotes the mandatory IS 15658:2021 minimum (3.30 MPa). Green bars: compliant; red bars: non-compliant.

3.4 Durability — Water Absorption and Abrasion Resistance

All six mixes satisfied both the 6.0% water absorption and 18,000 mm³ abrasion limits (Fig. 4). The FA10 series consistently outperforms FA0 at every C&D level — water absorption of 3.5–4.3% versus 3.8–4.6%, and abrasion volume loss of 12,600–15,600 mm³ versus 13,200–16,200 mm³ — owing to pozzolanic pore refinement and surface densification [3, 14]. Progressive increases with C&D waste content in both series reflect the inherent porosity of adhered mortar [12].

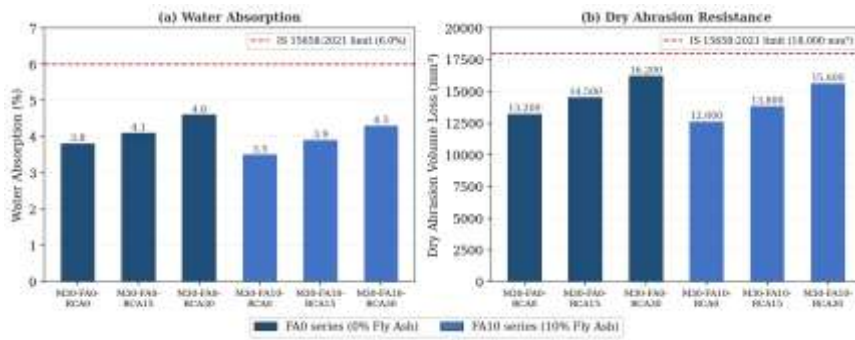


Fig. 4. Durability performance — (a) water absorption and (b) dry abrasion resistance. All mixes comply; the FA10 series consistently outperforms FA0 at every C&D replacement level.

3.5 Integrated Compliance and Optimum Mix Identification

A normalised radar chart against IS 15658:2021 acceptance limits (Fig. 5) consolidates the multi-property assessment. The non-compliant mixes lie inside the IS boundary on the flexural strength axis exclusively, confirming flexural strength as the sole discriminating criterion. Within the compliant set, M30-FA10-RCA0 is identified as the mechanical-performance optimum — highest compressive (40.8 MPa) and flexural (4.68 MPa) strength, lowest water absorption (3.5%), best abrasion (12,600 mm³) — while displacing 10% of OPC. M30-FA0-RCA15 is the waste-diversion optimum, incorporating 154 kg of unprocessed C&D waste per cubic metre while remaining fully compliant. Combining fly ash and C&D waste is counter-productive at the 15–30% replacement range tested: M30-FA10-RCA15, despite higher pozzolanic potential, fails flexurally — a result not widely reported for laboratory-graded RCA and likely reflecting the compositional variability of unprocessed C&D waste.

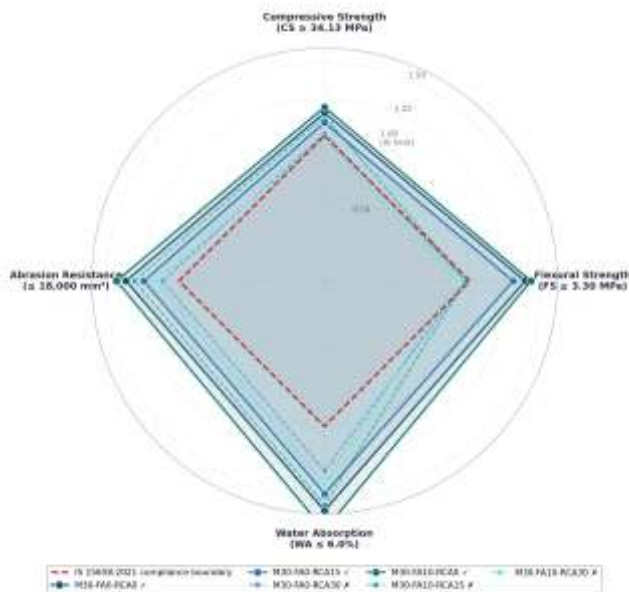


Fig. 5. Normalised radar chart against IS 15658:2021 limits (radius = 1.0). Solid polygons (✓) denote compliant mixes; dashed polygons (X) denote non-compliant. Failures occur exclusively on the flexural strength axis.

4 Conclusions

A 2×3 factorial investigation on M30 paver blocks with Class F fly ash (0%, 10% of OPC) and unprocessed C&D waste (0%, 15%, 30% of NCA), benchmarked against IS 15658:2021, yields the following conclusions:

- Flexural strength — elevated to mandatory status in the 2021 revision of IS 15658 — is the sole discriminating compliance criterion. Three mixes (M30-FA0-RCA30, M30-FA10-RCA15, M30-FA10-RCA30) fail the 3.30 MPa threshold despite passing compressive, water absorption, and abrasion requirements.
- M30-FA10-RCA0 is the mechanical optimum (40.8 MPa CS, 4.68 MPa FS, 3.5% WA, 12,600 mm³ abrasion), outperforming the pure OPC control across every parameter while displacing 10% of OPC. M30-FA0-RCA15 is the waste-diversion optimum, retaining full compliance while incorporating 154 kg of unprocessed C&D waste per m³.

(iii) Unprocessed C&D waste degrades flexural strength disproportionately (29–36% reductions at 30% replacement) versus compressive (12–18%), consistent with multi-zone ITZ fracture under tensile loading. Class F fly ash at 10% benefits all properties at zero and 15% C&D replacement, but the combination with unprocessed C&D waste at these levels amplifies the flexural deficit beyond IS limits.

(iv) For non-traffic pedestrian paving under Indian conditions, 15% unprocessed C&D waste represents a practical upper bound for single-variable substitution; 10% fly ash can be independently adopted for mechanical and durability enhancement. Combined substitution at these levels is not recommended without aggregate pre-conditioning.

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