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# Replacement of Coarse Aggregate with Construction and Demolition Concrete Waste in Concrete Blocks: An Experimental Study

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## Abstract
Rapid urban growth generates large quantities of construction and demolition (C&D) waste and, at the same time, raises the demand for natural aggregate. This paper examines whether hardened concrete waste can replace natural coarse aggregate in concrete blocks. Waste concrete from a demolished government school building was crushed, sieved and used as the coarse aggregate. An M20 mix was designed by IS 10262:2009 with a water–cement ratio of 0.55, and specimens with 100% recycled coarse aggregate were cast and tested at 7, 14 and 21 days. The average compressive strengths were 19.01, 20.68 and 23.52 N/mm², which are 16% and 13% lower than the control values of 22.61 and 27.14 N/mm² at 7 and 21 days. The results indicate that recycled blocks may suit lightly loaded uses such as compound walls and single-storey construction.

***Index Terms—construction and demolition waste, recycled aggregate, concrete blocks, compressive strength, sustainability.***

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## I. Introduction

India's construction sector is projected to grow at 7–8% a year over the next decade, and a large share of the buildings expected to exist by 2030 is still to be built. Such growth depends on sand, soil, stone and limestone, whose extraction has significant ecological effects, and some of these materials, sand in particular, already face supply limits because of environmental restrictions.

The same boom produces large quantities of C&D waste, especially in older cities where demolition precedes new high-rise construction. A study by TIFAC in 2001 reported 12–15 million tonnes a year [3], a figure many experts consider an underestimate, and the BMTPC ready reckoner of 2018 puts the national value near 100 million tonnes [2]. Table I lists the daily generation reported for ten Indian cities. The annual figures are the daily values multiplied by 300, because generation almost stops in the monsoon [1].

Table I
C&D waste generation in selected Indian cities [1]

| City | Daily (t/day) | Annual (Mt/yr) |
|---|---|---|
| Mumbai | 2,500 | 0.75 |
| Delhi | 4,600 | 1.38 |
| Bengaluru | 875 | 0.26 |
| Chennai | 2,500 | 0.75 |
| Kolkata | 1,600 | 0.48 |
| Jaipur | 200 | 0.06 |
| Patna | 250 | 0.08 |
| Ahmedabad | 700 | 0.21 |
| Bhopal | 50 | 0.02 |
| Coimbatore | 92 | 0.03 |

Most cities have no formal demolition permits. Recoverables such as metal, pipes and wooden frames are salvaged by the informal sector, and the remaining rubble is partly used as back-fill, which accounts for only 10–30% of the waste. The rest goes to landfills or to unauthorised places such as roadsides, river beds and low-lying land. Delhi started a public–private processing facility in 2010, which grew from 500 to 2,000 t/day, and Ahmedabad followed in 2014 with a 300 t/day plant that reached 1,000 t/day in 2018. In both cities the market uptake of recycled products remains a challenge.

This project therefore studies a direct use of the waste: replacing natural coarse aggregate fully with crushed demolished concrete in concrete blocks, and measuring the loss of compressive strength against a control mix. Related work on recycled concrete aggregate and on waste materials in concrete blocks is reported in [9]–[12].

## II. Literature Review

Mbereyaho and Ntitanguranwa [4] made blocks from crushed C&D concrete with mix ratios of 1:2:2 and 1:4:4. At 28 days the 1:2:2 blocks reached 5.13 N/mm², which met the Rwanda Standards Board requirement for hollow blocks. This was 0.87 times the strength of ordinary blocks, and the recycled block cost 15.6% less. They concluded that such blocks suit one- or two-storey dwellings.

Malešev *et al.* [5] compared natural-aggregate concrete with concrete using 50% and 100% recycled coarse aggregate. From 99 specimens and load tests on reinforced beams, they found that recycled aggregate concrete performed satisfactorily, provided that good recycled aggregate was used and that the special rules for this concrete were followed. Husain and Assas [7] reported that the compressive strength of partial and full

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replacement mixes was higher than that of normal concrete. In contrast, dos Santos *et al.* [8] found that strength differed from conventional concrete by about 4 MPa, which made it usable for shallow foundations of small structures, and that the higher absorption of the waste called for more mixing water. Galán *et al.* [6] studied recycled concrete aggregate in hot-mix asphalt and suggested limits of 17% for schist and 14% for calcite–dolomite aggregate.

## III. Materials

### *A. C&D waste*

The waste was hardened concrete taken from a demolished government school building at Hukkeri (Fig. 1). It was broken first by an excavator and then by hand with heavy hammers at the production site. The crushed material was sieved to obtain a uniform sample, so that the new blocks would be of uniform quality.



Fig. 1. (a) Demolished building, (b) crushing of the waste, (c) crushed and stockpiled aggregate.

### *B. Cement and fine aggregate*

Ordinary Portland cement of 43 grade conforming to IS 8112 [13] was used. The fine aggregate was manufactured sand (M-sand), and the water came from local sources.

## IV. Tests on Aggregates

### *A. Crushed C&D coarse aggregate*

The aggregate impact value was 16%, which is well below the 45% limit given in IS 383 [15] for concrete other than wearing surfaces. The specific gravity from the flask test was 2.54, calculated as

$$G = (W_2 - W_1) / [(W_4 - W_1) - (W_3 - W_2)] \quad (1)$$

with $W_1 = 880$ g, $W_2 = 3680$ g, $W_3 = 4380$ g and $W_4 = 2680$ g, which gives 2800/1100 = 2.54. In the sieve analysis a 4.80 kg sample was retained entirely on the 16 mm and 12.5 mm sieves (2.41 and 2.39 kg), so the coarse aggregate was a single-size fraction between about 12.5 and 20 mm.

### *B. Fine aggregate*

A 1000 g sample of M-sand was sieved, and Table II gives the result. The fineness modulus, the sum of the cumulative percentages retained divided by 100, is 396.3/100 = 3.96, which is coarser than the 2.2–3.2 range usual for concrete sand (Fig. 2). The specific gravity from the pycnometer test is reported as [2.53].

Table II
Sieve Analysis of M-Sand (1000 g Sample)

| Sieve (mm) | Retained (g) | Retained (%) | Cum. retained (%) | Passing (%) |
|---|---|---|---|---|
| 4.75 | 9 | 0.9 | 0.9 | 99.1 |
| 2.36 | 408 | 40.8 | 41.7 | 58.3 |
| 1.18 | 267 | 26.7 | 68.4 | 31.6 |
| 0.60 | 189 | 18.9 | 87.3 | 12.7 |
| 0.30 | 107 | 10.7 | 98.0 | 2.0 |
| 0.15 | 20 | 2.0 | 100.0 | 0.0 |
| Total | 1000 | | 396.3 | |

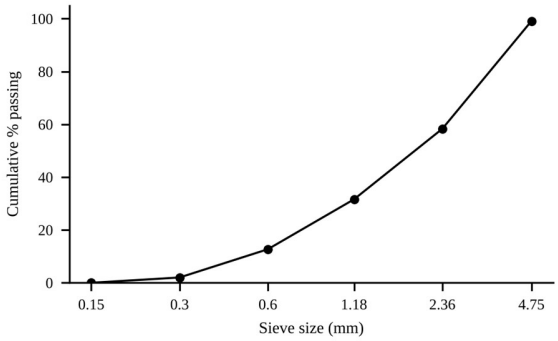



Fig. 2. Grading curve of the M-sand.

Table III
Summary of Material Properties

| Material | Property | Value |
|---|---|---|
| C&D coarse aggregate | Impact value | 16% |
| | Specific gravity | 2.54 |
| M-sand | Fineness modulus | 3.96 |
| | Specific gravity | [2.53] |
| Cement | Type | OPC 43 grade |

## V. Mix Design

An M20 mix was designed by IS 10262:2009 [14] for a nominal aggregate size of 20 mm, a water–cement ratio of 0.55, a water content of 186 L/m³ and a cement content of 338 kg/m³, with pumping as the placing method and good supervision. The volume fractions of coarse and fine aggregate were 0.59 and 0.41. The volumes of cement and water per cubic metre are

$$338/3.15/1000 = 0.107 \text{ m}^3; \quad 186/1000 = 0.186 \text{ m}^3 \quad (2)$$

so the aggregate occupies $1 - (0.107 + 0.186) = 0.707$ m³. The proportions adopted for casting were 1 : 2.05 : 3.10 : 0.55 (cement : fine aggregate : coarse aggregate : water, by mass). Table IV gives the quantities for a 9 kg batch.

Table IV
Batch Quantities for the Adopted Mix

| Ingredient | Mass per 9 kg batch |
|---|---|
| Cement | 1.34 kg |
| Fine aggregate (M-sand) | 2.75 kg |
| Coarse aggregate (C&D) | 4.15 kg |
| Water | 0.74 L |

## VI. Casting and Testing

The specimens were cast in the college laboratory (Fig. 3a) with the designed mix. The control mix used natural coarse aggregate, and the test mix used 100% C&D concrete aggregate in its place. The specimens were crushed in a compression

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testing machine (Fig. 3b) at 7, 14 and 21 days. Three recycled-aggregate specimens were tested at each age.



Fig. 3. (a) Casting of specimens in moulds, (b) testing in the compression testing machine.

## VII. Results and Discussion

### A. Compressive strength

Table V gives the loads and strengths of the nine specimens, and Fig. 4 compares the averages with the control. The average strength of the recycled-aggregate specimens was 19.01 N/mm² at 7 days, 20.68 N/mm² at 14 days and 23.52 N/mm² at 21 days. This is a rise of 8.8% from 7 to 14 days and 13.7% from 14 to 21 days, 23.7% in all. The individual results at each age are close to one another, within about 0.6 N/mm² at 7 days, 0.5 N/mm² at 14 days and 1.4 N/mm² at 21 days. The 21-day average of 23.52 N/mm² is above the characteristic strength of 20 N/mm² for M20.

TABLE V
COMPRESSIVE STRENGTH OF RECYCLED-AGGREGATE SPECIMENS

| Specimen | Age (d) | Load (kN) | Strength (N/mm²) |
|---|---|---|---|
| 1 | 7 | 429.3 | 19.00 |
| 2 | 7 | 435 | 19.33 |
| 3 | 7 | 421 | 18.71 |
| | | Average | 19.01 |
| 4 | 14 | 465 | 20.60 |
| 5 | 14 | 472 | 20.97 |
| 6 | 14 | 461 | 20.48 |
| | | Average | 20.68 |
| 7 | 21 | 536.9 | [23.00] |
| 8 | 21 | 550 | 24.44 |
| 9 | 21 | 520 | 23.11 |
| | | Average | 23.52 |

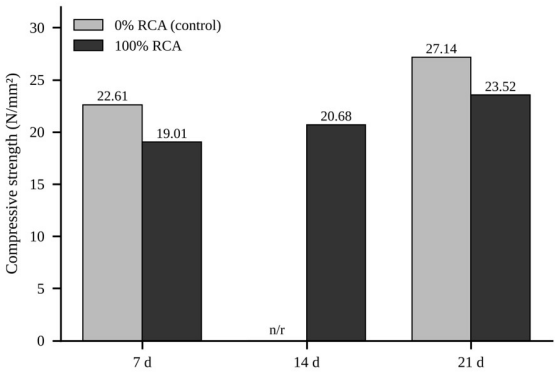



Fig. 4. Average compressive strength of the control and 100% recycled-aggregate specimens (n/r: not reported).

### B. Comparison with the control

The control mix averaged 22.61 N/mm² at 7 days and 27.14 N/mm² at 21 days. Full replacement of the coarse aggregate therefore lowered the strength by 15.9% at 7 days and 13.3% at 21 days, so the recycled blocks kept 84% and 87% of the control strength. The strength lost is of the same order as that reported in earlier work, in which recycled blocks reached 0.87 times the strength of ordinary blocks [4]. The relative loss became smaller with age, which suggests that the recycled mix continued to gain strength, but only two ages are available for comparison. Mortar attached to the crushed concrete and the cracks left by demolition and crushing are the usual reasons given for the lower strength of recycled aggregate, although this study did not measure them.

### C. Limitations

The results should be read with the following points in mind. The control values are given only as averages, with no individual loads and no 14-day result. Testing stopped at 21 days, so 28-day conformity with M20 is not shown. The specimen size is not stated in the report, but the loads and strengths agree with a loaded area of about 22,500 mm², that is, 150 mm cubes. The mix design assumed a specific gravity of 2.74 for the aggregates, whereas the measured values were 2.54 and 2.53, and the 21-day target mean strength of 26.6 N/mm² from IS 10262:2009 [14] (with s = 4 N/mm²) was not reached by the recycled mix. Water absorption, density and cost, which Mbereyaho and Ntitanguranwa [4] also examined, were not measured.

## VIII. Conclusion

Hardened concrete waste from a demolished school building was crushed and used as the whole coarse aggregate of an M20 mix. The recycled aggregate had an impact value of 16% and a specific gravity of 2.54. The blocks reached an average of 19.01, 20.68 and 23.52 N/mm² at 7, 14 and 21 days, which is 16% and 13% below the control at 7 and 21 days. The strength is lower than that of conventional concrete, so the use of such blocks should be limited to lightly loaded work such as precast compound walls and single-storey houses. They would reduce the demand for natural aggregate and the volume of waste sent to disposal. Further work should cover 28-day strength, other replacement levels such as 25%, 50% and 75%, water absorption and density, and the availability of C&D waste for a recycling industry.

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