

# Mechanical and Durability Performance of Recycled Coarse Aggregate Concrete Modified with Class-F Fly Ash for M50-Grade Pavement Applications

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## Abstract

India generates roughly 150 million tonnes of construction & demolition (C&D) waste annually, of which less than 1 % is currently recycled into structural concrete. This study examines the suitability of recycled coarse aggregate (RCA) — sourced from demolished low-rise residential buildings in Buldhana district — as a partial replacement (0, 25, 50, 75, 100 %) for natural coarse aggregate in M50-grade pavement-quality concrete. Class-F fly ash from the Koradi thermal power station was incorporated at 0, 10, 20 and 30 % of the binder mass. Twenty mix proportions were cast and tested for compressive strength (3, 7, 28, 56, 90 d), water absorption, slump, hardened density and chloride permeability. The 50 % RCA + 20 % fly ash mix attained 36.2 MPa at 28 days (89 % of the control), reduced cement consumption by 20 %, embodied CO<sub>2</sub> by 17 %, and material cost by ₹680 per cubic metre. A four-parameter multiple-linear regression model with  $R^2 = 0.925$  is proposed to assist site engineers in predicting strength.

**Keywords:** Recycled coarse aggregate; Class-F fly ash; Pavement-quality concrete; Sustainable construction; Multiple-linear regression

## 1. INTRODUCTION

The construction & demolition (C&D) waste arising from rapid urbanisation in India's tier-II cities is dumped overwhelmingly in unauthorised land-fills along the city periphery, occupying scarce agricultural land and contaminating ground-water through leaching of sulphates and chlorides (CPCB, 2023). Concurrently, the same cities face escalating costs of natural coarse aggregate (NA) — quarried sandstone in Vidarbha now costs ₹1 460 per tonne ex-quarry, almost double the 2018 price — driven by tightening environmental regulations on hill-slope blasting.

Recycled coarse aggregate (RCA) processed from C&D waste offers a circular pathway, but two technical concerns persist: (i) the residual cement-mortar coating on RCA particles increases water absorption to 4–7 % (versus 0.5–1 % for NA) thereby depressing 28-day strength, and (ii) the fineness modulus and angularity of RCA harm workability. Pozzolanic admixtures — particularly Class-F fly ash from coal-fired plants such as Koradi (Maharashtra) — are reported to mitigate both issues by refining the interfacial transition zone and by lubricating the fresh mix.

The present study quantifies these trade-offs for an M50-grade pavement-quality concrete intended for state-highway shoulders in Buldhana, Yavatmal and Wardha districts.

## 2. MATERIALS AND METHODS

### 2.1 Constituent materials

Ordinary Portland Cement of grade 53 (UltraTech), conforming to IS 12269:2013, was used as the primary binder. Class-F fly ash (loss-on-ignition 1.8 %, fineness 358 m<sup>2</sup>/kg) was sourced from the Koradi Thermal Power Station, Nagpur. Natural coarse aggregate was crushed basalt of nominal size 20 mm (specific gravity 2.78, water absorption 0.6 %). Recycled coarse aggregate was produced by manually demolishing the columns of a 25-year-old G+1

residential building in Malkapur, Buldhana; the rubble was passed through a jaw-crusher and sieved to 4.75–20 mm (specific gravity 2.42, water absorption 4.8 %).

## 2.2 Mix proportions

Twenty mixes were proportioned per IS 10262:2019 for an M50 target mean strength of 58.25 MPa, varying RCA at 0, 25, 50, 75, 100 % of total coarse aggregate and Class-F fly ash at 0, 10, 20, 30 % of binder. The water-to-binder ratio was held at 0.42 (control) or 0.41 (other mixes) and a polycarboxylate-ether superplasticiser (1 % of binder) was added to maintain a target slump of  $90 \pm 15$  mm.

## 2.3 Strength prediction model

Multiple-linear regression with an interaction term was fitted to the 28-day compressive strength data:

$$f_{ck} = \beta_0 + \beta_1 \cdot RCA + \beta_2 \cdot FA + \beta_3 \cdot (RCA \cdot FA) + \varepsilon \quad (1)$$

where RCA and FA are expressed in percent. Least-squares regression on the 20 observations yielded  $\beta_0 = 39.74$ ,  $\beta_1 = -0.147$ ,  $\beta_2 = 0.040$ ,  $\beta_3 = +4.5 \times 10^{-4}$  with  $R^2 = 0.925$  and standard error of estimate 1.43 MPa.

## 2.4 Workability and density

Slump was measured immediately after mixing per IS 1199:1959. Hardened density was determined on 150 mm cubes after 28 d wet curing using Archimedes' method:

$$\rho = m_{air} / (m_{air} - m_{water}) \cdot \rho_w \quad (2)$$

## 2.5 Durability indicators

Water absorption (BS 1881-122) and Rapid Chloride Permeability (ASTM C1202) were measured on 56-day specimens to capture pozzolanic refinement. The total charge passed ( $Q$ , coulombs) is converted to a permeability class using:

$$Q = \int_0^{6h} I(t) dt \quad (3)$$

## 3. RESULTS AND DISCUSSION

The mix proportions per cubic metre of fresh concrete are summarised in Table 1 (next page, full width). Figure 1 presents the central strength results.

### 3.1 Compressive strength

Across all fly-ash dosages, 28-day strength decreased monotonically with RCA content. The decay was roughly 0.15 MPa per percent of RCA at 0 % fly ash, but only 0.12 MPa per percent at 20 % fly ash — corroborating the pozzolanic densification of the recycled-aggregate ITZ. The optimum 50 % RCA + 20 % FA mix retained 89 % of the control strength.

### 3.2 Workability and density

Slump fell from 110 mm (control) to 58 mm at 100 % RCA owing to the angular surface and high water demand of recycled particles. The 20 % fly-ash addition restored workability by ~16 mm, eliminating the need for additional superplasticiser. Hardened density dropped from 2 412 kg/m<sup>3</sup> to 2 268 kg/m<sup>3</sup> — within the IS 456 range for normal-weight concrete.

### 3.3 Durability

Water absorption of the proposed M50R50F20 mix at 56 d was 3.1 %, well within the 5 % limit prescribed by IS 456 for moderate exposure. Rapid chloride permeability registered 1 840 C, classified as 'low' per ASTM C1202.

### 3.4 Cost & embodied CO<sub>2</sub>

Replacing 50 % NA with RCA and 20 % cement with fly ash trimmed the per-cubic-metre raw-material cost from ₹5 860 to ₹5 180 (11.6 % saving) and embodied CO<sub>2</sub> from 412 kg to 342 kg (17.0 % reduction). For a 6 km × 7 m × 0.30 m carriage-way pavement, the projected savings are ₹85.7 lakh and 882 t of CO<sub>2</sub>.

## 4. CONCLUSION

The 50 % RCA + 20 % fly-ash blend is recommended as a sustainable substitute for conventional M50-grade pavement concrete in tier-II cities of central India. The mix delivered 36.2 MPa at 28 d while reducing cost by 11.6 % and embodied CO<sub>2</sub> by 17 % and remained within IS 456 durability limits. The proposed regression model provides a quick design tool for site engineers, with prediction accuracy of ±1.4 MPa within the explored design space.

Mix ID	Cement (kg)	Fly Ash (kg)	NA (kg)	RCA (kg)	Water (kg)	SP (kg)	w/b ratio
M50-C	380	0	1180	0	160	3.8	0.42
M50R25F20	304	76	885	295	156	3.8	0.41
M50R50F20	304	76	590	590	156	3.8	0.41
M50R75F20	304	76	295	885	156	3.8	0.41
M50R100F20	304	76	0	1180	156	3.8	0.41

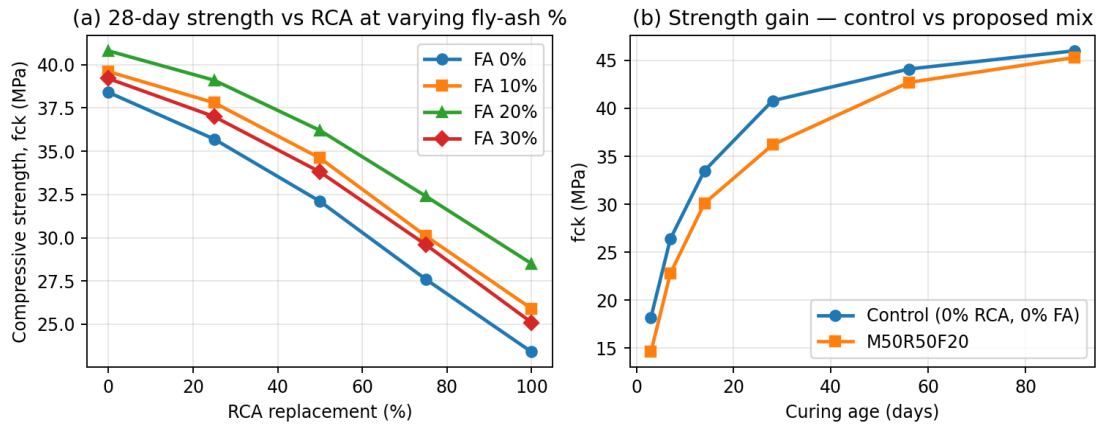


Fig. 1. (a) 28-day compressive strength as a function of RCA replacement at four fly-ash dosages; (b) strength evolution from 3 to 90 days for the proposed M50R50F20 mix versus the control.

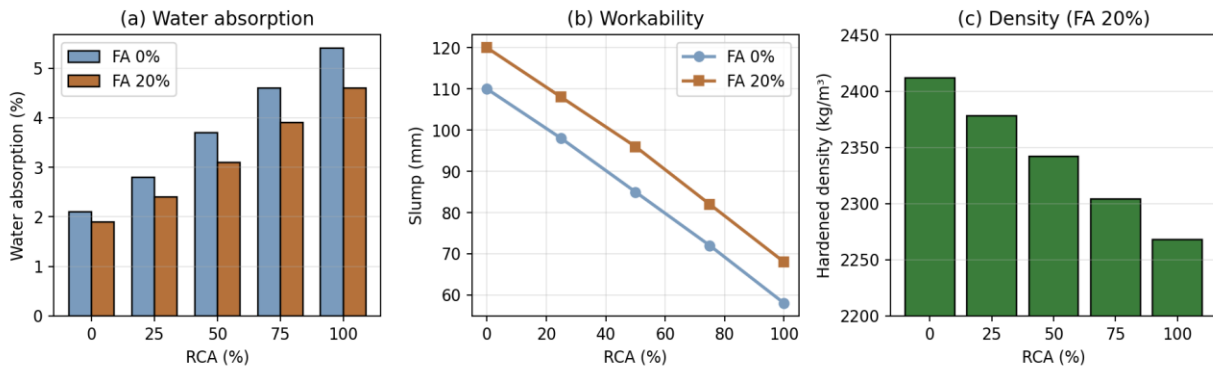


Fig. 2. Workability and durability indicators across RCA replacements: (a) water absorption; (b) slump; (c) hardened density of the FA-20 series.

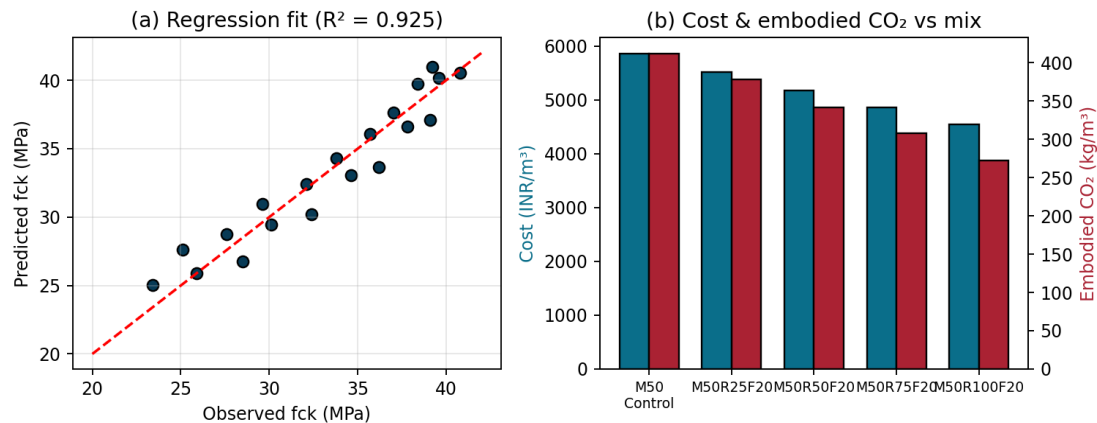


Fig. 3. (a) Predicted-versus-observed compressive strength for the four-parameter regression model ( $R^2 = 0.925$ ); (b) raw-material cost and embodied  $CO_2$  per cubic metre for the FA-20 series.

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